ANT+ Device Profile

Bicycle Power

PWR CTF

Copyright Information and Usage Notice

Revision History

Revision	Effective Date	Description
1.0	July 3, 2007	Initial Release
1.1	July 2007	Corrected accumulated power description
1.2	July 31, 2007	Made all message names general
1.3	August 1, 2007	Made it clear that 2 byte fields are little endian
1.4	September 13, 2007	Revised a typo – all standard torque fields are 1.32 resolution
1.5	November 14, 2007	Corrected formatting. Corrected equation 10 (Torque Frequency)
1.6	February 6, 2008	Added clarification for calibration of bike power sensors
1.7	March 5, 2008	Modified 0x11 and 0x12 messages
1.8	March 11, 2008	Modified 0x10 Added Auto Zero Message Added Notes for best practice
1.9	March 17, 2008	Corrected constants in Eq. 2 (Speed) Revised Calibration messages and Auto Zero flowchart
1.95	May 8, 2008	Corrected byte order for offset data in Calibration Responses
2.00	September 16, 2008	New formatting
2.1	August 2010	Re-format, added common page descriptions and new calibration criteria
2.2	November 10, 2011	Edited 'Copyright Information and Usage Notice' section Added Custom Calibration Parameters to calibration messages (optional) Added 'Set/Get' Bicycle Parameters page (optional) Removed use of forward direction acknowledged messages
2.3	April 2012	Corrected typo in Section on Set/Get parameters
3.0	February 2012	Added page 0x13 (Torque Effectiveness and Pedal Smoothness metrics) Updated section 13 to clarify that sensors may not send acknowledged messages Added section explaining the requirements to be met before using the icons Updated section 3.3 to include CTF-only Receiver Implementation Updated section 7.1 Event Count. Updated figures in section 13. Updated section 16.2.1 to reflect current version of Common Pages document. Added section 16.2.4: Common Page 82 (0x52): Battery Status Added section 17.3 Handling Invalid Values Clarified background page transmission pattern requirements. Added description of extended device numbers to transmission type field. Added note that sensors may send forward direction calibration messages. Updated template to 2013 version and added CTF icon to front page
4.0	August 2013	Added Measurement Output Data Page 0x03 Updated Calibration Sequence diagrams in section 13 Updated section 13.3 to remove outdated references to torque Updated Figure 13-11. Coasting Offset Calibration Example Updated Table 6-1, Table 6-2 and Table 6-3 to include messages 0x02 and 0x03. Added custom calibration status flag to data page 0x02. Updated Common Page 82 to reflect latest version of common pages document. Removed common pages 80 and 81 and referred to the common pages document.

		Clarified CTF calibration requirements Clarified rollover power rollover values as 65.535kW Specified default messages should be sent at least 2 out of 4 messages Updated section 18.2 to clarify the method for handling rollovers.
4.1	June 2014	Minor fix: Fixed table of contents bookmarks for PDF. Updated copyright.

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1 Overview of ANT+

The ANT+ Managed Network is comprised of a group of devices that use the ANT radio protocol and ANT+ Device Profiles to determine and standardize wireless communication between individual devices. This management of device communication characteristics provides interoperability between devices in the ANT+ network.

Developed specifically for ultra low power applications, the ANT radio protocol provides an optimal balance of RF performance, data throughput and power consumption.

ANT+ Device Profiles have been developed for devices used in personal area networks and can include, but are not limited to, devices that are used in sport, fitness, wellness, and health applications. Wirelessly transferred data that adheres to a given device profile will have the ability to interoperate with different devices from different manufacturers that also adhere to the same standard. Within each device profile, a minimum standard of compliance is defined. Each device adhering to the ANT+ Device Profiles must achieve this minimum standard to ensure interoperability with other devices.

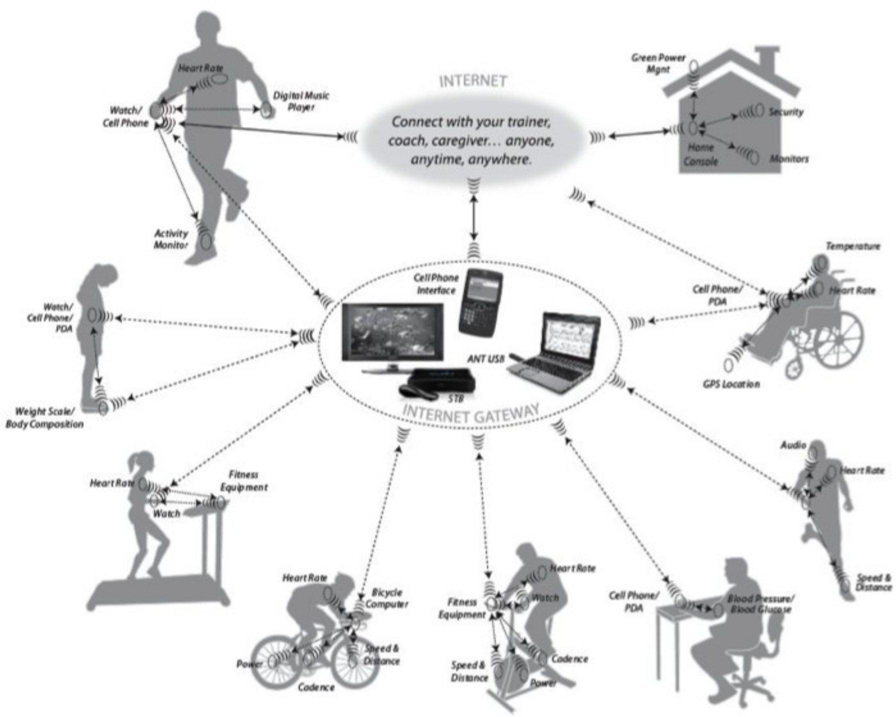


Figure 1-1. ANT+ Device Ecosystem

This document details the wireless communication between devices adhering to this ANT+ Device Profile. The typical use case of the device(s), wireless channel configuration, data format(s), minimum compliance for interoperability, and implementation guidelines are also detailed.

IMPORTANT:

If you have received this document you have agreed to the terms and conditions of the Adopter's Agreement and have downloaded the ANT+ Managed network key. By accepting the Adopter's Agreement and receiving the ANT+ device profiles you agree to:

- **Implement and test your product to this specification in its entirety**
- **To implement only ANT+ defined messages on the ANT+ managed network**

2 Related Documents

Refer to current versions of the listed documents. To ensure you are using the current versions, check the ANT+ website at www.thisisant.com or contact your ANT+ representative.

1. ANT Message Protocol and Usage

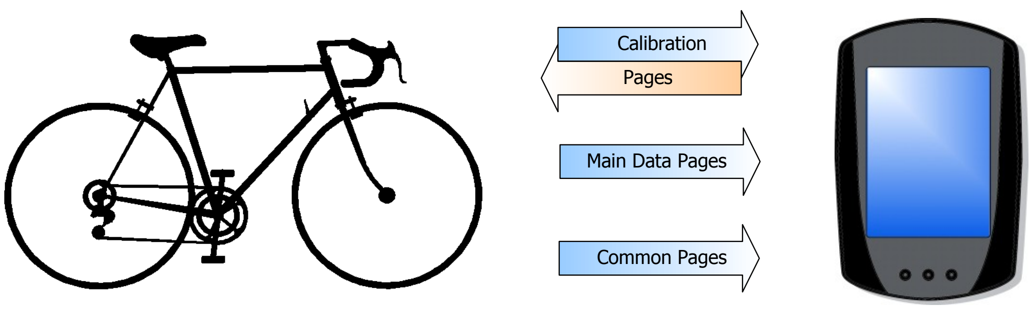
2. ANT+ Common Pages

3 Typical Use Case of Bicycle Power Sensors

A bike power sensor is a sensor that is mounted on a bicycle and that allows the cyclist to measure his or her power output, which is the force required to move the bike forward and is measured in Watts. The meter transmits the information to a display device; the device can be a bike mounted display unit, watch, cell phone, piece of fitness equipment, or other personal display device. The purpose of the ANT+ Bicycle Power device profile is to provide a robust means of interoperable communication between bicycle power sensors and display units that are produced by separate manufacturers.

This document provides information, message definitions, and sample code to explain how sensors transmit bike power information and how display units properly interpret that information. The specification covers the main power information from a variety of supported bike power sensor types as well as the interaction between the display and sensor for calibration. Figure 3-1 illustrates how a bike meter is typically used. The sensor transmits the user's power information and responds to calibration requests. Some device-specific information is transmitted at a slower rate in common data pages. The ANT+ bicycle power device profile describes messages that perform three main functions:

- Power information is transmitted from the sensor to the display in main data pages.
- Interaction occurs between the sensor and display for servicing calibration or configuration requests.
- Background support and status is passed periodically from the power sensor to the display in common data pages.



Power Sensor **Display**

Figure 3-1. Standard Use Case of an ANT+ Bike Power sensor

3.1 Bicycle Power Sensor Types

Bike power sensors vary in two ways: in the method used to measure power and in the conditions and interval used to update and broadcast power information.

3.1.1 Power Measurement Types

The ANT+ message definition currently supports power sensors that:

- measure power directly
- measure torque and rotational velocity at the crank (includes pedal sensors)
- measure torque and rotational velocity at the wheel

Future power sensors may require additional messages. For displays to be compatible with future devices refer to section 5.

3.1.2 Power Information Update Types

All of the broadcast power messages have an Update Event Counter that is used by the receiver to calculate information accurately. There are two methods used by bicycle power sensors for information updates: event-synchronous and time-synchronous.

3.1.2.1 Event-Synchronous Update

The sensor calculates data and updates messages after detecting a rotation event, such as crank or wheel revolution. The elapsed time between each event fluctuates but the number of motion events in each update is constant.

Example: The power information is updated each time the power sensor detects a new crank rotation.

3.1.2.2 Time-Synchronous Update

The sensor calculates data and updates messages at a fixed time interval, regardless of the number of motion events.

Example: The power information is updated at 1Hz.

3.2 Messages Transmitted from the ANT+ Bike Power Sensor

ANT+ bike power data pages support various types of bike power sensors. It is the goal of ANT+ to support both a basic power format common across all power sensors, as well as to provide the ability to extract more detailed information from the power sensor. The basic power format is implemented using a simple Power-Only message transmitted at a slow rate along with more detailed main power messages at a higher data rate. Main power messages are specific to the power methods used; there are four currently supported methods. Other non-time-critical messages, such as battery status and device identification, are grouped as background common data pages and are sent at the slow rate. Each data message has an indicator associated with it describing the data that is being transmitted in that message.

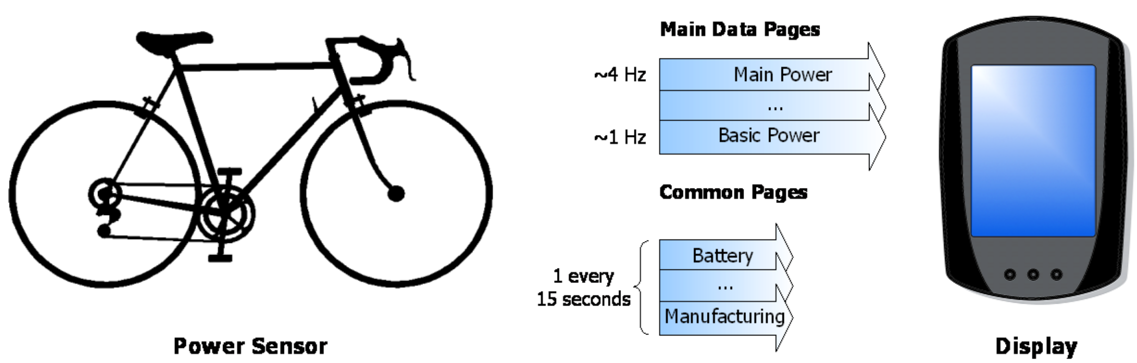


Figure 3-2. Timing of ANT+ Bike Power Sensor Message Formats

3.3 ANT+ Bike Power Sensor Receiver Implementation

In a full receiver implementation the display can receive and interpret all messages from the power sensor; to provide the best features and data, most bicycle-specific displays use a full receiver implementation. A simple receiver that interprets only the basic power-only message may be implemented using a smaller amount of memory. The simple implementation allows cost-reduced, non-bicycle specific or resource-constrained ANT+ devices to receive bicycle power messages. In cases where the power sensor is broadcasting messages that are newer than the display, the simple receiver can interpret at least the basic power-only messages. Alternatively a CTF-Only Receiver Implementation is permitted, which allows displays to receive from Crank Torque Frequency sensors only.

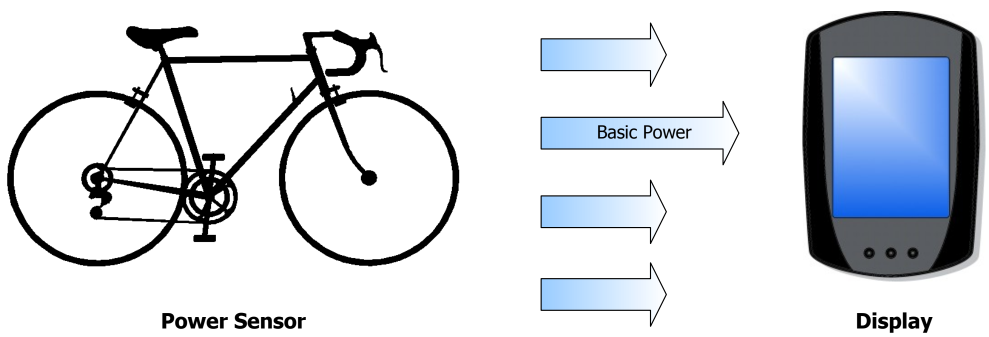


Figure 3-3. Simple Receiver Implementation

A summary of the differences between the simple and full receiver implementations is shown below in Table 3-1.

Table 3-1. Bike Power Receiver Implementation Comparison

Simple Receiver Implementation (PWR)	CTF-Only Receiver Implementation	Full Receiver Implementation (PWR and CTF)
Receives the basic Power-Only message (0x10)	Receives CTF Main Data Page (0x20)	Receives all ANT+ messages
Message contains instantaneous power and cadence	Message contains detailed information such as torque and cadence.	Messages contain detailed information such as torque, cadence, and wheel speed
No calculations required to retrieve data from messages	Calculations are required to retrieve data from the messages	Calculations are required to retrieve data from messages
Data updated at 0.4Hz minimum; supports only time-synchronous updates	Messages support fine-time resolution of event data; e.g. an event-synchronous crank torque meter can capture every single pedal stroke up to 240RPM	Messages support fine-time resolution of event data; e.g. an event-synchronous crank torque meter can capture every single pedal stroke up to 240RPM
Allows receive-only implementation	Provides calibration and configuration interaction	Provides calibration and configuration interaction
Does not support calibration interaction	Support for manual CTF calibration is required as described in section 13.5	Full support for manual calibration
Does not support Torque Frequency message. Optional support for TE & PS message	Does not support Power-Only message	Support for background messages and (optional) support for extended features such as Auto Zero configuration
No protection for RF outage	Accuracy maintained during loss of RF reception; average power can be accurately calculated over an RF outage lasting up to 30s	Accuracy maintained during loss of RF reception; average power can be accurately calculated over an RF outage lasting up to 30s

3.4 Calibration Interaction

Another important feature of the ANT+ bike power device profile is defining the interaction between the power sensor and the display during calibration operations.

Most power sensors require occasional calibration or offset re-zeroing. An example of the interaction between the sensor and display for a manual calibration operation is shown in Figure 3-4.

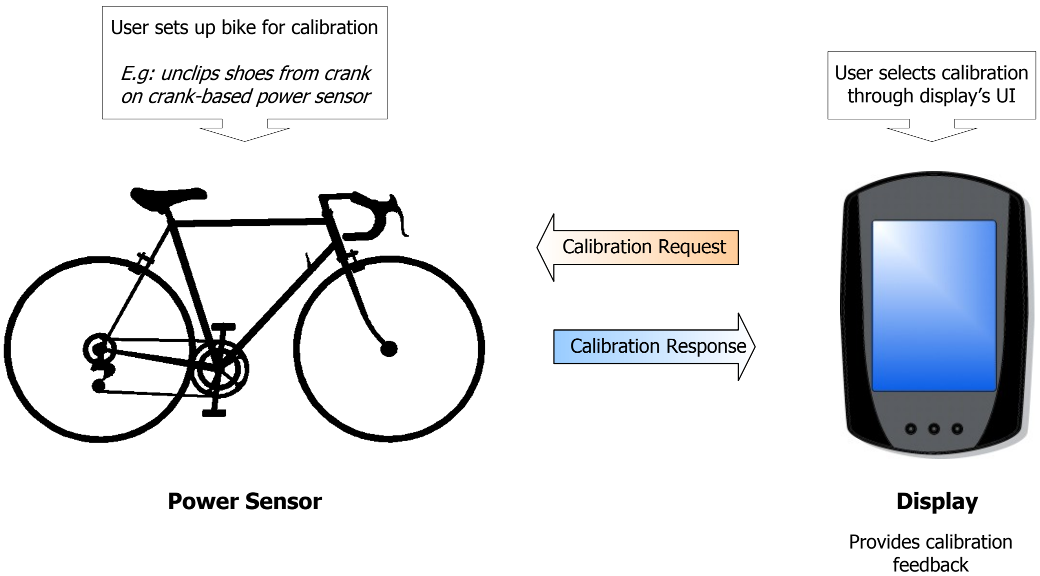


Figure 3-4. A Typical Manual Calibration Operation

Calibration request and response messages are detailed in Section 13.

4 Channel Configuration

The channel configuration parameters of the bike power sensor and all other ANT-enabled devices are defined by the ANT protocol. Refer to the ANT Message Protocol and Usage document for definitions of the various channel parameters.

4.1 Slave Channel Configuration

The device expected to receive data from an ANT+ bike power sensor must configure an ANT channel with the parameters listed in Table 4-1.

Table 4-1. ANT Channel Configuration for Receiving Bike Power Sensor Information

Parameter	Value	Comment
Channel Type	Receive (0x00)	Power sensors require bi-directional communication for calibration and manufacturing purposes.
Network Key	ANT+ Managed Network Key	The ANT+ Managed Network key is governed by the ANT+ Managed Network licensing agreement.
RF Channel Frequency	57	RF Channel 57 (2457 MHz) is used for the ANT+ bike power sensor.
Transmission Type	0 for pairing	The transmission type must be set to 0 for a pairing search. Once the transmission type is learned, **the receiving device should remember the type for future searches.** To be future compatible, any returned transmission type is valid. Future versions of this spec may allow additional bits to be set in the transmission type.
Device Type	11 (0x0B)	The device type shall be set to 11 (0x0B) when searching to pair to an ANT+ bike power sensor. Please see the ANT Message Protocol and Usage document for more details.
Device Number	1-65535 0 for searching	The transmitting sensor contains a 16-bit number that uniquely identifies its transmissions. Set the Device Number parameter to zero to allow wildcard matching. Once the device number is learned, the receiving device should remember the number for future searches. Please see the ANT Message Protocol and Usage document for more details.
Channel Period	8182 counts	Data is transmitted from the bike power sensor every 8182/32768 seconds (approximately 4.00 Hz)
Search Timeout	(Default = 30 seconds)	The default search timeout is set to 30 seconds in the receiver. This timeout is implementation specific and can be set by the designer to the appropriate value for the system.

4.1.1 Transmission Type

The most significant nibble of the transmission type may optionally be used to extend the device number from 16 bits to 20 bits. In this case, the most significant nibble of the transmission type becomes the most significant nibble of the extended 20 bit device number. Therefore a wildcard pairing scheme shall always be used by a display that does not know the transmission type of the power sensor that it is searching for.

4.1.2 Channel Period

All receivers shall use the 8182/32768 channel period (~4.00 Hz) to ensure reliable performance.

4.1.3 Minimum Receiver Requirements for Full Compliance with the ANT+ Bike Power Specification

The following conditions must be met for a receiver to be fully compliant with the ANT+ Bike Power profile:

- Receive all power messages
- Provide the user a means to initiate and confirm a manual zero-offset calibration procedure (0x01). See Section 13.2.1
- Receive Manufacturer Information (ANT Common Data Page)
- Receive Product Information (ANT Common Data Page)

4.1.4 Optional Receiver Functions

The following messages may be supported but are not required for the minimum level of compliance with the ANT+ bike power specification.

- Auto Zero configuration (0x01, Calibration ID: 0xAB)
- Torque Effectiveness and Pedal Smoothness data page (0x13)
- Battery Status (ANT Common Data Page)

4.1.5 Power-Only Receiver Implementation

It is possible to receive basic data from most ANT+ power sensors by receiving the Power-Only message, and optionally the Torque Effectiveness and Pedal Smoothness message. No calculations are required – instantaneous power and cadence measurements are available directly in the message. However the resolution of the data available from this message is not as high as that available from the torque at wheel and torque at crank data pages.

In addition:

- There is no protection for RF outage, and the update period may be as long as 2.25 seconds (maximum).
- Power-Only receivers are not compatible with torque frequency sensors.

4.2 Master Channel Configuration

The ANT+ bike power sensor shall establish its ANT channel as shown in Table 4-2.

Table 4-2. ANT Channel Configuration for Transmitting Bike Power sensor Information

Parameter	Value	Comment
Channel Type	Master (0x10)	Power sensors require bi-directional communication for calibration and manufacturing purposes
Network Key	ANT+ Managed Network Key	The ANT+ Managed Network key is governed by the ANT+ Managed Network licensing agreement
RF Channel	57	Channel 57 is used for the ANT+ bike power sensor
Transmission Type	Set MSN to 0 (0x0) or MSN of extended device number. Set LSN to 5 (0x5)	ANT+ devices follow the transmission type definition as outlined in the ANT protocol. This transmission type cannot use a shared channel address and must be compliant with the global data messages defined in the ANT protocol
Device Type	11 (0x0B)	The device shall transmit its device type as 11 (0x0B) Please see the ANT Message Protocol and Usage document for more details
Device Number	1-65535	This is a two-byte field that allows for a unique identification of a given bike power sensor. It is imperative that the implementation allow for a unique device number to be assigned to a given device. An example of a method to implement a unique device ID is to use the lowest 2 bytes of the device's serial number. **NOTE:** The device number for the transmitting sensor must not be 0x0000
Channel Period	8182	Data is transmitted every 8182/32768 seconds (approximately 4.0049Hz). Period chosen for compatibility with ANT devices

4.2.1 Channel Type

The transmit channel type (0x10) is used instead of a transmit only channel type (0x50) for a number of reasons. The most compelling reason to use the transmit channel (0x10) is that this channel uses the interference avoidance features inherent to the ANT protocol. A transmit only channel (0x50) does not use these features and is much more susceptible to interference from other 2.4GHz sources including other ANT and ANT+ devices. Also, calibration pages use acknowledged message types, which require bidirectional channels.

4.2.2 Transmission Type

The most significant nibble of the transmission type may optionally be used to extend the device number from 16 bits to 20 bits. In this case, the most significant nibble of the transmission type becomes the most significant nibble of the 20 bit device number.

4.2.3 Device Number

The device number needs to be as unique as possible across production units. An example of achieving this specification is to use the lowest two bytes of the serial number of the device for the device number of the ANT channel parameter.

The device number of the bicycle power sensor shall not be 0x0000. Be careful if the device number is derived from the lower 16-bits of a larger serial number that multiples of 0x10000 (65536) do not cause the device number to be set to 0.

5 General Bike Power Message Payload Format

An ANT channel configured as described in section 4 delivers bike power sensor messages. An 8-byte broadcast data packet payload is received every channel period.

It is important to note that all of the ANT+ messages sent by the bike power sensor — main data pages and common data pages — use page numbers to distinguish the different data page formats; the first byte of the data payload is always used to indicate the data page number. The ANT+ bike power specification provides multiple data page numbers to meet the requirements of the various ANT+ compatible power sensors.

All ANT messages have an 8-byte payload. For ANT+ bike power messages the first byte contains the data page number and the remaining 7 bytes are used for sensor-specific data.

Table 5-1. ANT+ Bike Power General Message Format

Byte	Description	Length
0	Data Page Number	1 Byte
1-7	Data	7 Bytes

5.1 Data Page Number

The data page number is a single byte, which identifies to the host the type of power sensor and the format of the power message including any special data. Data page numbers may be extended to include new power sensors and different message types.

5.2 Data

The data portion of the power message usually includes an update event counter, a time stamp, and an accumulated power value. The time stamp and update event counter are used together to allow the receiver to accurately calculate power over an interval that may include missed messages.

5.3 Byte Order

Standard ANT messages are little endian for multi-byte fields; an exception is the Crank Torque-Frequency message format, which is big endian. All byte fields are explicitly defined in each message format.

There are three main types of bike power sensors. This section will describe the different sensor types and the data that these sensors transmit. A more detailed description of data pages for the different sensors will be provided in later sections of the device profile.

6 Bicycle Power Sensor Types

There are three types of bicycle power sensors and they have differing abilities to transmit information. This section will give an overview of what types of sensors can transmit certain types of data. The following sections will detail each type of sensor and the data that is available for transmission.

6.1 Overview of Defined Bike Power Data Pages

The following main data pages are defined for ANT+ bike power messages. Pages not defined in Table 6-1 are reserved for future use.

Table 6-1. ANT+ Bike Power Sensor Data Pages

Data Page Number	Sensor Type	Direction	Message Description
0x01	All	Sensor → Display Display → Sensor	Calibration Messages
0x02	Standard	Display → Sensor Sensor → Display	Get/Set Parameters
0x03	Standard	Sensor → Display	Measurement Output
0x10	Standard	Sensor → Display	Standard – Power Only
0x11	Standard	Sensor → Display	Standard – Torque At Wheel
0x12	Standard	Sensor → Display	Standard – Torque At Crank
0x13	Standard/ Power-Only	Sensor → Display	Standard – Torque Effectiveness & Pedal Smoothness
0x20	CTF	Sensor → Display	Crank Torque-Frequency Message

6.2 Power-Only Sensors

Power-Only sensors measure power, but not torque or rotational speed. More details on power-only sensors can be found in section 7.

Update Method for all main data pages: Time-synchronous only. All Power-Only messages shall be updated at regular time intervals.

Table 6-2. Power-Only Sensor Messages

Function	**Page Number**		**Message**	**Details**
Required Power Main Data Page	0x10		Standard Power Only	Default broadcast message
Optional TE & PS Main Data Page	0x13		Torque Effectiveness and Pedal Smoothness	Minimum: Interleave every 5 messages (1.25s)
Required Common Data Page	0x50		Manufacturer's Information	Minimum: Interleave every 121 messages (30.25 s)
Required Common Data Page	0x51		Product Information	Minimum: Interleave every 121 messages (30.25s)
Optional Common Data Page	0x52		Battery Voltage	Minimum: Interleave every 61 messages (15.25s)
Calibration Function	**Page**	**Cal ID**	**Message**	**Details**
Required Manual Calibration (Zero Offset) Page	0x01	0xAA	Rx: Calibration request (0xAA)	Service calibration request when received from display. See section 13 for details.
		0xAC	Tx: Acknowledge (0xAC)	
		0xAF	Tx: Fail (0xAF)	
Optional Auto Zero	0x01	0xAB	Rx: Autozero configuration (0xAB)	Service autozero configuration request when received from display (for sensors that self-monitor zero offset)
		0xAC	Tx: Acknowledge (0xAC)	
		0xAF	Tx: Fail (0xAF)	
Optional Custom Calibration Parameters	0x01	0xBA	Custom Cal Parameter Request	Set custom calibration parameters See section 13 for details.
		0xBB	Custom Cal Parameter Response	
		0xBC	Custom Cal Parameter Update	
		0xBD	Custom Cal Parameter Update Response	
Optional Auto Zero Support	0x01	0x12	Tx: Auto zero status	Minimum: Interleave every 121 messages (30.25s)
Optional Get/Set Parameters	0x02		Allows the display to get and set parameters on the sensor	Requested by display
Optional Measurement Output	0x03		Allows raw measurement values, and progress to be sent to the display during calibration	Sent as part of calibration process only

6.3 Torque Sensors

Torque may be measured at the bicycle crank or wheel. A separate message ID is used to identify the location of the torque sensor so that rotational velocity may be properly interpreted as either cadence or wheel speed. More details on torque sensors can be found in sections 8 and 0.

Update Method for all main data pages: Time-synchronous or event-synchronous

Table 6-3. Torque Sensor Messages

Function	Page Number		Message	Details
Required Torque Main Data Page	0x11 0x12		Tx: Standard Torque At Wheel OR Tx: Standard Torque At Crank	Default broadcast message
Required Power Main Data Page	0x10		Standard Power Only	Minimum: Interleave every 9th message Preferred: Interleave every 5th message
Optional TE & PS Main Data Page	0x13		Torque Effectiveness and Pedal Smoothness	Minimum: Interleave every 5 messages (1.25s)
Required Common Data Page	0x50		Manufacturer's Information	Minimum: Interleave every 121 messages (30.25s)
Required Common Data Page	0x51		Product Information	Minimum: Interleave every 121 messages (30.25s)
Optional Common Data Page	0x52		Battery Voltage	Minimum: Interleave every 61 messages (15.25s)
Calibration Function	**Page**	**Cal ID**	**Message**	**Details**
Required Manual Calibration (Zero Offset) Page	0x01	0xAA	Rx: Calibration request (0xAA)	Service calibration request when received from display. See section 13 for details.
		0xAC	Tx: Acknowledge (0xAC)	
		0xAF	Tx: Fail (0xAF)	
Optional Auto Zero	0x01	0xAB	Rx: Auto zero configuration (0xAB)	Service auto zero configuration request when received from display (for sensors that self-monitor zero offset)
		0xAC	Tx: Acknowledge (0xAC)	
		0xAF	Tx: Fail (0xAF)	
Optional Custom Calibration Parameters	0x01	0xBA	Custom Cal Parameter Request	Set custom calibration parameters See section 13 for details.
		0xBB	Custom Cal Parameter Response	
		0xBC	Custom Cal Parameter Update	
		0xBD	Custom Cal Parameter Update Response	
Optional Auto Zero Support	0x01	0x12	Tx: Auto zero status	Minimum: Interleave every 121 messages (30.25s)
Optional Get/Set Parameters	0x02		Allows the display to get and set parameters on the sensor	Requested by display
Optional Measurement Output	0x03		Allows raw measurement values, and progress to be sent to the display during calibration	Sent as part of calibration process only

6.4 Crank Torque Frequency Sensors

Crank torque frequency (CTF) power sensors are a special case for ANT+ power messages. They are not designed to convert torque to power at the sensor, they cannot broadcast the Power-Only main data page, and they do not broadcast any ANT+ common pages. For more details on crank torque frequency sensors refer to section 11.

Update Method: Event-synchronous only

Table 6-4. Crank Torque Frequency Sensor Messages

<table>
<tr><th>Function</th><th colspan="2">Page Number</th><th>Message</th><th>Details</th></tr>
<tr><td>Required
CTF Main Data Page</td><td colspan="2">0x20</td><td>Tx: Crank Torque Frequency</td><td>Default broadcast message</td></tr>
<tr><th>Calibration Function</th><th>Page</th><th>Cal ID</th><th>Message</th><th>Details</th></tr>
<tr><td rowspan="2">Required
Manual Calibration
(Zero Offset) Page</td><td rowspan="2">0x01</td><td>0xAA</td><td>Rx: Calibration request (0xAA)</td><td rowspan="4">Service calibration request when received from display. See section 13 for details.</td></tr>
<tr><td>0x10</td><td>Tx: CTF offset data (0x10)</td></tr>
<tr><td rowspan="2">Optional
Save Slope to Flash</td><td rowspan="2">0x01</td><td>0x20</td><td>Rx: Save new slope value (0x20)</td></tr>
<tr><td>0xAC</td><td>Tx: Acknowledge (0xAC)</td></tr>
</table>

7 Standard Power-Only Main Data Page (0x10)

The standard power-only page is used to transmit power output directly in Watts. There are no conversions, calibrations, or calculations required. An accumulated power field is provided for greater reliability in degraded RF conditions.

All power sensors (except CTF sensors) are required to support the standard power-only message in addition to any torque-based messages. Power-Only messages should be interleaved at least once in every 9 messages, but interleaving at least once in every 5 messages is preferred. Byte 2 is an optional data field that shall be set to an invalid value if not used. Byte 2 is also a newer feature and may not be supported by all displays.

Table 7-1. Power-Only Message Format

Byte	Description	Length	Value	Units	Rollover or Range
0	Data Page Number	1 Byte	0x10: standard Power-Only message	N/A	N/A
1	Update Event Count	1 Byte	Power event count	N/A	255
2	Pedal Power	1 Byte	Bit 7: Pedal Differentiation 1 - Right Pedal Power Contribution 0 – Unknown Pedal Power Contribution Bits 0-6: Pedal Power Percent Special Values: 0xFF – pedal power not used	%	0-100%
3	Instantaneous Cadence	1 Byte	Crank cadence – if available Otherwise: 0xFF indicates invalid	RPM	0-254rpm
4	Accumulated Power LSB	2 Bytes	Accumulated power 1-watt resolution	1 Watt	65.535kW
5	Accumulated Power MSB				
6	Instantaneous Power LSB	2 Bytes	Instantaneous power 1-watt resolution	1 Watt	Max=65.535kW
7	Instantaneous Power MSB				

The instantaneous power value can be used by the receiver directly and has 1-watt resolution. No calculations are required to interpret the power.

7.1 Update Event Count

The update event count field is incremented each time the information in the message is updated. There are no invalid values for update event count. For Power-only sensors (refer to section 6.2) the time period of the update count depends on the system but must be a regular interval for accurate averaging.

The update event count in this message refers to updates of the standard Power-Only main data page (0x10). This update event count value is also used by the optional Torque Effectiveness and Pedal Smoothness data page (0x13). The values in Data page 0x13 must correspond to those sent in a Power-only page, and shall include the update event count value of the related Power-only page (See section 12). The update event count shall not be incremented due to data page 0x13 updates. This update event count should never be used as the update event count of any other data pages.

Note that it is not permissible to send two different Torque Effectiveness and Pedal Smoothness data pages using the same update event counter value. Therefore the Power-only page must be calculated at least as often as the TE & PS page, and care must be taken with interleaving. The Power-only page and /or the Torque Effectiveness and Pedal Smoothness page must be sent each time the update event counter is incremented. This is to ensure that the display is able to identify missed messages.

7.2 Pedal Power

The pedal power data field provides the user's power contribution (as a percentage) between the left and right pedals, as measured by a pedal power sensor. For example, if the user's power were evenly distributed between the left and right pedals, this value would read 50%. If the power were not evenly distributed, for example if the pedal power measured 70%, some sensors may or may not know which pedal has the greatest power contribution. The most significant bit is used to indicate if the pedal power sensor is capable of differentiating between the left and right.

7.2.1 Pedal Differentiation Bit

This bit is used to indicate the pedal power sensor's ability to determine between the left and right pedals. If this bit is set to 1, then the value stored in bits 0 – 6 represent the percent power contribution applied to the *right* pedal, and the remaining percent (i.e. 100% - value) is the percent power contribution applied to the left pedal.

If the pedal power sensor is unable to differentiate between the left and right pedals, this bit is set to zero.

7.2.2 Pedal Power Percent

This data field represents the user's power contribution to a single pedal, and is an integer value representing percent. If the pedal differentiation bit is set to 1, this value corresponds to the percent contribution applied to the *right* pedal.

7.3 Instantaneous Cadence

The instantaneous cadence field is used to transmit the pedaling cadence recorded from the power sensor. This field is an instantaneous value only; it does not accumulate between messages.

The value 0xFF is sent in this field to indicate that the power sensor cannot measure pedaling cadence. 0xFF is interpreted as an invalid value and is ignored by the display.

7.4 Accumulated Power

Accumulated power is the running sum of the instantaneous power data and is incremented at each update of the update event count. The accumulated power field rolls over at 65.535kW. At 2Hz power event updates, there are sufficient buffers over all power levels.

Table 7-2. Time to Buffer Overflow for a Given Power

Power (Watts)	Time to Buffer Overflow (seconds)
100	327
500	65
2000	16

7.5 Average Power Calculations

In the following formula, *N* refers to the most recent message received, and *N-1* refers to the received message immediately preceding *N*.

$$AveragePower = \frac{\Delta AccumulatedPower}{\Delta EventCount} = \frac{AccumulatedPower_N - AccumulatedPower_{N-1}}{EventCount_N - EventCount_{N-1}}$$

Equation 1. Average Power Calculation

Under normal conditions with complete RF reception, average power equals instantaneous power. In conditions where packets are lost, average power accurately calculates power over the interval between the received messages.

8 Standard Wheel Torque Main Data Page (0x11)

The standard wheel torque page is used to send event timing information and torque values from a power sensor that measures torque on the rear wheel. Timing is based on a 2048Hz clock and torque is transmitted in Newton meters.

Table 8-1. Wheel Torque Message Format

Byte	Description	Length	Value	Units	Rollover or Valid Range
0	Data Page Number	1 Byte	0x11 – sensor measures torque at wheel	N/A	N/A
1	Update Event Count	1 Byte	Event counter increments with each information update.	N/A	255
2	Wheel Ticks	1 Byte	Wheel tick count increments with each wheel revolution.	Wheel revolutions	255 (~550 meters)
3	Instantaneous Cadence	1 byte	Crank cadence – if available Otherwise: 0xFF indicates invalid	RPM	0-254rpm
4	Wheel Period LSB	2 bytes	Accumulated wheel period (updated each event)	1/2048s	32s
5	Wheel Period MSB				
6	Accumulated Torque LSB	2 bytes	Accumulated torque (updated each event)	1/32Nm	2048Nm
7	Accumulated Torque MSB				

8.1 Update Event Count

The update event count is incremented each time the information in the data page is updated. There are no invalid values for update event count. The update event count in this message refers **only** to updates of the standard Wheel Torque main data page (0x11). It should never be used with the update event count of other data pages.

Rollover: Power sensors may update information at a fixed time interval (time-synchronous updates) or each time a wheel rotation event occurs (event-synchronous update). The Wheel Torque message works for both update methods.

The update event count in time-synchronous update systems rolls over at a fixed time interval equal to 256 times the update period.

Table 8-2. Time to Update Event Counter Rollover for a Given Update Rate

Fixed Update Rate (Hz)	Time to Rollover (seconds)
1	256
4	64

Alternately, the update event count may increment with each complete wheel revolution. The update event counter rolls over at 256 events; based on typical speeds this ranges between 20 seconds and three minutes as outlined in Table 8-3.

Table 8-3. Time to Update Event Counter Rollover for a Given Speed

Speed (km/h)	Time to Rollover (seconds)
10	192
30	64
60	32
80	24

8.2 Wheel Ticks

The wheel ticks field increments with each wheel revolution and is used to calculate linear distance traveled. The wheel ticks field rolls over every 256 wheel revolutions, which is approximately 550 meters assuming a 2m wheel circumference. There are no invalid values for this field.

For event-synchronous systems, the wheel ticks and update event count increment at the same rate.

8.3 Instantaneous Cadence

The instantaneous cadence field is used to report the pedaling cadence recorded from the power sensor. This is an instantaneous value only and does not accumulate between messages. The value 0xFF is sent in this field to indicate that the power sensor cannot measure pedaling cadence. 0xFF is interpreted as an invalid value and is ignored by the display.

8.4 Accumulated Wheel Period

The accumulated wheel period is used to indicate the average rotation period of the wheel during the last update interval, in increments of 1/2048s. This frequency is chosen because it is a factor of the common 32.768kHz crystal and because it provides a practical balance between resolution and available data bandwidth.

Each Wheel Period tick represents a 488-microsecond interval. In event-synchronous systems, the accumulated wheel period time stamp field rolls over in 32 seconds. In fixed time interval update systems, the time to rollover depends on wheel speed but is greater than 32 seconds.

As a rider increases velocity, the period of each revolution decreases and the uncertainty due to the resolution of the wheel period time interval becomes a proportionally larger part of the calculated speed. This means that the resolution of speed measurement changes with speed. For a practical speed range between 20 and 50km/h, the speed resolution is finer than 0.2km/h; for speeds as high as 80km/h the resolution is less than 0.5km/h.

Table 8-4. Speed Measurement Resolution for a Given Speed

Speed (km/h)	Seconds Per Revolution (seconds)	Wheel Rotation Ticks Per Revolution	Speed Measurement Resolution (km/h)
2	3.88	7937	0.00
20	0.38	774	0.03
60	0.13	129	0.23
80	0.09	97	0.41

8.4.1 Interpreting Zero Speed from Standard Wheel Torque Data

8.4.1.1 Time-synchronous Update

To indicate zero rotational velocity, do not increment the accumulated wheel period and do not increment the wheel ticks. The update event count continues incrementing to indicate that updates are occurring, but since the wheel is not rotating the wheel ticks do not increase. Displays should interpret a zero change in accumulated wheel period as zero speed.

8.4.1.2 Event-synchronous Update

If the wheel is not rotating in an event-synchronous system, new power updates cannot occur and the sensor continues to broadcast the last message. Displays should interpret repeated messages as zero rotational velocity. The number of seconds of repeated messages before interpreting zero speed is left to the manufacturer.

8.5 Accumulated Torque

The accumulated torque is the cumulative sum of the average torque measured every update event count. The accumulated torque field is 2 bytes. The resolution of power measurement changes with speed, but stays below the 1-watt level for the most useful speed range.

Table 8-5. Power Resolution for a Given Speed

Speed (km/h)	Power Resolution (Watts)
20	0.5
40	0.8
60	1.0
80	1.6

The amount of time required to reach the rollover value of the accumulated torque field (2048Nm) varies with power output.

Table 8-6. Time to Accumulated Torque Rollover for a Given Power Output

Power (Watts)	Time to Rollover (seconds)
200	64
400	32
1000	13

8.6 Speed and Distance Computations

To calculate speed and distance, the receiving device requires knowledge of the wheel circumference in meters. This value is entered by the user. *N* refers to the most recent message received, and *N-1* refers to the received message immediately preceding *N*.

$$Speed_{AVE} = \frac{3600}{1000} \cdot \frac{Circumference \cdot \left(UpdateEventCount_{N} - UpdateEventCount_{N-1}\right)}{\left(\frac{WheelPeriod_{N} - WheelPeriod_{N-1}}{2048}\right)} [km/h]$$

Equation 2. Average Speed Calculation for Wheel Torque Sensor

$$\Delta Dist = Circumference \cdot \left(WheelTicks_{N} - WheelTicks_{N-1}\right) [m]$$

Equation 3. Distance Calculation for Wheel Torque Sensor

NOTE: Do **not** use wheel ticks to calculate linear speed.

8.7 Power Calculations

See Section 10 for details.

9 Standard Crank Torque Main Data Page (0x12)

The standard crank torque page is used to send event timing information and torque values from a power sensor that measures torque at the crank. Timing is based on a 2048Hz clock and torque is transmitted in Newton meters.

Table 9-1. Crank Torque Message Format

Byte	Description	Length	Value	Units	Rollover or Valid Range
0	Data Page Number	1 Byte	0x12 – sensor measures torque at crank	N/A	N/A
1	Update Event Counter	1 Byte	Event counter increments with each information update.	N/A	255
2	Crank Ticks	1 Byte	Crank ticks increment with each crank revolution.	Crank Revolutions	255
3	Instantaneous Cadence	1 Byte	Crank cadence – if available Otherwise: 0xFF	RPM	0-254rpm
4	Period LSB	2 Bytes	Accumulated crank period (updated each event)	1/2048s	32s
5	Period MSB				
6	Accumulated Torque LSB	2 Bytes	Accumulated torque (updated each event)	1/32Nm	2048Nm
7	Accumulated Torque MSB				

9.1 Update Event Count

The update event count is incremented each time the information in the message is updated. There are no invalid values for update event count. The update event count in this message refers **only** to updates of the Crank Torque main data page (0x12). It should never be used with the update event count of other data pages.

Rollover: Power sensors may update information on a fixed frequency (time-synchronous) or with each rotation event (event-synchronous).

If the power sensor uses a fixed period for updates (time-synchronous system), the event count increments each time an update is available and rolls over at a rate equal to the update period times 256.

Table 9-2. Time to Update Event Count Rollover for a Given Update Rate

Fixed Update Rate (Hz)	Time to Rollover (seconds)
1	256
4	64

Alternatively, in event-synchronous systems, the update event count increments with every complete crank revolution. Even at extreme cadences, there is more than one minute of buffer before a rollover occurs.

Table 9-3. Time to Update Event Count Rollover for a Given Cadence

Cadence (RPM)	Time to Rollover (mm:ss)
20	12:45
60	4:15
120	2:33
240	1:03

9.2 Crank Ticks

The crank ticks increment with each crank revolution and indicates a full rotation of the crank. The crank ticks field rolls over every 256 crank revolutions. There are no invalid values for crank ticks.

For systems that update synchronously with crank events (event-synchronous), the crank ticks and update event count increment at the same rate.

9.3 Instantaneous Cadence

The instantaneous cadence field is used to report the pedaling cadence recorded from the power sensor. This is an instantaneous value only and does not accumulate between messages. The value 0xFF is sent in this field to indicate that the power sensor cannot measure pedaling cadence. 0xFF is interpreted as an invalid value and is ignored by the display.

9.4 Accumulated Crank Period

The accumulated crank period is used to indicate the average rotation period of the crank during the last update interval, in increments of 1/2048s. This frequency is chosen because it is a factor of the common 32.768kHz crystal and because it provides a practical balance between resolution and available data bandwidth. Refer to section 9.4.1 for information on how to handle zero cadence situations.

Each crank period tick represents a 488-microsecond interval. In event-synchronous systems, the accumulated crank period field rolls over in 32 seconds. In fixed update (time-synchronous) systems the time to rollover depends on wheel speed, but is greater than 32 seconds.

Table 9-4. Cadence Resolution for a Given Cadence

Cadence (RPM)	Seconds Per Revolution	Ticks Per Revolution	Cadence Resolution (RPM)
0 (by definition)	-	16384 (0x4000)	0.00
8	7.5	15360	0.00
20	3	6144	0.00
60	1	2048	0.03
120	0.5	1024	0.12
240	0.25	512	0.47

As a rider pedals faster, the period of each crank revolution decreases and the uncertainty in the Crank Period interval due to timing resolution becomes a proportionally larger part of the calculated cadence. The cadence resolution remains finer than 0.5 RPM for the entire practical input range.

9.4.1 Interpreting Zero Cadence from Standard Crank Torque Data

9.4.1.1 Time-synchronous Update

To indicate zero rotational velocity, the accumulated crank period should not be incremented. The update event count continues to be incremented to indicate that updates are occurring, but since the crank is not rotating, the crank ticks do not increase. Displays should interpret a zero change in accumulated crank period as zero cadence.

9.4.1.2 Event-synchronous Update

If the crank is not rotating in an event-synchronous system, new power updates cannot occur and the sensor continues to broadcast the last message. Displays should interpret repeated messages as zero cadence. The number of seconds of repeated messages that must occur before interpreting zero cadence is left to the manufacturer to decide.

9.5 Accumulated Torque

The accumulated torque is the cumulative sum of the average torque measured every crank rotation event. The accumulated torque field is 2 bytes.

Table 9-5. Crank Power Resolution for a Given Cadence

Cadence (RPM)	Power Resolution (Watts)
60	0.2
80	0.3
100	0.3
120	0.4

The time required to reach the rollover value of the accumulated torque field (2048Nm) varies with power output.

Table 9-6. Time to Accumulated Torque Rollover for a Given Cadence Power Output

Power (Watts)	Time to Rollover (seconds)
200	64
400	32
1000	13

9.6 Cadence Computation

The average cadence in RPM is computed from the update event count and elapsed time. *N* refers to the most recent message received, and *N-1* refers to the received message immediately preceding *N*.

$$Cadence_{AVE} = 60 \cdot \frac{\left(UpdateEventCount_N - UpdateEventCount_{N-1}\right)}{\left(\dfrac{CrankPeriod_N - CrankPeriod_{N-1}}{2048}\right)} [RPM]$$

Equation 4. Average Cadence Computation for Crank Torque Sensor

9.7 Power Calculations

See Section 10 for details.

10 Computing Power from Standard Torque Data Messages

The device that is receiving the standard torque data messages must apply the following calculations to properly derive and display the computed bike power.

The period, update event count, and cumulative torque are used to calculate angular velocity and power. In the calculations that follow *N* refers to the most recent message received, and *N-1* refers to the message immediately preceding *N*. The following calculations apply to the standard wheel torque message and the standard crank torque message.

NOTE: If the wheel or crank is revolving at less than 240RPM (4Hz), multiple messages may arrive that describe the same event.

10.1 Average Angular Velocity

The average angular velocity (rad/s) between two received messages is computed from the number of rotation events divided by the rotation period.

$$AngularVel_{AVE} = \frac{2\pi \cdot \left(UpdateEventCount_{N} - UpdateEventCount_{N-1}\right)}{\left(\frac{Period_{N} - Period_{N-1}}{2048}\right)}[radians/s]$$

Equation 5. Calculation of Angular Velocity

10.2 Average Torque

The average torque between two received messages is computed from the difference in accumulated torque, divided by the number of rotation events. Accumulated torque is broadcast in 1/32Nm, which must be factored back out.

$$Torque_{AVE} = \frac{\left(AccumulatedTorque_{N} - AccumulatedTorque_{N-1}\right)}{32 \cdot \left(UpdateEventCount_{N} - UpdateEventCount_{N-1}\right)}[Nm]$$

Equation 6. Calculation of Average Torque

10.3 Average Power

The average power in Watts between two received messages is the product of average torque and average angular velocity over the interval.

$$Power_{AVE} = Torque_{AVE} \cdot AngularVel_{AVE}[Watts]$$

Equation 7. Calculation of Average Power 1

If average torque and angular velocity are not used, the average power in Watts can be calculated directly from the accumulated torque and period.

$$Power_{AVE} = 128\pi \frac{\left(AccumulatedTorque_{N} - AccumulatedTorque_{N-1}\right)}{Period_{N} - Period_{N-1}}[Watts]$$

Equation 8. Calculation of Average Power 2

11 Torque Effectiveness and Pedal Smoothness Main Data Page (0x13)

This data page is an optional page that can be used by power-only or torque sensors, as described in section 6. It is used to send the instantaneous values of left and right Torque Effectiveness and either left and right, or combined, Pedal Smoothness from the sensor. This page should be interleaved with other messages such that it is sent at least once every 5 messages. Calculations may be performed by the display to create averaged values if desired.

Table 11-1. Torque Effectiveness and Pedal Smoothness Message Format

Byte	Description	Length	Value	Units	Rollover or Valid Range
0	Data Page Number	1 Byte	0x13 – Torque Effectiveness and Pedal Smoothness percentages	N/A	N/A
1	Update Event Count	1 Byte	Event counter increments with each power-only information update. This value is tied to the event counter on the Power Only page.	N/A	255
2	Left Torque Effectiveness	1 Byte	Left leg torque effectiveness 0xFF: Invalid or negative values	1/2%	0-100%
3	Right Torque Effectiveness	1 Byte	Right leg torque effectiveness 0xFF: Invalid or negative values	1/2%	0-100%
4	Left (or combined) Pedal Smoothness	1 Byte	Left pedal smoothness, or combined pedal smoothness if byte 5 is set to 0xFE 0xFF: Invalid	1/2%	0-100%
5	Right Pedal Smoothness	1 Byte	Right pedal smoothness FE: Combined pedal smoothness being sent in byte 4 0xFF: Invalid	1/2%	0-100%
6-7	Reserved	2 Bytes	Set to 0xFF	N/A	N/A

NOTE: The sensor must transmit 0xFF for all byte fields marked as 'Reserved'. The receiver must not interpret these values.

11.1 Update Event Count

The update event count value in this data page is tied to the value used in the standard power-only page. There are no invalid values for update event count. This is described in section 7.1.

11.2 Torque Effectiveness

Values for left and right torque effectiveness can be sent in bytes 2 and 3 (Table 11-1). As torque effectiveness cannot be measured on combined systems, then any sensors that cannot distinguish between the torque applied to the left and right crank arms should set these bytes to invalid (0xFF).

In addition, although it is possible to measure negative values of torque effectiveness (for example if a cyclist resists the pedal more than they push it) it is expected that the range of interesting values will lie between 0 – 100%. Therefore negative values of torque effectiveness shall be sent as invalid (0xFF).

11.2.1 Calculating Torque Effectiveness

The Torque Effectiveness is calculated for each crank arm based on the positive (clockwise) and negative (anti-clockwise) torque applied to the crank over each revolution. Figure 11-1 shows a typical torque curve, where P_+ represents the positive power applied to the bike and is the sum of the instantaneous power measurements. Similarly, P_- is the sum of the negative instantaneous power measurements (i.e. power lost from the bike as negative torque is applied to the pedals).

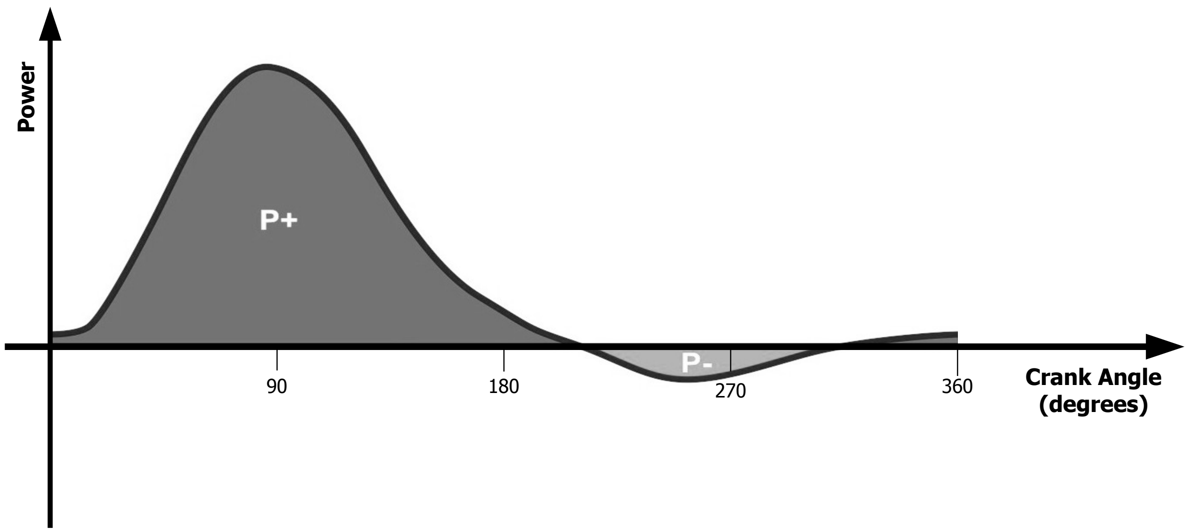


Figure 11-1 Instantaneous Power vs. Crank Angle

Equation 9 defines Torque Effectiveness in terms of P_+ and P_- (note that P_- will be a negative value):

$$\mathit{Torque\ Effectiveness} = \frac{100 \times (P_+ + P_-)}{P_+}$$

Equation 9. Calculation of Torque Effectiveness

11.3 Pedal Smoothness

If the sensor is able to distinguish between the left and right leg's Pedal Smoothness values, then the appropriate values should be sent according to Table 11-1. If the Pedal Smoothness is calculated as a combined value across both pedals, then the resulting value should be sent in byte 4, and byte 5 should be set to 0xFE. If a single sensor is in use that measures either left or right pedal smoothness, then pedal smoothness should be sent in either the byte 4 or byte 5 respectively, and the unused byte should be set to invalid (0xFF).

11.3.1 Calculating Pedal Smoothness

P_{avg} is the mean power averaged across 1 crank cycle and P_{max} is the peak power applied during that cycle, as shown in Figure 11-2. These values can be used to calculate pedal smoothness, as defined as in Equation 10. The shape of the power curve and the resulting value of pedal smoothness will vary depending on the style of riding, and on whether the power is measured per crank arm (i.e. in left-right systems) or for the whole system.

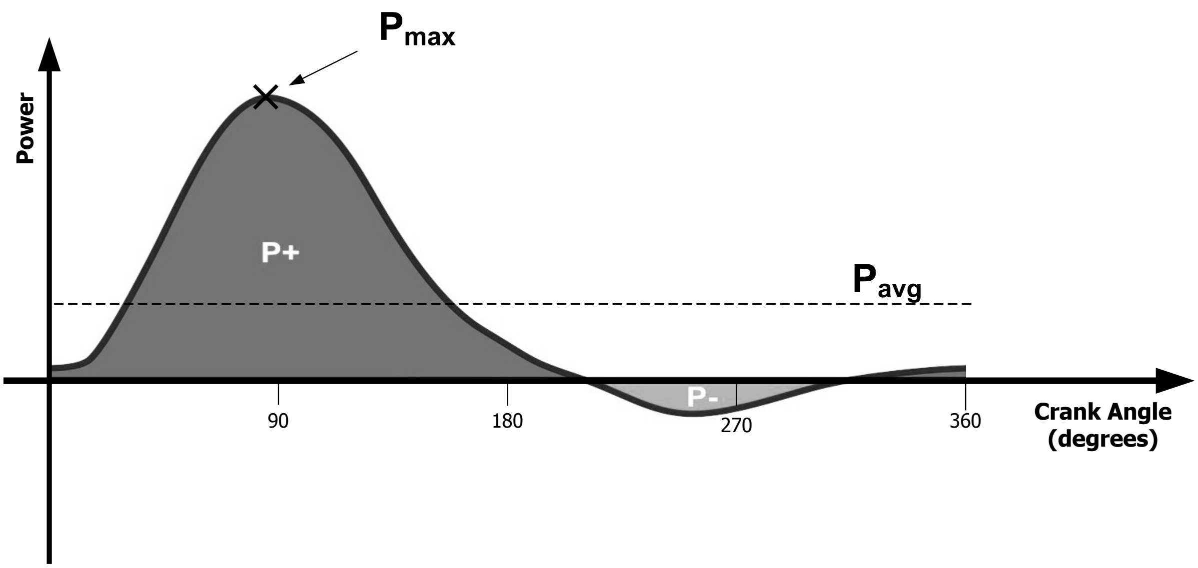


Figure 11-2. Values used to calculate Pedal Smoothness

$$\textit{Pedal Smoothness} = \frac{P_{avg}}{P_{max}}$$

Equation 10. Calculation of Pedal Smoothness

12 Crank Torque Frequency Main Data Page (0x20)

Crank Torque Frequency main data pages for power sensors are similar in form to the other main data pages, but allow the power sensor to transmit torque as a frequency. Currently only one Crank Torque Frequency main data page is defined. The necessary calibration values are passed such that the receiver can calculate power from the time stamp and torque ticks stamp. Time stamping uses a 2000Hz clock.

NOTE: Crank torque-frequency messages are big endian. The byte order for multi-byte fields in these messages is reversed with respect to standard ANT+ messages

Table 12-1. Crank Torque Frequency Message Format

Byte	Description	Length	Value	Units	Rollover or Valid Range
0	Data Page Number	1 Byte	0x20 – Crank Torque Frequency	N/A	N/A
1	Update Event Count	1 Byte	Rotation event counter increments with each completed pedal revolution.	N/A	255
2	Slope MSB	2 Bytes	Slope defines the variation of the output frequency.	1/10 Nm/Hz	100 – 500
3	Slope LSB				
4	Time Stamp MSB	2 Bytes	Time of most recent rotation event	1/2000s	32.7s
5	Time Stamp LSB				
6	Torque Ticks Stamp MSB	2 Bytes	Count of most recent torque event	N/A	65535 ticks
7	Torque Ticks Stamp LSB				

12.1 Update Event Count

The update event count increments with each complete pedal stroke. The update event count is used to indicate the number of cadence events that have occurred between two consecutively received messages. Even at extreme cadences there is more than one minute of buffer before a rollover occurs.

Table 12-2. Time to Crank Torque Frequency Rollover for a Given Cadence

Cadence (RPM)	Time to Rollover (mm:ss)
20	12:45
60	4:20
120	2:05
240	1:05

NOTE: After 3 seconds without a new cadence event, the display should change the displayed cadence to zero.

12.2 Slope Value

The slope is a configuration value required by the display to convert torque ticks into units of Newton metres. It is saved to the power sensor’s flash memory during manufacturing. Slope ranges in value from 10.0Nm/Hz to 50.0Nm/Hz. To send slope as an integer, the slope field is sent in units of 1/10 Nm/Hz, with values ranging between 100 and 500. Slope is included in every message so that special messaging is not required at startup to retrieve it.

12.3 Time Stamp

The crank torque-frequency message uses a 2000Hz clock to time cadence events. The time stamp field indicates the time of the most recent cadence event. Each time stamp tick represents a 500-microsecond interval. The time stamp field rolls over every 32.7 seconds.

Table 12-3. Cadence Resolution for a Given Cadence

Cadence (RPM)	Seconds Per Revolution	Ticks Per Revolution	Cadence Resolution (RPM)
20	3	6000	0.0 RPM
60	1	2000	0.0 RPM
120	0.5	1000	0.1 RPM
240	0.25	500	0.5 RPM

As a rider pedals faster, the period of each revolution decreases and the uncertainty in time stamp interval becomes a proportionally larger part of the calculated cadence or speed. At cadences below 120 RPM, the timing resolution is finer than the required display resolution.

12.4 Torque Ticks Stamp

The torque ticks stamp represents the most recent value of torque ticks since the last registered revolution. The amount of time that the torque ticks stamp provides protection against RF outage depends on torque, cadence, and calibration values. Under the most extreme conditions, with maximum slope (50Nm/Hz) and maximum offset (1000Hz) there is adequate buffer for transmission loss.

Table 12-4. Time until Overflow of Torque Ticks for a Given Cadence

Cadence (RPM)	Time until Overflow (seconds) for Output of 1000W	Time until Overflow (seconds) for Output of 300W
60	7	19
80	9	23
100	11	27
120	13	30
240	22	41

12.5 Encoding Crank Torque Frequency Messages

The torque ticks stamp is incremented every 2kHz clock cycle. When a cadence event occurs the current update event count is incremented by one, the time stamp of the 2kHz clock is recorded, and the value of the torque accumulator is incremented. At each channel period the information from the most current cadence event is broadcast.

12.6 Power Calculations Using Crank Torque Frequency Messages

The device that is receiving the Crank Torque Frequency main data pages must apply the following calculations to properly derive and display the computed bike power.

The ANT+ protocol calculates the average power and cadence over the pedal strokes that have occurred between the two most recently received messages. In most cases, this refers to a single crank rotation, since the received messages are consecutive. When degraded RF transmission results in packet loss, the ANT+ protocol maintains an accurate measurement of average power and cadence during the RF interruption.

In the following calculations, *N* refers to the most recent message received, and *N-1* refers to the message immediately preceding *N*.

12.6.1 Calculating Cadence

$$CadencePeriod = \frac{Timestamp_N - TimeStamp_{N-1}}{EventCount_N - EventCount_{N-1}} \times 0.0005s[s]$$

$$Cadence = round(60 / CadencePeriod)[rpm]$$

Equation 11. Calculation of Cadence using Crank Torque Frequency

12.6.2 Calculating Torque

$$ElapsedTime = (Timestamp_N - TimeStamp_{N-1}) \times 0.0005s$$

$$TorqueTicks = TorqueTicksStamp_N - TorqueTicksStamp_{N-1}$$

Equation 12. Calculations for Elapsed Time and Torque Ticks

$$TorqueFrequency = \left(\frac{1}{\frac{ElapsedTime}{TorqueTicks}} - Offset \right)[Hz]$$

The average torque per revolution of the pedal is calculated using the calibrated Offset parameter.

Equation 13. Calculation of Torque Frequency

Torque in Nm is calculated from torque rate (Torque Frequency) using the calibrated sensitivity Slope.

Equation 14. Calculation of Torque from the Torque Rate

Finally, power is calculated from the cadence and torque.

$$Power = \left(Torque \cdot Cadence \cdot \frac{\pi}{30} \right)[Watts]$$

$$Torque = \left(\frac{TorqueFrequency}{\frac{Slope}{10}} \right)[Nm]$$

Equation 15. Calculation of Power using Torque

12.7 Cadence Time Out

When the user stops pedaling, the update event count field in broadcast messages does not increment. After receiving 12 messages with the same update event count (approximately 3 seconds), the receiving device should change the cadence and power displays to zero.

13 Calibration Main Data Pages

Most power sensors have a procedure for periodic recalibration. ANT+ calibration data pages provide a standard means for a user-initiated calibration sequence to be coordinated between the sensor and display. For the crank torque frequency power sensor, calibration messages are used to assign or check configuration values in the power sensor memory.

Users may optionally initiate calibration via a display or directly from the sensor, for example by back pedalling or coasting during a ride. Therefore it is recommended that displays should accept spontaneous forward direction calibration messages, and display the calibration result to the user.

Because it is important to know that these messages have been received, all calibration messages sent from the display shall use ANT acknowledged messages. Firmware in the display device should be written so that messages are re-sent when ANT responds with EVENT_TRANSFER_TX_FAILED from the acknowledged message as there are no automatic retries using the acknowledged data transfers. **Note that the sensor shall respond to the calibration request using broadcast messages only. The sensor shall never send an acknowledged message to the display.** Firmware on the display should also account for the possibility of the devices becoming unsynchronized during a calibration request. In this case, a timeout for acknowledged messages is required.

Using ANT acknowledged messages means that calibration messages may be re-sent multiple times if they are not acknowledged. The sensor side must correctly handle repeated messages.

13.1 Standard Calibration Message Format

The standard calibration message format is shown below in Table 13-1.

Table 13-1. Standard Calibration Message Format

Byte	Description
0	Data Page Number
1	Calibration ID
2-7	Calibration data (defined by Calibration ID)

13.1.1 Calibration ID

The calibration ID is used to identify the operation requested and how to interpret the remaining contents of the message.

Table 13-2. Currently Defined Calibration IDs

Value	Description
0xAA	Calibration Request: Manual Zero
0xAB	Calibration Request: Auto Zero Configuration
0xAC	Calibration Response: Manual Zero Successful
0xAF	Calibration Response: Failed
0x10	Crank Torque Frequency (CTF) Power sensor Defined Message
0x12	Auto Zero Support
0xBA	Custom Calibration Parameter Request
0xBB	Custom Calibration Parameter Response
0xBC	Custom Calibration Parameter Update
0xBD	Custom Calibration Parameter Update Response

13.2 General Calibration Main Data Pages

In the most general case, a calibration request sent from the display device to the power sensor instructs the power sensor to begin calibration. The instructions required by the sensor for calibration vary for each manufacturer. The power sensor responds to the request with a calibration response message - the calibration was successful or the calibration failed. The sensor returns up to two bytes of calibration data.

13.2.1 General Calibration Request Main Data Page (0xAA)

Different power sensors may have different procedures for self-calibration, but in general they require the user to put the sensors in a known state. For example, a user with a crank-mounted power sensor might turn on the sensor without clipping his/her pedals in so that no torque is applied to the pedals.

The generic calibration request page (Table 13-3) is sent from the display device to the sensor to indicate that the specific conditions required for calibration have been met and that a calibration is requested.

Table 13-3. General Calibration Request Message Format

Byte	Description	Length	Value	Units
0	Data Page Number	1 Byte	0x01 (calibration message)	N/A
1	Calibration ID	1 Byte	0xAA (calibration request)	N/A
2	Reserved	6 Bytes	0xFF (reserved for future use)	N/A
3	Reserved			
4	Reserved			
5	Reserved			
6	Reserved			
7	Reserved			

13.2.2 Auto Zero Configuration Main Data Page (0xAB)

In addition to manually resetting offset values, some power sensors are able to maintain their offset values automatically. Settings for auto zero features are controlled using the Auto Zero Configuration page and are reported in all calibration responses.

Table 13-4. Auto Zero Configuration Message Format

Byte	Description	Length	Value	Units
0	Message ID	1 Byte	0x01 (Calibration Message)	N/A
1	Calibration ID	1 Byte	0xAB (Calibration Request: auto zero configuration)	N/A
2	Auto Zero Status	1 Byte	0x00 – Auto Zero OFF 0x01 – Auto Zero ON 0xFF – Auto Zero Not Supported	N/A
3	Reserved	5 Bytes	0xFF (reserved for future use)	N/A
4	Reserved			
5	Reserved			
6	Reserved			
7	Reserved			

The Auto Zero Configuration page is used to change the auto zero settings on the power sensor. The power sensor must indicate that auto zero features are enabled for this feature to be supported properly at the display. It is recommended that the auto zero capable power sensors regularly interleave Torque Meter Capabilities data page (0x12) (see Section 13.3).

- Displays are not required to support Auto-Zero configuration messages in the user interface. If auto zero configuration is not provided, the user cannot adjust auto zero with that display.

- Note that Auto Zero status is contained in all calibration messages, because the use of manual operations and the use of automatic operations are not exclusive.

13.2.3 General Calibration Response Main Data Page (0xAC/0xAF)

The general calibration response page is shown in Table 13-5. The power sensor transmits this page to the display device in response to a calibration request.

Table 13-5. General Calibration Response Message Format

Byte	Description	Length	Value	Units
0	Data Page Number	1 Byte	0x01 (Calibration Message)	N/A
1	Calibration ID	1 Byte	0xAC (Calibration Response Successful) 0xAF (Calibration Response Failed)	N/A
2	Auto Zero Status	1 Byte	0x00 – Auto Zero Is OFF 0x01 – Auto Zero Is ON 0xFF – Auto Zero Is Not Supported	N/A
3	Reserved	3 Bytes	Set to 0xFFFFFF	N/A
4	Reserved			
5	Reserved			
6	Calibration Data LSB	2 Bytes	This is a signed two-byte number allowing for values ranging from -32768 to +32767	N/A
7	Calibration Data MSB			

The last two bytes of this message are defined as the Calibration Data and are sent whether or not the Calibration ID is responding with a successful calibration response (0xAC) or a failure response (0xAF). This value is passed back from the sensor to the display to provide an indication to the user about the quality of the calibration. The Calibration Data bytes do not have units and may vary for each manufacturer. This value is a signed number allowing for both negative and positive data.

For example, upon completing calibration a torque-sensing power sensor could save the current zero-offset to the calibration data. A display can then show this value to the user each time a calibration is requested. In the case of a failed calibration, the sensor could use the calibration data bytes to report an error code.

NOTE: The calibration data is not used by the display to calculate or correct the power messages received by the sensor. It is intended to indicate the result of the calibration to the user. If the calibration data value is significantly different from the number the user is accustomed to seeing, it may indicate to the user that calibration should be performed again or that the power sensor requires service.

13.2.4 General Calibration Process Data Flow

Figure 13-1 describes the calibration data flow expected between the bike power sensor and the display device.

NOTE: The acknowledgement portion of the message, labeled 'ANT Ack*', is automatically sent by ANT. No application level code is required to send the acknowledgement; however, instead of waiting for the EVENT_TX message, the EVENT_TRANSFER_TX_COMPLETED or EVENT_TRANSFER_TX_FAILED is used as an event. Refer to the ANT Message Protocol and Usage document for more details.

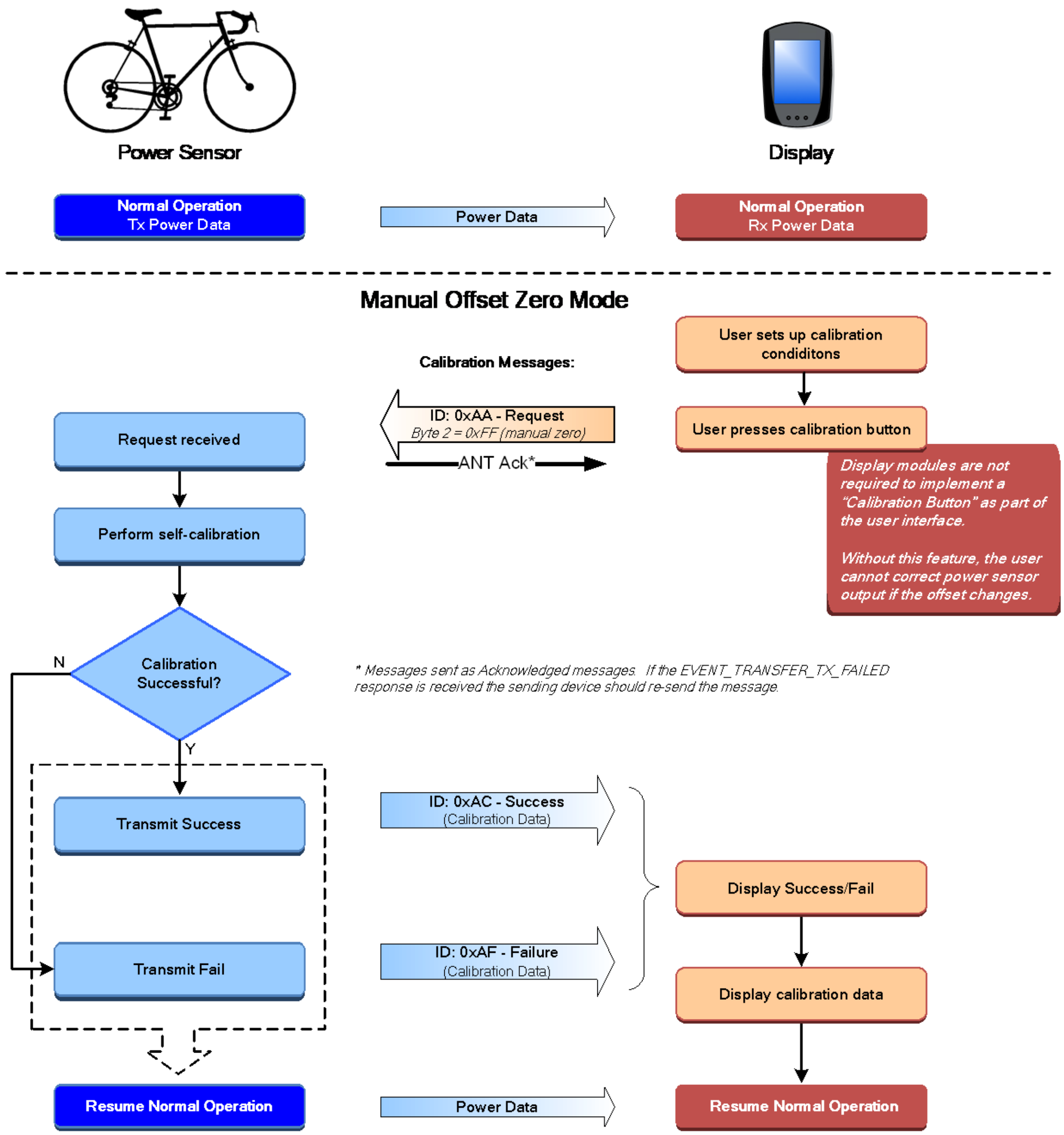


Figure 13-1. General Calibration Process Flow Chart

In Figure 13-2 the sequence diagram shows the same procedure as shown in the previous flow chart to give a different representation of the same procedure. In the event that the Display does not receive either an EVENT_TRANSFER_TX_SUCCESS or EVENT_TRANSFER_TX_FAILED, the Display shall resend the calibration request.

Note: Previous revisions of this profile described using acknowledged data types when sending calibration responses from the power sensor. Forward direction acknowledgement from sensor to display should be avoided as it introduces race conditions in the one-to-many network topology that this profile is designed to support. Messages sent from the Sensor to the Display should use broadcast data types only.

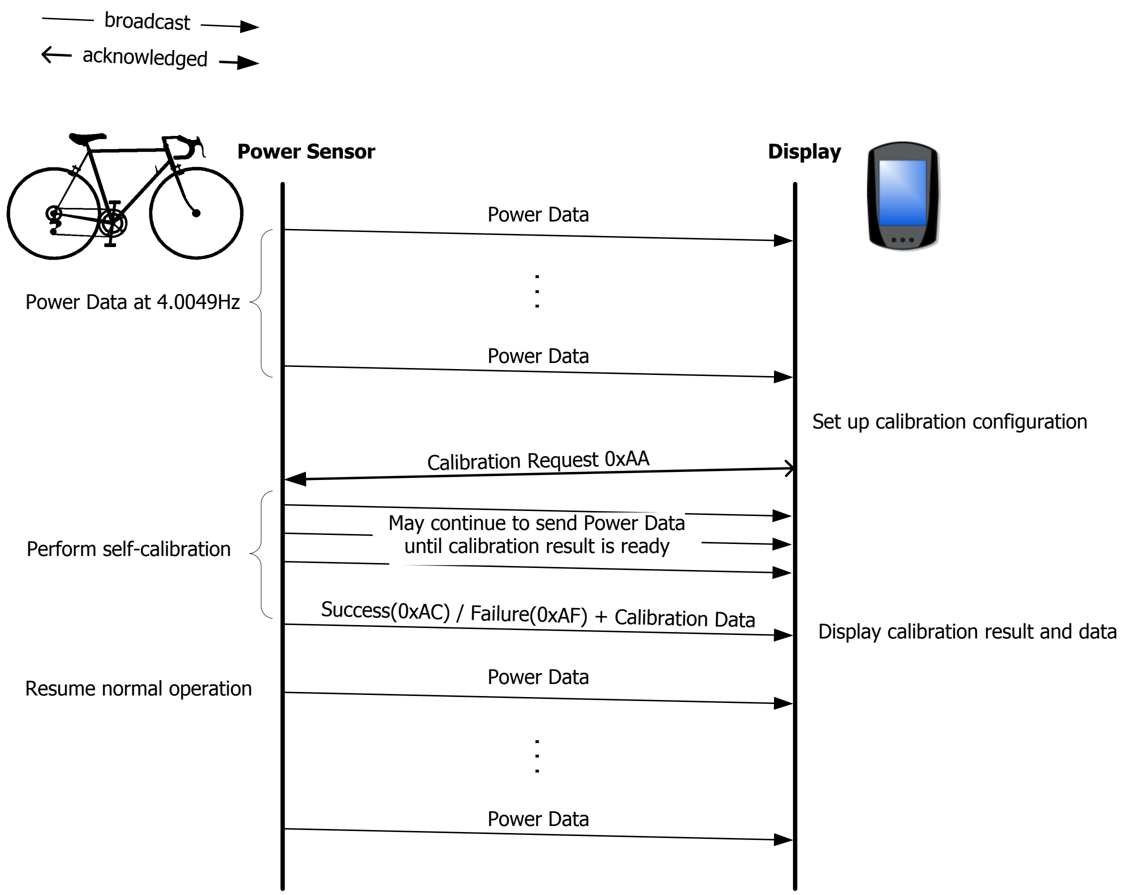


Figure 13-2. Calibration Process Sequence Diagram

13.2.5 Auto Zero Configuration Data Flow

Figure 13-3 describes the data flow expected between the bike power sensor and the display device for setting the Auto Zero configuration. It is important to note that the acknowledged portion of the message, labeled 'ANT Ack*', is automatically sent by ANT. No application level code is required to send the acknowledgement; however, instead of waiting for the EVENT_TX message, the EVENT_TRANSFER_TX_COMPLETED or EVENT_TRANSFER_TX_FAILED is used as an event. Refer to the ANT Message Protocol and Usage document for more details.

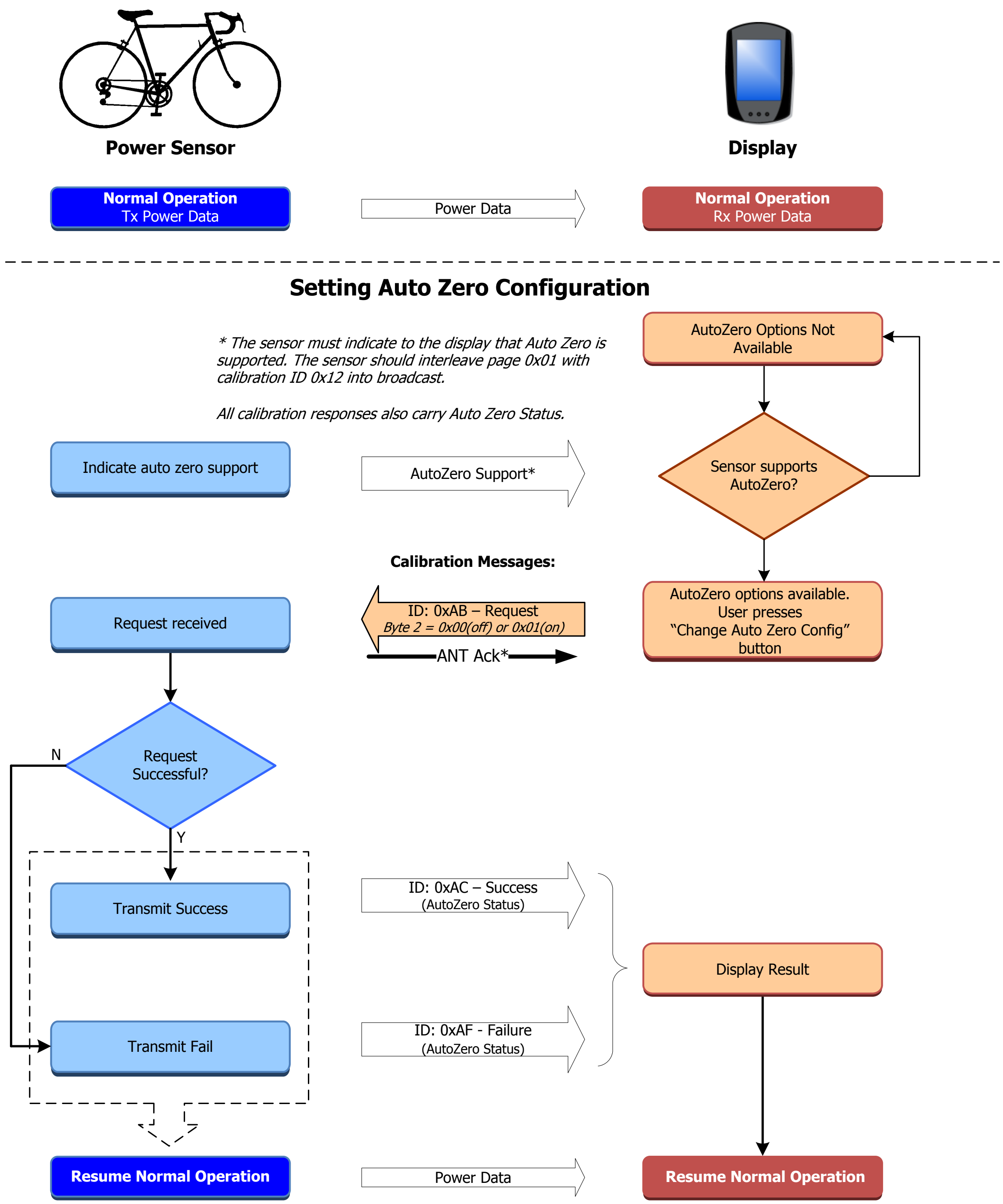


Figure 13-3. Auto Zero Configuration Flow Chart

Figure 13-4 shows the message flow that is also described in Figure 13-3. It illustrates the display receiving the calibration message described in section 13.3, which shows that the power sensor supports Auto Zero, and indicates whether it is currently on or off. The display therefore allows the user to change the auto zero settings and receives a success or failure response from the power sensor, before resuming normal operation.

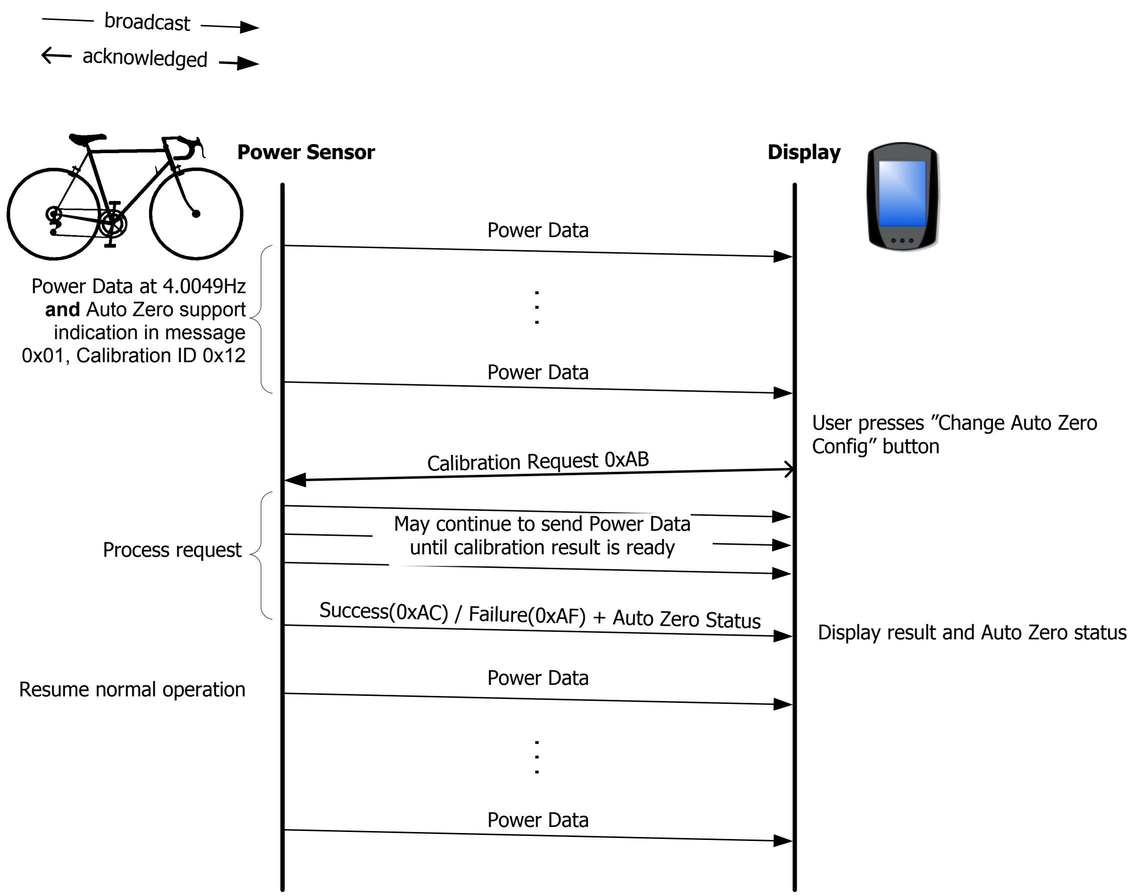


Figure 13-4. Auto Zero Configuration Sequence Diagram

13.3 Auto Zero Support Main Data Page

The Torque Meter Capabilities page is defined to allow extended information to be passed from the sensor to the display. The message provides status information on auto zero functions. The information does not need to be interpreted by the display for proper calculation of power.

For the display to support auto zero functions, the Torque Meter Capabilities main data page should be interleaved at least once every 121 messages.

Table 13-6. Auto Zero Support Message Format

<table>
<tr><th>Byte</th><th>Description</th><th>Length</th><th colspan="2">Value</th><th>Units</th></tr>
<tr><td>0</td><td>Data Page Number</td><td>1 Byte</td><td colspan="2">0x01 (Calibration Message)</td><td>N/A</td></tr>
<tr><td>1</td><td>Calibration ID</td><td>1 Byte</td><td colspan="2">0x12 Auto Zero Support message</td><td>N/A</td></tr>
<tr><td rowspan="5">2</td><td rowspan="5">Sensor Configuration Descriptive Bit Field</td><td rowspan="5">1 Byte</td><td rowspan="2">0 – Auto Zero Enable</td><td>0 – Not Supported</td><td rowspan="5"></td></tr>
<tr><td>1 - Supported</td></tr>
<tr><td rowspan="2">1 – Auto Zero Status</td><td>0 – Auto Zero Off</td></tr>
<tr><td>1 – Auto Zero On</td></tr>
<tr><td>2 – 7 – Reserved</td><td>Value = 0</td></tr>
<tr><td>3</td><td>Reserved</td><td rowspan="5">5 Bytes</td><td colspan="2" rowspan="5">0xFF (reserved for future use)</td><td rowspan="5">N/A</td></tr>
<tr><td>4</td><td>Reserved</td></tr>
<tr><td>5</td><td>Reserved</td></tr>
<tr><td>6</td><td>Reserved</td></tr>
<tr><td>7</td><td>Reserved</td></tr>
</table>

13.3.1 Reserved Bytes

In earlier revisions of this device profile, bytes 3 through 6 were specified as raw and offset torque values. These values were not in use in the field and have been removed from this page.

13.3.2 Sensor Configuration

Byte 2 of the message is a bit field providing information about the power sensor, including whether the power sensor supports auto zero functions.

13.4 Get/Set Custom Calibration Parameters

Some power sensors may support custom calibration parameters that can be set by a display to customize performance. The 'Custom Calibration Parameters' messages provide a common method for requesting and setting custom calibration data on the power sensor.

Support for this messaging is optional, and the interpretation of the custom calibration parameters is controlled by the manufacturer, not ANT+. Table 13-7 lists the available custom calibration messages.

Table 13-7. Custom Parameter Request

Byte	Description	Length	Value	Units
0	Data Page Number	1 Byte	0x01 (Calibration Message)	N/A
1	Calibration ID	1 Byte	0xBA (Request Custom Calibration Parameters) 0xBB (Custom Calibration Parameter Response) 0xBC (Set Custom Calibration Parameter) 0xBD (Set Custom Parameters Successful)	N/A
2	Reserved	6 Bytes	Manufacturer Specific	N/A
3	Reserved			
4	Reserved			
5	Reserved			
6	Reserved			
7	Reserved			

Figure 13-5 below describes the expected data flow between the bike power sensor and display for requesting or setting the custom calibration parameters. Note, this process makes use of acknowledged messages. Note that ANT automatically handles the acknowledgement (ANT Ack*). The application does not need additional code to send the acknowledgement; however, instead of waiting for the EVENT_TX message, EVENT_TRANSFER_TX_COMPLETED or EVENT_TRANSFER_TX_FAILED will be received and should be handled accordingly. Refer to the ANT Message and Protocol and Usage document for more details.

Note: If the 'Set Parameters' request is not successful, a 'Calibration Failed' (0xAF) is returned.

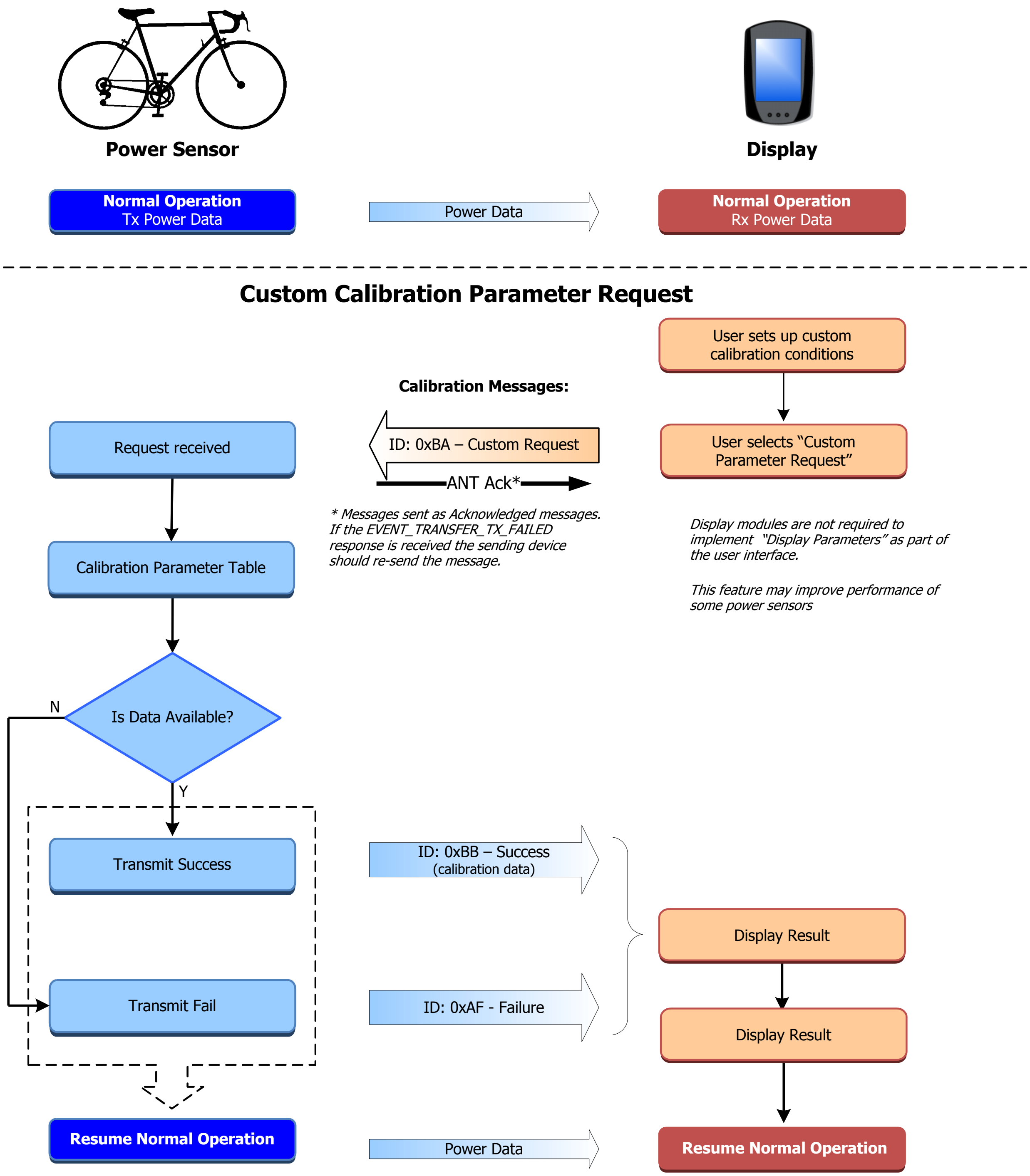


Figure 13-5. Request Custom Parameter Process Flow Chart

Figure 13-6 shows the sequence diagram of the same request custom calibration parameter procedure. Note that normal operation does not resume until the calibration result is successfully received by the power meter sensor.

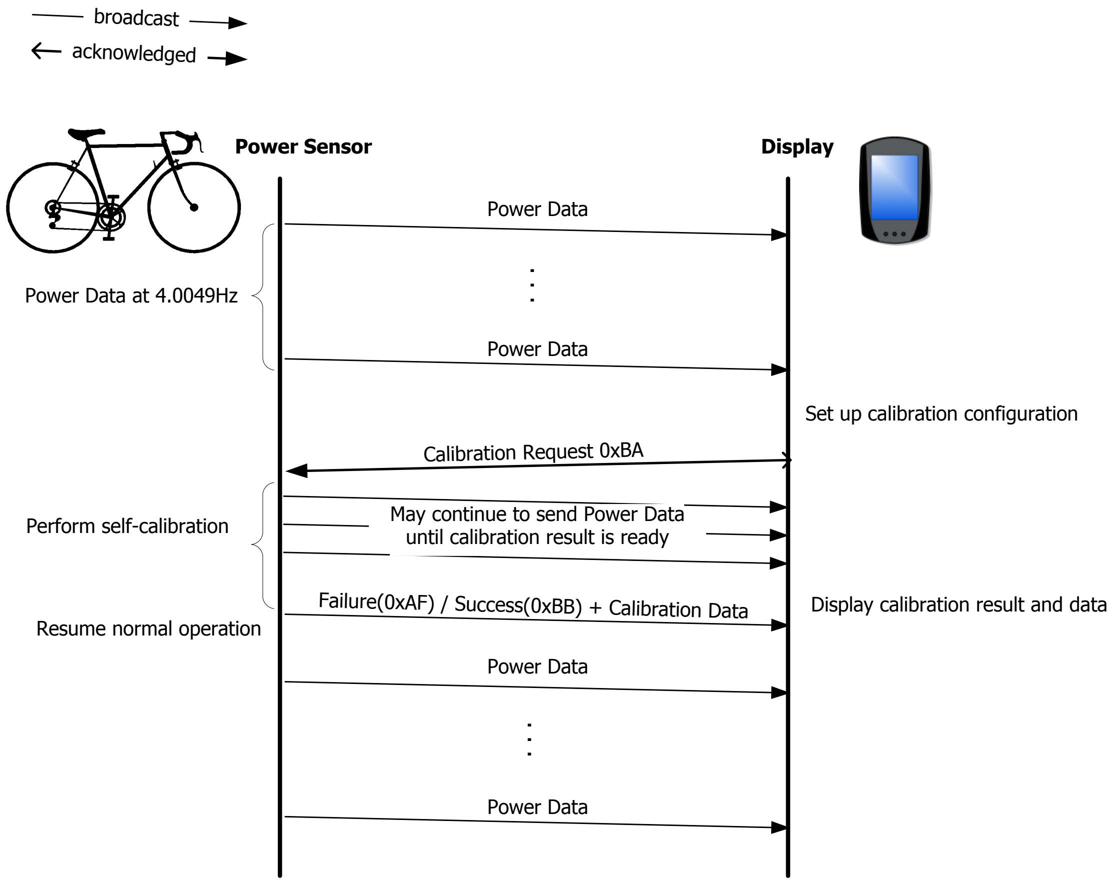


Figure 13-6. Custom Calibration Request Sequence Diagram

Figure 13-7 and Figure 13-8 show the flow chart and sequence diagram of the set custom calibration parameter procedure.

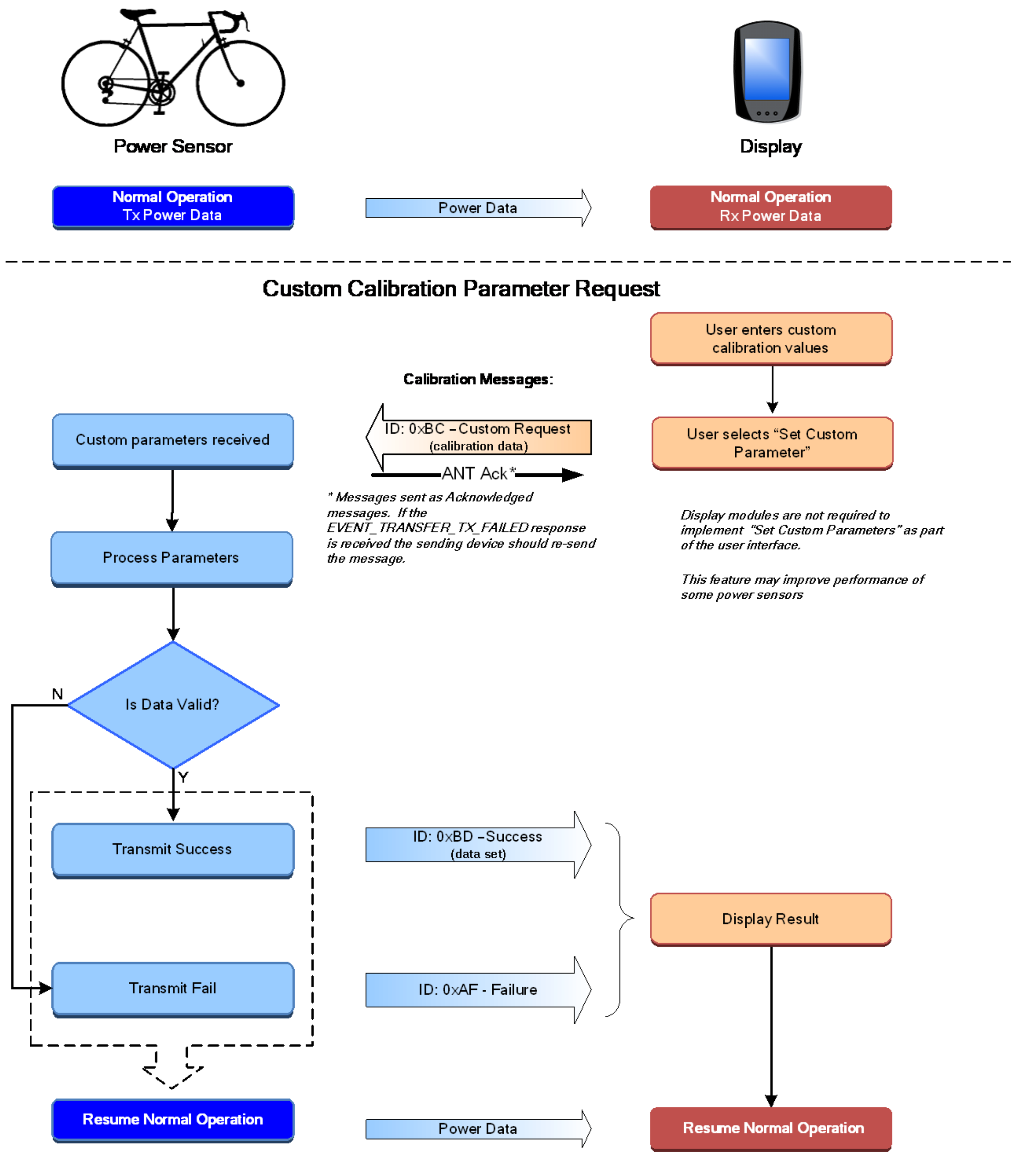


Figure 13-7. Set Custom Parameter Process Flow Chart

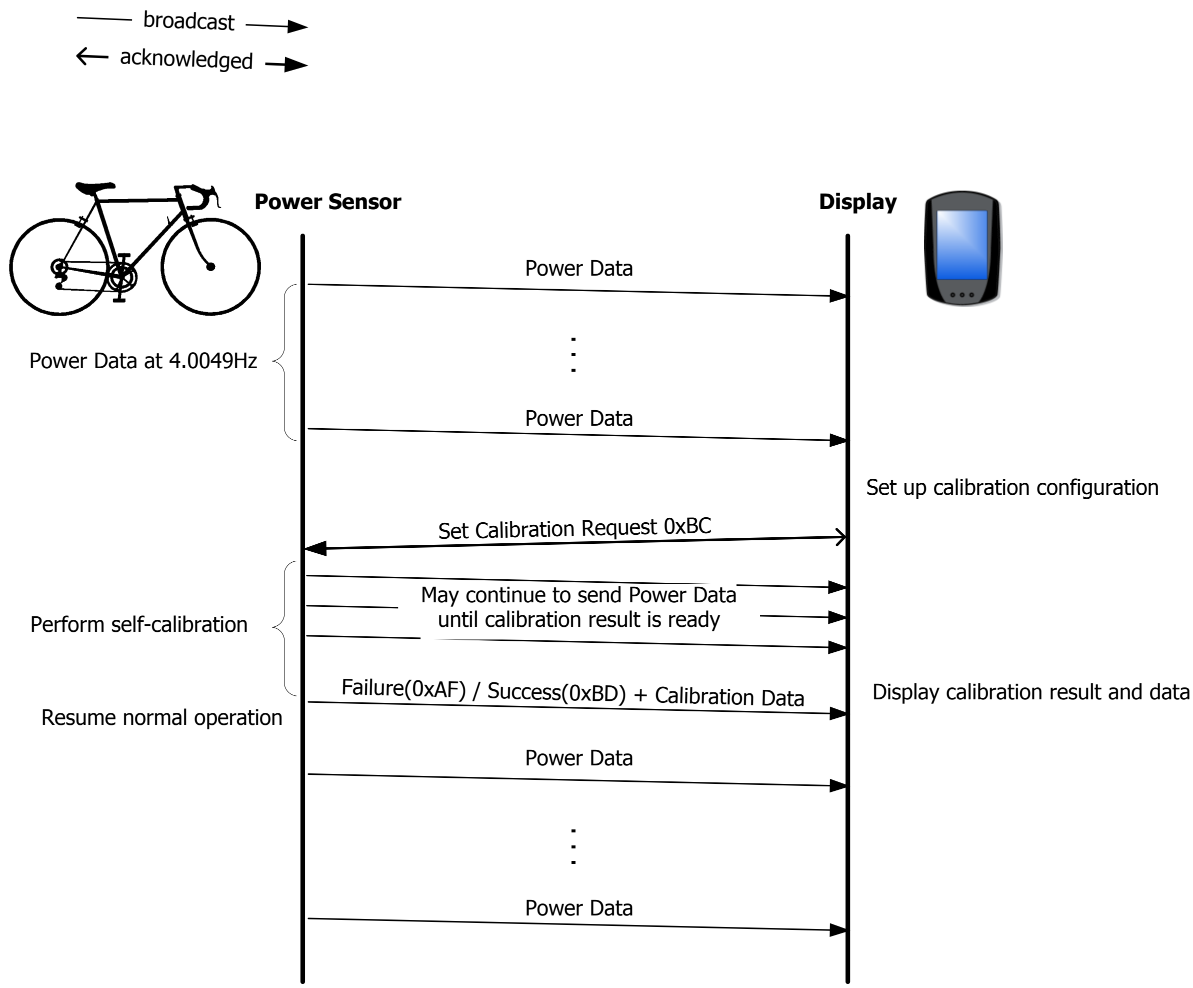


Figure 13-8. Set Custom Calibration Sequence Diagram

13.5 Torque-Frequency Defined Calibration Main Data Pages

Calibration pages specific to crank torque-frequency type power sensors (CTF) are used to pass the serial number, slope, and offset information. The second byte (Byte 1) of the calibration message specifies the type of data being sent (i.e. CTF defined message). The Request for CTF calibration data is sent using an acknowledged message from the display. The power sensor shall respond using broadcast messages. Byte 2 is used to identify the CTF defined message that is being sent. Currently, only four CTF Defined messages are supported, but this may be expanded in the future.

NOTE: All Torque-Frequency Defined calibration messages are big endian. The power sensor must transmit the value 0xFF for all byte fields marked as 'Reserved'. The receiver must not interpret these values.

Table 13-8. CTF Defined Calibration Messages

Calibration Parameter	CTF Defined ID	Value	Units
Offset	0x01	0 – 65535	Hz
Slope	0x02	100 – 500	1/10 Nm/Hz
Serial Number	0x03	0 – 65535	N/A
Acknowledgement	0xAC	N/A	N/A

13.5.1 Calibration Process for a Torque-Frequency Power Sensor

There are two ways to put a CTF power sensor into calibration mode:

- the display sends a calibration request page and the power sensor responds with calibration data
- the power sensor automatically sends calibration data when the bike has been coasting for more than 5 seconds.

When the display requests the calibration, it will send the request data page shown in Table 13-3. On receiving the request, the power sensor responds for 10 seconds with a Torque Frequency Calibration Response page as outlined in Table 13-9.

Table 13-9. Torque Frequency Calibration Response Message Format

Byte	Description	Length	Value	Units
0	Data Page Number	1 Byte	0x01 (calibration message)	N/A
1	Calibration ID	1 Byte	0x10 (CTF defined message)	N/A
2	CTF Defined ID	1 Byte	0x01 (Zero Offset)	N/A
3	Reserved	3 Bytes	0xFF (reserved for future use)	N/A
4	Reserved			
5	Reserved			
6	Offset MSB	2 Bytes	0 – 65535	N/A
7	Offset LSB			

If the sensor has not detected a cadence event when the 10-second period expires, the power unit shuts off.

NOTE: Previous revisions of this device profile described using acknowledged messages for CTF offset response pages. To prevent possible race conditions in a one to many topology, only broadcast messages shall be sent from a power sensor.

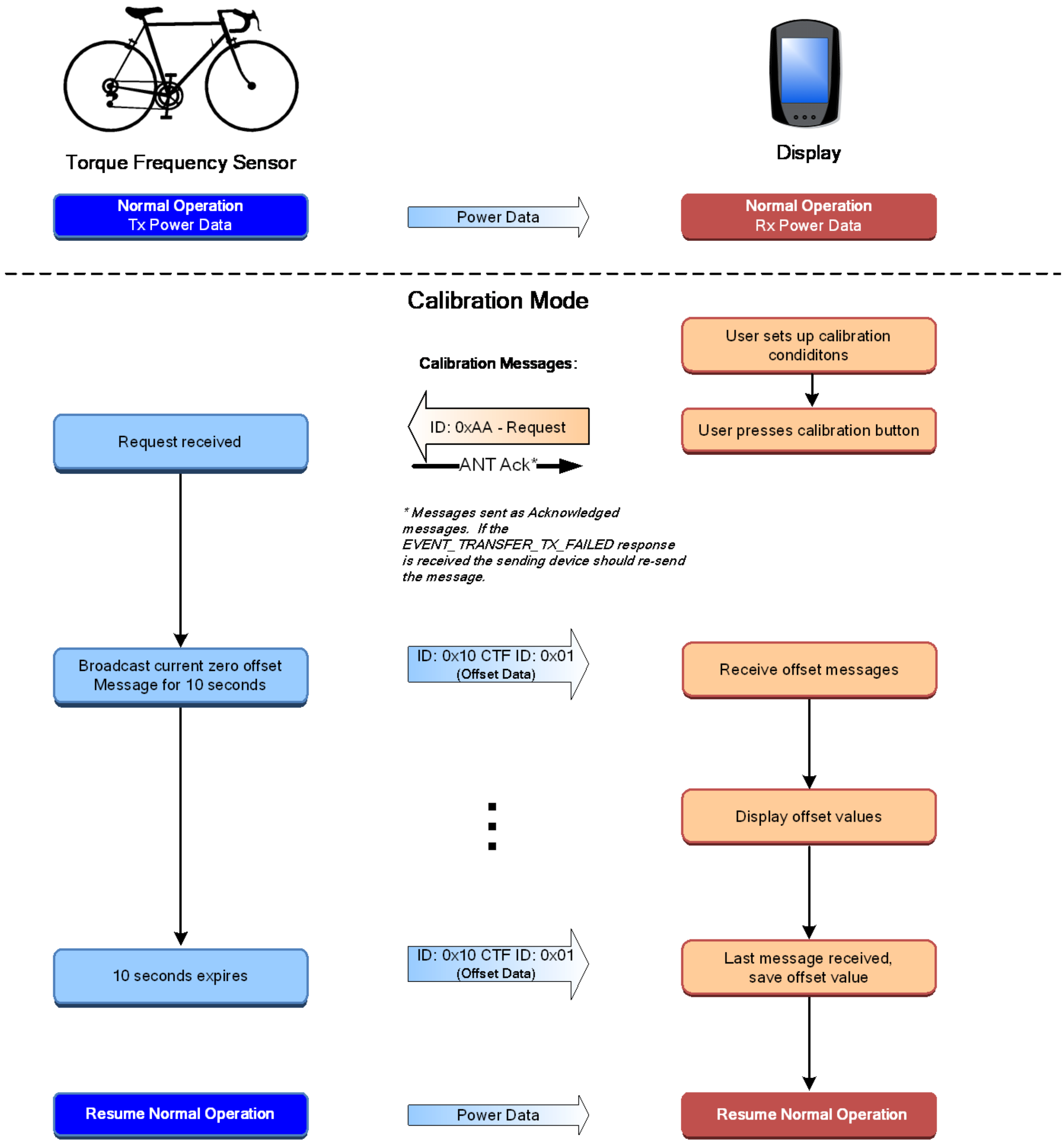


Figure 13-9. Torque Frequency Calibration Flow Chart

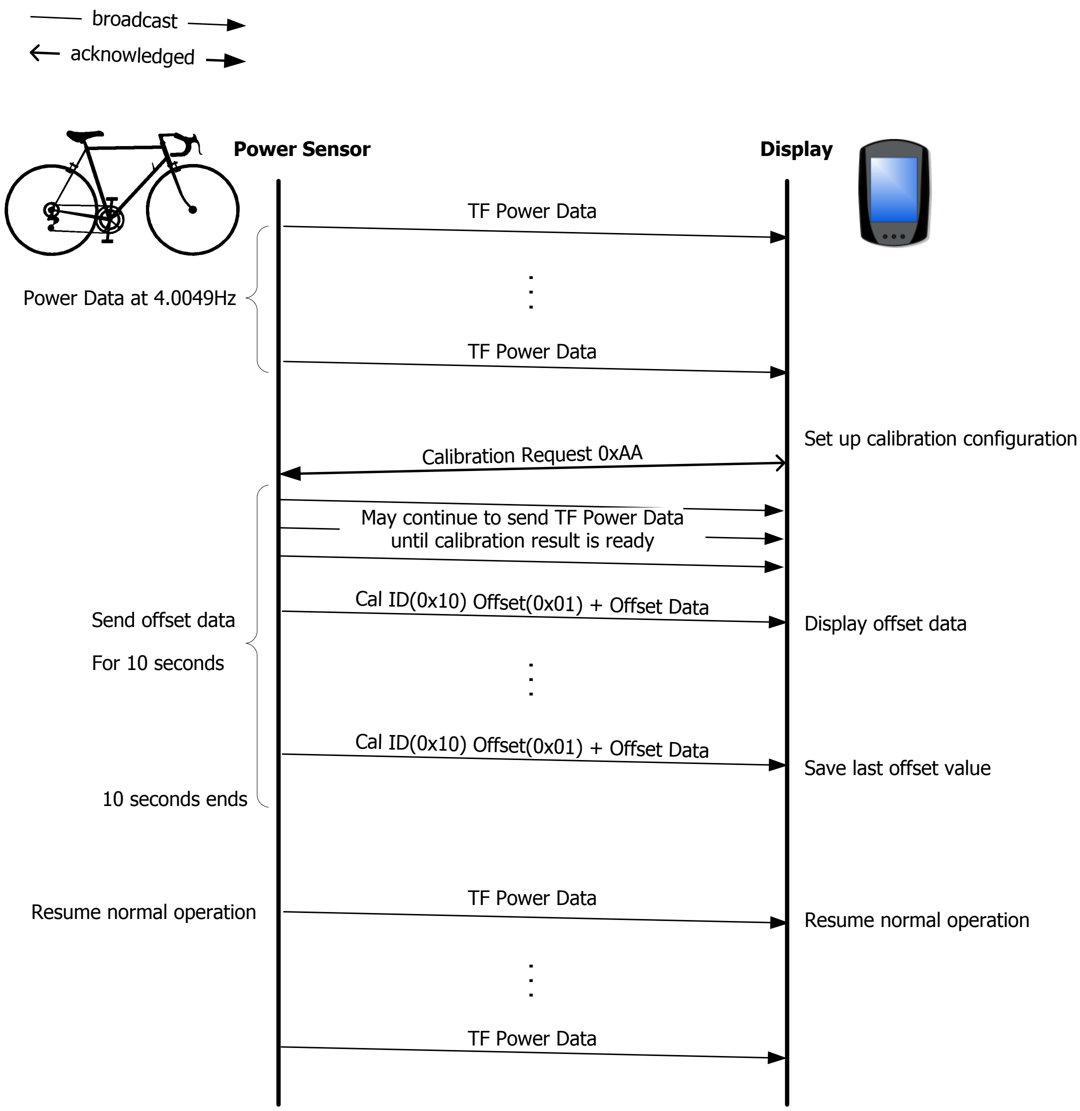


Figure 13-10. Torque Frequency Calibration Process Sequence Diagram

The second calibration use case is when the bike is coasting for more than 5 seconds. Coasting is defined as zero pedal events, and speed must be 5 km/h or greater over during the calibration period (i.e. bike must be moving the entire time). After 5 seconds of coasting, the power sensor will send the Torque Frequency Calibration Response page as outlined in Table 13-9 and shown in Figure 13-11.

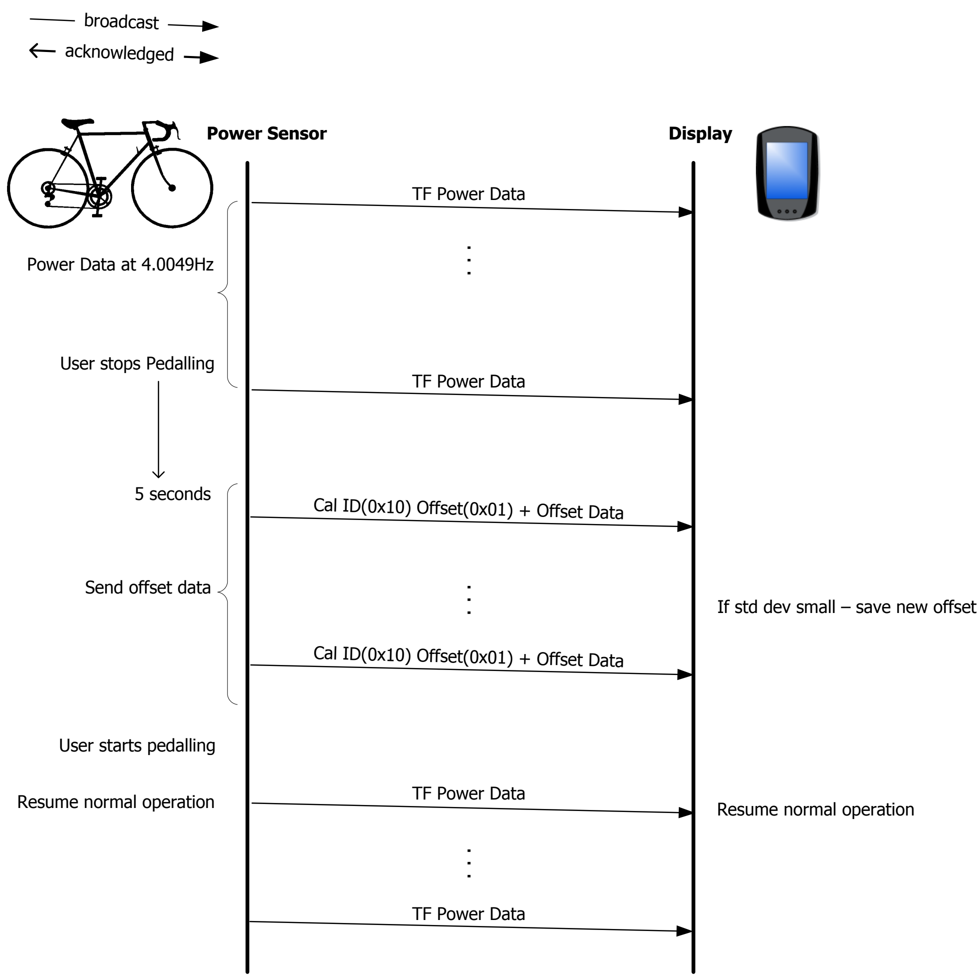


Figure 13-11. Coasting Offset Calibration Example

The transmitted offset value should be averaged over at least 5 samples during the coasting period. The standard deviation between the previous and current sample should be within +/- 4Hz. If the standard deviation of the received messages is within this +/- 4Hz range, the display shall save the sampled average as the new offset value.

13.5.2 Save Slope to Flash Main Data Page

To save a new value for slope to the power sensor flash, the display unit sends a CTF defined calibration message for slope to the power sensor.

Table 13-10. Torque Frequency Calibration Request for Slope Message Format

Byte	Description	Length	Value	Units
0	Data Page Number	1 Byte	0x01 (calibration message)	N/A
1	Calibration ID	1 Byte	0x10 (CTF defined message)	N/A
2	CTF Defined ID	1 Byte	0x02 (Slope)	NA
3	Reserved	3 Bytes	0xFF (reserved for future use)	N/A
4	Reserved			
5	Reserved			
6	Slope MSB	2 Bytes	100–500	1/10 Nm/Hz
7	Slope LSB			

When the power sensor receives the set slope value it responds with the CTF acknowledgement message (Table 13-11), which is sent as a broadcast message to the display device.

Table 13-11. Torque Frequency Calibration Response for Slope Message Format

Byte	Description	Length	Value	Units
0	Data Page Number	1 Byte	0x01 (calibration message)	N/A
1	Calibration ID	1 Byte	0x10 (CTF defined message)	N/A
2	CTF Defined ID	1 Byte	0xAC (Acknowledgement)	N/A
3	CTF ACKed Message	1 Byte	0x02 (Slope CTF message)	N/A
4	Reserved	4 Bytes	0xFF (reserved for future use)	N/A
5	Reserved			
6	Reserved			
7	Reserved			

NOTE: The successful setting of slope data can also be confirmed by checking the slope value in the next regular power message.

13.5.3 CTF: Save Serial to flash

To save a new serial number to the power sensor flash, the display device sends a CTF defined message for serial number to the power sensor.

NOTE: this message is intended only for use by CTF sensor manufacturers. It is not recommended that other CTF displays support this message.

Table 13-12. Torque Frequency Request to Save Serial Number in Flash Message Format

Byte	Description	Length	Value	Units
0	Message ID	1 Byte	0x01 (calibration message)	N/A
1	Calibration ID	1 Byte	0x10 (CTF defined message)	N/A
2	CTF Defined ID	1 Byte	0x03 (Serial Number)	N/A
3	Reserved	3 Bytes	0xFF (reserved for future use)	N/A
4	Reserved			
5	Reserved			
6	Serial Number MSB	2 Bytes	0 - 65535	N/A
7	Serial Number LSB			

When the power sensor receives the set value it responds with the CTF acknowledgement message (Table 13-13), which is sent as a broadcast message to the display device.

Table 13-13. Torque Frequency Response to Save Serial Number in Flash Message Format

Byte	Description	Length	Value	Units
0	Data Page Number	1 Byte	0x01 (calibration message)	N/A
1	Calibration ID	1 Byte	0x10 (CTF defined message)	N/A
2	CTF Defined ID	1 Byte	0xAC (Acknowledgement)	N/A
3	CTF ACKed Message	1 Byte	0x03 (Serial Number)	N/A
4	Reserved	4 Bytes	0xFF (reserved for future use)	N/A
5	Reserved			
6	Reserved			
7	Reserved			

14 Bicycle Power Meter Get/Set Parameters (Page 0x02)

The Get/Set Bicycle Parameters page is used to pass ANT+ defined common information between a display and sensor. It is similar in purpose to the 'Custom Calibration Parameters', but the information is defined by ANT+ and contains common information that may be relevant to multiple manufacturers.

The display may set common bicycle parameters, such as Crank Length, by sending this page to the power meter sensor. The display may also request this data using the Request Data Page (common page 70).

Support for the Get/Set Parameters page is not required for interoperability. Power meter sensors that do not support this page shall ignore the request. Displays shall handle this lack of response gracefully.

14.1 Basic Format

The Get/Set Parameters page uses sub-paging to provide extensibility. The content of the remaining 6 bytes is defined by the subpage number as shown in Table 14-1.

Table 14-1. Get/Set Parameter Page Format

Byte	Description	Length	Value	Units	Rollover or Valid Range
0	Data Page Number	1 Byte	0x02 – Get/Set Bicycle Parameters	N/A	N/A
1	Subpage Number	1 Byte	Subpage Number	N/A	N/A
2-7	Subpage Defined Data	6 Bytes	Data contents defined by Subpage number. Refer section 14.2.	N/A	N/A

14.1.1 Setting Parameters

To set parameters on the power meter sensor, the display shall send a data page 0x02 containing the desired data and the relevant subpage. Any subpage fields that are read only will be ignored by the sensor and should be set to 0x00. The read only fields are set by the sensor and are populated when sent from the sensor to the display (i.e. in a Get command). The Set message should be sent from the display using an acknowledged message. After receiving the Set message, the sensor does not send any messages to confirm that the values have been changed. To confirm the values on the sensor, the display will use the standard Request Data Page (common page 70).

14.1.2 Requesting Parameters

To confirm or query parameters on the sensor, the display may send a Request Data Page (using common page 70). Refer to the ANT+ Common Pages document for more details.

An example of the Request Data Page (page 70) for a display requesting subpage 0x01 is shown in Table 14-2.

Table 14-2. Common Page 70 Format for Requesting Parameters

Byte	Description	Length	Value	Units
0	Command ID	1 Byte	70 (0x46) – Data Page Request	N/A
1	Reserved	1 Byte	Value = 0xFF	N/A
2	Reserved	1 Byte	Value = 0xFF	N/A
3	Descriptor Byte 1	1 Byte	1 (0x01) for requesting subpage 1 (i.e. crank parameters)	N/A
4	Descriptor Byte 2	1 Byte	Invalid: 255 (0xFF)	N/A
5	Requested Transmission Response	1 Byte	Set As desired Note: a display may not request acknowledged data from the power sensor	N/A
6	Requested Page Number	1 Byte	0x02 for requesting the Get/Set Parameter page	N/A
7	Command Type	1 Byte	Value = 1 (0x01) for Requesting a Data Page	N/A

14.2 Subpages

14.2.1 Subpage 0x01 – Crank Parameters

The Crank Parameters subpage allows the length of the user's crank to be set in 0.5 mm increments from 110 to 236.5 mm. When this page is requested by the display, the sensor shall communicate its current Crank Length value. It can also report the status of firmware on systems with multiple sensors (such as pedal, cleats, or cranks).

Table 14-3. Subpage 1 - Crank Parameters Format

Byte	Description	Length	Value	Units	Rollover or Valid Range
0	Data Page Number	1 Byte	0x02 – Set/Get Bicycle Parameters	N/A	N/A
1	Subpage Number	1 Byte	0x01 Crank Parameters	N/A	N/A
2	Reserved	2 Bytes	0xFF Reserved	N/A	N/A
3	Reserved				
4	Crank Length Value	1 Byte	CL Value = (Full Crank Length – 110mm)/0.5 Set to 0xFF if invalid. Display sets to 0xFE to request AutoCrank	0.5 mm	110.0 – 236.5mm
5	Sensor Status	1 Byte	From Display: Read only, set to 0x00 From Sensor: Status bit field. Refer Table 14-4.	N/A	N/A
6	Sensor Capabilities	1 Byte	From Display: Read only, set to 0x00 From Sensor: Sensor capabilities bit field. Refer to Table 14-5	N/A	N/A
7	Reserved	1 Byte	Reserved: 0xFF	N/A	N/A

14.2.1.1 Crank Length

Byte 4 of the Crank Parameters subpage describes the length of the user's crank in millimeters. This field may be calculated in real time by the sensor, or some systems may require the user to set this value.

The scale of the crank length value is 0.5 mm, and an offset of 110 mm must be added to the received value to calculate full crank length.

Examples:

(1) To indicate that the crank length is 172.5, the value in the Crank Length field is sent as 125.

(172.5 mm– 110.0 mm)/0.5 mm = 125.

(2) A value of 130 is received in the Crank Length field. The length of the crank is 175 mm

130*0.5 mm + 110.0 mm = 175 mm

Special Values

The value 0xFF is used to set the crank length to invalid.

A value of 0xFE is used by a display to set the calculation of crank length to be automatically determined by the sensor. This is used only by sensors that indicate automatic crank length support in the capabilities bit field described in Section 14.2.1.3.

14.2.1.2 Sensor Status Bit Field

Byte 5 of the Crank Parameters subpage describes the status of sensors in a two sensor system; including which sensors are present, whether they have matching firmware and the method used to set the crank length. Byte 5 is read only, and shall be set to 0x00 when this subpage is sent by the display. The following table describes the bit field.

Table 14-4. Sensor Status Bit Field Description

Bit	Description	Value
0 1	Crank Length Status	00 - Crank length Invalid 01 - Default crank length used 10 - Crank length manually set 11 - Crank length automatically set
2 3	Sensor SW Mismatch Status	00 - Undefined 01 - SW mismatch, Right sensor is older 10 - SW Mismatch, Left sensor is older 11 - SW on left and right sensor is the same
4 5	Sensor Availability Status	00 – Undefined 01 – Left Sensor Present 10 – Right Sensor Present 11 – Left and Right Sensor Present
6 7	Custom Calibration Status	00 – Undefined 01 – Custom calibration not required 10 – Custom calibration required 11 – Reserved for future use

14.2.1.3 Sensor Capabilities

Byte 6 of the Crank Parameters subpage describes the capabilities of the sensor related to Crank Parameters. Bit 0 describes whether the sensor is capable of determining the length of the crank automatically; all other bits are reserved.

Byte 6 is read only when using the Crank Parameters page to set values, and shall be set to 0x00 when this subpage is sent by the display. The following tables describe the bit field.

Table 14-5. Sensor Capabilities Bit Field

Bit	Description	Value
1:7	Reserved	Set to 0. Do not interpret.
0	Auto Crank Length	0: The head unit should manually set the crank length 1: The sensor is capable of automatically determining crank length

15 Measurement Output Data Page (0x03)

The measurement output data page is an optional page that may be used by PWR sensors (including power-only, torque at wheel and torque at crank). It is intended to provide a richer user experience during the calibration process by providing raw system measurements and/or an indication of progress. **The measurement output data page shall only be sent as a broadcast message from the sensor to the display.**

Display manufacturers are encouraged to display the values sent using this page to give the user feedback during calibration and provide access to additional diagnostic information available from the sensor. For example, this page may be used to send countdown values while the sensor is processing a calibration request, enabling the display to indicate to the user how far the sensor has progressed through the calibration process e.g. using a progress bar. Other measurement output messages may also be sent both during and after calibration is completed. Refer to section 15.6 for an example message flow.

The sensor shall return to sending power data in the normal transmission pattern when triggered by any one of the following events:

- The user begins to pedal (recommended as best practice)
- A time-out occurs (optional)
- The sensor receives a request for page 0x10 e.g. in response to user input as described in section 16.2.1 (mandatory)

This data page shall not be sent as part of the normal power data transmission pattern.

If a sensor needs to send several different values, this message can be updated to rotate through those values. In this case the display may optionally make a multi-field display available, or allow the user to scroll through the values. **Note that sensors shall not send more than one variable of a given data type at any one time.**

Table 15-1. Measurement Output Message Format

Byte	Description	Length	Value	Units	Rollover or Valid Range
0	Data Page Number	1 Byte	0x03 – Measurement Output	N/A	N/A
1	Bits 0-3: Number of Data Types	4 Bits	Set to the number of data types currently being transmitted. Refer to section 15.1	N/A	1-11
	Reserved	4 Bits	Reserved for future use, set to 0x00	N/A	N/A
2	Data Type	1 Byte	Data type and engineering units applicable to the measurement value. Refer to Table 15-2	N/A	N/A
3	Scale Factor	1 Byte	Binary decimal justification	2^x	-127 to 127
4	Timestamp LSB	2 Bytes	Timestamp corresponding to the measurement instant	1/2048s	32s
5	Timestamp MSB				
6	Measurement Value LSB	2 Bytes	Data value, signed	As specified	-32768 to 32767
7	Measurement Value MSB				

Note: all fields in the measurement output data page are required fields.

15.1 Number of Data Types

Number of data types is a required field that allows the display to format the data it receives effectively. This field should be set to the number of data types currently being transmitted from the sensor. I.e. if the sensor is only sending measurement output data pages containing a countdown value, it should be set to 1. Or if the sensor is currently sending measurement output data pages containing torque, force, zero offset and temperature values, then this field should be set to 4.

15.2 Data Type

The data type field specifies the parameter that is encoded in the measurement value field as described in Table 15-2.

Table 15-2. Currently Defined Data Types

Value	Data Type	Units	Description
0	Countdown (progress bar)	%	Percentage of process remaining until process is complete.
1	Countdown (time)	s	Seconds remaining until process is complete.
2 - 7	Reserved	N/A	Reserved for future use
8	Torque (whole sensor)	Nm	Forward driving torque is represented as positive, back-pedalling torque is represented as negative
9	Torque (left)	Nm	Torque applied to the left pedal. Forward driving torque is represented as positive, back-pedalling torque is represented as negative
10	Torque (right)	Nm	Torque applied to the right pedal. Forward driving torque is represented as positive, back-pedalling torque is represented as negative
11-15	Reserved	N/A	Reserved for future use
16	Force (whole sensor)	N	Forward driving force is represented as positive, back-pedalling force is represented as negative
17	Force (left)	N	Force applied to the left pedal. Forward driving force is represented as positive, back-pedalling force is represented as negative
18	Force (right)	N	Force applied to the right pedal. Forward driving force is represented as positive, back-pedalling force is represented as negative
19-24	Reserved	N/A	Reserved for future use
24	Zero-offset	No units	Scalar value representing the zero offset
25	Temperature	degC	Sensor temperature
26	Voltage	V	Voltage measured within the sensor
27-255	Reserved	N/A	Reserved for future use.

15.3 Scale Factor

The scale factor field describes the location of the binary decimal point in the data value. A positive scale factor x implies that the measurement value should be multiplied by 2^x to obtain the desired parameter value, while a negative scale factor -x implies that the measurement value has a fractional component of x bits.

Example: To encode a value of 3.375 Nm with 5 bits of fractional significance, the scale factor is set to -5 and the measurement value is set to 108, as illustrated in Figure 15-1.

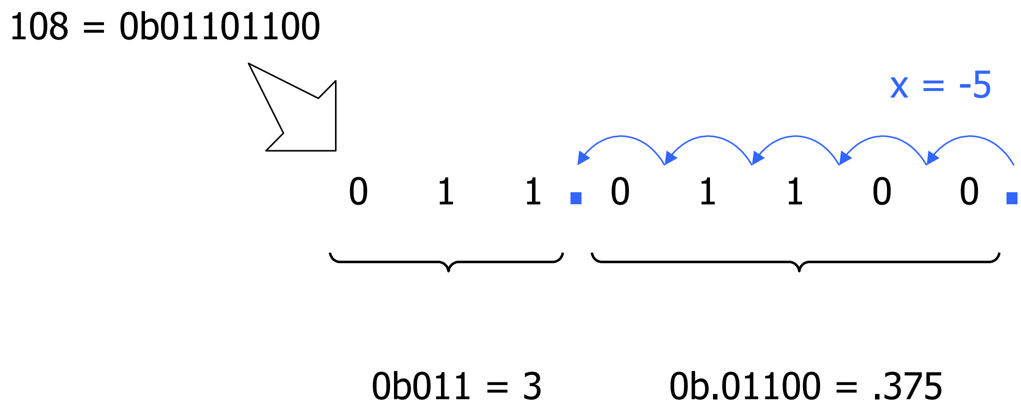


Figure 15-1. Example showing how to send a Scaled Value

15.4 Timestamp

The timestamp field is used to report the time instant of the measurement. This can be useful in the case where the measurement value is changing as a function of time.

15.5 Measurement Value

The measurement value field is used to encode the desired parameter. The value is signed; values larger than 32767 or with fractional significance can be encoded using the scale factor field as described in section 15.3.

15.6 Use of the Measurement Output Data Page

Figure 15-2 shows an example usage of the measurement output data page, and illustrates how this data can be displayed to the user. This message flow provides an optional alternative to the standard calibration process message flow described in Figure 13-2.

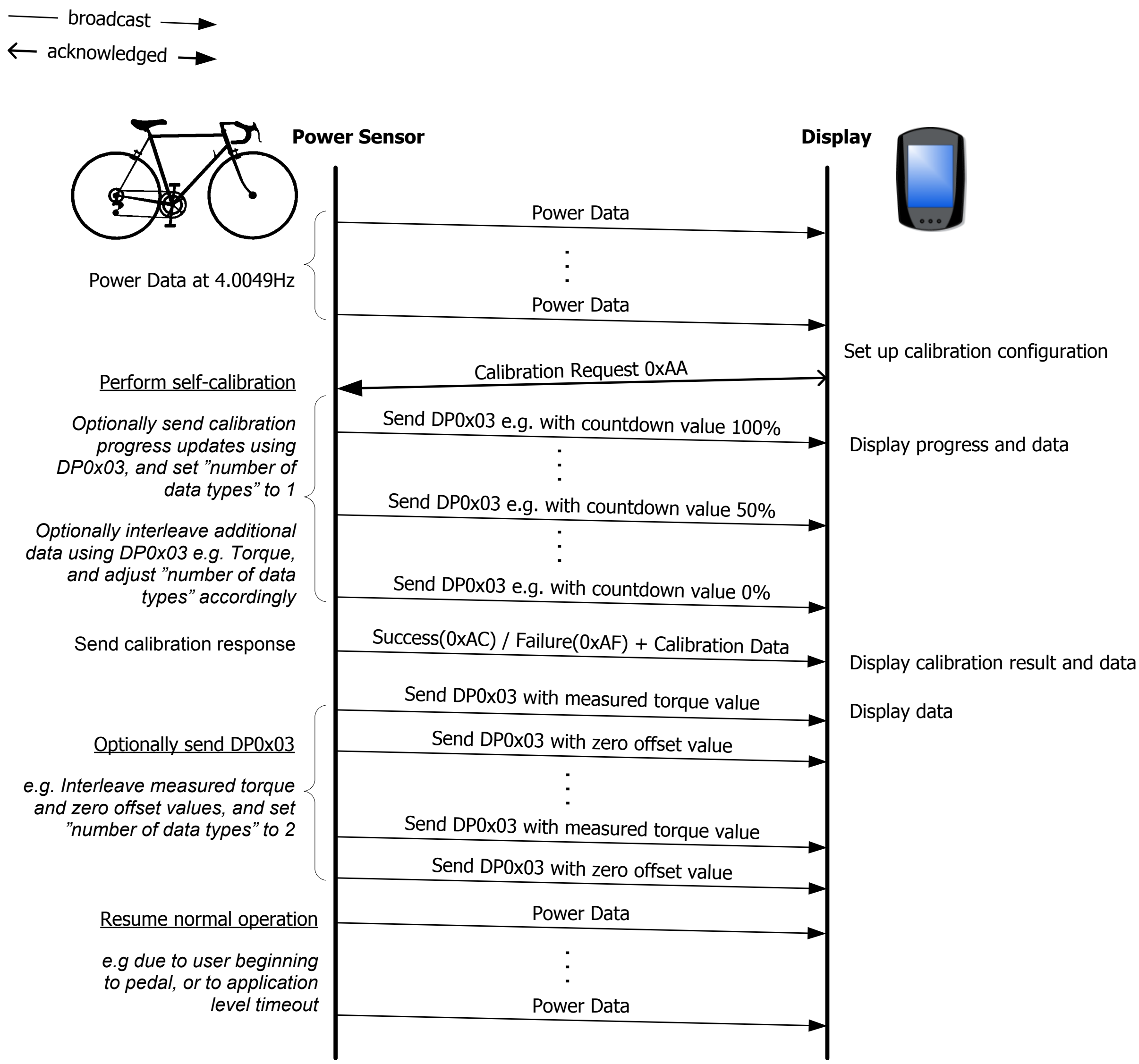


Figure 15-2. Example Message Flow Diagram illustrating the use of Data Page 0x03

16 Common Pages

Data page numbers above 0x40 are globally defined across all ANT devices. Formats exist to provide information about battery status and operating hours as well as hardware and software versions. These common data pages may be interleaved with the power messages to provide the display with information about the sensor's status.

For more detailed information, refer to the ANT+ Common Pages document.

16.1 Required Common Pages

16.1.1 Common Page 80 (0x50) – Manufacturer's Identification

Common data page 80 transmits the manufacturer's ID, model number, and hardware revision.

Refer to the ANT+ Common Pages document for details of this page.

16.1.2 Common Page 81 (0x51) – Product Information

Common data page 81 transmits the device's software revision and its 32-bit serial number.

Refer to the ANT+ Common Pages document for details of this page.

16.2 Optional Common Pages

16.2.1 Common Page 70 (0x46): Request Data Page

Common Data Page 70 allows an ANT+ device to request a specific data page from another ANT+ device; in this case, it allows the display to request the Get/Set Parameters pages from the ANT+ power meter. The request data page shall be sent using an acknowledged message by the display and shall be formatted as shown in Table 16-1.

This is an optional data page. Power meter sensors that do not support this page shall ignore the request. Displays shall handle this lack of response gracefully.

Table 16-1. Common Data Page 70 Format

Byte	Description	Length	Value	Units
0	Command ID	1 Byte	70 (0x46) – Data Page Request	N/A
1	Reserved	1 Byte	Value = 0xFF	N/A
2	Reserved	1 Byte	Value = 0xFF	N/A
3	Descriptor Byte 1	1 Byte	Allows subpages to be requested within the requested data page. Valid Values: 0 – 254 Invalid: 255 (0xFF)	N/A
4	Descriptor Byte 2	1 Byte	Allows subpages to be requested within the requested data page. Valid Values: 0 – 254 Invalid: 255 (0xFF)	N/A
5	Requested Transmission Response	1 Byte	Describes transmission characteristics of the data requested. Bit 0-6: Number of times to transmit requested page. Bit 7: Setting the MSB means the device replies using acknowledged messages if possible. Special Values: 0x80 - Transmit until a successful acknowledge is received. 0x00 – Invalid	N/A
6	Requested Page Number	1 Byte	Page number to transmit.	N/A
7	Command Type	1 Byte	Value = 1 (0x01) for Request Data Page	N/A

16.2.1.1 Descriptor Bytes 1 & 2

The descriptor byte fields are used to describe requested subpages and shall be populated when requesting data page 0x01 or 0x02. Refer to section 14.1.2 for an example. Otherwise these bytes are set to invalid (e.g. when requesting data page 0x10).

16.2.1.2 Requested Transmission Response

The power meter shall be able to support all requested transmission response types; however, the ANT+ bicycle power device profile further stipulates that **the display shall only request broadcast messages from a power meter sensor.**

Refer to the ANT+ Common Pages document for more details on the request data page and possible requested transmission response types.

16.2.2 Common Page 82 (0x52): Battery Status

Common data page 82 transmits the device's battery voltage and status. If this page is sent by power sensors that contain more than one battery (e.g. in left–right pedal systems), then this page should be populated to represent the values from the battery with the lowest voltage.

This is an optional data page; however if it is used, then it shall be interleaved at least once every 61 messages.

Table 16-2. Global Data Page 82 - Battery Status

Byte	Description	Length	Value	Units	Rollover
0	Data Page Number	1 Byte	82 (0x52) – Battery Status	N/A	N/A
1	Reserved	1 Byte	Value = 0xFF	N/A	N/A
2	Battery Identifier	1 Byte	Identifies the battery in the system to which this battery status pertains and specifies how many batteries are available in the system. Bits 0-3_Number of Batteries Bits 4-7: Identifier Set to 0xFF if not used.	N/A	N/A
3	Cumulative Operating Time LSB	3 Bytes	This will give the cumulative operating time of the device and should be reset on insertion of a new battery.	2 seconds or 16 seconds	1.1 years 8.5 years
4	Cumulative Operating Time				
5	Cumulative Operating Time MSB				
6	Fractional Battery Voltage	1 Byte	Value = 0 – 255 (0x00 – 0xFF)	1/256 (V)	N/A
7	Descriptive Bit Field	1 Byte	Refer to ANT+ Common Pages	Binary	N/A

16.2.2.1 6.7.1 Battery Identifier

The battery identifier is used by systems that are made up of components and have a need to report battery status information from multiple batteries. The upper nibble of this field is used identify the battery in the system to which this message pertains while the lower nibble is used to indicate the total number of batteries in the system.

Identifier: Identifies battery in system to which this message pertains.

Number of batteries: Total number of batteries in the system needing to report battery status.

Only the battery with the lowest battery level should be broadcast in the regular common page transmission pattern. This ensures that display devices that do not support the device identifier field still show a consistent and meaningful value. The display may request battery information of all other devices individually using the Request Data Page (Common Page 70), and setting descriptor byte 1 to the value of the desired identifier.

For bicycle power sensors, identifier values 0 and 1 are reserved for the right and left pedal batteries respectively. For example, a pedal based power meter may report power for both the right and the left pedals by setting the 'Identifier' field to 0 for the right pedal battery and 1 for the left pedal battery while setting the 'Number of batteries' field to 2. If the left pedal battery had the lower voltage its value would be reported in the regular transmission for the Battery Status page. The display may request the battery status of the right pedal to get a better picture of the entire system's battery status.

If this field is not used its value should be set to 0xFF.

16.3 Other Common Pages

Other common data pages that are listed in the ANT+ Common Pages document can be sent from the ANT+ bike power sensor. Other common data pages are implemented in the bike power sensor at the discretion of the developer.

17 Guidelines for Best Practice

17.1 Accumulate Positive Values Only

The ANT+ data page definitions make use of accumulated values to maintain accuracy in the event of packet loss. All of these accumulated values are scalar quantities and should be incremented only by positive amounts. If a negative number is added to an accumulated value, it cannot be interpreted correctly on the receive side.

17.2 Handle Stop and Coasting Conditions

It is important that the display properly handle the display of power, speed, and cadence in cases when the bicycle is stopped and when the bicycle is coasting.

17.2.1 Event-synchronous Updates

Since no wheel (crank) events are occurring, no updates occur. The last page is repeated until either a rotation event occurs or the unit shuts down. The display should recognize that an extended period of repeated messages indicates a stop or coasting. (For torque frequency sensors refer to section 12.7.)

It is recommended that event-synchronous power sensors self-detect coasting or stopped conditions and force an update to explicitly indicate this state to the display.

17.2.2 Time-synchronous Updates

If the wheel (or crank) is not moving in a system with fixed interval updates, the update count increases but the accumulated Wheel Ticks (crank ticks) and Accumulated Wheel (Crank) Period do not increase. The display should interpret a zero increase in these values as a stop or coasting. For Power-only sensors (i.e. sensors that only send data page 0x10) a stop or coasting condition is indicated by the accumulated power remaining constant while the event updates continue to increment.

How and when the display handles these cases is up to the individual manufacturer.

17.3 Handling Invalid Values

If a display receives an invalid value from the sensor, it is recommended that this is indicated to the user by clearing the display field or showing dashes, rather than leaving the last valid value in place.

18 Using Accumulated Values

The ANT+ data page definitions make use of accumulated values to maintain accuracy in the event of packet loss. This section explains how to properly transmit and receive accumulated data:

- Transmitters: Add only positive values to message fields that are accumulated.
- Receivers: Reconstruct accumulated values from rollover fields as described in section 18.2.
- Receivers: Use average values to properly calculate and store data after RF reception loss.

18.1 Transmitting Data in Accumulated Values

Instantaneous values from the sensor, such as power and wheel period, are calculated during each update period and added to a running sum. The update event count and the accumulated sum are then transmitted in the next broadcast message. For example, during update event *N* the data field would be accumulated as in Equation 16.

$$AccumulatedValue_N = AccumulatedValue_{N-1} + CurrentValue$$

Equation 16. Example of Accumulating a Value

Each message field has a maximum value, after which the running sum rolls over, as shown in Figure 18-1. Note that a rollover makes it possible for the Accumulated Value N to be less than it was in the previous message.

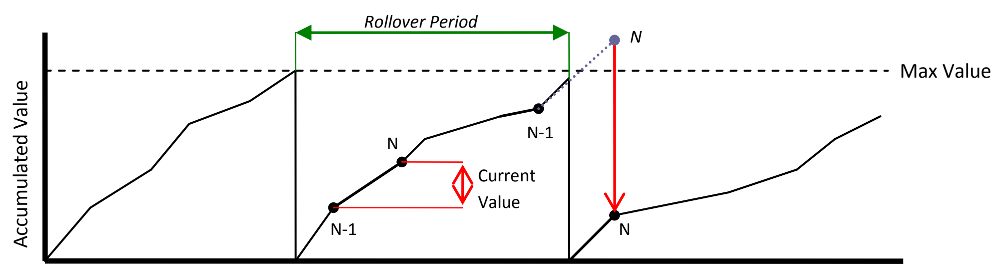


Figure 18-1. Accumulating Values

NOTE: All accumulating message fields must use only positive values.

A decrease in an accumulated value is interpreted by the receiver as a rollover event. For this reason, negative values cannot be added to accumulated fields as they will be incorrectly calculated at the receive side.

The expected amount of time separating rollover events is called the rollover period. This is the maximum amount of time that accuracy in calculations can be maintained during an interruption of RF reception. Rollover periods vary by application and are described in the data page sections.

18.2 Receiving and Calculating Data from Accumulated Values

When messages are received by the display, the current value can be determined by subtracting the data from the previous message, and dividing by the difference in update event counts between the two messages.

NOTE: The following calculations assume signed numbers are used.

To properly span rollovers, the calculations on the receiver side must first reconstruct the accumulated value and the event count from the received values, as shown:

1. Initialize AccumulatedValue to 0; initialize PreviousReceivedValue to the value received in the first data message.
2. For each subsequent data message:
    a. AccumulatedValue += ReceivedValue – PreviousReceivedValue
    b. If PreviousReceivedValue > ReceivedValue

        { AccumulatedValue += 256 }

    c. PreviousReceivedValue = ReceivedValue

Note that the event count is reconstructed in exactly the same way as the accumulated value. The current value can then be calculated from the reconstructed accumulated value and the reconstructed event count as shown in Equation 17. In the following, *N* refers to the most recently calculated value, and *N-1* refers to the calculation immediately preceding *N*.

$$CurrentValue = \frac{(AccumulatedValue_N - AccumulatedValue_{N-1})}{(AccumulatedEventCount_N - AccumulatedEventCount_{N-1})}$$

Equation 17. Calculating a Value from Two Messages

During normal RF conditions, every message is received and the calculated value is equal to the instantaneous value.

When RF reception is compromised, the calculated value is the average value over the period of the RF outage.

18.3 Handling Data during RF Reception Loss

An important benefit of using accumulated values in message fields is that accuracy can be maintained during RF reception loss. Under normal operating conditions with adequate RF reception, instantaneous values are calculated at the receiver. When reception is interrupted, the average value of the data is automatically reconstructed.

Figure 18-2 shows bicycle power data that is sent during a period of RF reception loss. During the outage (A), the instantaneous value is unavailable and the display may choose to show the most recent power value or to indicate that messages are not being received.

After reception resumes (B), the first value calculated at the receiver is the average power over the period of the outage. It is important that display units properly calculate the average power over the interval and then save these values correctly into memory and into any summary statistics. Storing either zeros or the last received data before the loss results in inaccurate data.

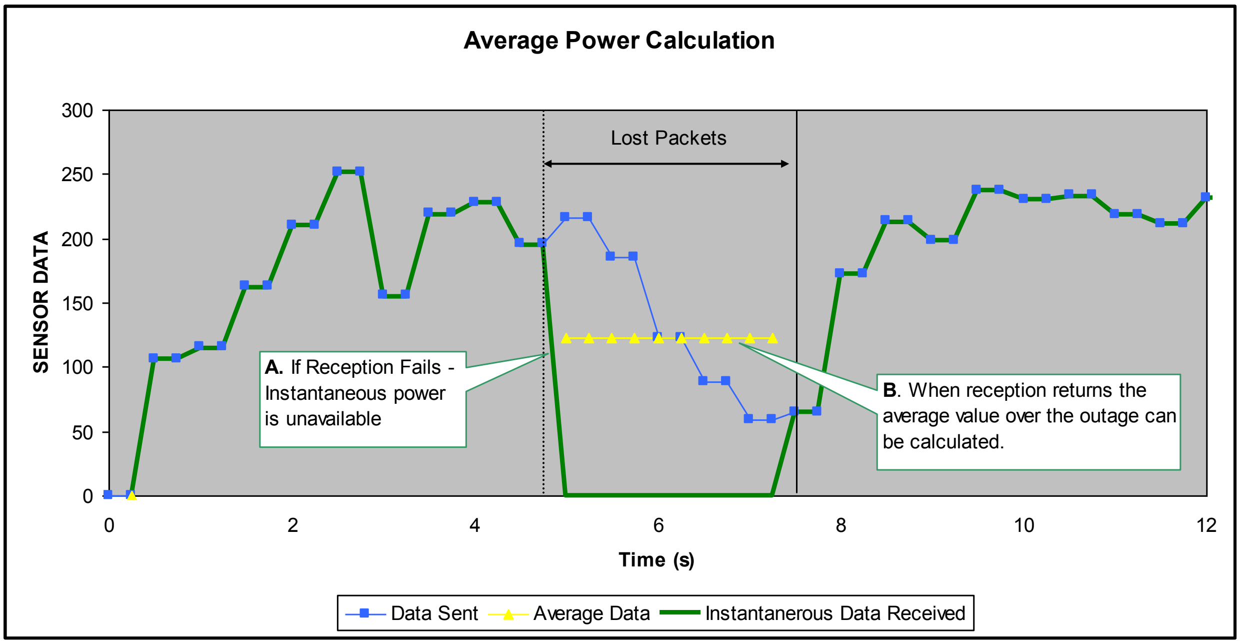


Figure 18-2. Averaging Power through an RF Outage

19 Minimum Requirements

The ANT+ Bicycle Power Device Profile divides bicycle power sensors into two groups: standard PWR sensors (including power-only, torque at wheel and torque at crank sensors), and CTF sensors. Each of these types must meet a set of minimum transmission requirements, and is associated with a distinct interoperability icon, as described below.

19.1 Minimum Transmission Requirements for ANT+ Bicycle Power Sensors and Displays

19.1.1 Sensor requirements (PWR)

ANT+ Bicycle Power (PWR) sensors must behave as described in either section 6.2 or 0. The pages marked as required in Table 19-1 shall be sent, and comply with the timing requirements. Any optional pages used shall also comply.

Table 19-1. Minimum Transmission Requirements for ANT+ Bicycle Power Sensors (PWR)

Function	Page Number		Message	Details
Optional Torque Main Data Page	0x11 0x12		Tx: Standard Torque At Wheel OR Tx: Standard Torque At Crank	Default broadcast message (if used) interleave at least twice every 4 messages
Required Power Main Data Page	0x10		Standard Power Only	Default broadcast message, interleave at least twice every 4 messages OR if page 0x11 or 0x12 is in use, then: Minimum: Interleave every 9 messages Preferred: Interleave every 5 messages OR if page 0x13 is in use, then: Minimum: Interleave as often as page 0x13
Optional TE & PS Main Data Page	0x13		Torque Efficiency and Pedal Smoothness	Minimum: Interleave every 5 messages (1.25s)
Required Common Data Page	0x50		Manufacturer’s Information	Minimum: Interleave every 121 messages (30.25s)
Required Common Data Page	0x51		Product Information	Minimum: Interleave every 121 messages (30.25s)
Optional Common Data Page	0x52		Battery Voltage	Minimum: Interleave every 61 messages (15.25s)
Calibration Function	**Page**	**Cal ID**	**Message**	**Details**
Required Manual Calibration (Zero Offset) Page	0x01	0xAA	Rx: Calibration request (0xAA)	Service calibration request when received from display. See section 13 for details.
		0xAC	Tx: Acknowledge (0xAC)	
		0xAF	Tx: Fail (0xAF)	
Optional Auto Zero	0x01	0xAB	Rx: Auto zero configuration (0xAB)	Service auto zero configuration request when received from display (for sensors that self-monitor zero offset)
		0xAC	Tx: Acknowledge (0xAC)	
		0xAF	Tx: Fail (0xAF)	
Optional Custom Calibration Parameters	0x01	0xBA	Custom Cal Parameter Request	Set custom calibration parameters See section 13 for details.
		0xBB	Custom Cal Parameter Response	
		0xBC	Custom Cal Parameter Update	
		0xBD	Custom Cal Parameter Update Response	
Optional Auto Zero Support	0x01	0x12	Tx: Auto zero status	Minimum: Interleave every 121 messages (30.25s)

19.1.2 Display Requirements (PWR)

To qualify as an ANT+ Bicycle Power (PWR) display the device must implement the Simple Receiver Implementation (PWR) described in Table 3-1 as a minimum. However the Full Receiver Implementation is preferred as it offers a greater feature set to the user.

19.2 Minimum Transmission Requirements for ANT+ Crank Torque Frequency Sensors and Displays

19.2.1 Sensor requirements (CTF)

To qualify as an ANT+ Crank Torque Frequency sensor the device must behave as described in section 6.4.

19.2.2 Display Requirements (CTF)

To qualify as an ANT+ Crank Torque Frequency (CTF) display the device must implement the CTF-only Receiver Implementation described in Table 3-1 as a minimum. However the Full Receiver Implementation is preferred as it offers a greater feature set to the user.

19.3 Additional Requirements

In addition to the requirements outlined in sections 19.1 and 19.2, the following general requirements apply:

- A sensor shall only send broadcast messages to the display, and shall never send acknowledged or burst messages. However a display shall decode (and display) data sent as acknowledged messages from the sensor.
- A display shall not decode any unexpected burst messages that are sent from the sensor, and shall handle this situation gracefully.
- A display shall not decode reserved bytes in received data pages.
- The display shall handle gracefully the receipt of undefined data pages.

19.4 ANT+ Device Interoperability Icons

The ANT+ interoperability icons inform the end user of the product's capabilities. These icons indicate to the user that this specific device will transmit/receive bicycle power or crank torque frequency information, and that it is interoperable with other devices that carry the same icon. The use of these icons is optional for certified devices (and prohibited for uncertified devices), however it is strongly recommended that they are used because consumers may not otherwise be able to distinguish between PWR and CTF devices. Devices that that have been certified against both sets of requirements (e.g. displays using the Full Receiver Implementation) can use both icons.

An ANT+ Bicycle Power sensor or display that meets the minimum compliance specifications and has been certified may use the icon shown in Figure 19-1on packaging, documentation, and marketing material.

Figure 19-1. ANT+ Bicycle Power Device Interoperability Icons

An ANT+ Crank Torque Frequency sensor or display that meets the minimum compliance specifications and has been certified may use the icon shown in Figure 19-2 on packaging, documentation, and marketing material.

Figure 19-2. ANT+ Crank Torque Frequency Device Interoperability Icons