APDM SDK
DEVELOPER GUIDE

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1 Welcome

The following documentation will guide you through understanding the architecture of the system and how to use it as a developer. The core SDK documentation will focus on the C language implementation utilizing a dynamically linked library. Other language bindings such as Java will be documented as well. For the C language or any language binding not provided it is assumed that the end user should know how to properly load the dynamically linked library and call its functions using the correct calling convention. Most of the documentation will use a cross platform approach with specific platform specific notes if needed. Example code will be provided for all included language bindings to assist in getting the user up and running.

2 System Overview

The APDM movement monitoring system allows the user to record data from multiple monitors; each integrating a suite of sensors. The system can be configured in 3 recording modes allowing for a wide rage of applications. Some movement monitors are limited to a subset of these modes allowing for a lower cost solution. The modes of operation are robust synchronized streaming, rapid synchronized streaming, synchronized logging, and low power logging. Regardless of the mode the movement monitor always will record data to its local memory card which can be imported from the monitor for offline analysis.

2.1 Movement Monitors

Movement monitors are the key element of the system and combine a complement of sensors within a single package. Sensors include a 3 axis accelerometer, a 3 axis gyro, a 3 axis magnetometer, and a temperature sensor. The accelerometers can be configured in a high 6G mode, or a low 2G mode depending on the target application. There are a number of options for securing the monitors on subjects using a selection of straps.

2.1.1 The Opal

The Opal is APDM's full featured movement monitor allowing for use of all 4 recording modes.

The Opal movement monitor

2.1.2 The Emerald

The Emerald is an option that supports the synchronized and low power logging modes, but does not support the streaming modes. These monitors are optimized for long duration recordings or recordings where it is not desirable to have a computer at hand to collect streaming data.

2.1.3 The Sapphire

The Sapphire only supports the low power logging mode. This version of the movement monitor has no wireless capabilities and may be the optimal choice for RF sensitive environments or where a single movement monitor is needed without synchronization.

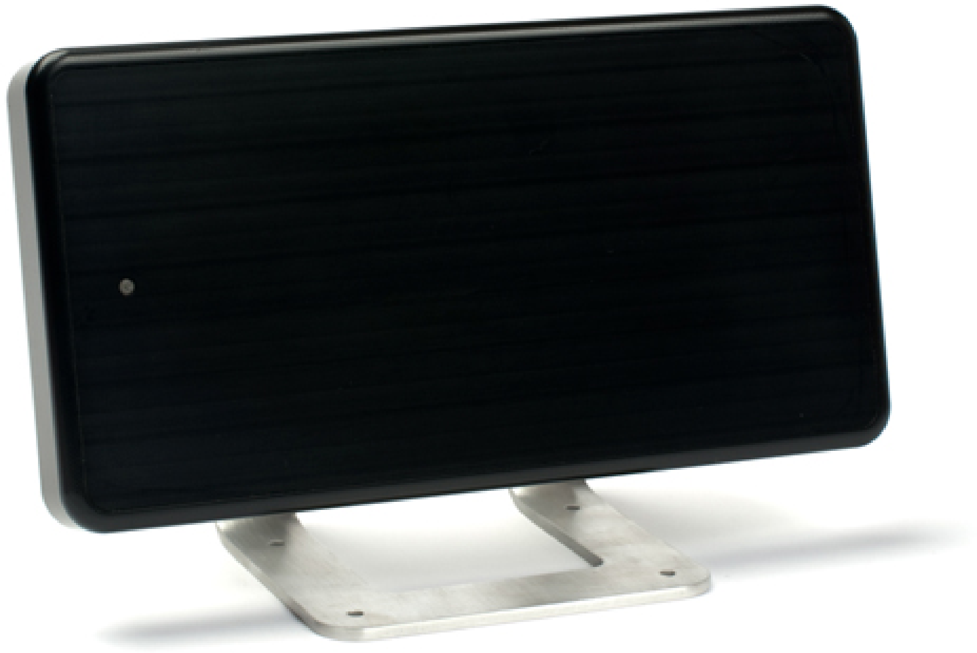
The docking station, for charging, configuring, and downloading data from your movement monitors

2.2 Docking Station

The docking station is used to configure, charge, and download data from the movement monitors.

2.3 Access Point

The wireless access control point (access point for short) allows for wireless communication between the host computer and Opal movement monitors, as well as synchronization with external 3rd party hardware. A single access point can support up to 6 Opals. If you wish to stream from more than 6 synchronized Opals at the same time, you will have to use more than 1 access point and connect them with an RCA (standard stereo) cable.



The access point, for communicating wirelessly with your movement monitors

2.4 Recording Modes

To suit a range of different recording requirements, a number of different recording modes are possible. Some monitor types do not support all recording modes.

2.4.1 Robust Synchronized Streaming

In the robust synchronized streaming mode, you can stream data from multiple, synchronized monitors directly to your computer. Data is buffered on the monitors, so no data is lost even if there are interruptions in the wireless signal. Only the Opals can be used in this mode.

2.4.2 Rapid Synchronized Streaming

The rapid synchronized streaming mode is similar to the robust synchronized streaming mode, except data is not buffered on the monitors in order to minimize the latency of the streaming data. Latency on Linux and Mac OS is typically in the range of 8ms to 25ms, while latency on Windows is typically in the range of 10ms to 75ms. This recording mode is appropriate for biofeedback applications. In the event of interruptions in the wireless signal, data will be dropped from the steram. Only the Opals can be used in this mode.

2.4.3 Synchronized Logging

In the synchronized logging mode, monitors log recorded data to their on-board flash memory. The monitors are synchronized wirelessly with each other while recording, so the individual logs can easily be synchronized with each other after the data has been imported from your monitor(s). In this mode, up to 24 monitors can be synchronized within a single “mesh”. Only Emeralds and Opals are able to use this mode.

2.4.4 Low Power Logging

All movement monitor products (Opals, Emeralds, and Sapphires) are able to operate in the low power logging mode. In this mode, the monitors’ wireless radios are disabled, decreasing the power required for operation and enabling the monitors to run for longer periods of time. Since the mode does not use any wireless synchronization, each movement monitor will collect data independently and potentially at slightly different rates due to clock drift.

2.5 Motion Studio

Motion Studio is the default software suite bundled with the APDM movement monitor system. It provides an easy way to get up and running collecting data with your movement monitors.

2.6 APDM Software Development Kit

The APDM Software Development Kit (SDK) provides programming tools for software developers. These tools enable developers to write their own software capable of configuring and streaming data from the movement monitors. In addition, it also provides functions for converting the raw data files found on the monitor's memory card into either a HDF5 (recommended) format or CSV. The SDK provides the same low level interface to the hardware that Motion Studio is built upon.

3 Downloading the SDK

To obtain the latest version of the SDK, download the following archive:

http://share.apdm.com/libraries/release/apdm_sdk.zip

and unzip it to your desired location.

3.1 SDK Directory Structure

The SDK contains a number of folders useful to the developer. Their descriptions are as follows:

/doc	Documentation for users, developers guide and API references.
/include	Header files to be included in C or C++ applications.
/libs	Libraries (DLL's, SO's, DYLIBS's) to be dynamically loaded into applications providing programmatic access to the hardware.
/samples	Sample applications in C, Java and Matlab utilizing the libraries.
/Java	Java APIs for programmatic access to hardware
/Matlab	Matlab prototypes allowing for access to DLL's, SO's or DYLIBS's

4 Software Tools and Libraries

4.1 Developer Skills

Use of the SDK will require some basic development skills:

- Loading, using, and unloading dynamic libraries (DLL's, SO's, DYLIB's).
- Proficiency in the target language or development environment.
- General understanding of error handling strategies, in particular, return error codes and/or exceptions in languages that support exceptions.
- General understanding of memory management (allocation, deallocation).
- General understanding of API usage (initialization, usage, teardown).
- General understanding of the differences between bandwidth and latency as it relates to sampled data.

4.2 Programming Libraries

APDM provides programming libraries to allow integration on the following operating systems and versions:

Language	Supported Operating Systems	Comments
C/C++	Windows 10, 64bit Windows 8, 64bit Windows 7, 64bit Mac OSX 10.5 or later Linux, 64bit	
Java Windows 8, 64bit	Windows 10, 64bit JNI Bindings Windows 7, 64bit Mac OSX 10.6, Snow Leopard or later Linux, 64bit	JNI Bindings
Matlab	Windows 64bit Mac OSX 10.6, Snow Leopard or later Linux, 64bit	Library Loading with C calls
Python	Linux, 32bit Linux, 64bit	Python 2.6 and 2.7 bindings provided
Other	*	Any environment that supports loading of DLL's, SO's, or DYLIBS and allows calls to functions on those libraries. Development environments, 3rd party applications such as LabView and many other tools allow for this method of integration. See your tools' manual for details on how to do this.

4.2.1 Development Environments

Dynamic libraries are provided, DLL's, DYLIB's and SO's for linking into applications. Any language or environment that can load dynamic libraries and call into said libraries should be usable with the dynamic libraries. Most languages/development enviroments support this functionality.

- Windows / Visual Studio 2005 / MinGW / GCC
- Mac OSX / GCC
- Linux / GCC

4.3 C API

4.3.1 Documentation

Included in the APDM software distribution is function API documentation, including descriptions of functions purpose, parameters and return values. This can be found under “docs” in the software distribution.

4.3.2 Using the Host Libraries

The host libraries allow you to create handles to any given access point or docking station attached to the system. With an AP handle or docking station handle, you can query the given device for information, and send configuration commands to the given device. If there is an movement monitor attached to a docking station, then you can also send commands to the movement monitor through the docking station handle.

4.3.3 Headers

Two headers will be necessary to include in your project, `apdm.h` and `apdm_types.h`.

4.3.4 System Context

The host libraries provide the notion of a system context. A context is a logical collection of access points and docking stations (movement monitors attached therein) that can be configured as a group and work in concert with each other. The context allows you to correctly configure wireless channels and redundant wireless streaming AP’s, as well as provide correlation of the samples sent out by all the sensors (correlation in time by sync value).

The data type used for a context is: `apdm_ctx_t`

and can be allocated with the `apdm_ctx_allocate_new_context()` function, and freed with the `apdm_ctx_free_context()` function .

4.3.5 Docking Station Handle

The data type used for a docking station handle is: `apdm_device_handle_t`

The easiest way to create a handle is to use the `apdm_sensor_allocate_and_open()` function, passing in the index of the given docking station number that you want a handle on. Similarly, calling the `apdm_sensor_close_and_free_handle()` function to cleanly close the handle and free it's respective memory.

4.3.6 Configuration of Movement Monitors on a Docking Station

The host libraries contain a number of functions, starting with `apdm_sensor_cmd_XXXX()` that are used to configure movement monitors. Settings such as sampling rates, enabling and disabling different sensors, configuration of wireless parameters etc can be done using thees function calls. See low level API documentation for details on these commands.

4.3.7 Access Point Handle

The data type used for an access point handle is: `apdm_ap_handle_t`

An AP handle can be allocated with the `apdm_allocate_ap_handle()` function, freed with the `apdm_free_ap_handle()` function. Once a handle is allocated, you can open a given access point by index using the `apdm_ap_connect()` function. Once you've connected, you can then send commands to the AP and query the AP for information using AP specific functions.

Access Point specific functions are of the form with `apdm_ap_XXXX()`.

4.3.8 Configuration of Synchronized Wireless Streaming & Logging Mode

The host libraries provide a function `apdm_autoconfigure_devices_and_accesspoint4()` that can be used to configure a group of AP's and movement monitors for streaming mode. After a context has been allocated and initialized, and the `apdm_ctx_open_all_access_points()` function has been called with the respective context, you can call auto configure to configure the system. Once the system is configured, you can disconnect the movement monitors from the docking station to allow them to stream data, and begin to use the `apdm_ctx_get_next_access_point_record_list()` and `apdm_ctx_extract_data_by_device_id()` functions to stream data.

The maximum number of movement monitors in a single configuration is 36

The maximum number of access points in a single configuration is 6

4.3.9 Variable Output Rates

Movement monitors can be configured to generated samples at a configureable rate. Movement monitors can sample at 20, 32, 40, 64, 80 and 128 Hz. For each given output rate, there are specific decimation rates that are valid. The table below indicates which combinations can be used.

Output Rate / Decimate	1x1	2x1	2x2	5x1	4x2	5x2	4x4	5x4	8x4	8x5	8x8
20	valid	valid	valid		valid		valid		valid		
32	valid	valid	valid	valid	valid	valid		valid		valid	
40	valid	valid	valid		valid		valid		valid		
64	valid	valid	valid	valid		valid		valid			
80	valid	valid	valid		valid		valid				
128	valid	valid		valid		valid					

You can set the sampling rate and decimation rate on a movement monitor using the `apdm_sensor_cmd_config_set()` function. Detailed documentation is provided in the API docs for the function. The decimation rate can be changed in wireless streaming mode by pre-configuring the movement monitors using the desired configurations, and calling the `apdm_autoconfigure_devices_and_accesspoint_wireless()` function. Details are provided in the respective API documentation for the function.

4.3.10 Wireless Channel Selection

Movement monitors transmit data in the 2.4ghz wireless spectrum range. Channel zero corresponds to roughly 2.4000ghz, and channel 90 corresponds to roughly 2.4900ghz. The 2.4ghz spectrum has many other consumer electronic devices, such as WiFi routers, cordless phones and blue-tooth devices, that also operate in this area of the spectrum. As such, it's important to choose a channel that is not already in use by another device.

The most common source of interference is from wireless network access points. You can determine the channel that the WiFi router is running on and determine its corresponding frequency from the following URL: `http://en.wikipedia.org/wiki/IEEE_802.11`

4.3.11 Configuration of Rapid Streaming Mode

You can find sample code for configuring rapid mode streaming in `autoconfigure_rapid_streaming.c`in the samples directory of the SDK.

Configuration of rapid streaming mode is almost identical to that of normal streaming mode, with the exception of two settings that must be set to specific values.

To configure rapid streaming mode, call the `apdm_ctx_autoconfigure_devices_and_accesspoint5()` function, making sure to set ‘`decimation_rate`’ to ‘`APDM_DECIMATE_1x1`’ , and ‘`enable_sd_card`’ to ‘`false`’.

There are two variants of rapid streaming mode. The first uses the correlation code provided by APDM, which will emit sets of correlated samples, and deal with duplicate transmissions or cases where opals switch from one AP to a second. From the perspective of the application, this will be identical to other normal modes of streaming. The second mode, which will remove some additional latency (on the order of 5ms to 10ms), retrieves individual samples as soon as they are available on the AP. However, in this mode of operation, the application will have to deal with duplicate samples and gaps in the data if transient wireless/RF problems occur.

4.3.12 Rapid Streaming with Correlation

This mode of operation is identical to normal streaming mode, with the exception of configuring the system to disable the SD card and to set the decimation rate to ‘`APDM-DECIMATE_1x1`’.

4.3.13 Rapid Streaming without Correlation

This mode of operation requires slightly different library interfacing function calls. Example code can be found in `stream_data_rapid.c` in the samples directory of the SDK. The basic function call sequence is as follows:

`apdm_ctx_allocate_new_context()`
`apdm_ctx_open_all_access_points()`
`apdm_ctx_flush_ap_fifos()`
`apdm_ctx_extract_next_sample()` (called many times)
`apdm_ctx_disconnect(context)`
`apdm_ctx_free_context(context)`

4.3.14 Persisting Configurations to Disk

When streaming, after auto configuration, the configuration of the AP's and all the Opals can be persisted to disk, such that at a later time (after restarting a system for example), the configuration can be re-read from disk, re-applied to the AP's, and streaming can be started again without having to go thru autoconfiguration.

The `apdm_ctx_persist_context_to_disk()` function and the `apdm_ctx_restore_context_from_disk()` functions allow you to do this. An example of auto configuration with persisting to disk can be found in `autoconfigure_system.c` in the examples directory of the SDK. An example of streaming data utilizing a persisted context can be found in `stream_data_recover_context.c` in the examples directory of the SDK.

4.3.15 Configuration of Synchronized Logging Mode

The host libraries provide a function, `apdm_autoconfigure_mesh_sync()`that will allow you to configure all movement monitors attached to the host in mesh time synchronization and data logging mode.

In synchronized logging mode, the movement monitors will transmit and receive their current time values, to and from each other such that their internal clocks all maintain the same notion of time.

There can be a maximum of 24 devices used in synchronized logging mode.

4.3.16 Configuration of Low Power Logging Mode

Low power logging mode consists of enabling/disabling the sensors of interest on the movement monitor, and disabling wireless. Wireless can be disabled with a call to `apdm_sensor_cmd_config_set()` and passing in `CONFIG_ENABLE_WIRELESS` and a value of 0.

4.3.17 Storing streaming data in HDF5 or CSV format

In addition to streaming data into an application, functionality exists to stream data to a .h5 file or a .csv file. The basic process is as follows:

1. Create a file with `apdm_create_file_hdf()` or `apdm_create_file_csv()`.
2. Get the device info structure for each device that's streaming using the `apdm_sensor_populate_device_info()` function.
3. Pass an array of records and device info structures to the `apdm_write_record_hdf()` or `apdm_write_record_csv()` function for each new sample.
4. Close the data file with `apdm_close_file_hdf()` or `apdm_close_file_csv()` when done.

4.3.18 Converting .apdm files to HDF5 or CSV

Data stored on the movement monitor is in a binary .apdm format. APDM libraries provide functionality to convert this data to a more usable format, apply calibration to the raw data, and generate orientation estimates. `apdm_process_raw()` is used to convert .apdm files to HDF5 or CSV. Raw data can also be optionally stored in the output format. To convert a raw data, first locate the .apdm files you wish to convert in the filesystem. Only one .apdm file for each monitor can be converted, but files from multiple monitors can be combined into a single output file. Files will appear in the filesystem of the host operating system while docked as removable storage drives with names corresponding. Then call `apdm_convert_raw()`with an array of the .apdm filenames. You can specify the output file and output file format. Calibration files do not need to be specified. Calibration data is stored in the raw .apdm files and will be used in the conversion process.

4.3.19 Return Codes

Most library functions return a value of type `int`, which has a value from `enumAPDM_Status` (defined in `apdm_types.h`), which indicates success or failure code of the given function that was called. A convenience function, `apdm_strerror()` is provided for converting these error codes to strings if necessary. Refer to function specific documentation for the details of each function.

4.3.20 Logging

The APDM libraries have logging information that is generated at various points of it's internal processing. Each log event that occurs has a specified severity, all logging funnels through a single piece of common infrastructure. By default, log messages are sent to `STDOUT`, but by calling `apdm_set_log_file()` you can re-direct logging output to a file.

4.3.21 Threading

The APDM host libraries are not thread safe. Thread safety, synchronization and enforcement of mutual exclusion are left up to the application in which the libraries are to be used.

4.4 Wireless Buffering and Data Correlation

In wireless streaming mode, the system utilizes numerous levels of buffering, including on-device buffering, in access point buffering, and buffering in the host libraries. There are many reasons that this buffing is necessary, including temporary wireless issues, scenarios where the host application does not retrieve data from the access point and times when the application wants to wait a short amount of time for a movement monitor to retransmit data after the wireless issues pass.

Due to the hardware level properties of the system, it becomes necessary to process data from sensors and access points knowing about potential transient problems at the hardware level. Some of the issues include the following:

- Duplicate data transmission by a sensor to one or more access points in the event that the sensor does not receive the ACK from the access point

- Variable delay in the relative streams of data from the movement sensors. e.g. one sensor may be transmitting data that is older then then the other sensors while it is catching up from a transient wireless problem.
- Missing data from a sensor, in the event that the sensor is turned off, or goes out of range for an extended period of time.

By in large, when the system context is used for streaming data, it will resolve these issues prior to emitting data from the libraries. There are some configuration parameters that will affect the behavior of the libraries with regard to timing and potentially missing data.

`apdm_ctx_sync_record_list_head()`

Before the application begins to received data, it should call the `apdm_ctx_sync_record_list_head()` function. This will cause the host libraries and access point to clear out all it's buffers, stream in a few samples such that a subsequent call to `apdm_ctx_get_next_access_point_record_list()` will return a full sample set, with data from all sensors in the system.

If this function is not called, you may get old data, or partial sets of data from a call to
`apdm_ctx_get_next_access_point_record_list()`

4.4.1 Max Delay / Max Latency

During auto configuration, and via library calls to `apdm_ctx_set_max_sample_delay_seconds()` you can specify the maximum amount of time to wait for sample(s) to be re-transmitted from an movement sensor.

This setting has some important implications with regards to data reliability and the latency of data by the time it's received by the user application.

- If a movement monitor is unable to transmit samples to an access point, the host libraries will stall their data output, waiting until max-latency seconds elapse, before giving up and emitting a partial sample set. E.G. If there are 6 sensors configured, and one of them is unable to transmit, the libraries will emit 5 samples, and indicate that they have missed the 6th sample.
- For as long as the given sensor is having problems transmitting, the host libraries will continue to delay outputting of data until the max-latency threshold for data age has elapses. So, if you have max-latency set to 15 seconds, and a sensor goes out of range, you'll find an initial pause of 15 seconds while the max-latency period elapses, then you will continue to receive data from the libraries, but as long as the sensor cannot transmit, the data will be 15 seconds old.

- The default max-latency setting is 15 seconds

4.5 Real-time Systems

The phrase ”realtime” is a context sensitive phrase, which according to Wikipedia has a few dozen meanings depending on when and where it's used (http://en.wikipedia.org/wiki/Real-time). As it applies to data streaming and possible uses of opals, there are two classes that will need to be distinguished.

1. The computer science definition, where real-time refers to a system that has hard timing deadlines, which if not meet, will cause the system to behave in an undesirable manor or fail outright.
   (see http://en.wikipedia.org/wiki/Real-time_computing)
2. The end-user description, which often means ”really fast”, or ”fast enough that a human cannot notice the latency”. In this context, the consequences of not satisfying the timing requirements are no more then an annoyance to the end user. This is often the case with strip-charting of data, or on screen visual feedback to a user.

The engineering techniques used to solve the two classes of problems above are significantly different.

In the case of an end-user real-time system, it's fairly simple. Almost all mainstream operating systems and hardware are capable of operating fast enough, and with low enough latency, to satisfy what a human can notice with timing.

In the case of a hard real time system, it requires an operating system or embedded system that is capable of providing timing guarantees. This is not a normal operating system such as Windows or Mac OS. With the appropriate configuration, Linux can provide real-time functionality. There are many real-time operating systems in existence
(see http://en.wikipedia.org/wiki/List_of_real-time_operating_systems). With respect to supported operating systems, Linux is the only operating system, also supporting real-time features, that can be used with APDM hardware. If your intention is to use opals as sensor data to control something in real time, you will likely find the subject of ”closed loop feedback control systems” to be useful (http://en.wikipedia.org/wiki/Control_theory).

4.6 Timing and Protocol Properties

If APDM hardware is to be used in a hard real-time system, the developer must understand exactly what timing properties are provided by the APDM software/hardware stack.

1. The USB bus was not intended to be used in hard real time systems. However, depending on the

requirements of the problem at hand, the USB bus may be good enough if the limitations of the bus are taken into account in the application.

2. Transfers between the host and the access point are done via USB bulk transfers. Bulk transfers provided guaranteed delivery, but not guaranteed timing. In general, on a Linux machine, it takes 1ms to 2ms to do a transfer from the AP to the host computer. This 1ms to 2ms is not guaranteed however, due to the underlying properties of USB bulk transfers. There are some things that can be done to increase the probability of transfers falling into this latency range, such as making sure that each AP is on it's own root hub of the host.
3. The issue of late data, or missing data all together, is not limited to USB. In fact, almost all buses can have some scenario in which data will be late and/or not get to the recipient. In buses that are designed for critical controls, this tends to be due to hardware failures (electrical problem on the bus, broken wires, bad bus transceiver etc). In all cases, the application should handle this in a manor that is reasonable and appropriate for the problem at hand.
4. The opals are transmitting data in the 2.40-2.49 GHz wireless spectrum. There are many devices that operate in this frequency range that can cause interference and problems during data transmission. If this occurs, the opal has logic to retry the transmission of the sample a certain number of times before giving up. In the event that it gives up, the host application will see a gap in the data (e.g. a missing sample). The application should handle this in a manor that is reasonable and appropriate for the problem at hand.
5. Sometimes the system will be running in a marginal wireless environment, or will encounter RF asymmetries during the TX/RX process. This can have an effect of an opal successfully transmitting data to the AP, and the opal not receiving the ACK from the AP. In this scenario, the opal will think that the sample didn't get through to the AP, and re-transmit the sample. Usually, the second time, the ACK will be RX'ed by the opal. From the perspective of the host application however, this will manifest as a duplicate sample (based on the 64bit synchronization value in the sample). Again, the application will need to handle this in an appropriate manor for the problem at hand.
6. The opals use time division multiplexing when transmitting data to the AP's. During a given opals time slice, the opal has multiple opportunities to transmit data. When looking at the latency of samples as they come in, you may observe burstiness in the latencies, in the range of 10ms differences in latency values as they come in from the AP.

4.7 DLL's, DYLIB's and SO's

Depending on platform, a DLL, DYLIB or SO will be linked in with your application at run time. These library files provide access to all the functions necessary to configure and communicate with movement monitors, docking stations and access points.

These libraries are written in C and provide standard C-symbols so as to facilitate linking with as many other languages, systems and platforms as possible.

Common ways of getting the dynamic library to load include, but are not limited to the following:

- compile time flags in your build system and making available the dynamic library for the system in one of the standard library search paths
- a call to the LoadLibrary() function on Microsoft platforms

4.7.1 Java

Java language bindings are provided with the SDK. These provide an object oriented interface to access points, docking stations, movement monitors and contexts. When using the Java bindings, you'll need to make sure the DLL/DYLIB/SO library file is in one of the library search paths. Environmental variables can be set to achieve this or command line parameters can be passed into the JVM to indicate where it should search for these libraries.

4.7.2 Other Systems

Many other systems, such as MatLab and LabView provide the ability to load 3rd party DLL's and call functions provided in those DLL's. Please refer to the documentation provided by your application or system on how to load and call functions from external libraries.

4.7.3 External Sync

The host libraries make available functions for manipulating and reading the I/O signals on each AP. The functions are as follows: `apdm_ap_get_io_value()`, `apdm_ap_set_io_value()`, `apdm_ctx_ap_get_io_value()`, `apdm_ctx_ap_set_io_value()`.

Using these functions, you can read the current value from the digital input signal and the analog input signal, and you can set the values for the digital output signal and the analog output signal. The apdm.h header file contains documentation on the exact input and output parameters for the I/O functions listed.

Changes to input pins on the access point can also be handled in an event oriented manor. The `apdm_ctx_get_next` when called while streaming data, will populate a `apdm_external_sync_data_t`data structure if an event has occured on the AP.

5 External Synchronization

5.1 Synchronization Overview

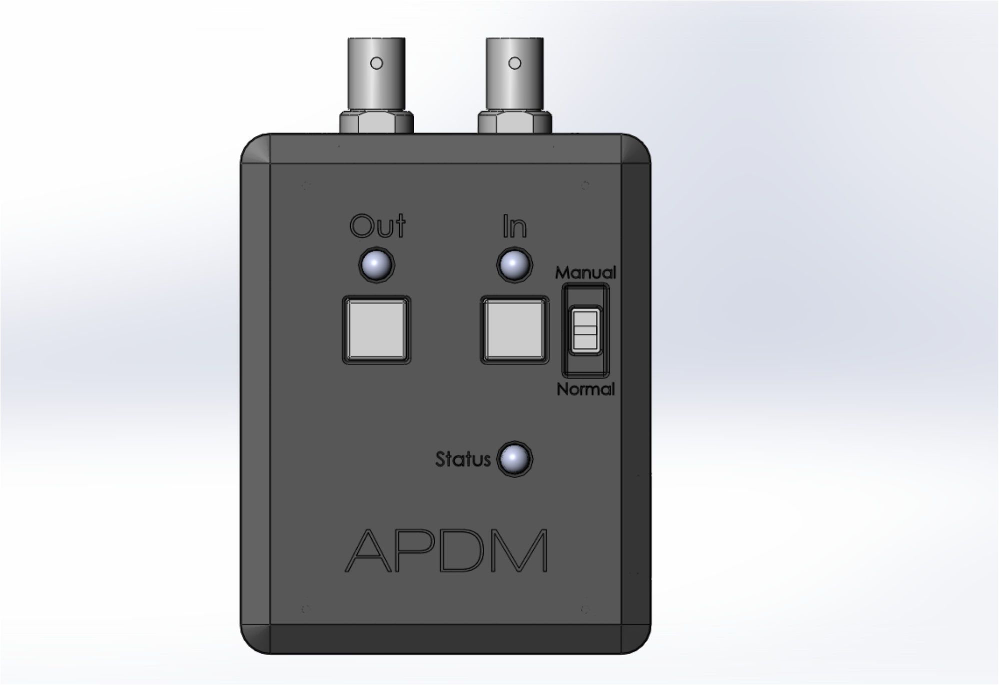
Opal recordings can be precisely time synchronized with external equipment. There are two supported synchronization modes:

- Output synchronization: when the Opal system begins recording data, it will output a signal to external equipment when the recording starts. Output signals can be edge or level triggered.
- Input synchronization: the Opal system will immediately begin recording when it receives a signal from external equipment. Input signals can be edge or level triggered as well.

External Synchronization requires:

- An APDM External Synchronization Box, or “Sync Box”
- A 3.5 mm 4-conductor cable to connect the Sync Box to the access point
- An APDM access point
- That the Opal system is configured for wireless streaming

5.2 Synchronization Hardware



APDM’s Sync Box (v2)

Access Point ↔ Sync Box Connectors and Cable Both the access point and Sync Box have a 4-conductor 3.5 mm receptacle. A standard 1 m long, 4-conductor, 3.5 mm cable is included with the Sync Box to connect it to the access point. These cables are often called "AV" cables becaus they contain 4, not the usual 3, conductors. A regular stereo audio cable will *not* operate correctly. A longer 4-conductor, 3.5 mm cable may be used, up to 10 m. This cable provides power from the access point to the Sync Box, and provides bidirectional communication between the two (using the Controller Area Network, or CAN, protocol). A green light on the side of the access point, near the 3.5 mm receptable, indicates that the access point is providing power to the Sync Box.

Mode Switch A toggle switch on the top of the Sync Box allows you to switch the operational "mode" of the Sync Box:

- **Normal Mode:** When in normal mode, the In and Out signals are controlled by software, and the square buttons on the top of the Sync Box are ignored.
- **Manual Mode:** When in manual mode, the square push buttons just below the "Out" and "In" LEDs allow the user to manually trigger input and output events. Pressing the "Out" button will toggle the output synchronization signal on the "Out" BNC connector high and low. Pressing the "In" button will toggle the input synchronization signal that goes into the access point high and low. In Manual mode, output signals sent by APDM software and actual input signals from external equipment are ignored.

Status indicator The Status LED is illuminated when the Sync Box has power. It is green when the Sync Box is in "Normal" mode, and blue when in "Manual" mode (described above).

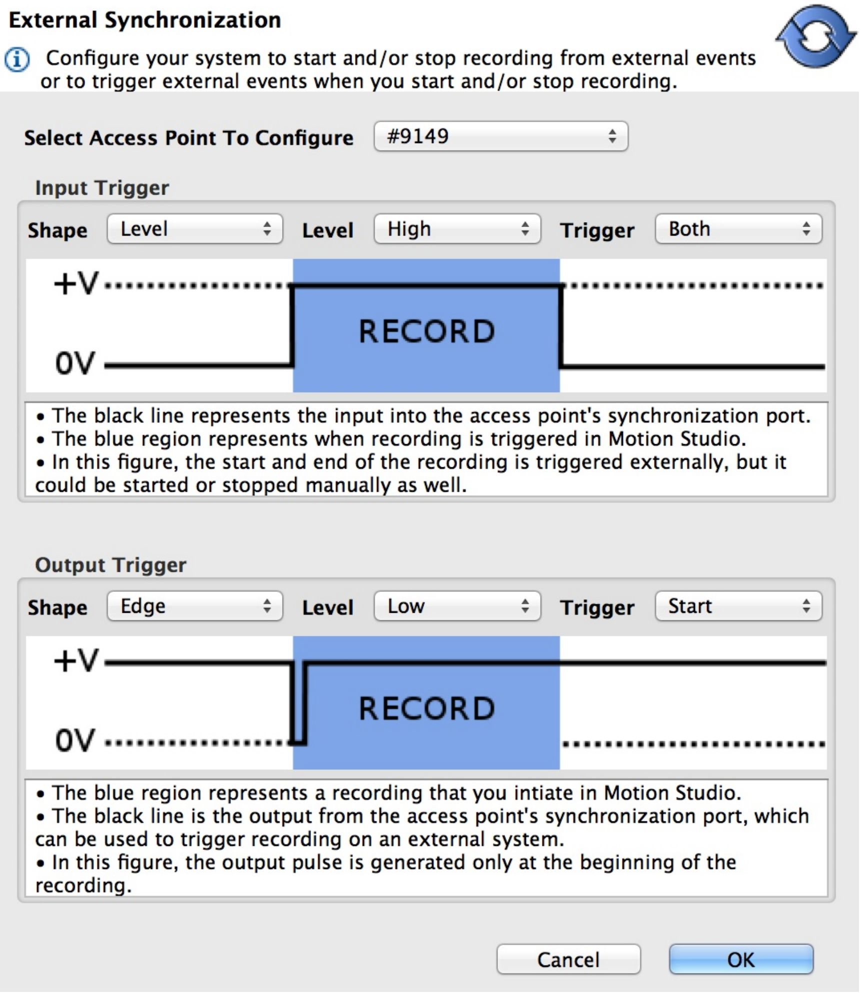
External Synchronization Connectors (BNC Connectors) The Sync Box has two external BNC connectors, labeled "In" and "Out".

- **In BNC Connector:** The In signal is designed to receive a 0 to 3.3 V (5V maximum) signal from external equipment. The logic high threshold is at 2.3V and the logic low threshold is 0.99V. This means a valid input signal must be below 0.99V when low, and above 2.3V when high. When the input signal is low, the In LED is off. When input is high), the In LED is green. For more technical details on the In signal, please see the *Schematic of Sync Box Input and Output Signals* (below).
- **Out BNC Connector:** The Out signal sends a 0 to 3.3V signal to external equipment. When not excessively loaded, the output high signal is greater than or equal to 2.9V and is typically 3.3V. When the output signal is low, it will be 0.4V or less. When output is low, the Out LED is off, and when output is high, the Out LED is green. For more technical details on the Out signal, please see the *Schematic of Sync Box Input and Output Signals* (below).

Firmware Updates If there is ever a need to update the Sync Box's firmware in the field, there is a small panel on the side of the Sync Box which exposes a USB port that can be used to perform the update.

5.3 Configuration

External synchronization options are selected using the External Synchronization Configuration dialog. You must specify the access point that will be connected to the Sync Box. Only one access point (and thus one Sync Box) can be specified at a time.



External Synchronization

Configure your system to start and/or stop recording from external events or to trigger external events when you start and/or stop recording.

Select Access Point To Configure: #9149

Input Trigger

Shape: Level | Level: High | Trigger: Both

• The black line represents the input into the access point's synchronization port.
• The blue region represents when recording is triggered in Motion Studio.
• In this figure, the start and end of the recording is triggered externally, but it could be started or stopped manually as well.

Output Trigger

Shape: Edge | Level: Low | Trigger: Start

• The blue region represents a recording that you intiate in Motion Studio.
• The black line is the output from the access point's synchronization port, which can be used to trigger recording on an external system.
• In this figure, the output pulse is generated only at the beginning of the recording.

The External Synchronization Configuration Dialog

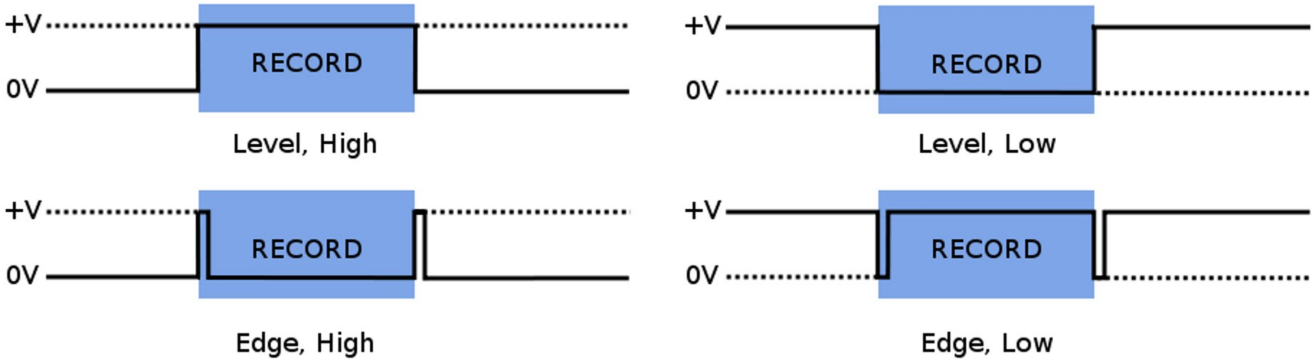
5.3.1 Input Trigger Shape

The input trigger shape indicates the type of signal that will be input into the specified access point and how you want your Opal system to respond. In the figure above, the four basic trigger shapes are shown. The solid black line represents the external synchronization signal being sent to the access point. The blue shaded region represents the period that will be recorded by your Opals.

5.3.2 Input Trigger Level

Input triggers can be either low or high, depending on the nature of the signal generated by your external synchronization source.

5.4 Input Synchronization



Input synchronization trigger types

5.4.1 Input Trigger

There are three input trigger options available:

- Start: The external trigger will only be used to start recording by your Opals.
- End: The external trigger will only be used to stop recording by your Opals.
- Both: The external trigger will be used to start and stop recording by your Opals.

5.4.2 Sample Selection with External Input Trigger Events

The time of the external input trigger events may not align exactly with the time of an individual samples being collected in Motion Studio due to the discreet sampling interval. If the start trigger event time does happen to align exactly with a sample captured in Motion Studio, the first sample recorded will correspond exactly to the time of the start trigger event. If these do not align exactly (as will generally be the case) the sample following the start trigger event will be the first sample recorded. Similarly, if the stop trigger event aligns exactly with a sample captured in Motion Studio, the last sample recorded will correspond exactly to the time of the stop trigger event. If these do not align exactly, the sample preceeding the stop trigger event will be the last sample recorded.

5.4.3 Annotation of Externally Triggered Recordings

Note: Annotations are implemented for the HDF file format only. When an external “Start” trigger event is detected, an annotation is added to the recording that indicates the name of the event (in this case “External trigger start time”) along with the timestamp of the event in epoch microseconds. Similarly, when an external “Stop” trigger event is detected, a timestamped annotation is added to the recording (in this case labeled as the “External trigger stop time”). These annotations allow you to align the recording captured by your Opals with your external events in the case where the external trigger event times do not exactly align with the samples captured in your HDF file.

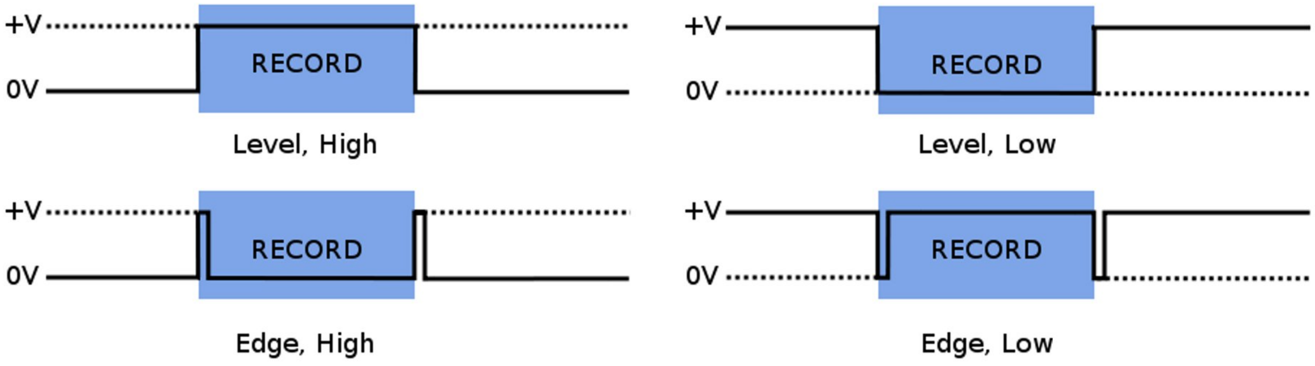
5.4.4 Output Trigger Shape

The output trigger shape indicates the type of signal that will be generated by the specified access point when recording is started and stopped by your Opals. The output trigger shapes are identical to the input trigger shapes, but in this case the solid black line in the figure above represents the signal being output by the configured access point. The blue shaded region represents the period being recorded by your Opals, initiated either through user selection of the start/stop buttons in the “Stream” dialog, use of the wireless remote, or an external synchronization event. Unlike input triggers, output triggers are processed even if the “External Sync” option is not specified in the “Record Duration” panel of the “Stream” dialog.

5.4.5 Output Trigger Level

Output triggers can be either low or high, depending on the requirements of the external system receiving the synchronization signal.

5.5 Output Synchronization



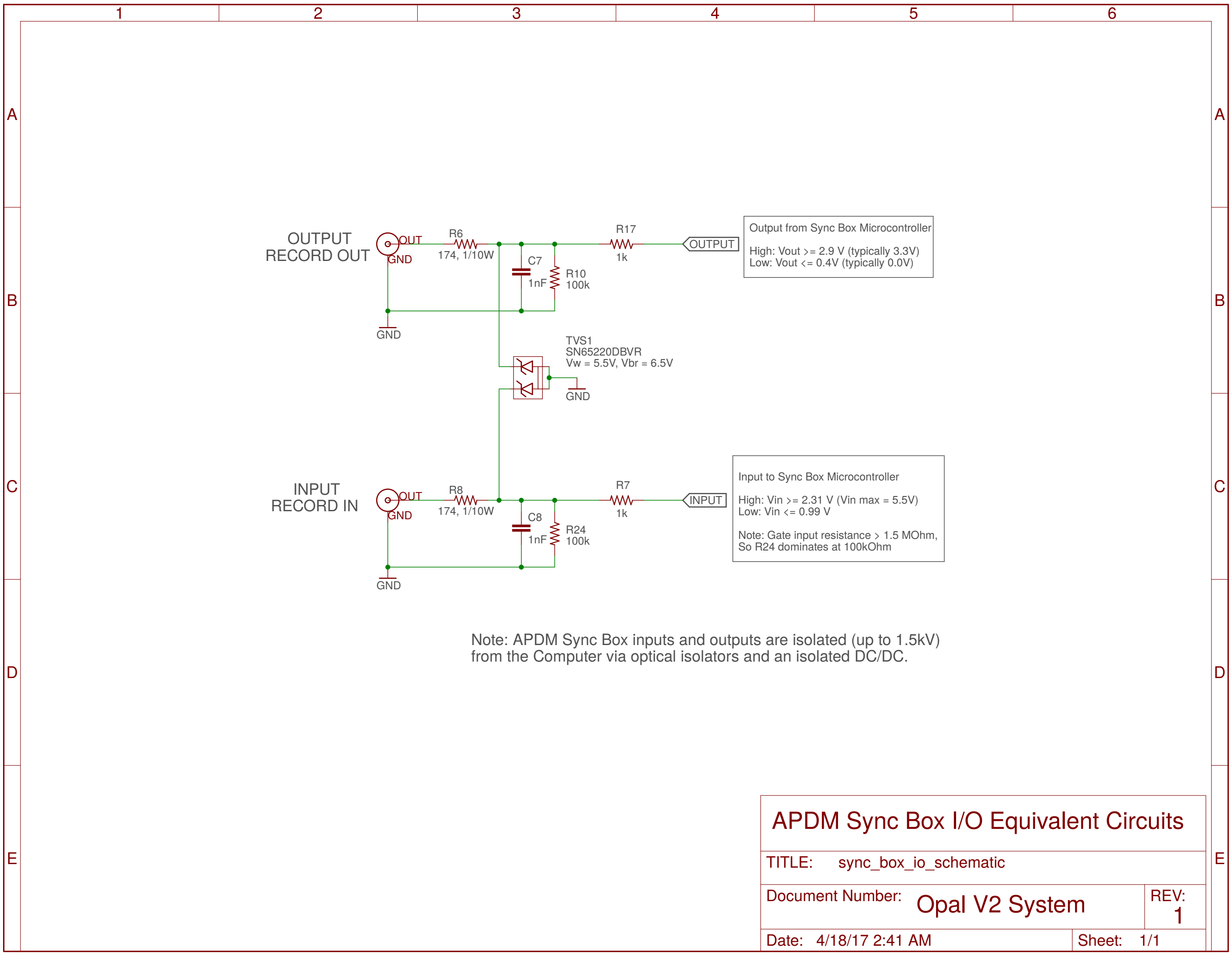
Output synchronization trigger types

5.5.1 Output Trigger

There are three output trigger options available:

- Start: The external signal will only be generated when recording is started by your Opals.
- End: The external signal will only be generated when recording is stopped by your Opals.
- Both: The external signal will be generated when recording is started and stopped by your Opals.

5.6 Schematics


1
2
3
4
5
6
A
B
C
D
E
OUTPUT
RECORD OUT
OUT
GND
R6
174, 1/10W
C7
1nF
R10
100k
R17
1k
OUTPUT
Output from Sync Box Microcontroller
High: Vout >= 2.9 V (typically 3.3V)
Low: Vout <= 0.4V (typically 0.0V)
GND
TVS1
SN65220DBVR
Vw = 5.5V, Vbr = 6.5V
GND
INPUT
RECORD IN
OUT
GND
R8
174, 1/10W
C8
1nF
R24
100k
R7
1k
INPUT
Input to Sync Box Microcontroller
High: Vin >= 2.31 V (Vin max = 5.5V)
Low: Vin <= 0.99 V
Note: Gate input resistance > 1.5 MOhm,
So R24 dominates at 100kOhm
GND
Note: APDM Sync Box inputs and outputs are isolated (up to 1.5kV)
from the Computer via optical isolators and an isolated DC/DC.
APDM Sync Box I/O Equivalent Circuits
TITLE: sync_box_io_schematic
Document Number: Opal V2 System
REV: 1
Date: 4/18/17 2:41 AM
Sheet: 1/1

Schematic of Sync Box Input and Output Signals

6 Programming Examples

6.1 Example Code Provided with the SDK

The host library distribution provides sample code under dist/samples. Samples include source code and pre-compiled binaries for the respective applications. The sample applications of most interest are as follows:

- `autoconfigure_system.c`: This is used to configure a set of attached movement monitors and access points into wireless streaming mode.
- `autoconfigure_rapid_streaming.c`: This is used to configure a set of attached movement monitors and access points into low-latency rapid streaming mode.
- `stream_data.c`: After a system has been autoconfigured and is streaming data to its respective access points, this sample will stream data off the access points and print the data, correctly grouped, to the console.
- `stream_data_rapid.c`: After a system has been autoconfigured in rapid mode, this demonstrates retreiving data using the lowest latency mode possible, however it uses in the libraries in such as was as correlation is not provided by the host libraries.
- `autoconfigure_mesh.c`: This program is used to configure a set of movement monitors into mesh time synchronization and logging mode.
- `convert_raw.c`: This program is used to convert raw ".apdm" files from a movement monitor into a CSV or HDF output file.
- `configure_low_power_mode.c`: This program is used to configure any attached movement monitors into low power, non-streaming mode.

6.2 Simple Configuration and Streaming Example

6.2.1 High Level Psuedocode

1. Allocate a handle:
   `apdm_ctx_allocate_new_context()`

2. Using the handle, open access points attached to the system:
   `apdm_ctx_open_all_access_points()`

3. Autoconfigure the access point(s) and attached movement monitors.
   `apdm_autoconfigure_devices_and_accesspoint2()`

4. Set the max latency value in the libraries.

   `apdm_ctx_set_max_sample_delay_seconds()`

5. Get the attached movement monitor ID list, if useful:

   `apdm_ctx_get_device_id_list()`

6. Synchronize the record head list in the libraries.

   `apdm_ctx_sync_record_list_head()`

7. Collect a list of sensor readings, from all movement monitors, for the same sample point in time. This is usually used within loop or as a regular event.

   `apdm_ctx_get_next_access_point_record_list()`

8. Extract data readings on a per-movement monitor basis, by movement monitor ID number.

   `apdm_ctx_extract_data_by_device_id()`

9. Disconnect from the attached access points and movement monitors

   `apdm_ctx_disconnect()`

10. Free the allocated context

    `apdm_ctx_free_context()`

6.2.2 C Programming Example

The example below implements the above pseudocode using the C programming language. This example is a combination of the `autoconfigure_system.c` and `stream_data.c` programs included in the SDK sample code. Much of the verbose output and error handling was removed for this example to keep it short and tidy.

```
#include "apdm.h"
#include <stdio.h>
#include <inttypes.h>

int main(void)
{
const int32_t num_itterations = 20000000;
int chan = 90;
int r = 0;

apdm_ctx_t apdm_context = ADPM_DEVICE_COMMUNICATIONS_HANDLE_NEW_T_INITIALIZER;
```

```
apdm_context = apdm_ctx_allocate_new_context();

// Open the context
r = apdm_ctx_open_all_access_points(apdm_context);

// Set the maximum delay for data, the maximum time the application is willing
// to wait for data from a given sensor to come in.
r = apdm_ctx_set_max_sample_delay_seconds(apdm_context, APDM_DEFAULT_MAX_LATENCY_SECONDS);

// Configure all attached monitors to stream data
r = apdm_autoconfigure_devices_and_accesspoint4(apdm_context, chan, true, false, true, true, true, true);

// Wait for the user to undock their monitors before streaming.
printf("\n\nRemove the monitors from their docks, wait until the AP\n");
printf("starts blinking green, and press the enter key to continue...\n");
getchar();

// Fetch the list of monitor IDs
uint32_t deviceIdList[APDM_MAX_NUMBER_OF_SENSORS];
r = apdm_ctx_get_device_id_list(apdm_context, deviceIdList, APDM_MAX_NUMBER_OF_SENSORS);

// Define the record into which sensor data is to be stored.
apdm_record_t raw_rec;

r = apdm_ctx_sync_record_list_head(apdm_context);

for (int i = 0; i < num_itterations; i++) {
  // Request the next full set of samples from the AP. All samples returned will be
  // from the same point in time for all sensors configured in the system.
  r = apdm_ctx_get_next_access_point_record_list(apdm_context);

  if( r == APDM_NO_MORE_DATA ) {
    // The host libraries have not received a full set of data,
    // wait a while for more data to stream in from the monitors.
    apdm_usleep(4000);//Note: this is a sensitive number while in rapid streaming mode
    continue;
  } else if( r != APDM_OK ) {
    printf("ERROR encountered: %d, '%s'\n", r, apdm_strerror(r));
    break;
  } else {
    // Successfully got a set of monitor samples.
  }

  printf("===============================================================================\n");
  printf("r = %d\n", r);
  for(int j = 0; j < APDM_MAX_NUMBER_OF_SENSORS; j++ ) {
    if( deviceIdList[j] == 0 ) {
      continue;
    }

    // Get the sensor data for the given device ID
    int ret = apdm_ctx_extract_data_by_device_id(apdm_context, deviceIdList[j], &raw_rec);

    if( ret != APDM_OK ) {
      if( ret == APDM_NO_MORE_DATA ) {
         // Depending on the error handling mode, this monitor may or may not have data for it.
         printf("No More data for device id %d...\n", deviceIdList[j]);
      }
      continue;
    }

    // Print some of the calibrated data to the screen
    if( raw_rec.accl_isPopulated ) {
      printf("si, ");
      printf("%.3f, %.3f, %.3f, ", raw_rec.accl_x_axis_si, raw_rec.accl_y_axis_si, raw_rec.accl_z_axis_si);
      printf("%.3f, %.3f, %.3f, ", raw_rec.gyro_x_axis_si, raw_rec.gyro_y_axis_si, raw_rec.gyro_z_axis_si);
      printf("%.3f, %.3f, %.3f, ", raw_rec.mag_x_axis_si, raw_rec.mag_y_axis_si, raw_rec.mag_z_axis_si);
      printf("\n");
    }
  }
}

apdm_ctx_disconnect(apdm_context);
apdm_ctx_free_context(apdm_context);

return(0);
}
```

6.2.3 Java Programming Example

An example program for configuring and streaming data from a Java application is provided below. Functions available in the Java libraries are usually mappings of the corresponding c-functions, and more detailed documentation can be found in the dOxygen documentation. This example is equivalent to the above example provided in C, with some additional modifications to provide insight into how to set the labels on the monitors and how to write streaming data to our HDF format.

```
import java.io.File;
import java.util.List;

import com.apdm.APDMException;
import com.apdm.APDMNoMoreDataException;
import com.apdm.Context;
import com.apdm.Device;
import com.apdm.DockingStation;
import com.apdm.RecordRaw;

public class StreamDataSample {
    public static void main(String args[]) throws Exception {
        setLabels();
        apAutoConfig();
        System.out.println("Please remove monitors from their docks and press enter...");
        System.in.read();
        streamData();
    }
    public static void setLabels() throws APDMException {
        Context context = null;
        try {
            context = Context.getInstance();
            context.open();
            int nDocks = DockingStation.getNumAttached();
            for (int iDock=0; iDock<nDocks; iDock++) {
                DockingStation dock = null;
                Device sensor = null;
                try {
                    dock = DockingStation.openByIndex(iDock);
                    if (!dock.isMonitorPresent()) {
                        return;
                    }
                    sensor = dock.attachedDevice;
                    String caseId = sensor.cmd_get_device_case_id();
                    // For this example, just set the label to the case ID. This can be any string <= 15 chara
                    // More typically, the user will know which label they which to apply to which sensor base
                    // unique case ID on the back of the sensor, so a mapping may be used here to determine th
                    sensor.cmd_set_device_label(caseId);
                    sensor.cmd_config_commit();
                    System.out.println("Set label on sensor in dock " + (iDock+1) + " to " + caseId);
                } finally {
                    if (dock != null) {
                        dock.close();
                    }
                }
            }
        } catch (Exception ex) {
            System.out.println(ex.getMessage());
            System.out.println("Could not set labels on docked sensors");
        } finally {
            if (context != null) {
                context.close();
            }
        }
    }
    public static void apAutoConfig() throws Exception {
        Context context = null;
        try {
            context = Context.getInstance();
            context.open();
            int wirelessChannel = 80;
            boolean enableSDCard  = true;
            boolean eraseSDCard = false;
            boolean accelFullScaleMode = true;
            boolean enableAccel = true;
            boolean enableGyro = true;
            boolean enableMag = true;
            context.autoConfigureDevicesAndAccessPoint4(
                    wirelessChannel,
                    enableSDCard,
                    eraseSDCard,
                    accelFullScaleMode,
                    enableAccel,
                    enableGyro,
                    enableMag);
            System.out.println("Done configuring system for wireless streaming");
        } finally {
            if (context != null) {
                context.close();
            }
        }
    }
    public static void streamAndRecordData() throws Exception {
        Context context = Context.getInstance();
        int hdfFileHandle = 0;
        try {
            context.open();

            // Create the HDF file to write to
            String filePath = "./recording.h5";
            hdfFileHandle = context.createHDFFile("recording.h5");
            File file = new File(filePath);
```

```
if (hdfFileHandle == 0 || !file.exists()) {
    throw new Exception("Could not create file at: " + filePath);
}
System.out.println("File created at " + file.getAbsolutePath());

int min_latency_seconds = 0;
int max_latency_seconds = 0xffff;
// Set the max latency to something small to flush
// any existing data buffered on the monitors
context.setMaxLatency(min_latency_seconds);

// Wait a little bit to give the monitors time to receive
// the command and process it.
Thread.sleep(3000);

// Set the max latency time back to something big.
// This will force the AP to process old packets if the sensors
// go out of range of the AP
context.setMaxLatency(max_latency_seconds);

// Sync the record head list. This is a method in the host
// libraries which waits to correlate data from all streaming devices
// before emitting correlated sets of data.
context.syncRecordHeadList();

// Call this many times to stream data
int sampleNum = 0;
for (int i = 0; i < 1000; i++) {
    List<RecordRaw> records = null;
    try {
        records = context.getNextRecordList();
    } catch (APDMNoMoreDataException ex) {
        // No data found, so wait just a bit for data to become available.
        Thread.sleep(100);
    }
    // The list of records will be empty if no data was found.
    if (!records.isEmpty()) {
        boolean storeRaw = false;
        boolean storeSI = true;
        boolean storeFiltered = false;
        boolean compress = true;
        context.writeRecordToHDF(hdfFileHandle, sampleNum, storeRaw, storeSI, storeFiltered, compr
        for (RecordRaw rec : records) {
            System.out.println(rec.toString());
        }
        sampleNum++;
```

```
                }
            }
        } finally {
            if (hdfFileHandle != 0) {
                context.closeHDFFile(hdfFileHandle);
            }
            if (context != null) {
                context.close();
            }
        }
    }
}
```

6.2.4 Matlab Programming Examples

A set of example matlab programs are provided in the APDM SDK, available from http://share.apdm.com/libraries/ In the SDK zip file, under the matlab/(operating system)/(arch)/ you will find respective .m code, libraries and thunk files.

7 Working with HDF5 Files

HDF5 is the preferred format for storing APDM movement monitor data. It is a standard format for scientific data that is efficient and widely supported. It uses less space than CSV, is faster to load, and supports more structured data. This section will cover the organization of the APDM movement monitor data and the basics of reading HDF5 files in Python.

7.1 HDFView

A free program called HDFView (http://www.hdfgroup.org/hdf-java-html/hdfview/) can be used to explore, plot, and export this data into other formats. Many free and commercial products are capable of reading, writing, and editing HDF data, including Matlab, Python, and LabView. Many programming languages are also supported, including, C, C++, Java, and Python.

7.2 Python

APDM embraces Python as a Mathematical scripting language. It has excellent support for reading, writing, editin HDF files through the h5py package. It is also widely used and open source, which makes it available to our entire customer base.

7.3 Data Organization

HDF5 files are organized like a file structure. The root of the file contains one or more attributes. One is the version number for the organization of the HDF 5 file. APDM is currently on version 5 of our HDF format.

7.4 File Structure

Note about the latest version: Version 5 of APDM's HDF format departs significantly from Version 4. It is specific to our second iteration of hardware, so if you are using v1 hardware (without the displays), your recordings will follow the Version 4 HDF convention. The information contained is largely identical, but it is organized differently to make it more extensible. If you have created custom parsers for your recordings or have used APDM's examples for post-processing your recordings, you will likely have to change these scripts to adapt. You can use the version attribute to modify your scripts to handle both versions from the same script.

7.4.1 Version 5

- **Annotations** Table containing annotations and button events
  - **Time** Annotation time in epoch microseconds
  - **Case ID** A movement monitor case ID associated with the annotation
  - **Annotation** The annotation string
- **Sensors** Group containing sensor data
  - **XI-XXXXXX** Group containing data from the monitor with this case ID. There is one of these groups for each sensor
    - **Accelerometer** Dataset containing accelerometer data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Barometer** Dataset containing barometer data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Gyroscope** Dataset containing gyroscope data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Magnetometer** Dataset containing magnetometer data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Temperature** Dataset containing internal temperature data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Time** Dataset containing timestamps in units of microseconds since 0:00 Jan 1, 1970 UTC
      - **Units** Attribute specifying the units used to store the timestamps
    - **Configuration** Group containing attributes that specify the configuration of the sensor
      - **Accelerometer Enabled** 1 for enabled. 0 for disabled
      - **Gyroscope Enabled** 1 for enabled. 0 for disabled
      - **Magnetometer Enabled** 1 for enabled. 0 for disabled
      - **Barometer Enabled** 1 for enabled. 0 for disabled
      - **Button Event 0 =** String configured to represent a button 0 event
      - **Button Event 1 =** String configured to represent a button 1 event
      - **Button Event 2 =** String configured to represent a button 2 event

      - **Button Event 3 =** String configured to represent a button 3 event
      - **Calibration Disabled** 1 to apply only the sensor data sheet typical conversion factors. 0 to use calibration data stored on the device
      - **Label 0** Custom label for this sensor. This is what is displayed on the LCD
      - **Location** Sensor location on the body
      - **Sample Rate** Sensor output data rate
      - **Timezone** Timezone code
      - **Timezone Offset** Timezone offset in units of hours from UTC
      - **Wireless Channel** Wireless channel
      - **Wireless Protocol** 0 for wireless disabled, 1 for synchronized logging, 2 for wireless streaming
      - **Wireless Latency (ms)** Configured maximum acceptable wireless latency
      - **Wireless rate divider** Data is streamed at the sample rate divided by this factor
    - **Metrics** Group containing information on the status of the sensor

- **Processed** Group containing derived signals from the sensor data
  - **XI-XXXXXX** Group containing derived signals from the sensor with this case ID
    - Orientation Dataset containing quaternions which can be used to rotate sensor data from the sensor frame to a local NWU reference frame

7.4.2 Versions 3 and 4

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaseIdList
- **CaseIdList Attribute** containing an array of monitor case IDs in the same order as the MonitorLabelList
- **FileFormatVersion** Attribute containing the file format version (3)
- **Annotations** Table containing annotations
  - **Time** Annotation time in epoch microseconds
  - **Case ID** A movement monitor case ID associated with the annotation
  - **Annotation** The annotation string
- **AA-XXXXXX** A group is included in the file for each monitor in the CaseIdList, with the name equal to the case ID
  - **FilteredDataPopulated (version 4)** Attribute indicating the present of the filtered data group
  - **SampleRate** Attribute containing the output data rate for the monitor
  - **DecimationFactor** Decimation factor for the monitor's internal processing
  - **ModuleID** The module ID for the monitor
  - **TimeGood** Flag indicating whether the time has been set on the monitor since it powered on
  - **RecordingMode** One of: "Wireless streaming", "Synchronized logging", or "Unsynchronized logging"
  - **DataMode** Indicates whether the data was retrieved wirelessly or copied from the monitor's internal storage while docked. One of: "Streamed wirelessly" or "Logged to monitor"
  - **AccelerometersEnabled** 1 for enabled, 0 for disabled
  - **GyroscopesEnabled** 1 for enabled, 0 for disabled
  - **MagnetometersEnabled** 1 for enabled, 0 for disabled
  - **DecimationBypass** Internal use, deprecated
  - **CalibrationVersion** Version of the calibration data used to convert from raw samples to calibrated SI units
  - **VersionString1** Firmware version string 1
  - **VersionString2** Firmware version string 2

- **VersionString3** Firmware version string 3
- **CalibratedDataPopulated (version 3)** 1 for populated, 0 for unpopulated
- **CalibratedData (version 4)** Calibration data for the monitor
- **LocalTimeOffset** Time in microseconds to add to UTC to convert to local time
- **SyncValue** Dataset containing the internal sync value for each sample
  - **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
- **Time** Dataset containing a timestamp for each sample
  - **Units** Attribute string containing the units (microseconds since 0:00 Jan 1, 1970 UTC)
- **ButtonStatus** Dataset containing the button status for each sample (1==pressed, 0==unpressed)
- **Calibrated** Group containing calibrated data
  - **Accelerometers** Dataset containing accelerometer data (Nx3)
    - **Units** Attribute string containing the accelerometer units (m/s^2)
    - **Range** Attribute containing the range setting for the accelerometer (2g or 6g)
    - **Gravity (version 4)** Attribute indicating the gravity constant used in orientation estimation
  - **Gyroscopes** Dataset containing gyroscope data (Nx3)
    - **Units** Attribute string containing the gyroscope units (rad/s)
  - **Magnetometers** Dataset containing magnetometer data (Nx3)
    - **Units** Attribute string containing the magnetometer units (μT)
  - **Temperature** Dataset containing the temperature (Nx1)
    - **Units** Attribute string containing the temperature units (°C)
    - **EarthFieldMagnitude (version 4)** The field constant used in orientation estimation
  - **TemperatureDerivative** Dataset containing the temperature derivative (Nx1)
    - **Units** Attribute string containing the temperature derivative units (°C/s)
  - **Orientation** Dataset containing the orientation quaternion (Nx4). The orientation is relative to a (magnetic) north, west, up reference frame. The scalar component of the quaternion is the first element.
- **Raw** Group containing raw data if selected during import
  - **Accelerometers**
  - **Gyroscopes**
  - **Magnetometers**
  - **DataFlags**
  - **OptData**
  - **Temperature**
  - **TemperatureDerivative**
- **Filtered (version 4)** Filtered data set. This set is intended for post-processed data. Currently the gyro biases are removed from the gyroscope signals. In the future, additional filtering may be implemented.
  - **Accelerometers**
  - **Gyroscopes**
  - **Magnetometers**

7.4.3 Version 3

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaseIdList
- **CaseIdList Attribute** containing an array of monitor case IDs in the same order as the MonitorLabelList

- **FileFormatVersion** Attribute containing the file format version (3)
- **Annotations** Table containing annotations
  - **Time** Annotation time in epoch microseconds
  - **Case ID** A movement monitor case ID associated with the annotation
  - **Annotation** The annotation string
- **AA-XXXXXX** A group is included in the file for each monitor in the CaseIdList, with the name equal to the case ID
  - **SampleRate** Attribute containing the output data rate for the monitor
  - **DecimationFactor** Decimation factor for the monitor's internal processing
  - **ModuleID** The module ID for the monitor
  - **TimeGood** Flag indicating whether the time has been set on the monitor since it powered on
  - **RecordingMode** One of: ”Wireless streaming”, ”Synchronized logging”, or ”Unsynchronized logging”
  - **DataMode** Indicates whether the data was retrieved wirelessly or copied from the monitor's internal storage while docked. One of: ”Streamed wirelessly” or ”Logged to monitor”
  - **AccelerometersEnabled** 1 for enabled, 0 for disabled
  - **GyroscopesEnabled** 1 for enabled, 0 for disabled
  - **MagnetometersEnabled** 1 for enabled, 0 for disabled
  - **DecimationBypass** Internal use, deprecated
  - **CalibrationVersion** Version of the calibration data used to convert from raw samples to calibrated SI units
  - **VersionString1** Firmware version string 1
  - **VersionString2** Firmware version string 2
  - **VersionString3** Firmware version string 3
  - **CalibratedDataPopulated** 1 for populated, 0 for unpopulated
  - **LocalTimeOffset** Time in milliseconds to add to UTC to convert to local time
  - **SyncValue** Dataset containing the internal sync value for each sample
    - **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
  - **Time** Dataset containing a timestamp for each sample
    - **Units** Attribute string containing the units (microseconds since 0:00 Jan 1, 1970 UTC)
  - **ButtonStatus** Dataset containing the button status for each sample (1==pressed, 0==unpressed)
  - **Calibrated** Group containing calibrated data
    - **Accelerometers** Dataset containing accelerometer data (N$\times$3)
      - **Units** Attribute string containing the accelerometer units (m/s^2)
      - **Range** Attribute containing the range setting for the accelerometer (2g or 6g)
    - **Gyroscopes** Dataset containing gyroscope data (N$\times$3)
      - **Units** Attribute string containing the gyroscope units (rad/s)
    - **Magnetometers** Dataset containing magnetometer data (N$\times$3)
      - **Units** Attribute string containing the magnetometer units (μT)
    - **Temperature** Dataset containing the temperature (N$\times$1)
      - **Units** Attribute string containing the temperature units (°C)
    - **TemperatureDerivative** Dataset containing the temperature derivative (N$\times$1)
      - **Units** Attribute string containing the temperature derivative units (°C/s)
    - **Orientation** Dataset containing the orientation quaternion (N$\times$4). The orientation is relative to a (magnetic) north, west, up reference frame. The scalar component of the quaternion is the first element.
  - **Raw** Group containing raw data if selected during import

        - **Accelerometers**
        - **Gyroscopes**
        - **Magnetometers**
        - **DataFlags**
        - **OptData**
        - **Temperature**
        - **TemperatureDerivative**

7.4.4 Version 2

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaseIdList
- **CaseIdList Attribute** containing an array of monitor case IDs in the same order as the MonitorLabelList
- **FileFormatVersion** Attribute containing the file format version (2)
- **Annotations** Table containing annotations
    - **Time** Annotation time in epoch microseconds
    - **Case ID** A movement monitor case ID associated with the annotation
    - **Annotation** The annotation string
- **AA-XXXXXX** A group is included in the file for each monitor in the CaseIdList, with the name equal to the case ID
    - **SampleRate** Attribute containing the output data rate for the monitor
    - **DecimationFactor** Decimation factor for the monitor's internal processing
    - **ModuleID** The module ID for the monitor
    - **TimeGood** Flag indicating whether the time has been set on the monitor since it powered on
    - **RecordingMode** One of: ”Wireless streaming”, ”Synchronized logging”, or ”Unsynchronized logging”
    - **DataMode** Indicates whether the data was retrieved wirelessly or copied from the monitor's internal storage while docked. One of: ”Streamed wirelessly” or ”Logged to monitor”
    - **AccelerometersEnabled** 1 for enabled, 0 for disabled
    - **GyroscopesEnabled** 1 for enabled, 0 for disabled
    - **MagnetometersEnabled** 1 for enabled, 0 for disabled
    - **DecimationBypass** Internal use, deprecated
    - **CalibrationVersion** Version of the calibration data used to convert from raw samples to calibrated SI units
    - **VersionString1** Firmware version string 1
    - **VersionString2** Firmware version string 2
    - **VersionString3** Firmware version string 3
    - **CalibratedDataPopulated** 1 for populated, 0 for unpopulated
    - **LocalTimeOffset** Time in milliseconds to add to UTC to convert to local time
    - **SyncValue** Dataset containing the internal sync value for each sample
        - **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
    - **Time** Dataset containing a timestamp for each sample
        - **Units** Attribute string containing the units (microseconds since 0:00 Jan 1, 1970 UTC)
    - **Calibrated** Group containing calibrated data
        - **Accelerometers** Dataset containing accelerometer data (Nx3)
            - **Units** Attribute string containing the accelerometer units (m/s^2)
            - **Range** Attribute containing the range setting for the accelerometer (2g or 6g)

        - **Gyroscopes** Dataset containing gyroscope data (Nx3)
            - **Units** Attribute string containing the gyroscope units (rad/s)
        - **Magnetometers** Dataset containing magnetometer data (Nx3)
            - **Units** Attribute string containing the magnetometer units (μT)
        - **Temperature** Dataset containing the temperature (Nx1)
            - **Units** Attribute string containing the temperature units (°C)
        - **TemperatureDerivative** Dataset containing the temperature derivative (Nx1)
            - **Units** Attribute string containing the temperature derivative units (°C/s)
    - **Raw** Group containing raw data if selected during import
        - **Accelerometers**
        - **Gyroscopes**
        - **Magnetometers**
        - **DataFlags**
        - **OptData**
        - **Temperature**
        - **TemperatureDerivative**

7.4.5 Version 1

This version is deprecated. All new files created will use the most recent version.

- **Device_List** Attribute containing a list of monitors present in the file
- **File_Format_Version** Attribute containing the file version
- **Annotations** Table containing annotations
    - **Time** Annotation time in epoch microseconds
    - **Device ID** A movement monitor ID associated with the annotation
    - **Annotation** The annotation string
- **Opal_xxx/** Group containing information about and data from monitor ID xxx
    - **Sample_Rate** Attribute containing the output data rate for the monitor
    - **Decimation_Factor** Decimation factor for the monitor's internal processing
    - **Time_Good** Flag indicating whether the monitor has had its time set since turning on
    - **Decimation_Bypass** Internal use, deprecated
    - **Calibration_Version** Version of the calibration data used to convert from raw samples to calibrated SI units
    - **Version_String1** Firmware version string 1
    - **Version_String2** Firmware version string 2
    - **Version_String3** Firmware version string 3
    - **Acceleration** Dataset containing data from the accelerometers (Nx3)
        - **Units** Attribute string containing the acceleration units (m/s^2)
    - **Angular_Velocity** Dataset containing data from the gyroscopes (Nx3)
        - **Units** Attribute string containing the angular velocity units (rad/s)
    - **Magnetic_Field** Dataset containing data from the magnetometers (Nx3)
        - **Units** Attribute string containing the magnetic field units (a.u.)

  - **Temperature** Dataset containing the temperature of the monitor (Nx1)
    - **Units** Attribute string containing the temperature units (°C)
  - **Temperature_Derivative** Dataset containing the rate of change of temperature
    - **Units** Attribute string containing the temperature derivative units (°C/s)
  - **Sync_Value** Dataset containing the internal timestamp of each sample
    - **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
    - **Time** Dataset containing the time for each sample in microseconds since 0:00 Jan 1, 1970 UTC

Additional fields present when raw data is also stored:

- **Opal_XX/**
  - **Calibration_Data** Attribute containing binary block of calibration data
  - **Raw_File_Version** Attribute containing the version string of the raw file (if this was converted from a .apdm file instead of streamed)
  - **Accelerometers_Raw** Dataset containing raw accelerometer data $(Nx3)$
  - **Gyroscopes_Raw** Dataset containing raw gyroscope data $(Nx3)$
  - **Magnetometers_Raw** Dataset containing raw magnetometer data $(Nx3)$
  - **Data_Flags** Dataset containing flags used for processing the raw data
  - **Opt_Data** Dataset containing several measurements taken at a low data rate
  - **Temperature_Raw** Dataset containing lowpass filtered, but uncalibrated temperature data $(Nx1)$

7.5 Working with HDF 5 in MATLAB

MATLAB contains native functionality for working with HDF5 files. Additional help and examples are included in the built in help documentation for these functions. The first example below uses an older Matlab interface (hdf5read,...) which is compatible with Matlab 2008b and later. It also assumes version 4 of APDM's HDF format. The second example uses Matlab's updated interfacd (h5read, ...) and assumes version 5 of APDM's HDF format.

7.5.1 Matlab, hdf5read, Version 4 of APDM's HDF format

```
filename = 'example.h5';
try
   vers = hdf5read(filename, '/FileFormatVersion');
catch
   try
      vers = hdf5read(filename, '/File_Format_Version');
   catch
      error('Couldn''t determine file format');
   end
end
if vers< 2
```

```
   error('This example only works with version 2 or later of the data file')
end
caseIdList = hdf5read(filename, '/CaseIdList');
groupName = caseIdList(1).data;
accPath = [groupName '/Calibrated/Accelerometers'];
fs = hdf5read(filename, [groupName '/SampleRate']);
fs = double(fs);
acc = hdf5read(filename, accPath)'; %Transposed to make Nx3 in MATLAB}
t = (1:size(acc,1))/fs;
figure;
plot(t,acc);
```

A more complicated example using the flexibility of HDF5 to load and process only part of a data set. This can be useful when the data set is too large to fit into memory. Care is taken not to attempt to read beyond the end of the file.

```
filename = 'example.h5';
try
    vers = hdf5read(filename, '/FileFormatVersion');
catch
    try
        vers = hdf5read(filename, '/File_Format_Version');
    catch
        error('Couldn''t determine file format');
    end
end
if vers < 2
    error('This example only works with version 2 or later of the data file')
end
idList = hdf5read(filename, '/CaseIdList');
groupName = idList(1).data;
accPath = [groupName '/Calibrated/Accelerometers'];
fs = hdf5read(filename, [groupName '/SampleRate']);
fs = double(fs);
fhandle = H5F.open(filename, 'H5F_ACC_RDONLY', 'H5P_DEFAULT');
dset = H5D.open(fhandle, [groupName '/Calibrated/Accelerometers'], 'H5P_DEFAULT');
dspace = H5D.get_space(dset);
[ndims, dims] = H5S.get_simple_extent_dims(dspace);
nSamples = dims(1);
nSamplesRead = min(nSamples, 60*fs); %read at most one minute of data
accSegment = hdf5readslab(filename, accPath, [0,0], [nSamplesRead, 3])';
t = (1:nSamplesRead)/fs;
figure;
plot(t,accSegment);
```

7.5.2 Matlab, h5read, Version 5 of APDM's HDF format

Plot the accelerometer dataset for the sensor labeled ”Lumbar”.

```
filePath = '/my_files/20170329-090555_TUG.h5'

fileFormat = h5readatt(filePath, '/', 'FileFormatVersion');

if fileFormat < 5
    error('TruncateHDF only works on fileFormat versions 5+');
end

sensors = h5info(filePath, '/Sensors')

for i = 1:length(sensors.Groups)
    label = h5readatt(filePath, [sensor(i).Name '/Configuration'], 'Label 0');
    if strfind(label, 'Lumbar')
        acc = h5read(filePath, [sensor(i).Name '/Accelerometer'])
        figure;plot(acc')
    end
end
```

7.5.3 Notes

- Arrays in MATLAB use the FORTRAN convention of storing them in memory by column then row, instead of the C convention (used by HDF 5) of row then column. This has the effect of making the returned arrays transposed from how this document (and many other interfaces to HDF5) claim they are laid out.
- Older versions of MATLAB (before 2009a) did not support the compression used in Motion Studio's HDF 5 files. If you are using one of these older versions, the free h5repack utility available from the HDF Group can remove the compression. This utility is available at:
  http://www.hdfgroup.org/HDF5/release/obtain5.html
  The command to repack the file is:
  `h5repack -f NONE example.h5 example_no_compression.h5`

7.6 Working with HDF 5 in Python

Swap labels on a recording. For example, swap the ”Right Arm” with the ”Right Foot” Opal.

```
import h5py
def swapLabels(fn, oldLabel='Right', newLabel='Left'):
    with h5py.File(fn, 'r+') as f:
        for s in f['Sensors']:
            l = f['Sensors'][s]['Configuration'].attrs['Label 0']
            f['Sensors'][s]['Configuration'].attrs.modify('Label 0', l.replace(oldLabel, newLabel))
```

8 Calibration

There are two 2KB blocks of calibration data stored on each monitor's internal flash memory. The first of these contains factory calibration and should not be modified. The second one contains user calibration. If the user calibration block is valid, it will be used for calibrating raw data instead of the factory calibration. There are two ways to modify the user calibration: using the recalibration functionality in Motion Studio, or by loading a custom calibration .hex file in Motion Studio. This section details the .hex file format and contents.

8.1 File Format

The .hex file is a plain text (ASCII) file format based on the Tektronix extended HEX file format, with small modifications. The file format has two types of records:

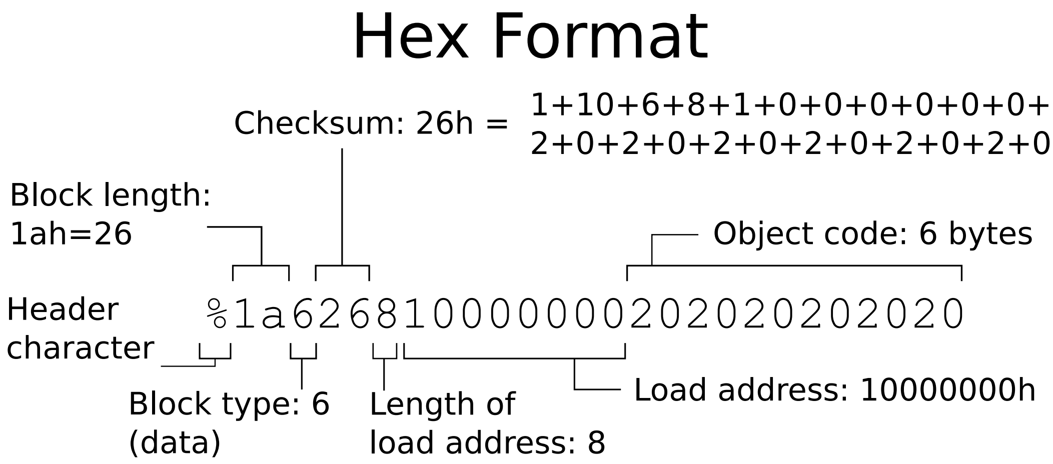
- Data records: contains the header field, the load address, and the object code.
- Termination records: signifies the end of a module.

The header field in the data record contains the following information.

Item	Number of ASCII Characters	Description
%	1	Data type is Tektronix format
Block Length	2	Number of characters in the record, minus the %
Block Type	1	6 = data record 8 = termination record
Checksum	2	A 2-digit hex sum modulo 256 of all values in the record except the % and the checksum itself

The load address in the data record specifies where the object code will be located. The first digit specifies the address length; this is always 8. The remaining characters of the data record contain the object code, two characters per byte.

The termination record is not used in this context. It is also assumed that lines starting with '#' are comments and should be ignored by the parser. Metadata lines are designated with a leading ':' character. The comments and meta data extensions are not part of the original format.



8.2 Data Format

8.2.1 Calibration version 5

The tables below show the organization of the calibration data in the hex file. The first 64 bits are a version number, and must be equal to the specified value. Wherever a zero is present in the tables, it should be interpreted as a literal zero to be stored in that memory location. All of the calibration data is represented in one of two data types. The first is a fixed point 64-bit integer with 50 fractional bits in 2's compliment format (Q13.50). The second is an unsigned 16-bit integer.

16-bit integers are used for representing temperature dependent bias for each sensor. The subscript on the values in the table below denotes the temperature in degrees Celsius. There are two temperature sensors on the monitor (one on the gyro, and one on the microcontroller), and each has a different set of scale and offset values. Of the two, the gyro temperature sensor is more accurate, so it is used by default. If the gyro is configured to be turned off, the MSP temperature sensor is used instead.

Near the end of the memory block there are three magnetometer bias values. These are used as part of the internal bias compensation and should not be modified.

offset	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x000	0x8000000000000005								acc_x_scale							
0x010	acc_y_scale								acc_z_scale							
0x020	acc_x_scale_temp								acc_y_scale_temp							
0x030	acc_z_scale_temp								acc_xy_sensitivity							
0x040	acc_xz_sensitivity								acc_yz_sensitivity							
0x050	0								xacc_b_-10		xacc_b_-09		xacc_b_-08		xacc_b_-07	
0x060	xacc_b_-06		xacc_b_-05		xacc_b_-04		xacc_b_-03		xacc_b_-02		xacc_b_-01		xacc_b_00		xacc_b_01	
0x070	xacc_b_02		xacc_b_03		xacc_b_04		xacc_b_05		xacc_b_06		xacc_b_07		xacc_b_08		xacc_b_09	
0x080	xacc_b_10		xacc_b_11		xacc_b_12		xacc_b_13		xacc_b_14		xacc_b_15		xacc_b_16		xacc_b_17	
0x090	xacc_b_18		xacc_b_19		xacc_b_20		xacc_b_21		xacc_b_22		xacc_b_23		xacc_b_24		xacc_b_25	
0x0a0	xacc_b_26		xacc_b_27		xacc_b_28		xacc_b_29		xacc_b_30		xacc_b_31		xacc_b_32		xacc_b_33	
0x0b0	xacc_b_34		xacc_b_35		xacc_b_36		xacc_b_37		xacc_b_38		xacc_b_39		xacc_b_40		xacc_b_41	
0x0c0	xacc_b_42		xacc_b_43		xacc_b_44		xacc_b_45		xacc_b_46		xacc_b_47		xacc_b_48		xacc_b_49	
0x0d0	xacc_b_50		yacc_b_-10		yacc_b_-09		yacc_b_-08		yacc_b_-07		yacc_b_-06		yacc_b_-05		yacc_b_-04	
0x0e0	yacc_b_-03		yacc_b_-02		yacc_b_-01		yacc_b_00		yacc_b_01		yacc_b_02		yacc_b_03		yacc_b_04	
0x0f0	yacc_b_05		yacc_b_06		yacc_b_07		yacc_b_08		yacc_b_09		yacc_b_10		yacc_b_11		yacc_b_12	
0x100	yacc_b_13		yacc_b_14		yacc_b_15		yacc_b_16		yacc_b_17		yacc_b_18		yacc_b_19		yacc_b_20	
0x110	yacc_b_21		yacc_b_22		yacc_b_23		yacc_b_24		yacc_b_25		yacc_b_26		yacc_b_27		yacc_b_28	
0x120	yacc_b_29		yacc_b_30		yacc_b_31		yacc_b_32		yacc_b_33		yacc_b_34		yacc_b_35		yacc_b_36	
0x130	yacc_b_37		yacc_b_38		yacc_b_39		yacc_b_40		yacc_b_41		yacc_b_42		yacc_b_43		yacc_b_44	
0x140	yacc_b_45		yacc_b_46		yacc_b_47		yacc_b_48		yacc_b_49		yacc_b_50		zacc_b_-10		zacc_b_-09	
0x150	zacc_b_-08		zacc_b_-07		zacc_b_-06		zacc_b_-05		zacc_b_-04		zacc_b_-03		zacc_b_-02		zacc_b_-01	
0x160	zacc_b_00		zacc_b_01		zacc_b_02		zacc_b_03		zacc_b_04		zacc_b_05		zacc_b_06		zacc_b_07	
0x170	zacc_b_08		zacc_b_09		zacc_b_10		zacc_b_11		zacc_b_12		zacc_b_13		zacc_b_14		zacc_b_15	
0x180	zacc_b_16		zacc_b_17		zacc_b_18		zacc_b_19		zacc_b_20		zacc_b_21		zacc_b_22		zacc_b_23	
0x190	zacc_b_24		zacc_b_25		zacc_b_26		zacc_b_27		zacc_b_28		zacc_b_29		zacc_b_30		zacc_b_31	
0x1a0	zacc_b_32		zacc_b_33		zacc_b_34		zacc_b_35		zacc_b_36		zacc_b_37		zacc_b_38		zacc_b_39	
0x1b0	zacc_b_40		zacc_b_41		zacc_b_42		zacc_b_43		zacc_b_44		zacc_b_45		zacc_b_46		zacc_b_47	
0x1c0	zacc_b_48		zacc_b_49		zacc_b_50		0		gyro_x_scale							
0x1d0	gyro_y_scale								gyro_z_scale							
0x1e0	gyro_xy_sensitivity								gyro_xz_sensitivity							
0x1f0	gyro_yz_sensitivity								gyro_accel_roll							
0x200	gyro_accel_pitch								gyro_accel_yaw							
0x210	gyro_x_scale_temp								gyro_y_scale_temp							
0x220	gyro_z_scale_temp								xgyr_b_-10		xgyr_b_-09		xgyr_b_-08		xgyr_b_-07	
0x230	xgyr_b_-06		xgyr_b_-05		xgyr_b_-04		xgyr_b_-03		xgyr_b_-02		xgyr_b_-01		xgyr_b_00		xgyr_b_01	

offset	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x240	xgyr_b_02		xgyr_b_03		xgyr_b_04		xgyr_b_05		xgyr_b_06		xgyr_b_07		xgyr_b_08		xgyr_b_09	
0x250	xgyr_b_10		xgyr_b_11		xgyr_b_12		xgyr_b_13		xgyr_b_14		xgyr_b_15		xgyr_b_16		xgyr_b_17	
0x260	xgyr_b_18		xgyr_b_19		xgyr_b_20		xgyr_b_21		xgyr_b_22		xgyr_b_23		xgyr_b_24		xgyr_b_25	
0x270	xgyr_b_26		xgyr_b_27		xgyr_b_28		xgyr_b_29		xgyr_b_30		xgyr_b_31		xgyr_b_32		xgyr_b_33	
0x280	xgyr_b_34		xgyr_b_35		xgyr_b_36		xgyr_b_37		xgyr_b_38		xgyr_b_39		xgyr_b_40		xgyr_b_41	
0x290	xgyr_b_42		xgyr_b_43		xgyr_b_44		xgyr_b_45		xgyr_b_46		xgyr_b_47		xgyr_b_48		xgyr_b_49	
0x2a0	xgyr_b_50		ygyr_b_-10		ygyr_b_-09		ygyr_b_-08		ygyr_b_-07		ygyr_b_-06		ygyr_b_-05		ygyr_b_-04	
0x2b0	ygyr_b_-03		ygyr_b_-02		ygyr_b_-01		ygyr_b_00		ygyr_b_01		ygyr_b_02		ygyr_b_03		ygyr_b_04	
0x2c0	ygyr_b_05		ygyr_b_06		ygyr_b_07		ygyr_b_08		ygyr_b_09		ygyr_b_10		ygyr_b_11		ygyr_b_12	
0x2d0	ygyr_b_13		ygyr_b_14		ygyr_b_15		ygyr_b_16		ygyr_b_17		ygyr_b_18		ygyr_b_19		ygyr_b_20	
0x2e0	ygyr_b_21		ygyr_b_22		ygyr_b_23		ygyr_b_24		ygyr_b_25		ygyr_b_26		ygyr_b_27		ygyr_b_28	
0x2f0	ygyr_b_29		ygyr_b_30		ygyr_b_31		ygyr_b_32		ygyr_b_33		ygyr_b_34		ygyr_b_35		ygyr_b_36	
0x300	ygyr_b_37		ygyr_b_38		ygyr_b_39		ygyr_b_40		ygyr_b_41		ygyr_b_42		ygyr_b_43		ygyr_b_44	
0x310	ygyr_b_45		ygyr_b_46		ygyr_b_47		ygyr_b_48		ygyr_b_49		ygyr_b_50		zgyr_b_-10		zgyr_b_-09	
0x320	zgyr_b_-08		zgyr_b_-07		zgyr_b_-06		zgyr_b_-05		zgyr_b_-04		zgyr_b_-03		zgyr_b_-02		zgyr_b_-01	
0x330	zgyr_b_00		zgyr_b_01		zgyr_b_02		zgyr_b_03		zgyr_b_04		zgyr_b_05		zgyr_b_06		zgyr_b_07	
0x340	zgyr_b_08		zgyr_b_09		zgyr_b_10		zgyr_b_11		zgyr_b_12		zgyr_b_13		zgyr_b_14		zgyr_b_15	
0x350	zgyr_b_16		zgyr_b_17		zgyr_b_18		zgyr_b_19		zgyr_b_20		zgyr_b_21		zgyr_b_22		zgyr_b_23	
0x360	zgyr_b_24		zgyr_b_25		zgyr_b_26		zgyr_b_27		zgyr_b_28		zgyr_b_29		zgyr_b_30		zgyr_b_31	
0x370	zgyr_b_32		zgyr_b_33		zgyr_b_34		zgyr_b_35		zgyr_b_36		zgyr_b_37		zgyr_b_38		zgyr_b_39	
0x380	zgyr_b_40		zgyr_b_41		zgyr_b_42		zgyr_b_43		zgyr_b_44		zgyr_b_45		zgyr_b_46		zgyr_b_47	
0x390	zgyr_b_48		zgyr_b_49		zgyr_b_50		0		mag_x_scale							
0x3a0	mag_y_scale								mag_z_scale							
0x3b0	mag_xy_sensitivity								mag_xz_sensitivity							
0x3c0	mag_yz_sensitivity								mag_accel_roll							
0x3d0	mag_accel_pitch								mag_accel_yaw							
0x3e0	mag_x_scale_temp								mag_y_scale_temp							
0x3f0	mag_z_scale_temp								xmag_b_-10		xmag_b_-09		xmag_b_-08		xmag_b_-07	
0x400	xmag_b_-06		xmag_b_-05		xmag_b_-04		xmag_b_-03		xmag_b_-02		xmag_b_-01		xmag_b_00		xmag_b_01	
0x410	xmag_b_02		xmag_b_03		xmag_b_04		xmag_b_05		xmag_b_06		xmag_b_07		xmag_b_08		xmag_b_09	
0x420	xmag_b_10		xmag_b_11		xmag_b_12		xmag_b_13		xmag_b_14		xmag_b_15		xmag_b_16		xmag_b_17	
0x430	xmag_b_18		xmag_b_19		xmag_b_20		xmag_b_21		xmag_b_22		xmag_b_23		xmag_b_24		xmag_b_25	
0x440	xmag_b_26		xmag_b_27		xmag_b_28		xmag_b_29		xmag_b_30		xmag_b_31		xmag_b_32		xmag_b_33	
0x450	xmag_b_34		xmag_b_35		xmag_b_36		xmag_b_37		xmag_b_38		xmag_b_39		xmag_b_40		xmag_b_41	
0x460	xmag_b_42		xmag_b_43		xmag_b_44		xmag_b_45		xmag_b_46		xmag_b_47		xmag_b_48		xmag_b_49	
0x470	xmag_b_50		ymag_b_-10		ymag_b_-09		ymag_b_-08		ymag_b_-07		ymag_b_-06		ymag_b_-05		ymag_b_-04	

offset	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x480	ymag_b_-03		ymag_b_-02		ymag_b_-01		ymag_b_00		ymag_b_01		ymag_b_02		ymag_b_03		ymag_b_04	
0x490	ymag_b_05		ymag_b_06		ymag_b_07		ymag_b_08		ymag_b_09		ymag_b_10		ymag_b_11		ymag_b_12	
0x4a0	ymag_b_13		ymag_b_14		ymag_b_15		ymag_b_16		ymag_b_17		ymag_b_18		ymag_b_19		ymag_b_20	
0x4b0	ymag_b_21		ymag_b_22		ymag_b_23		ymag_b_24		ymag_b_25		ymag_b_26		ymag_b_27		ymag_b_28	
0x4c0	ymag_b_29		ymag_b_30		ymag_b_31		ymag_b_32		ymag_b_33		ymag_b_34		ymag_b_35		ymag_b_36	
0x4d0	ymag_b_37		ymag_b_38		ymag_b_39		ymag_b_40		ymag_b_41		ymag_b_42		ymag_b_43		ymag_b_44	
0x4e0	ymag_b_45		ymag_b_46		ymag_b_47		ymag_b_48		ymag_b_49		ymag_b_50		zmag_b_-10		zmag_b_-09	
0x4f0	zmag_b_-08		zmag_b_-07		zmag_b_-06		zmag_b_-05		zmag_b_-04		zmag_b_-03		zmag_b_-02		zmag_b_-01	
0x500	zmag_b_00		zmag_b_01		zmag_b_02		zmag_b_03		zmag_b_04		zmag_b_05		zmag_b_06		zmag_b_07	
0x510	zmag_b_08		zmag_b_09		zmag_b_10		zmag_b_11		zmag_b_12		zmag_b_13		zmag_b_14		zmag_b_15	
0x520	zmag_b_16		zmag_b_17		zmag_b_18		zmag_b_19		zmag_b_20		zmag_b_21		zmag_b_22		zmag_b_23	
0x530	zmag_b_24		zmag_b_25		zmag_b_26		zmag_b_27		zmag_b_28		zmag_b_29		zmag_b_30		zmag_b_31	
0x540	zmag_b_32		zmag_b_33		zmag_b_34		zmag_b_35		zmag_b_36		zmag_b_37		zmag_b_38		zmag_b_39	
0x550	zmag_b_40		zmag_b_41		zmag_b_42		zmag_b_43		zmag_b_44		zmag_b_45		zmag_b_46		zmag_b_47	
0x560	zmag_b_48		zmag_b_49		zmag_b_50		0		temp_bias							
0x570	temp_scale								temp_bias_msp							
0x580	temp_scale_msp								mag_x_bias							
0x590	mag_y_bias								mag_z_bias							
0x5a0	mag_conversion_gain								0							
0x5b0	0								0							
⋮	⋮															
0x7f0	0								0							

9 Firmware Updates

Firmware controls the various hardware components of your APDM product line (monitors, access points, and docking stations). It is important to keep the firmware up to date to ensure that your system gets the latest bug fixes and has access to the latest features. Firmware updates are bundled with updates to our software products. Firmware can be updated either automatically or manually.

9.1 Automatic Firmware Updates

Whenever you configure your system, your hardware is first checked to ensure that the latest firmware is installed. If not, you will be prompted to automatically update your hardware to the latest versions of the firmware bundled with your system.

9.2 Manual Firmware Updates

Firmware can be updated manually as well. This functionality can be used to either flash the default firmware to one of the hardware components, or to flash a different version. To access the “Update Firmware” dialog, click on “Tools→ Update Firmware” in the menu bar.

9.2.1 Flash Default Firmware

Your system comes bundled with an up to date version of the firmware. This option will re-flash this version of the firmware onto the specified monitor.

9.2.2 Flash Alternate Firmware

For testing purposes or to address an issue in a timely fashion, it may be necessary to flash a monitor with a version of the firmware that is different than the bundled version. You will have to specify the alternate firmware file to use with this option.

9.2.3 Force Update

When using either of the options above, if the firmware version on the target device(s) matches the firmware version to be flashed, the device will be skipped. If the “Force update even if versions match” checkbox is selected, however, the firmware will be flashed even if the versions match. This may be necessary in some cases to recover a malfunctioning device.

10 Movement Monitor Reference

10.1 Charging

A movement monitor charges its internal battery any time it is connected to a docking station. At the optimal charge rate the movement monitors internal battery will complete its bulk charge (80%-90%) within an hour for a fully discharged battery. It is recommended that the movement monitor be charged for up to 3 hours to provide a peak charge to the battery ensuring it has the longest run time and improves battery life.

Warning: Your movement monitor uses a lithium battery. This battery may only be charged over a limited temperature range. Never attempt to dock or charge your Opal when the temperature experienced can be outside the range of 0 to 45 degrees Celsius (32 to 113 degrees Fahrenheit). The recommended charging and docking temperature range is between 5 to 35 degrees Celsius (40 to 95 degrees Fahrenheit).

10.2 Powering Down

If you wish to power down your monitors for storage or travel, dock the monitors you wish to power down and click on the “Power Off” button in Motion Studio. After this process is complete, these monitors will power down when they are undocked. They can be powered back on by re-applying the saved configuration or re-configuring the system.

10.3 Data Storage

The movement monitors utilize a flash card to store data while logging. This data can be downloaded by using a docking station to dock the movement monitor. When the movement monitor is docked it finishes up writing to the internal flash card and then releases it to the docking station. At this time the docking station indicates to the PC that there is a new read only removable drive to be mounted. Using your file browser you can navigate to the removable drive and copy the files off of it. The files are in a proprietary raw format and need to be converted to either a HDF5 or CSV format that will provide data in calibrated SI units. This conversion happens automatically if Motion Studiois used to import the data. Alternately, there are functions in the SDK to do this conversion programmatically.

10.4 Cleaning

Cleaning the movement monitors case should be done by wiping the bottom of the case where it contacts the skin with Rubbing alcohol or other cleaning wipe. If the entire case needs to be cleaned use only an ethyl alcohol or isopropyl alcohol based wipe. Methyl alcohol should be avoided for cleaning the top since it will cause degradation of the plastic over time. The movement monitor should not be submerged in any liquids or subjected to any high temperatures for cleaning. The straps on the monitor can be cleaned by wiping them down with Rubbing alcohol. Alternatively the straps can be removed and washed separately using mild soap and water.

10.5 Storage

Storage of the movement monitor should be in a dry static fee location. An anti-static bag or in the supplied case is recommended. The movement monitor should also not be subjected to any large G forces to prevent damage or changes to the calibration of the sensors in the monitor. It is recommended for the health of the battery to to have at least a bulk charge during storage.

10.6 Drivers

Drivers are provided as part of the library distribution and Motion Studio. The drivers are installed automatically as part of the Motion Studio installation process.

10.7 Firmware Updates

Updating the movement monitor firmware should be done using the Motion Studio software. This process is detailed in Section 9 of this document.

10.8 Technical Specifications

- The accelerometer range is $\pm 58.8\,\mathrm{m/s^2}$ (6 g) (optionally $\pm 19.6\,\mathrm{m/s^2}$ (2 g)).
- Accelerometers have a typical noise density of $1.3\,\mathrm{mm/s^2/\sqrt{Hz}}$.
- The X and Y axis gyros have a range of ± 34.9 rad/s (2000 dps)
- The Z axis gyro has a range of ± 26.8 rad/s (1500 dps)
- The X and Y axis gyros have a typical noise density of 0.81 $\mathrm{mrad/s/\sqrt{Hz}}$
- The Z axis gyro have a typical noise density of 2.2 $\mathrm{mrad/s/\sqrt{Hz}}$
- Magnetometers have a range of ± 6 Gauss
- The magnetometers have a typical noise density is 160 $\mathrm{nT/\sqrt{Hz}}$
- Positive X is pointing from the monitor toward the connector. Looking top down at the monitor with positive X pointing away from you, positive Y is pointing left. Z is pointing up out of the top of the case. Angular velocity sign is defined according to a right hand rule. A counterclockwise rotation about the Z axis looking from the +Z direction is positive.

10.9 LED Reference

10.9.1 Status Codes and LED Colors/Patterns

The LEDs on the access points and movement monitors provide important information about the operating state of the hardware, including error statuses. The tables below list the LED patterns associated with these states and can be useful in troubleshooting issues encountered with the hardware.

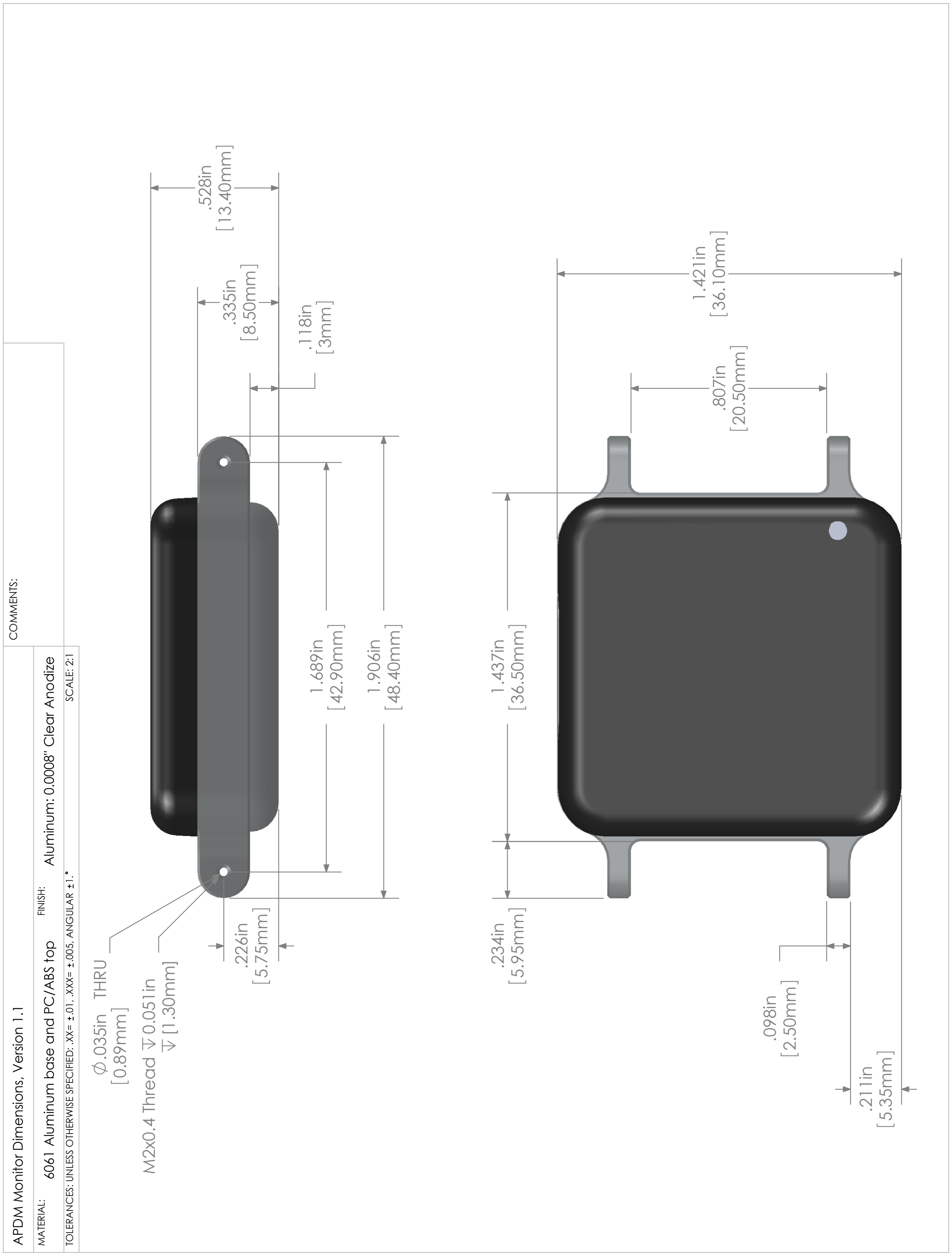
10.9.2 Movement Monitor LED Reference

Movement monitors contain a RGB LED capable of outputting a wide array of colors to the user to indicate its current state. The following colors are used: white (○), red (●), yellow (●), green (●), cyan (●), blue (●), magenta (●), and led off (_). In the off state the LED will appear as a non illuminated white dot in the corner of the monitor opposite the docking connector. All LED patterns are output on a repeating cycle which may vary in period depending on the pattern. In all cases the last color listed will stay constant until the pattern repeats. For example "●_●_" will blink yellow twice and then stay off until the pattern repeats.

State	**LED Pattern**
Startup Mode (boot loader)	
Startup wait (5 sec) v1.0, bootloader v1	🟡
Startup wait (5 sec) v1.1, bootloader v2	🟣
Failed to load firmware	🔴
Boot loader mode	○
Firmware Mode	
Docked mode (pre-charging – very low battery)	🔵🟡
Docked mode (bulk charging – low battery)	🔵🟢(fast)
Docked mode (trickle charging – 80-100% charge)	🔵🟢(slow)
Docked mode (full charge)	🔵
Docked mode (battery error)	🔴🔵
Docked mode (wait)	🟣
Docked mode (error)	🟡_🔴_🔵
Reset mode	○_
Transitioning into standby or powering off	●_
Hold mode	🔵_
Run mode (battery level 4, full)	🟢_🟢_🟢_🟢_
Run mode (battery level 3)	🟢_🟢_🟢_
Run mode (battery level 2)	🟢_🟢_
Run mode (battery level 1, low)	🟢_
Run mode (battery very low)	🟡_🟡_🟡_
Run mode (clock unset, battery level 4, full)	🔴_🟢_🟢_🟢_🟢_
Run mode (clock unset, battery level 3)	🔴_🟢_🟢_🟢_
Run mode (clock unset, battery level 2)	🔴_🟢_🟢_
Run mode (clock unset, battery level 1, low)	🔴_🟢_
Run mode (clock unset, battery very low)	🔴_🟡_🟡_🟡_
Run mode (no sync-lock, battery level 4, full)	🔵_🟢_🟢_🟢_🟢_
Run mode (no sync-lock, battery level 3)	🔵_🟢_🟢_🟢_
Run mode (no sync-lock, battery level 2)	🔵_🟢_🟢_
Run mode (no sync-lock, battery level 1, low)	🔵_🟢_
Run mode (no sync-lock, battery very low)	🔵_🟡_🟡_🟡_
Run mode (clock unset, no sync-lock, battery level 4, full)	🔴_🔵_🟢_🟢_🟢_🟢_
Run mode (clock unset, no sync-lock, battery level 3)	🔴_🔵_🟢_🟢_🟢_
Run mode (clock unset, no sync-lock, battery level 2)	🔴_🔵_🟢_🟢_
Run mode (clock unset, no sync-lock, battery level 1, low)	🔴_🔵_🟢_
Run mode (clock unset, no sync-lock, battery very low)	🔴_🔵_🟡_🟡_🟡_

State	LED Pattern
Error Modes	
Error mode: default	🟡_🔴_
Error mode: configuration	🟡_🔴_🔴_
Error mode: system	🟡_🔴_🔴_🔴_
Error mode: data buffer	🟡_🔴_🔴_🔴_🔴_
Error mode: SD buffer	🟡_🔴_🔴_🔴_🔴_🔴_
Error mode: SD I/O	🟡_🔴_🔴_🔴_🔴_🔴_🔴_
Card is full	🟣_
Wireless Streaming Debug LED Modes	
Normal	🟢_
CPU limited	🟢🟣_
Sync bad	🟢🔵_
CPU limited, Sync bad	🟢🔴_
Missed sync > 0	🟡_
Missed sync > 0, CPU limited	🟡🟣_
Missed sync > 0, Sync bad	🟡🔵_
Missed sync > 0, CPU limited, Sync bad	🟡🔴_

10.10 Technical Drawing



APDM Monitor Dimensions, Version 1.1

MATERIAL: 6061 Aluminum base and PC/ABS top

FINISH: Aluminum: 0.0008" Clear Anodize

TOLERANCES: UNLESS OTHERWISE SPECIFIED: .XX= ±.01, .XXX= ±.005, ANGULAR ±1.°

SCALE: 2:1

COMMENTS:

11 Access Point Reference

11.1 Drivers

Drivers are provided as part of the SDK distribution and Motion Studio.

11.2 Firmware Updates

Updating the movement monitor firmware should be done using the Motion Studio software.

11.3 Mounting and Placement

The antennas of the access point are located directly behind the black plastic face of the access point. The access point(s) should be aimed such that this face is in the approximate direction of the area where the movement monitors will be used.

11.4 Using Multiple Access Points

Having multiple access points is useful when redundancy is needed or when recording from more than 6 Opals. To configure multiple access points, you must have them attached to your computer via USB at the time of configuration. Additionally, the access points must be linked via RCA cable (a standard stereo cable). The rest of the configuration is handled automatically.

11.4.1 Redundancy

In some recording environments, it may be difficult to always maintain line of site from your streaming Opals to the access point. For example, you may have a bend in a hallway, or you may be operating in a large open space where you are unlikely to receive a reflected signal if the Opal is pointed away from the access point. In these scenarios, multiple access points can be used to provide better coverage. The streaming Opals will communicate with whichever access point is providing the stronger signal.

11.4.2 Streaming from more than 6 Opals

Each access point can communicate with up to 6 Opals simultaneously. You can therefore stream from up to 12 Opals with 2 access points, or 24 Opals with 4 access points.

11.5 LED Reference

Access points contain a RGB LED capable of outputting a wide array of colors to the user to indicate its current state. The following colors are used: white (○), red (🔴), yellow (🟡), green (🟢), cyan (●), blue (🔵), magenta (🟣), and led off (_). All LED patterns are output on a repeating cycle which may vary in period depending on the pattern. In all cases the last color listed will stay constant until the pattern repeats. For example "🟡_🟡_" will blink yellow twice and then stay off until the pattern repeats.

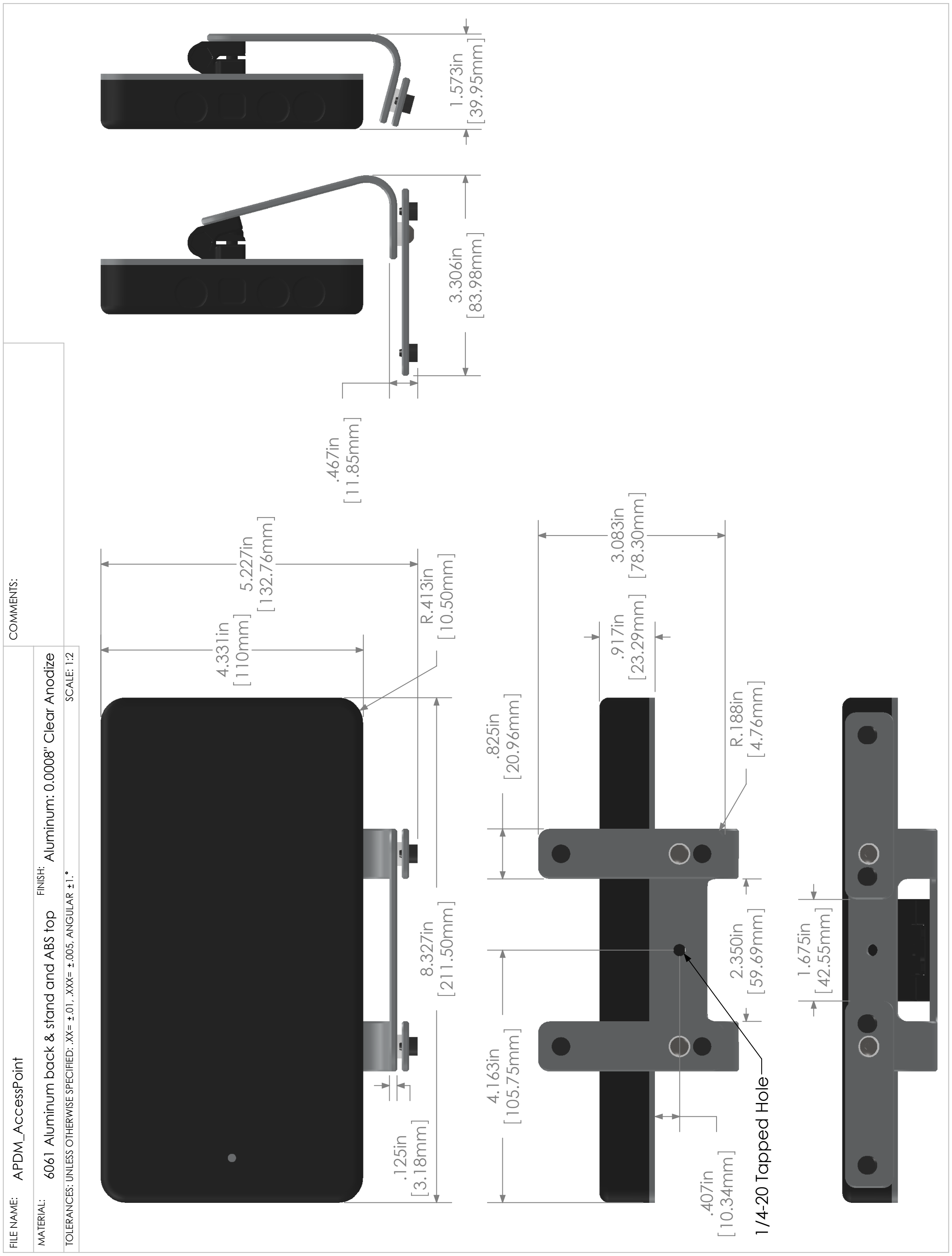
State	LED Pattern
Access point is powered on and is not receiving data from any monitors	🟢
Access point is receiving data from all monitors and there is no excessive latency for any of the monitors	🟢_
Access point is receiving data from all monitors but there is excessive latency (>3s) in one or more monitors. The latency is, however, decreasing (improving). This usually indicates that one or more monitors was temporarily obstructed and is now catching up.	🟢🔵
Access point is receiving data from all monitors but there is excessive latency (>3s) in one or more monitors which is increasing (getting worse). This usually indicates that one or more monitors is obstructed and is having trouble transmitting its data.	🟢🔴
Access point is receiving data from one or more, but not all, of the movement monitors	🔴_
Access point is receiving data from one or more monitors that it is not expecting to receive data (e.g. there is a monitor configured on another computer system streaming data)	🟡🔴 or 🟡🟠
Access point is in low power USB suspend mode.	🟡
Access point firmware error type 3, contact support Access point firmware error type 4, contact support Access point firmware error type 5, contact support Access point SDRAM Memory error, contact support	🔴_🔴_🔴__ 🔴_🔴_🔴_🔴__ 🔴_🔴_🔴_🔴_🔴__ 🔴_🔴_🔴_🔴_🔴_🔴_🔴_🔴__

11.6 Mechanical and Electrical Specifications

Weight: 1.2lbs, (550 grams)

Electrical: 290mA at 5V over USB connection

11.7 Technical Drawing



12 Docking Station Reference

12.1 Drivers

Drivers are provided as part of the SDK distribution and Motion Studio.

12.2 Power

- If running a single docking station, it can be powered from:
  - a USB cable plugged into a dedicated USB port on your computer
  - a USB cable plugged into a a powered USB hub
  - a USB cable plugged into a wall adapter (charging only)
  - the external AC adapter (charging only)
- If running a chain of 2 or more docking stations:
  - For data transfer, both USB and external AC power are required. If a power-related error occurs, then the docking station will blink yellow until external or power is plugged in.
  - if only charging is required, the external AC power must be used

12.3 Mechanical and Electrical Specifications

Weight: 0.2 lbs, (90 grams)

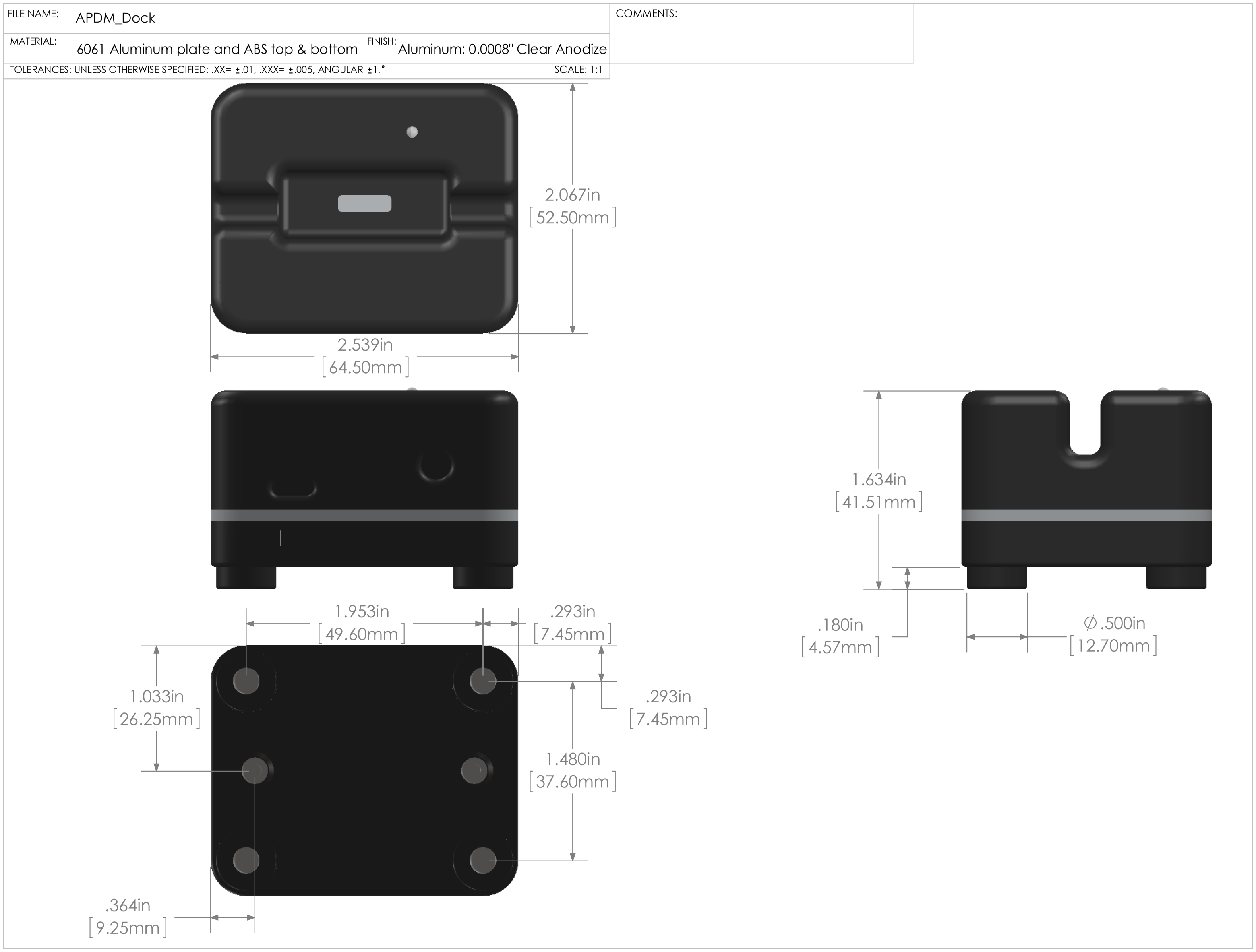
Electrical: 500mA at 5V over USB connection, or 500mA per dock when a chain is supplied by external power.

12.4 LED Reference

Docking stations contain a RGB LED capable of outputting a wide array of colors to the user to indicate its current state. The following colors are used: white (○), red (🔴), yellow (🟡), green (🟢), cyan (🩵), blue (🔵), magenta (🟣), and led off (_). All LED patterns are output on a repeating cycle which may vary in period depending on the pattern. In all cases the last color listed will stay constant until the pattern repeats. For example "🟡_🟡_" will blink yellow twice and then stay off until the pattern repeats.

State	LED Pattern
OK	🟢
Powered off, USB suspended, or booloader pause	⚫
OK, but USB not enumerated	🟡
Power problem. Need to plug in external power or USB power.	🟡_
Docking in progress	🩵_
Docked, but SD unavailable to host	🩵
SD Card mounting in progress	🔵_🩵_
SD Card mounted and avaliable to host	🔵
SD card read-access in progress	🔵_
USB error	🟠
Error	🔴_
Error: SD card mounting error	🔴_🔴_
Error: in-dock USB hub problem	🔴_🔴_🔴_
Firmware error type 4, contact support	🔴_🔴_🔴_🔴_
Firmware error type 5, contact support	🔴_🔴_🔴_🔴_🔴_
Firmware error type 6, contact support	🔴_🔴_🔴_🔴_🔴_🔴_
Bootloader mode	🟣
Updating firmware	○
Hardware Error - DA	🔴_○_🔴_○_🔴_○_
Hardware Error - GA	🔴_🔵_🔴_🔵_🔴_🔵_
Hardware Error - PA	🔴_🟡_🔴_🟡_🔴_🟡_
Hardware Error - UA	🔴_🟣_🔴_🟣_🔴_🟣_

12.5 Technical Drawing



FILE NAME: APDM_Dock		COMMENTS:
MATERIAL: 6061 Aluminum plate and ABS top & bottom	FINISH: Aluminum: 0.0008" Clear Anodize	
TOLERANCES: UNLESS OTHERWISE SPECIFIED: .XX= ±.01, .XXX= ±.005, ANGULAR ±1.°	SCALE: 1:1	

13 Technical Support

Please contact us at:

web: support.apdm.com

email: support@apdm.com