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# 1 Introduction

The Coral AHRST<sup>TM</sup> module communicates with a simple protocol over its RS-232 serial port device. Each packet follows a standard format: each packet begins with a single byte of value 255 (FF in hexadecimal). The next byte represents the type of packet being sent. The next byte represents the length of the data section of the packet. The data section then follows. An 8-bit checksum (the 8-bit arithmetic sum of each of the preceding bytes in the packet) follows the data section. The same packet format is used for all communications to the Coral AHRST<sup>TM</sup> module as well.

<b>FF</b>
Packet Type
Length
Data
⋮
8-bit Checksum

Figure 1: Coral AHRST<sup>TM</sup> Packet Format

# 2 Data Types

Packets sent to and from the Coral AHRST<sup>TM</sup> module contain data in several different formats. In all cases, data types which are longer than a single byte are sent with the most significant bytes first. The data types used by the Coral AHRST<sup>TM</sup> module are as follows:

**u8** An unsigned 8-bit integer.

**u16** An unsigned 16-bit integer.

**f16** A 16-bit signed (two's complement) fixed point number. To convert to the proper scale, divide the number by 4096.

**quat** A vector of four **f16** values, representing the  $w$ ,  $x$ ,  $y$ , and  $z$  components of a quaternion.

**matrix** A 3x3 matrix of **f16** values, in column-major format.

**vec3** A vector of three **f16** values, representing  $x$ ,  $y$ , and  $z$  components or *roll*, *pitch*, and *heading* components.

**string** A null-terminated string of up to 60 ASCII characters.

The unit each data type is sent in is as follows:

**Euler Angles** Radians

**Calibrated Gyros** Radians/Sec

**Calibrated Accelerometers** G ( $9.81m/s^2$ )

**Calibrated Magnetometers** Local field units

**Uncalibrated Sensors** Analog-digital converter counts

### 3 Packets Sent from Coral AHRS<sup>TM</sup>

#### 3.1 CORAL\_DATA\_QUAT

Packet Type: 21h

Length: 10 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS<sup>TM</sup> module's system timer, in units of milliseconds.
- **quat Orientation**  
A quaternion describing the orientation of the Coral AHRS<sup>TM</sup> module.

This packet is sent when the system output mode has been set to **CORAL\_QUAT**. It contains system time and quaternion orientation data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

#### 3.2 CORAL\_DATA\_EULER

Packet Type: 22h

Length: 8 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS™ module's system timer, in units of milliseconds.
- **vec3 Euler Angles**  
A fixed-point vector describing the roll, pitch, and heading of the Coral AHRS™.

This packet is sent when the system output mode has been set to **CORAL\_EULER**. It contains system time and euler angle orientation data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.3 CORAL\_DATA\_MATRIX

Packet Type: 23h  
Length: 20 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS™ module's system timer, in units of milliseconds.
- **matrix Orientation**  
A 3x3 matrix describing the Coral AHRS™ module's orientation.

This packet is sent when the system output mode has been set to **CORAL\_MATRIX**. It contains system time and matrix orientation data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.4 CORAL\_DATA\_SENSORS

Packet Type: 24h  
Length: 20 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS™ module's system timer, in units of milliseconds.
- **vec3 Gyros**  
A vector with the calibrated output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the calibrated output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the calibrated output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to `CORAL_SENSORS`. It contains system time and calibrated sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.5 CORAL\_DATA\_QUAT\_AND\_SENSORS

Packet Type: 25h  
Length: 28 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS™ module's system timer, in units of milliseconds.
- **quat Orientation**  
A quaternion describing the orientation of the Coral AHRS™ module.
- **vec3 Gyros**  
A vector with the calibrated output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the calibrated output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the calibrated output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to `CORAL_QUAT | CORAL_SENSORS`. It contains system time, quaternion orientation data, and calibrated sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.6 CORAL\_DATA\_EULER\_AND\_SENSORS

Packet Type: 26h

Length: 26 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS<sup>TM</sup> module's system timer, in units of milliseconds.
- **vec3 Euler Angles**  
A vector describing the roll, pitch, and heading of the Coral AHRS<sup>TM</sup> module.
- **vec3 Gyros**  
A vector with the calibrated output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the calibrated output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the calibrated output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to **CORAL\_EULER** | **CORAL\_SENSORS**. It contains system time, euler angle orientation data, and calibrated sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.7 CORAL\_DATA\_MATRIX\_AND\_SENSORS

Packet Type: 27h

Length: 38 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS<sup>TM</sup> module's system timer, in units of milliseconds.
- **matrix Orientation Matrix**  
A matrix describing the orientation of the Coral AHRS<sup>TM</sup> module.

- **vec3 Gyros**  
A vector with the calibrated output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the calibrated output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the calibrated output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to **CORAL\_MATRIX** | **CORAL\_SENSORS**. It contains system time, matrix orientation data, and calibrated sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.8 CORAL\_DATA\_RAW\_SENSORS

Packet Type: 28h  
Length: 20 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRSTM module's system timer, in units of milliseconds.
- **vec3 Gyros**  
A vector with the raw output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the raw output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the raw output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to **CORAL\_RAW\_SENSORS**. It contains system time and raw sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.9 CORAL\_DATA\_QUAT\_AND\_RAW\_SENSORS

Packet Type: 29h  
Length: 28 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS<sup>TM</sup> module's system timer, in units of milliseconds.
- **quat Orientation**  
A quaternion describing the orientation of the Coral AHRS<sup>TM</sup> module.
- **vec3 Gyros**  
A vector with the raw output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the raw output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the raw output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to **CORAL\_QUAT | CORAL\_RAW\_SENSORS**. It contains system time, quaternion orientation data, and raw sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.10 CORAL\_DATA\_EULER\_AND\_RAW\_SENSORS

Packet Type: 2Ah  
Length: 26 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS<sup>TM</sup> module's system timer, in units of milliseconds.
- **vec3 Euler Angles**  
A vector describing the roll, pitch, and heading of the Coral AHRS<sup>TM</sup> module.



- **vec3 Gyros**  
A vector with the raw output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the raw output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the raw output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to `CORAL_EULER` | `CORAL_RAW_SENSORS`. It contains system time, euler angle orientation data, and raw sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.11 CORAL\_DATA\_MATRIX\_AND\_RAW\_SENSORS

Packet Type: 2Bh  
Length: 38 bytes

Data:

- **u16 System Time**  
The value of the Coral AHRS™ module's system timer, in units of milliseconds.
- **matrix Orientation Matrix**  
A matrix describing the orientation of the Coral AHRS™ module.
- **vec3 Gyros**  
A vector with the raw output of the roll, pitch, and heading gyros.
- **vec3 Accelerometers**  
A vector with the raw output of the X, Y, and Z accelerometers.
- **vec3 Magnetometers**  
A vector with the raw output of the X, Y, and Z magnetometers.

This packet is sent when the system output mode has been set to `CORAL_MATRIX` | `CORAL_RAW_SENSORS`. It contains system time, matrix orientation data, and raw sensor data. These packets are sent at a constant rate equal to the standard system output rate divided by the output rate divisor.

### 3.12 CORAL\_ID\_STRING

Packet Type: 15h  
Length: 60 bytes

Data:

- **string System ID**  
A string indicating the system type, firmware revision, and serial number of a Coral AHRS<sup>TM</sup> module.

This packet is sent in reponse to a `CORAL_REQUEST_ID` packet. The string returned contains the system firmware revision and serial number.

### 3.13 CORAL\_CONFIGURATION

Packet Type: 1Ah  
Length: 3 bytes

Data:

- **u8 Serial Speed**  
A single byte indicating the system's current serial speed setting.
- **u8 Output Mode**  
A single byte indicating the system's current output mode.
- **u8 Output Rate Divisor**  
A single byte indicating the systme's current output rate divisor.

This packet is sent in reponse to a `CORAL_REQUEST_CONFIGURATION` packet. It returns the current serial speed setting, output mode, and output rate divisor. The output mode setting is 1 for `CORAL_QUAT` output mode, 2 for `CORAL_SENSORS` output mode, 3 for `(CORAL_SENSORS | CORAL_QUAT)` output mode, 4 for `CORAL_RAW_SENSORS`, and 0 for no output. The serial speed setting corresponds to an actual baud rate according to the following chart:

- 0 - 4800 bps
- 1 - 9600 bps

- 2 - 19200 bps
- 3 - 38400 bps
- 4 - 57600 bps
- 5 - 115200 bps
- 6 - 230400 bps
- 7 - 460800 bps

### 3.14 CORAL\_CALIBRATION

Packet Type: 1Ch  
Length: 24 bytes

Data:

- **matrix Calibration**  
A matrix containing the scale and misalignment transformation for a given sensor group.
- **vec3 Bias**  
A vector containing the bias data for a given sensor group.

This packet is sent in response to a `CORAL_REQUEST_CALIBRATION` packet. It contains the calibration data for a given sensor group (gyros, accelerometers, magnetometers, or declination). Calibration adjustments for the accelerometers and magnetometers are performed by taking each vector of sensor data, subtracting the bias vector from it, and then multiplying it by the calibration matrix. This produces a vector of calibrated data. Unlike the accelerometers and magnetometers, the vector of gyro data is multiplied by the calibration matrix, then the bias vector is subtracted out. Unlike the other matrices, only the first two components of the declination matrix are used. The first component represents the cosine of half the declination angle and the second component represents the sine of the declination angle. The declination bias vector is ignored

### 3.15 CORAL\_PONG

Packet Type: EEh  
Length: 0 bytes

This packet is sent as a response to a `CORAL_PING` packet. It is used as a means to verify that the Coral AHRS<sup>TM</sup> unit is responding to messages.

## 4 Packets Sent to Coral AHRS<sup>TM</sup>

### 4.1 `CORAL_SET_OUTPUT_MODE`

Packet Type: 01h

Length: 1 byte

Data:

- **u8 Output Mode**  
The desired output mode for the Coral AHRS<sup>TM</sup> module.

This packet changes the output mode on the Coral AHRS<sup>TM</sup> module. The output mode is a 4-bit field in which bits 0 and 1 choose an orientation data type (00 = None, 01 = Quaternion, 10 = Euler Angles, 11 = Orientation Matrix), and bits 2 and 3 choose a sensor data type (00 = None, 01 = Calibrated, 10 = Raw). If an invalid mode is selected, no data will be output until a proper mode is selected.

### 4.2 `CORAL_SET_CALIBRATION`

Packet Type: 02h

Length: 25 bytes

Data:

- **u8 Sensor Group**  
A byte selecting which group of sensors to adjust calibration settings for. A value of 0 corresponds to gyros. A value of 1 corresponds to accelerometers. A value of 2 corresponds to magnetometers. A value of 3 corresponds to declination information. Unlike the other matrices, only the first two

components of the declination matrix are used. The first component represents the cosine of half the declination angle and the second component represents the sine of the declination angle. The declination bias vector is ignored

- **matrix Calibration Matrix**  
A matrix with the desired calibration data for the sensor group.
- **vec3 Bias Data**  
A vector with bias data for the sensor group.

This packet adjusts calibration data for a given sensor group. Any changes made are lost when the power is cycled, unless a **CORAL\_SAVE\_SETTINGS** packet is sent. Calibration adjustments for the accelerometers and magnetometers are performed by taking each vector of sensor data, subtracting the bias vector from it, and then multiplying it by the calibration matrix. This produces a vector of calibrated data. Unlike the accelerometers and magnetometers, the vector of gyro data is multiplied by the calibration matrix, then the bias vector is subtracted out.

### 4.3 CORAL\_CAPTURE\_GYRO\_BIAS

Packet Type: 03h  
Length: 0 bytes

This packet requests that the Coral AHRS<sup>TM</sup> module use the current gyro readings as an estimate for its gyro biases.

### 4.4 CORAL\_REQUEST\_ID

Packet Type: 05h  
Length: 0 bytes

This packet requests that the Coral AHRS<sup>TM</sup> module send its system identification string. The Coral AHRS<sup>TM</sup> module sends a **CORAL\_ID\_STRING** packet in response.

## 4.5 CORAL\_RESTORE\_USER\_SETTINGS

Packet Type: 06h  
Length: 0 bytes

This packet requests that the Coral AHRSTM module restore its calibration, serial baud rate, output mode, and output divisor settings to the settings saved in the user settings section of EEPROM.

## 4.6 CORAL\_RESTORE\_FACTORY\_SETTINGS

Packet Type: 07h  
Length: 0 bytes

This packet requests that the Coral AHRSTM module restore its calibration, serial baud rate, output mode, and output divisor settings to the settings set by the factory. CORAL\_SAVE\_SETTINGS must still be sent to retain the change after power cycling the module, however.

## 4.7 CORAL\_SET\_OUTPUT\_RATE\_DIVISOR

Packet Type: 08h  
Length: 1 byte

Data:

- **u8 Output Rate Divisor**  
A single byte specifying the new output rate divisor.

This packet sets the output rate divisor. This specifies that the Coral AHRSTM is to only output orientation or sensor information at the standard system rate divided by the output rate divisor. This does not affect the accuracy of the output, as all calculations are still done at the standard system rate. If the serial speed is currently set at 4800 bps, the minimum output rate divisor allowed is 8. If the serial speed is currently set at 9600, the minimum output rate divisor allowed is 4. If the serial speed is currently set at 19200 bps, the minimum output rate divisor allowed is 2. Otherwise, the output rate divisor must be between 1 and 255.

## 4.8 CORAL\_SET\_SERIAL\_RATE

Packet Type: 09h  
Length: 1 byte

Data:

- **u8 Serial Rate Specifier**  
A single byte specifying the new serial baud rate.

This packet requests that the Coral AHRSTM module change the baud rate of its serial port. The **Serial Rate Specifier** argument reflects an actual baud rate as shown on the following chart:

- 0 - 4800 bps
- 1 - 9600 bps
- 2 - 19200 bps
- 3 - 38400 bps
- 4 - 57600 bps
- 5 - 115200 bps
- 6 - 230400 bps
- 7 - 460800 bps

## 4.9 CORAL\_REQUEST\_CONFIGURATION

Packet Type: 0Ah  
Length: 0 bytes

This packet requests that the Coral AHRSTM module send its current output mode, serial baud rate, and output rate divisor. The module sends a CORAL\_CONFIGURATION packet in response.

## 4.10 CORAL\_REQUEST\_CALIBRATION

Packet Type: 0Ch  
Length: 1 byte

Data:

- **u8 Sensor Group**  
The group of sensors for which calibration data is requested. A value of 0 represents gyros. A value of 1 represents accelerometers. A value of 2 represents magnetometers. A value of 3 represents declination information.

This packet requests that calibration data for a given sensor group be returned. The Coral AHRS<sup>TM</sup> module responds with a `CORAL_CALIBRATION` packet.

## 4.11 CORAL\_SAVE\_SETTINGS

Packet Type: 0Fh  
Length: 0 bytes

This packet requests that the Coral AHRS<sup>TM</sup> module save its current calibration, output mode, serial baud rate, and output rate divisor settings into the user settings section of EEPROM. These settings are loaded during the module's power-on cycle, and can be restored at any time by sending a `CORAL_RESTORE_USER_SETTINGS` packet.

## 4.12 CORAL\_PING

Packet Type: DDh  
Length: 0 bytes

This packet requests that the Coral AHRS<sup>TM</sup> module responds with a `CORAL_PONG` packet. This is used to verify that the module is active and responding.