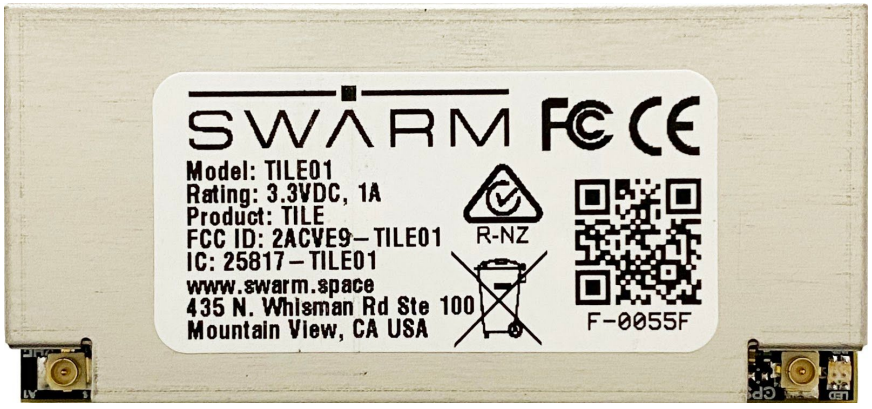
Swarm Tile

Product Manual



Swarm Tile Product Manual
Revision 1.10
October 2020

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Revision History

Revision	Date	Comment
0.95	03/16/2020	Tile Product Manual - Initial Release
1.00	6/3/2020	Updated Firmware Commands to reflect version 0.7.3. Improved specifications on Tile mechanical and electrical sections
1.10	10/5/2020	Including EU RED Declaration of Conformity Enhanced integration guidance Update to firmware commands to reflect firmware version 0.9.0

1 Safety Information and Compliance

The Tile is designed to comply with the standards for Radio Emissions Compliance and Electromagnetic Compatibility in the United States, Canada, Australia, New Zealand, United Kingdom, European Union, as well as worldwide.

1.1 FCC Compliance

1.1.1 FCC Interference Statement (Part 15.105 (b))

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

This device complies with part 15 of the FCC Rules. Operation is subject to the condition that this device does not cause harmful interference.

1.1.2 FCC Part 15 Clause 15.21:

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

1.1.3 FCC Part 15.19(a):

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

1.1.4 FCC ID:

The FCC ID for the Tile is **2AVE9-TILE01**. All manufacturers integrating the Tile into their products are advised to provide a physical or e-label stating “Contains FCC ID: **2AVE9-TILE01**”.

1.1.5 Part 15 Subpart B Disclaimer:

The final host product requires Part 15B compliance testing with the modular transmitter installed.

1.2 ISED Compliance

1.2.1 ISED RSS-Gen Notice CAN ICES-3 (B)NMB-3(B):

This device complies with Industry Canada’s licence-exempt RSSs. Operation is subject to the following two conditions:
(1) This device may not cause interference; and
(2) This device must accept any interference, including interference that may cause undesired operation of the device.

Le présent appareil est conforme aux CNR d’Industrie Canada applicables aux appareils radio exempts de licence. L’exploitation est autorisée aux deux conditions suivantes :
1) l’appareil ne doit pas produire de brouillage;
2) l’appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d’en compromettre le fonctionnement.

1.2.2 IC ID:

The IC ID for the Tile is **25817-TILE01**. All manufacturers integrating the Tile into their products are advised to provide a physical or e-label stating “Contains IC ID: **25817-TILE01**”

1.3 RF Exposure Guidance

In order to comply with FCC / ISED RF Exposure requirements, this device and antenna must be installed to provide at least 29 cm separation from the human body at all times.

Afin de se conformer aux exigences d'exposition RF FCC / ISED, cet appareil doit être installé pour fournir au moins 29 cm de séparation du corps humain en tout temps.

1.4 EU RED Certification

1.4.1 Declaration of Conformity:

EU DECLARATION OF CONFORMITY

Number: CB-20-0110 i01

Name and address of the Manufacturer

Swarm Technologies, Inc.
435 N Whisman Rd Ste 100
Mountain View, CA 94043, USA

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

Object of the declaration

Product information

Product Name: Swarm Tile

Model Name: TILE01

Additional information

Battery : n/a
Earphone : n/a
Travel Adapter : n/a
SW version : 1.0
HW version : 1.0

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

- References to the relevant harmonised standards used or references to the technical specifications in relation to which conformity is declared

Radio Equipment Directive 2014/53/EU		RoHS Directive 2011/65/EU
EN62368-1:2014/A11:2017 *EN 62311:2008*	*EN 301 489-1 V2.2.1* *EN 301 489-19 V2.1.1* *EN 301 489-20 V2.1.1* *EN 62311:2008* *EN303 413 v1.1.1* *EN301 721 V2.1.1*	*EN 50581:2012*

The notified body Name: *TÜV SÜD America*
Number: *1929*

performed

- a conformity assessment of the technical construction file

and issued the certificate **CB-0020-0109**

Additional information

N/A

Signed for and on behalf of: Swarm Technologies, Inc.

Authorised Representative

Name and Surname / Function:

Kyle Wesson

Kyle Wesson, Regulatory Engineer

Date of issue:
12 June 2020

1/1

1.4.2 Article 10(2)/(10):

This product has been so constructed that the product complies with the requirement of with Article 10(2) as it can be operated in at least one Member State as examined and the product is compliant with Article 10(10) as it has no restrictions on putting into service in all EU member states.

1.5 Transceiver Regulatory Certification

The Tile is a regulatory approved modular transmitter that is designed to be integrated into an enclosed host system. With appropriate external connections, the host can be designed to meet full regulatory tests and sold as a regulatory certified product that meets FCC, IC, and CE requirements. **Table 1** below is a partial list of regulatory approvals.

Regulatory Approvals	Radio Tests	EMC Tests	Safety Tests
FCC	FCC CFR47 Parts 2, 15, and 25		
IC	Industry Canada RSS170 Issue 2 - March 2011		
CE	ETSI EN 301 721 V2.1.1 (2016-05) ETSI EG203 367 V1.1.1	CISPR 16-23:2010/A1:2010 EN 55032:2012 EN 6100-4-2/EN55024:2010 EN 6100-4-3/EN55024:2010 EN 6100-4-8/EN55024:2010	EN 62368-1:2014/A11:2017

Table 1: Overview of the Swarm Tile regulatory approvals.

2 Product Overview

The Swarm Tile (Model: TILE01) satellite data modem transmits and receives data to and from Swarm's space network and is designed to be embedded into a third-party product. Swarm backend systems support the delivery of customer data via a REST API to the cloud service of each user's choice.

The Tile is a module suitable for a variety of low-bandwidth use cases: from connecting people and tracking vehicles, ships, or packages to relaying sensor data for agriculture, energy, and industrial IoT applications.

Tile is a Surface Mount Technology (SMT) module that can be easily integrated into any new or existing PCB design. The Tile communicates via a standard 3.3V CMOS serial UART interface or a PC interface with a USB-to-serial converter.

<table>
<tr><th>Category</th><th>Description</th></tr>
<tr><td>Satellite data</td><td>Maximum latency will be <1 min (95% of the time)</td></tr>
<tr><td>Components</td><td>GPS, VHF radio with integrated T/R switch, U.FL connector for GPS and VHF antenna (SMD interface also available), indicator LEDs, 3.3V serial interface, 3.3V GPIO</td></tr>
<tr><td>Sensors</td><td>Onboard GPS (lat/lon/alt), 1 pulse per second signal, Temperature sensor</td></tr>
<tr><td>Dimensions and Mass</td><td>58.7 mm x 27.4 mm x 6.0 mm, 14g
See detailed description in the Mechanical Specification section.</td></tr>
<tr><td>Power</td><td>
<table>
<tr><th>Mode</th><th>Average</th><th>Peak</th></tr>
<tr><td>Sleep, 3.3V</td><td>N/A</td><td>22 µA</td></tr>
<tr><td>Receiver Active, 3.3V</td><td>30 mA</td><td>35 mA</td></tr>
<tr><td>Transmitter on, 3.3V</td><td>888 mA</td><td>939 mA</td></tr>
</table>
</td></tr>
<tr><td>Protocol</td><td>Modified NMEA two-letter command set</td></tr>
<tr><td>Bit rate</td><td>1 kbps. Maximum packet size is 200 bytes</td></tr>
</table>

Table 2: Overview of the Swarm Tile.

3 Mechanical Specification

3.1 Tile Dimensions

The overall dimensions of the Tile and its weight are summarized in **Table 3**.

Parameter	Value
Length	58.67±0.3 mm
Width	27.43±0.3 mm
Height	6.00±0.1 mm
Weight	14 g

Table 3: Tile Mechanical Dimensions and Weight.

A diagram of the Tile's mechanical dimensions is shown in **Figure 1**.

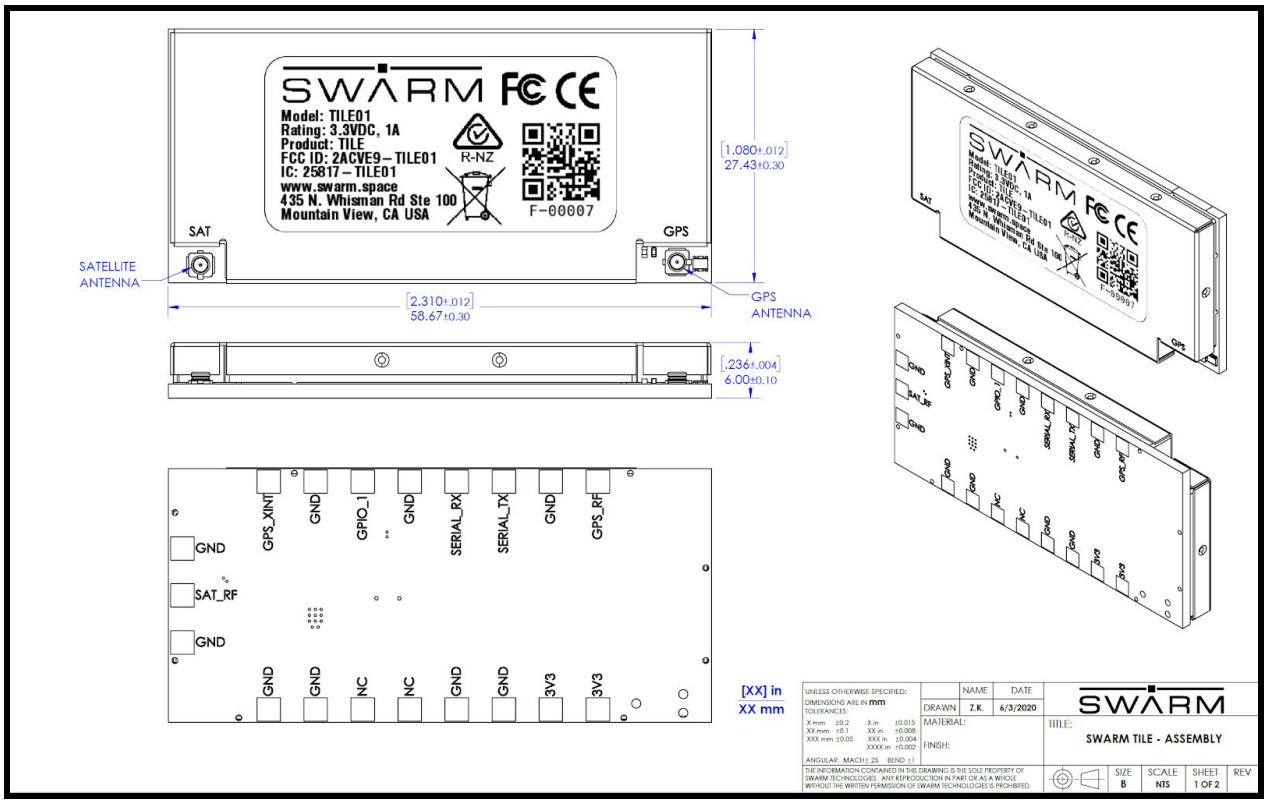

Figure 1: Tile front and back views.

3.2 Environmental

The environmental specifications of the Tile are summarized in **Table 4** below. The Tile is not conformally coated, and as such the user needs to provide any weatherproofing for their application.

Parameter	Value
Operating Temperature Range	-55 °C to +85 °C
Storage Temperature Range	-220 °C +160 °C
Operating Humidity Range	0% to 95%, non-condensable
Storage Humidity Range	0% to 95%, non-condensable

Table 4: Environmental Specifications.

3.3 Mechanical Specification – Placement

The Tile must be fitted within an enclosed host system. The Tile is designed to be soldered directly to a PCB, and is provided with solder pads on its underside.

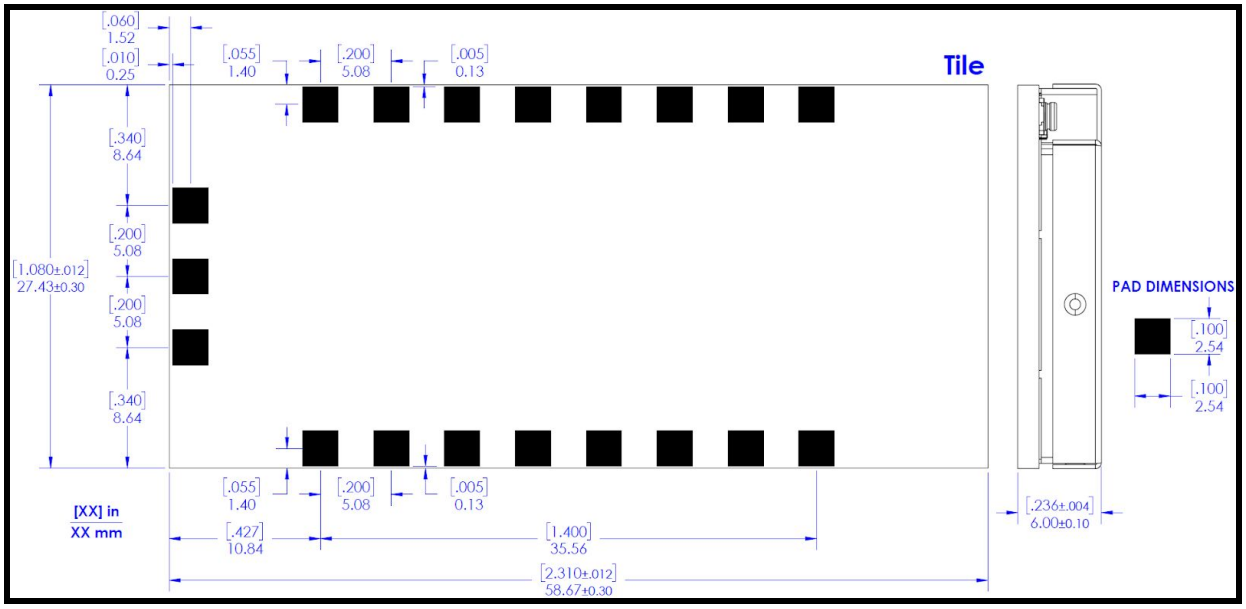

Figure 2: Location of solder pads on the underside of the Tile. Bottom view.

3.4 Reflow Soldering

The Tile is designed to be reflow soldered onto a PCB. A recommended reflow profile can be found below in **Figure 3** and **Table 5.**

Use of "No Clean" soldering paste is recommended. An example “No Clean” paste can be found below:

Soldering Paste: M8 SAC305 / PN#89268 (AIM Solder)
Alloy specification: Sn 95.5/ Ag 4/ Cu 0.5 (96.5% Tin/ 3% Silver/ 0.5% Copper)
Melting Temperature: 217° C
Stencil Thickness: 100 to 150 µm for base boards

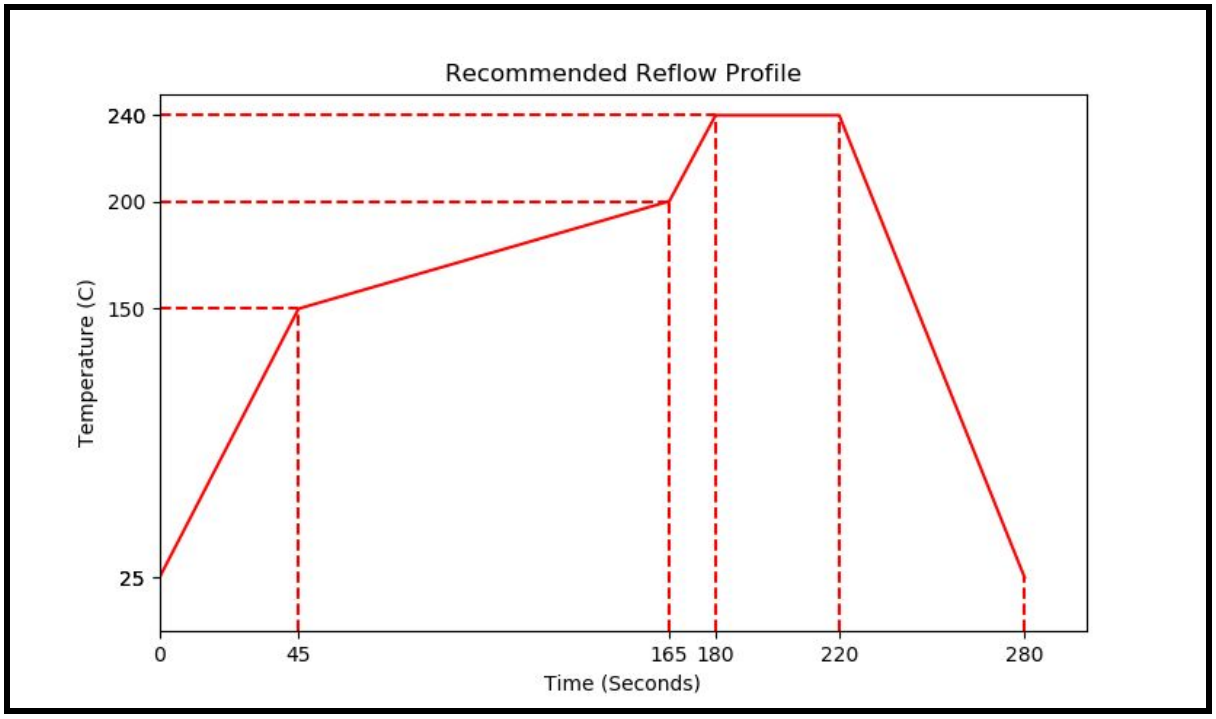

Figure 3: Recommended reflow profile for lead-free solder paste.

Time (Seconds)	Temperature (℃)
0	25
45	150
165	200
180	240
220	240
280	25

Table 5: Data points for reflow soldering.

3.5 Physical Interface Connectors

The Tile incorporates two connectors:

• A GPS Antenna U.FL male connector [TE Connectivity #1909763-1]

• An RF Antenna U.FL male connector [TE Connectivity #1909763-1]

4 Electrical Interfaces

The following subsections contain information for the electrical interfaces of the Tile.

4.1 User Host Device

The user host device provides the following connections to the Tile:

- DC power supply input: 3.3V, 1000 mA peak
    - The DC power supply is required to be contained within an EMI shielding can
    - Additional filtering of the 3.3V supply is highly recommended
- 3.3 volt serial data interface
- Satellite signal (Use either the provided U.FL connector labeled SAT **or** Pin 18. See section 5.3 - RF Trace Layout Design for more information)
- GPS signal (Use either the provided U.FL connector labeled GPS **or** Pin 8)
- GPIO_1 (optional)

4.2 Tile Pin Allocation

The pin numbering scheme of the Tile is shown in **Figure 4**. The module pins allow soldering onto a printed circuit board (PCB) using standard reflow soldering techniques. The pin function assignment is given in **Tables 6** and **7**. Multiple supply grounds are provided and all supply and supply grounds are required to be connected to the power supply in order to limit the current on any one pin. Multiple signal grounds are provided to reduce cross-talk. Pins 13 and 14 are intentionally left empty, and must be left unconnected.

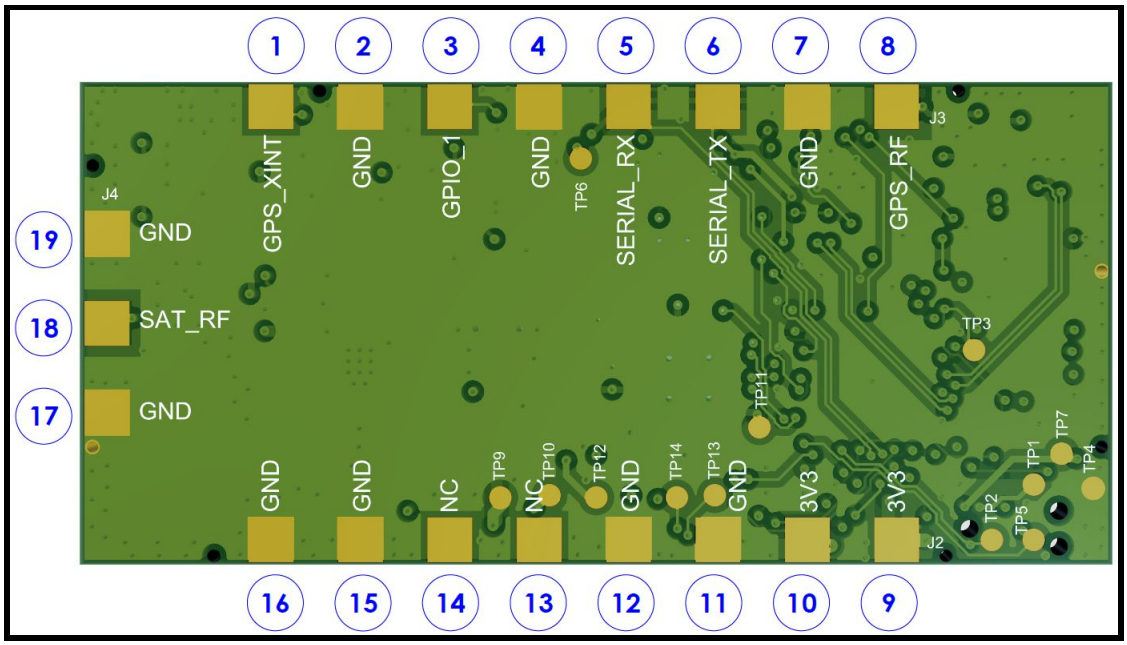

Figure 4: Tile pinout and pin numbers. Bottom view.

Pin Number	Name	Type	Description
1	GPS_XINT	Not Connected	RESERVED - DO NOT CONNECT
2	GND	Ground	Ground
3	GPIO_1	Input/Output	General purpose input/output
4	GND	Ground	Ground
5	SERIAL_RX	Input	3.3V serial receive
6	SERIAL_TX	Output	3.3V serial transmit
7	GND	Ground	Ground
8	GPS_RF	RF	External GPS antenna connection
9	3V3	VCC	3.3V at up to 1000mA
10	3V3	VCC	3.3V at up to 1000mA
11	GND	Ground	Ground
12	GND	Ground	Ground
13	NC	Not Connected	RESERVED - DO NOT CONNECT
14	NC	Not Connected	RESERVED - DO NOT CONNECT
15	GND	Ground	Ground
16	GND	Ground	Ground
17	GND	Ground	Ground
18	SAT_OUT	RF	External satellite radio antenna connection
19	GND	Ground	Ground

Table 6: Tile pin numbers and descriptions.

Additional Notes

Pin Number	Note
3	Connection is unbuffered directly to a GPIO on the Tile processor. Configuration will be provided via Tile firmware. GPIO pin is 3.3V tolerant and open drain, with a sink current limit of 8 mA (20 mA with a relaxed VOL/VOH)
8	GPS_RF uses 50 Ohm input impedance. Pin 8 by default is not connected - by default the GPS U.FL connector is selected. To enable Pin 8 the resistor R5 (adjacent to GPS U.FL connector) must have a 0-ohm resistor (0402) placed and a 50 ohm strip line to the RF connector.
9, 10	The 3.3V connection points are in parallel with one another and power the Tile. If the designer wants to enable a complete power off mode, a load switch can be provided here.
18	SAT_RF uses 50 Ohm input impedance. Use of SAT_RF instead of the SAT U.FL connector requires the user to use the FCC certified layout as defined in section 5.3 - RF Trace Layout Design

Table 7: Additional notes on pin numbers.

4.3 DC Power Interface

The DC power interface consists of the DC power inputs as summarized in **Table 8**. The power requirements apply to DC power measured at the Tile user connector input and not at the output of the power supply. It is required that users incorporate the required bypass capacitors for the supplied power input as can be seen in **Figure 5.**

Name	Description	Min	Typ	Max	Unit
VCC	Module supply voltage	-	3.30±3%	-	V
VCC Ripple	Module supply voltage ripple	-	-	75	mVpp
VCC Limits	Module supply voltage **absolute** limits	3.15	-	3.60	V
	Current consumption - Sleep Mode	-	-	22.0	µA
	Current consumption - Receiver Active	26.9	27.6	30.4	mA
	Current consumption - GPS Acquisition Mode*	44.7	49.1	55.2	mA
ICC (3.15V)	Current consumption - Transmitter on	904	910	963	mA
	Current consumption - Sleep Mode	-	-	22.0	µA
	Current consumption - Receiver Active	27.2	27.9	30.5	mA
	Current consumption - GPS Acquisition Mode*	46.0	49.3	54.8	mA
ICC (3.30V)	Current consumption - Transmitter on	880	888	939	mA
	Current consumption - Sleep Mode	-	-	22.0	µA
	Current consumption - Receiver Active	27.9	29.1	35.0	mA
	Current consumption - GPS Acquisition Mode*	47.6	49.6	55.2	mA
ICC (3.60V)	Current consumption - Transmitter on	845	853	902	mA

Table 8: Power supply characteristics for 3.15, 3.30, and 3.60V supplies to the Tile.

*Includes satellite receiver active current with GPS in acquisition mode. The Tile enters into GPS acquisition mode for approximately 30 seconds after exiting from sleep mode, on powerup, or when the Tile needs to re-acquire a GPS fix (approximately once every 3 hours) while the Tile is continuously powered on and not in sleep mode.

An example power profile for a Tile powered with 3.3V can be found below in **Figure 5.**

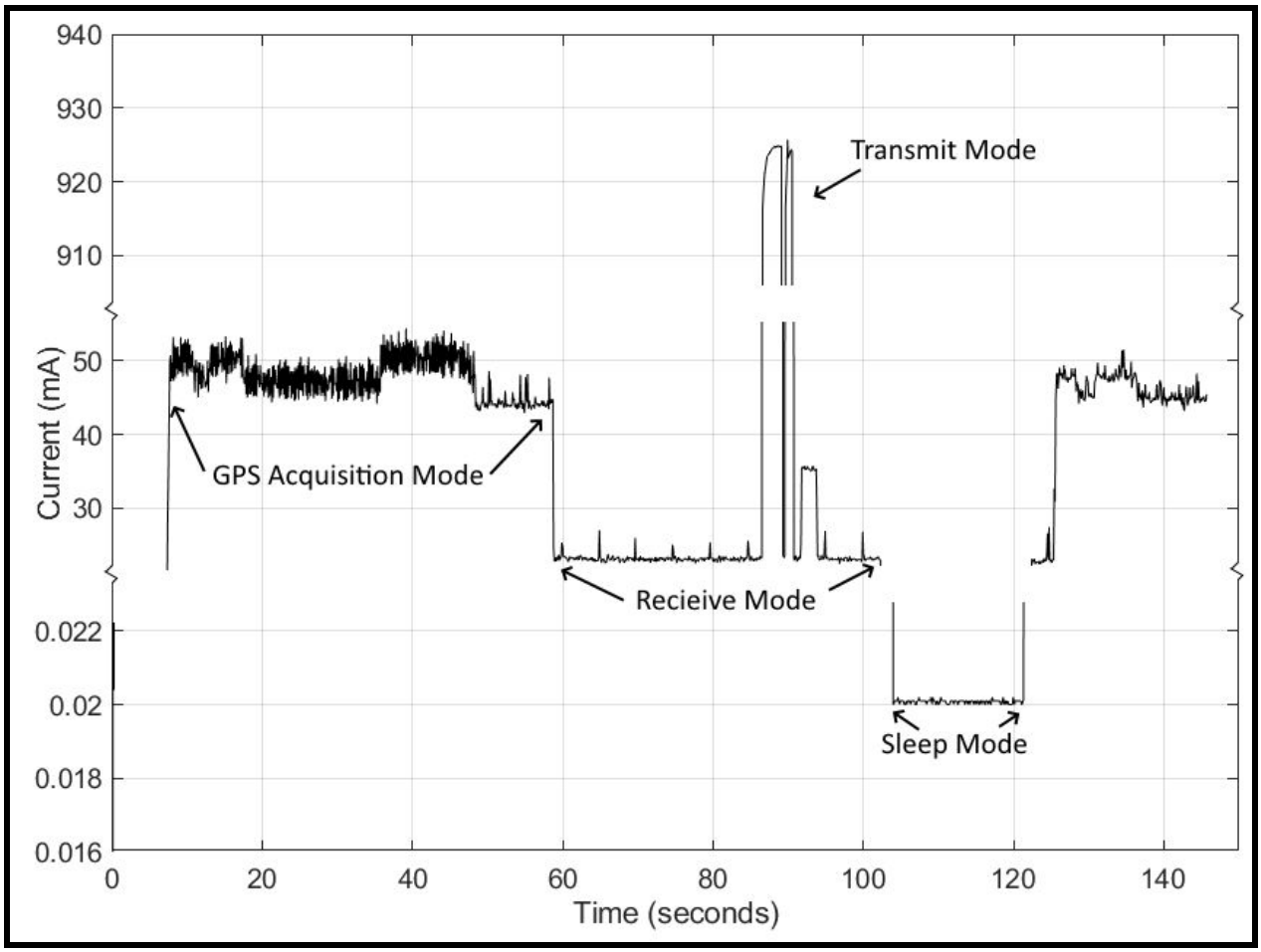

Figure 5: Example current use for a Tile with a 3.3 V input from wake-up, GPS acquisition, Transmit, Receive mode, and then sleep mode. Note the two breaks in the y-axis scale.

Transmissions from the Tile consist of short periods of high current draw conforming to the following characteristics:

Parameter	Value	Note
Transmission Length	3.7 s	Length of transmission for sending a 200 byte packet to space. Actual length may be shorter with a smaller packet size
Transmission Energy	3.1 mW-hrs (11.2 J)	Total amount of energy required for 1 transmission to space (200 bytes)
Recovery Time	0.4s	When sending multiple messages, this is the minimum amount of time that will pass before the Tile will attempt another transmission

Table 9: Sample Tile transmission characteristics for sending a user payload of 200 bytes. Tile provided with 3.3V input.

Other electrical characteristics of the Tile can be found below in **Table 10**:

Parameter	Value
Maximum power at antenna connector	3300 mW
Sum total of all capacitance on Tile	110 µF
Sum total of all inductance on Tile	1983 nH
Largest capacitor on Tile	47 µF
Largest inductor on Tile	1000 nH

Table 10: Other electrical characteristics for the Tile

An example of the interface between a Tile and a third-party host device is shown in **Figure 6.** A photo of a Tile integrated onto a third party device can be found in **Figure 7.**

A separate programming header (**TILE PROG HEADER**) is included in the sample hardware design to upgrade the Tile firmware. It is highly recommended that users include the programming header in their design to easily upgrade the Tile's firmware in the future.

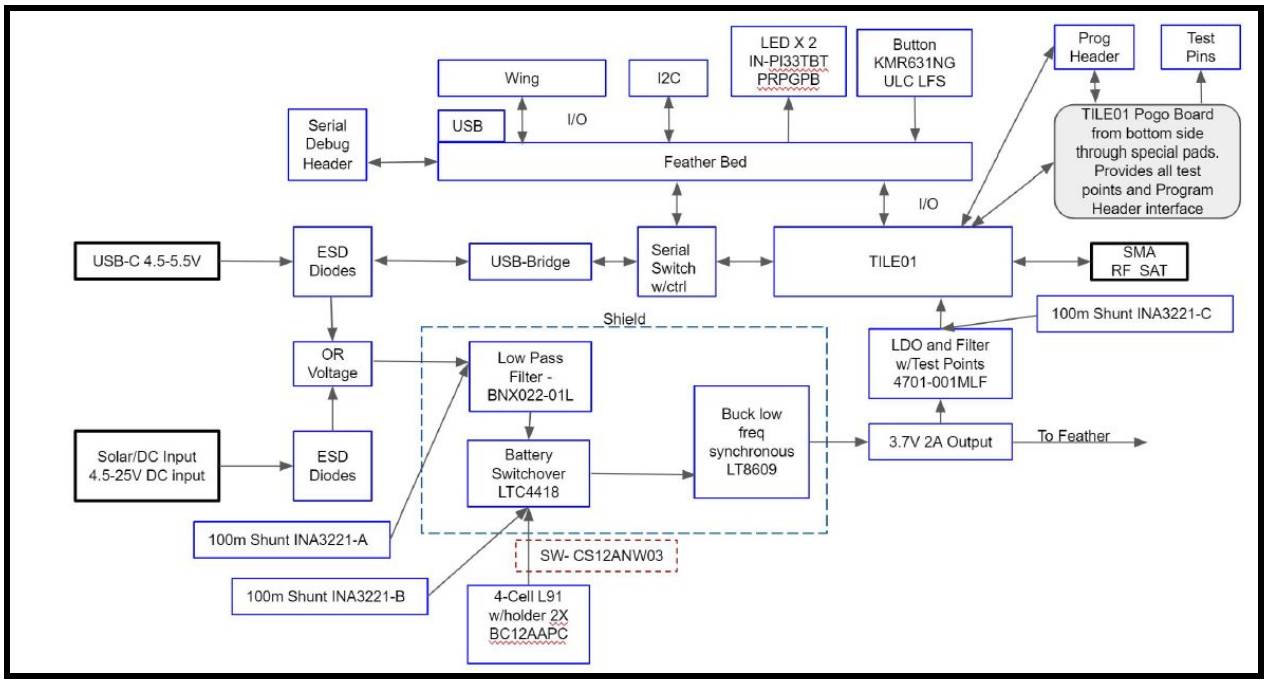

Figure 6: High level diagram of a Swarm Tile Eval Kit design integration.

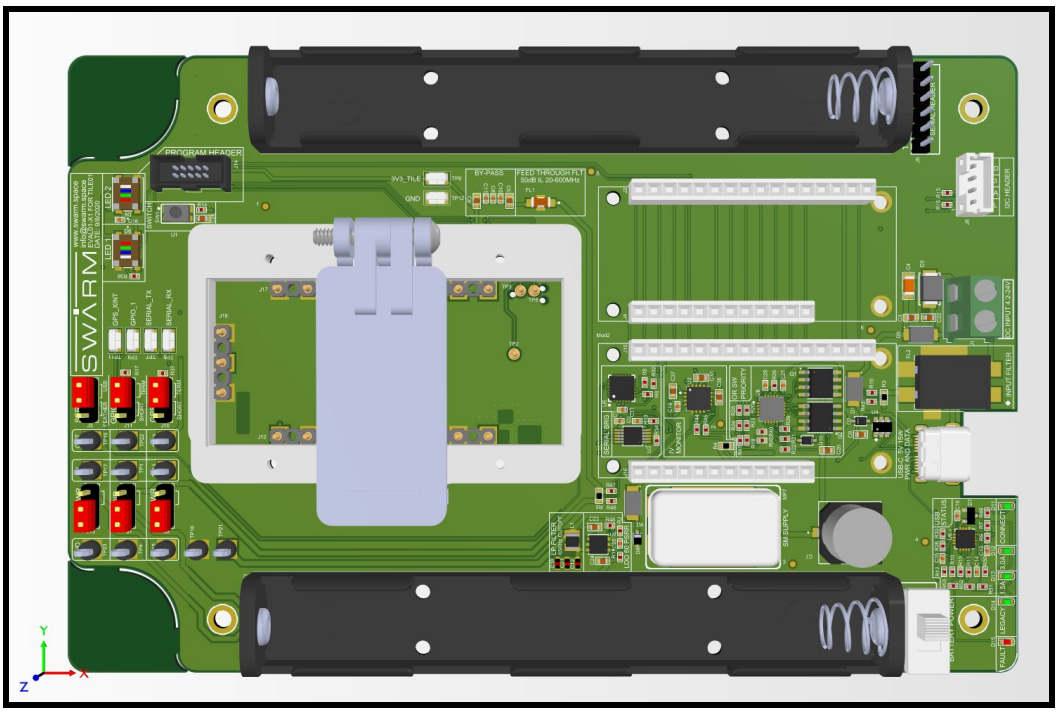

Figure 7: Sample hardware reference design integration for Tile into the Swarm Tile Eval Kit. A 6-pin serial programming header (upper-right of image) is highly encouraged so that the Tile firmware can be easily updated in the future.

4.4 Power On/Off Control

The Tile can be externally switched on/off by an user-supplied load switch on the 3V3 power rail. After a Tile has been powered off, power should not be restored until at least 1 second has elapsed. Additionally, if a unit does not respond to software commands, power off the module, wait for at least 1 second and then power it back on. If the 1 second minimum wait time is not adhered to, the reset circuit may not operate and the Tile could be placed in a non-operational state. The state is not permanent and can be rectified by the above procedure.

4.5 Serial Data Interface

The serial data interface is a CMOS serial UART 3-wire (serial Rx, serial Tx, and ground) interface at 3.3V digital signal levels over which the Tile transfers commands, responses, and message data. The serial communication parameters can be found in **Table 11**.

Parameter	Value
Baud Rate	115200
Data Bits	8 Bits
Parity	None
Stop bits	1 Bit
Flow Control	None

Table 11: Serial communication parameters.

In addition, the electrical characteristics for SERIAL_RX, SERIAL_TX, and GPIO1 can be found in **Table 12.**

Symbol	Parameter	Min	Typ	Max	Unit
VIL	I/O input low level voltage	-0.3	-	0.3*VCC	V
VIH	I/O input high level voltage	0.7*VCC	-	VCC	V
RPU/RPD	Weak pull up/down equivalent resistor (for GPIO1)	25	40	55	kΩ

Table 12: Electrical characteristics for SERIAL_RX, SERIAL_TX, and GPIO1.

4.6 LED Indicators

The Tile contains two indicator LEDs, whose function is described below in **Table 13**. All LEDs are off when the Tile is placed into sleep mode.

LED	Function
Red	While the Tile has no GPS fix, the red LED will blink with a 50% duty cycle (100ms on, 100ms off). If a GPS fix is acquired and then lost, the red LED will blink with a 2% duty cycle (100ms on, 4900ms off) after the green LED. While the Tile has a valid GPS fix, the red LED will not blink at all.
Green	During the bootup sequence or shutdown, the green LED will be on. Afterwards, the green LED will blink with a 2% duty cycle (100ms on, 4900ms off) while the Tile is powered on

Table 13: LED functions.

5 RF Interface

This section describes the physical characteristics of the RF connectors and specifications of the RF Interface.

5.1 RF Connectors

The Tile satellite and GPS connectors are male U.FL connectors [TE Connectivity Part Number 1909763-1]. This is a surface mount connector that is directly attached to the Tile. A Swarm VHF antenna must be used to ensure that the RF output is within certification limits. Swarm antennas are tuned for a VSWR of 1.8 or better at both 137.000 MHz and 150.000 MHz.

5.2 RF Connectors

For illustrative purposes, a picture of two example Swarm antennas is shown in **Figure 8**

Figure 8: Swarm Coiled ¼ Wave Antenna and Swarm ½ Wave Antenna.

5.2.1 Antenna Characteristics

The Tile is certified with the following antennas as described in **Tables 14** and **15**. No power reduction compensation is required for use with these antennas.

Swarm Coiled ¼ Wave Antenna	
Parameter	**Value**
Length	22 cm
Diameter (Connector)	11.2 mm
Diameter (along major length)	7.6 mm
Weight	31.5 g
Operating Temperature	-55 °C to +130 °C
Operating Humidity	0-100% humidity, condensable
Impedance	50 Ohms nominal
Polarization	Linearly Polarized
VSWR (in Swarm Bands)	1.8
Gain	2.0 dBi
Frequency	137.000-138.000 MHz (Rx) 148.000-150.000 MHz (Tx)
Connector	SMA male
Antenna Ground Plane	**Required**
Antenna Classification	Mobile, Fixed
Minimum separation distance from body	29cm

Table 14: Antenna characteristics for Swarm Coiled ¼ Wave Antenna.

Swarm ½ Wave Antenna	
Parameter	**Value**
Length	108 cm
Diameter (Connector)	40.7 mm
Diameter (along major length)	3.3 mm
Weight	150g
Operating Temperature	-55 °C to +130 °C
Operating Humidity	0-100% humidity, condensable
Impedance	50 Ohms nominal
Polarization	Linearly Polarized
VSWR (in Swarm Bands)	1.8
Gain	2.15 dBi
Frequency	137.000-138.000 MHz (RX) 148.000-150.000 MHz (TX)
Connector	NMO Female
Antenna Ground Plane	Recommended
Antenna Classification	Mobile, Fixed
Minimum separation distance from body	29cm

Table 15: Antenna characteristics for Swarm ½ wave Antenna.

A GPS antenna is **required for operation**. Any passive GPS antenna with an appropriate connection to the Tile's U.FL male connector or via the GPS_OUT pin is acceptable for use. One such example of a passive antenna is: [Molex Part Number 1461860300].

Active GPS antennas are supported at 3.3V and up to 35mA. Any active antennas that require a different voltage or maximum current must be powered by the user's host device.

5.2.2 Ground Plane Requirements

An antenna ground plane is required for the Swarm Coiled ¼ Wave Antenna, and is highly recommended but not required for the Swarm ½ Wave Antenna. Ground planes are electrically conductive surfaces that are connected to the ground conductor of the antenna that serve as a reflecting surface for radio waves.

An ideal ground plane for the two Swarm antennas would be a flat, metal sheet with a radius of at least 55cm. To date Swarm has reliably communicated with its satellites using a coiled ¼-wave antenna mounted on top of a ground plane as small as: 15cm x 30cm x 0.3cm

5.3 RF Trace Layout Design

The Tile is certified with a PCB edge SMA connectors [Samtec Part Number SMA-J-P-H-ST-EM1] for the RF and GPS outputs, with a micro-strip trace layout (along with copper keep-out areas) as shown in **Figure 8**.

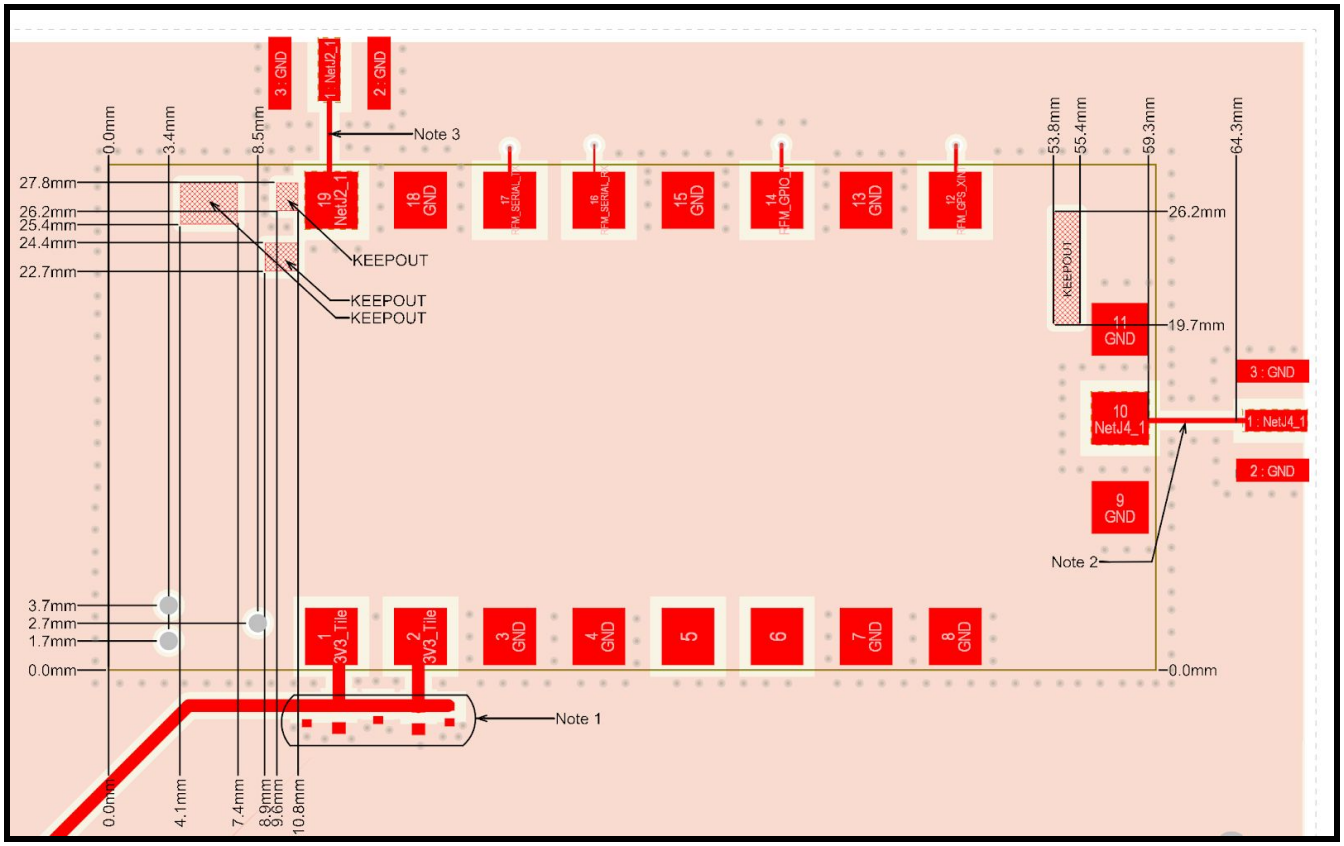

Figure 8: RF trace routing and keep out area for RF output (top layer).

Note 1: The location for the module input and bypass capacitance.
Note 2: SAT_RF track should utilize a 50 Ohm micro-strip specific to the customer board layout, with a ground plane below.
Note 3: GPS_RF track should utlize a 50 Ohm micro-strip specific to the customer board layout, with a ground plane below.
Note 4: Mounting holes - 1.067mm diameter. Not required in customer design

5.4 Integration Guidance

The following recommendations are provided for the host device:

- Place the Tile close to the edge of the host PCB, preferably on a corner
- Use a solid GND plane on an inner layer (for best EMC and RF performance).
- Place GND vias close to module GND pads as possible. An example layout can be found in **Figure 8.**
- Route traces to avoid noise being picked up on VCC supply.
- RF Trace keep out areas:
    - Ensure there is no copper in the keep-out areas on any layer of the host PCB as can be seen in **Figure 8**.
    - Locate all mounting hardware and metal as far as possible from the Tile to not impede antenna performance.

5.5 Antenna Debugging

To quickly verify antenna connection to Tile:

1. Turn on the Tile
2. After bootup, issue **$RT 1*17**. The noise floor the Tile hears (in dBm) will begin displaying at a rate of once per second
3. While the Tile's LED is blinking red rapidly (indicates it has not yet acquired a GPS fix)
    a. Touch the Tile's antenna with your hand or with another object. The noise floor measurement should noticeably change
    b. The Tile will not transmit until it has a GPS fix **and** it hears a Swarm Satellite. There is no risk of the Tile transmitting during this procedure if the red LED is blinking rapidly

6 Software interface

Message types

There are two types of messages:

- **Unsolicited messages** - which include status messages, date/time and GPS information, and notifications that user data has been received
- **Command responses** - which include responses to input commands, as well as notifications that user data has been sent or settings have been updated

General command structure

All messages sent and received are NMEA formatted sentences. NMEA sentences are terminated with a single newline character. Each sentence begins with a **$** and ends with ***xx** where **xx** is a two digit hexadecimal checksum of the characters between the **$** and ***xx**. The checksum conforms to the NMEA standard and does not include either the **$** or the ***xx**. Messages with a bad checksum are silently ignored and are not retained. A sample implementation of the NMEA checksum can be found below (written in C)

A **$** will never occur within a command, and may be used to reset the receiving state machine.

An ***** may occur within a command. The receiving state machine will verify the last three characters in the command are ***xx** after the **\n** is received and before the checksum is calculated. Each **x** may be any legal ASCII character in the range **0..9**, **A..F**, or **a..f**.

An example command is provided below to illustrate the command structure and a valid checksum. This command returns the most recent date/time message :

```
$DT @*70
```

```
$DT 20190408195123,V*41
```

Command timing

Once the **$** is received, all subsequent characters must occur within 5 milliseconds of the previous character. If the inter-character delay exceeds 5 ms, the command will be silently discarded, and the receiving state machine will consume and ignore any characters received until the next **$**.

Command responses

An **OK** response confirms that the input parameters have been updated in response to a command. An **ERR** response indicates that additional or invalid characters were included between the two-character command designator and the ***** of the command.

Boot up sequence

The user application should ignore any characters received during startup until the following NMEA sentence has been received:

$TILE BOOT,RUNNING*49

The bootloader may output non-NMEA formatted messages during this time. These messages include, but are not limited to: status messages, firmware update progress messages, and error messages. These messages should be ignored and are for Swarm debugging purposes only.

Implementation of NMEA checksum in C

```
uint8_t nmeaChecksum (const char *sz, size_t len)
{
 size_t i = 0;
 uint8_t cs;

 if (sz [0] == '$')
   i++;

 for (cs = 0; (i < len) && sz [i]; i++)
   cs ^= ((uint8_t) sz [i]);

 return cs;
}
```

$CS - Configuration Settings

Retrieve and display the configuration settings for the Swarm device ID, application ID, emulation mode, and unique ID (UUID). These settings are determined by Swarm for identifying and communicating with each individual device. Since there are no variable parameters, the correct checksum has been added.

$CS*10

Returns:

$CS AI=<app_ID>,DI=<dev_ID>,DN=<dev_name>,EM=<emu_mode>,UU=<uuid>*xx

Value	Description
app_ID	Application ID assigned and programmed by Swarm
dev_ID	Device ID that identifies this device on the Swarm network
dev_name	Device type name
emu_mode	Internal operating mode (for Swarm use only)
uuid	Unique ID (for Swarm use only)

Notes:

An **ERR** response will be generated if the command is not entered exactly as shown with no additional spaces or characters.

Example:

```
$CS*10
```

```
$CS AI=1999,DI=0x00051b,DN=TILE,EM=0,UU=0x001e002f4847500720373841*75
```

The device has an application ID of **1999**, the Device ID is **0x00051b**, and the device is a **Tile**

$DT - Date/Time

Set or query the rate for **$DT** unsolicited report messages for date and time. Also can retrieve the most current **$DT** message. See unsolicited message description for **$DT** message format.

$DT <@|?|<rate>>*xx

Parameter	Description
@	Repeat most recent **$DT** message
?	Query current **$DT** rate
rate	Disable or set rate of **$DT** messages

Returns one of:

Value	Description
$DT <YYYY><MM><DD><hh><mm><ss>,<flag>*xx	The most recent **$DT** message.
$DT <rate>*xx	The current **$DT** rate
$DT OK*xx	**rate** updated successfully
$DT ERR*xx	Command input error

Parameter	Description
YYYY	Year (1970..2038)
MM	Month (01..12)
DD	Day (01..31)
hh	Hour (00..23)
mm	Minutes (00..59)
ss	Seconds (00..59)
flag	**I** Date/time is invalid **V** Date/time is valid

Notes:

<rate> is a value between 1 and 2147483647 (2^{31}-1) or 0. It will be the number of seconds in between each message. If **<rate>** is 0, no messages will be sent.

If **<rate>** is valid, no **$DT** messages will be sent by the device until the GPS has obtained a valid time reference to set its internal date and time, as indicated by the **$TILE DATETIME*35** message . If the GPS loses its time reference, the message is sent with a flag indicating an invalid state.

Examples:

Calling the most recent date/time message:

`$DT @*70`

`$DT 20190408195123,V*6d`

Returns a date/time of **`April 8th, 2019 7:51:23 PM GMT`**. The date/time is **`valid.`** **`<rate>`** Does not have to be valid to call the most recent date/time message.

Setting the rate of date/time messages:

`$DT 300*03`

`$DT OK*34`

Sets the rate of date/time messages to one message every **`300`** seconds.

Querying the rate of date/time messages:

`$DT ?*0f`

`$DT 60*36`

Returns a rate of one message every **`60`** seconds.

$FV - Firmware Version

Returns the current device firmware version. Since there are no parameters, the correct checksum has been added.

`$FV*10`

Returns one of:

Value	Description
`$FV <version_string>*xx`	The current firmware version
`$FV ERR*xx`	Command input error

Notes:

An **ERR** response will be generated if the command is not entered exactly as shown with no additional spaces or characters.

Example:

```
$FV*10
```

```
$FV 2020-09-21 19:42:39,v0.9.0*3c
```

The firmware version on the device is **0.9.0**.

$GJ - GPS Jamming/Spoofing Indication

Set or query the rate for **$GJ** unsolicited report messages for jamming and spoofing indicators. Also can retrieve the most current **$GJ** message.

`$GJ <@|?|<rate>>*xx`

Parameter	Description
`@`	Repeat most recent **$GJ** message
`?`	Query current **$GJ** rate
`rate`	Disable or set rate of **$GJ** messages

Returns one of:

Parameter	Description
`$GJ <spoof_state>,<jamming_level>*xx`	The most recent **$GJ** message.
`$GJ <rate>*xx`	The current **$GJ** rate
`$GJ OK*xx`	Parameters updated successfully
`$GJ ERR*xx`	Command input error

Parameter	Description
`spoof_state`	**0** Spoofing unknown or deactivated **1** No spoofing indicated **2** Spoofing indicated **3** Multiple spoofing indications
`jamming_level`	Value ranging from 0 to 255 indicating how much carrier wave (CW) jamming is detected. 0 = no CW jamming, 255 = strong CW jamming

Notes:

<rate> is a value between 1 and 2147483647 (2^{31}-1). It will be the number of seconds in between each message. If **<rate>** is 0, no messages will be sent.

Examples:

Calling the most recent GPS jamming/spoofing message:

$GJ @*6d

$GJ 1,23*31

Returns a spoof state of **No spoofing indicated**. The carrier wave jamming level is **23.**

Setting the rate of GPS jamming/spoofing messages:

$GJ 3600*28

$GJ OK*29

Sets the rate of GPS jamming/spoofing messages to one message every **3600** seconds.

Querying the rate ofGPS jamming/spoofing messages:

$GJ ?*12

$GJ 10*2c

Returns a rate of one message every **10** seconds.

$GN - Geospatial information

Set or query the rate for **$GN** unsolicited report messages for date and time. Also can retrieve the most current **$GN** message.

`$GN <@|?|<rate>>*xx`

Parameter	Description
`@`	Repeat most recent **$GN** message
`?`	Query current **$GN** rate
`rate`	Disable or set rate of **$GN** messages

Returns one of:

Value	Description
`$GN <latitude>,<longitude>,<altitude>, <course>,<speed>*xx`	The most recent **$GN** message
`$GN <rate>*xx`	The current **$GN** rate
`$GN OK*xx`	Parameters updated successfully
`$GN ERR*xx`	Command input error

Parameter	Description
latitude	Latitude in d.dddd format (float). The latitude is presented in the N basis (negative latitudes are in the southern hemisphere)
longitude	Longitude in d.dddd format (float). The longitude is presented in the E basis (negative longitudes are in the western hemisphere)
altitude	Altitude in meters (float)
course	Course in degrees (0..359) (float). Course proceeds clockwise, with 0=north, 90=east, 180=south, and 270=west
speed	Speed in kilometers per hour (0..999) (float)

Notes:

<rate> is a value between 1 and 2147483647 (2^{31}-1). It will be the number of seconds in between each message. If **<rate>** is 0, no messages will be sent.

If **<rate>** is valid, no **$GN** messages will be sent by the device until the GPS has obtained a valid position reference as indicated by the **$TILE POSITION*2d** message .

Examples:

Calling the most recent GPS message:

```
$GN @*69
```

```
$GN 37.8921,-122.0155,77,89,2*0c
```

Returns a location of **37.8921N, 122.0155W**. The device's altitude is **77m**, its course is **89 degrees**, and it is moving at **2 kilometers per hour**.

Setting the rate of GPS messages:

```
$GN 30*2a
```

```
$GN OK*2d
```

Sets the rate of GPS messages to one message every **30** seconds.

Querying the rate of GPS messages:

```
$GN ?*16
```

```
$GN 15*2d
```

Returns a rate of one message every **15** seconds.

$GP - GPIO1 Control

This command allows control of the GPIO1 pin to allow indications or control the operation of the Tile.

$GP <?|<mode>>*xx

Parameter	Description
?	Display current GPIO1 mode
mode	Set GPIO1 pin mode

Returns one of:

Value	Description
$GP <mode>*xx	The current **$GP** mode
$GP OK*xx	Parameters updated successfully
$GP ERR*xx	Command input error

Notes:

The **?** option allows reading back the current setting. The **mode** parameter allows specifying how the GPIO1 pin will operate. The available modes are:

Mode	Description
0	Analog, pin is internally disconnected and not used (default)
1	Input, low-to-high transition exits sleep mode
2	Input, high-to-low transition exits sleep mode
3	Output, set low (1)
4	Output, set high (1)
5	Not used
6	Not used
7	Output, low while transmitting. Otherwise output is high
8	Output, high while transmitting. Otherwise output is low
9	Output, low indicates in sleep mode (2). Otherwise output is high
10	Output, high indicates in sleep mode (2). Otherwise output is low

It is the responsibility of the client to provide pull-up resistors to the 3.3V supply rail. See the reference design for resistor sizing. All output modes are open drain.

(1) - These two variations allow the user application to use GPIO1 as a general purpose output.

(2) - If either of these modes are selected, the pin will be set to the selected state after the client has issued the **$SL** command. The pin will return to the awake state only if the sleep mode is terminated by the **S** or **T** parameter being reached, or activity is detected on the serial RX line.

Examples:

Querying the GPIO1 pin mode:

```
$GP ?*08
```

```
$GP 7*00
```

The GPIO1 pin mode is set to **Output, low while transmitting. Otherwise output is high**.

Setting the GPIO1 pin mode to input and wake on a high-to-low transition:

```
$GP 2*05
```

```
$GP OK*33
```

Sets the GPIO1 pin mode to **input and wake on a high-to-low transition**.

$GS - GPS Fix Quality

Set or query the rate for **$GS** unsolicited report messages for date and time. Also can retrieve the most current **$GS** message..

`$GS <@|?|<rate>>*xx`

Parameter	Description
`@`	Repeat most recent **$GS** message
`?`	Query current **$GS** rate
`rate`	Disable or set rate of **$GS** messages

Returns one of:

Parameter	Description
`$GS <hdop>,<vdop>,<gnss_sats>,<unused>,<fix>*xx`	The most recent **$GS** message
`$GS <rate>*xx`	The current **$GS** rate
`$GS OK*xx`	Parameters updated successfully
`$GS ERR*xx`	Command input error

Parameter	Description
hdop	Horizontal dilution of precision (0..9999) (integer = actual hdop * 100)
vdop	Vertical dilution of precision (0..9999) (integer = actual vdop * 100)
gnss_sats	Number of GNSS satellites used in solution (integer)
unused	Always reads as 0, unused
fix_type	**NF** No fix **DR** Dead reckoning only solution **G2** Standalone 2D solution **G3** Standalone 3D solution **D2** Differential 2D solution **D3** Differential 3D solution **RK** Combined GNSS + dead reckoning solution **TT** Time only solution

Notes:

<rate> is a value between 1 and 2147483647 (2^{31}-1). It will be the number of seconds in between each message. If **<rate>** is 0, no messages will be sent.

If **<rate>** is valid, no **$GS** messages will be sent by the device until the GPS has obtained a valid position reference as indicated by the **$TILE POSITION*2d** message .

Examples:

Setting the rate for geospatial information messages to 1 per second:

```
$GS 1*05
```

```
$GS OK*30
```

If **<rate>** is valid, no **$GN** messages will be sent by the device until the GPS has obtained a valid position reference as indicated by the **$TILE POSITION*2d** message .

Calling the most recent geospatial information message:

```
$GS @*74
```

```
$GS 109,214,9,0,G3*46
```

Returns a HDOP of **1.09,** VDOP of **2.14,** the device is using **9** GNSS satellites for this solution**,** and it is a **Standalone 3D solution**.

Querying the rate of geospatial information messages:

```
$GS ?*0b
```

```
$GS 120*07
```

Returns a rate of one message every **120** seconds.

$PO - Power Off

Power off the device. If fully supported, the customer should command any Tile power supplies to disconnect. If power is not disconnected, the Tile enters a low power mode until power is completely removed and restored. Since there are no variable parameters, the correct checksum has been added.

`$PO*1f`

Returns one of:

Value	Description
`$PO OK*xx`	Command has been accepted and the Tile will immediately attempt to power off
`$PO ERR*xx`	Command input error

Notes:

An **`OK`** response confirms that the Tile will shut down. The user should disconnect power from the Tile at this point. If left connected, the Tile will draw approximately 6mA on its 3.3V input. The Tile will not boot again until power has been completely removed and then restored.

Example:

`$PO*1f`

`$PO OK*3b`

`$TILE BOOT,SHUTDOWN*06`

$PW - Power Status

Set or query the rate for **$PW** unsolicited report messages for device power state. Also can retrieve the most current **$PW** message.

`$PW <@|?|<rate>>*xx`

Parameter	Description
`@`	Repeat most recent **$PW** message
`?`	Query current **$PW** rate
`rate`	Disable or set rate of **$PW** messages

Returns one of:

Parameter	Description
$PW <unused>,<unused>,<unused>,<unused>,<temp> *xx	The most recent **$PW** message
`$PW <rate>*xx`	The current **$PW** rate
`$PW OK*xx`	Parameters updated successfully
`$PW ERR*xx`	Command input error

Parameter	Description
`unused`	Will always show as 0.00000
`temp`	CPU Temperature in degrees C to one decimal point (float)

Notes:

<rate> is a value between 1 and 2147483647 (2^{31}-1). It will be the number of seconds in between each message. If **<rate>** is 0, no messages will be sent.

Examples:

Calling the most recent power status message:

```
$PW @*67
```

```
$PW 0.00000,0.00000,0.00000,0.00000,25.0*3c
```

Returns a device temperature of **25.0**℃.

Setting the rate of power status messages:

```
$PW 30*24
```

```
$PW OK*23
```

Sets the rate of power status messages to one message every **30** seconds.

Querying the rate of power status messages:

```
$PW ?*18
```

```
$PW 900*1e
```

Returns a rate of one message every **900** seconds.

$RS - Restart Device

Perform a software cold restart of the device. Since there are no variable parameters, the correct checksum has been added.

`$RS*01`

Returns one of:

Value	Description
`$RS OK*xx`	Command has been accepted and the device will immediately perform a hardware restart
`$RS ERR*xx`	Command input error

Notes:

An **`OK`** response confirms that the device will successfully restart. No external power cycling is required.

Example:

`$RS*01`

`$RS OK*25`

`$TILE BOOT,RESTART*59`

$RT - Receive Test

Set or query the rate for **$RT** unsolicited report messages for device power state. Also can retrieve the most current **$RT** message.

`$RT <@|?|<rate>>*xx`

Parameter	Description
`@`	Repeat most recent **$RT** message
`?`	Query current **$RT** rate
`rate`	Disable or set rate of **$RT** messages

Returns one of:

Parameter	Description
$RT RSSI=<rssi_sat>,SNR=<snr>,FDEV =<fdev>,TS=<time>,DI=<sat_id>*xx	The most recent **$RT** message from a satellite. Appears independently of the background noise messages
`$RT RSSI=<rssi>*xx`	The most recent **$RT** message
`$RT <rate>*xx`	The current **$RT** rate
`$RT OK*xx`	Parameters updated successfully
`$RT ERR*xx`	Command input error

Parameter	Description
rssi	Received background noise signal strength in dBm for open channel (integer). For reliable operation, this value should consistently be less than (more negative) than **-93** dBm
rssi_sat	Received signal strength in dBm for packet (integer)
snr	Signal to noise ratio in dB for packet (integer)
fdev	Frequency deviation in Hz for packet (integer)
time	Date and time (UTC) of received packet
sat_id	Device ID of satellite heard

Notes:

<rate> is a value between 1 and 2147483647 (2^{31}-1). It will be the number of seconds in between each message. If **<rate>** is 0, no messages will be sent, and no packets received from a satellite will be displayed.

For reliable performance, the noise floor can be measured with an antenna connected to the device in the final built up configuration. The value reported by **$RT** should be less than (a larger negative number) than **-93** dBm. If the noise floor is greater than **-93** dBm (e.g. -88 dBm), then the customer should relocate the device to a different location.

Examples:

Calling the most recent receive test message. This will return the last packet received from a satellite:

```
$RT @*66
```

```
$RT RSSI=-102,SNR=-1,FDEV=426,TS=2020-10-02 13:56:21,DI=0x000568*04
```

Returns a satellite packet RSSI of **-102** dBm, SNR of **-1** dB, frequency deviation of **426** hz, a received time of **October 2nd, 2020 at 1:56:21 PM**, and the satellite's device ID is **0x000568**.

Setting the rate of receive test messages:

$RT 1*17

$RT OK*23

Sets the rate of receive test messages to one message every **1** second. The format of these scheduled messages will be the simple noise floor message. Any packets received from a satellite will be displayed as they are received, independently of the **$RT** rate.

Querying the rate of receive test messages:

$RT ?*19

$RT 5*13

Returns a rate of one message every **5** seconds.

$SL - Sleep mode

This command puts the device into a low-power sleep mode.

$SL [S=<seconds>|U=<[YYYY-MM-DD]hh:mm:ss>]*xx

Parameter	Description
S=<seconds>	Sleep for this many seconds
U=<[YYYY-MM-DD]hh:mm:ss>	Sleep until date (optional) and time

Returns one of:

Value	Description
$SL OK*xx	Sleep period accepted, device is now non-responsive
$SL WAKE,<cause>*xx	Device has woken from selected sleep mode
$SL ERR,TIMENOTSET*xx	Time not yet set from GPS
$SL ERR,BADPARAM*xx	Invalid number of seconds or date/time value
$SL ERR,NOCOMMAND*xx	No **S** or **U** parameter is present
$SL ERR,NOTIME*xx	Attempt to sleep before time is set

The **S** parameter is the number of seconds to sleep. This value may range from 5 to 31536000 (approximately 1 year) seconds. A value not within this range will return **$SL ERR,BADPARAM**. If the command is accepted, the device will emit **$SL OK** and enter sleep mode for the requested duration.

The **U** parameter is a time and optional date the device should sleep until and then wake. If the date is not specified and the time to sleep until is less than the current time, the time is presumed to be in the next day. For example, if the current time is 11:00:00 and **$SL U=09:00:00** is issued, the device will wake 22 hours from now. If a date and time are

specified, and that date/time is before the current date/time, **$SL WAKE** will be immediately issued.

The **$SL WAKE,<cause>** message is emitted after the Tile wakes from a user commanded sleep mode (as opposed to the Tile waking to perform internal housekeeping and then returning to sleep). The value of **cause** will be one of the following:

Cause	Description
GPIO	GPIO input changed from inactive to active state
SERIAL	Activity was detected on the RX pin of the Tile's UART
TIME	The **S** or **U** parameter time has been reached

If UART activity wakes the Tile, the **TIMEOUT** message will not be emitted as the Tile is now awake.

In sleep mode, the real-time clock is not GPS disciplined, and is therefore subject to some degree of drift. The longer the device is asleep, the more the drift will accumulate. The user should be aware of this when selecting a sleep with a long duration.

If the GPIO1 pin is configured as an input to wake the Tile, the sleep mode will be terminated if activity occurs on GPIO1. If the GPIO1 pin is configured as an output that indicates the Tile's sleep mode, GPIO1 will transition to the appropriate state if the **$SL OK** message is emitted.

Examples:

Commanding the Tile to sleep for 3600 seconds (1 hour):

```
$SL S=3600*54
```

```
$SL OK*3b
```

```
$SL WAKE,TIME @ 2019-04-11 18:58:03*77
```

If the Tile receives any serial input before the planned wake time, then the Tile will wake with a message such as:

```
$SL WAKE,SERIAL @ 2019-04-11 18:57:45*6f
```

Similarly, if the GPIO1 pin is configured to wake on a high-to-low (or low-to-high) transition, then on transition on the GPIO1 pin, the Tile will also wake with a message such as:

```
$SL WAKE,GPIO @ 2019-04-11 18:57:55*7f
```

Commanding the Tile to sleep until October 1st, 2021 at 4:30:00 PM:

```
$SL U=2021-10-01 16:30:00*72
```

```
$SL OK*3b
```

$TILE - Tile Status

These unsolicited status messages indicate the readiness of the Tile for normal operation. This includes the conditions at power up, GPS acquisition, and certain error conditions. Tile status messages cannot be disabled.

`$TILE <msg>,[<data>]*xx`

Parameter	Description
`msg`	**BOOT** - Boot process progress with the following **`data`** reason: ● **ABORT** - A firmware crash occurred that caused a restart ● **POWERON** - Power has been applied ● **RUNNING** - Boot has completed and ready to accept commands ● **UPDATED** - A firmware update was performed ● **VERSION** - Current firmware version information **DATETIME** - The first time GPS has acquired a valid date/time reference **POSITION** - The first time GPS has acquired a valid position 3D fix **DEBUG** - Debug message (**`data`** - debug text) **ERROR** - Error message (**`data`** - error text)

Notes:

A **`data`** message follows the **BOOT** message to indicate the reason for the startup.

The **POSITION** message and **DATETIME** message may occur in any order. Depending on the GPS signal quality, it may take several minutes before the **DATETIME** or **POSITION** message is emitted.

The customer application should wait until the boot process is complete and it has received the **$TILE BOOT,RUNNING*49** message before executing any commands.

$TD - Transmit data

This command transmits data to the Swarm network.

`$TD [HD=<hold_dur>|ET=<expire_time>,]<[string|data]>*xx`

Parameter	Description
HD=<hold_dur>	Hold duration of message in seconds (optional, default = 172800 seconds)
ET=<expire_time>	Time to expire message in epoch seconds
<string|data>	1 to 200 bytes of data (ASCII string) 2 to 400 bytes (hexadecimal written as ascii)

Returns one of:

Value	Description
$TD OK,<msg_id>*xx	Message accepted for sending
$TD SENT RSSI=<rssi_sat>,SNR=<snr>,FDEV=<fdev>,<msg_id>*xx	This is an unsolicited response that occurs at the time when the message is sent to and acknowledged by the satellite. It includes the RF information from the acknowledgement
$TD ERR,BADDATA,0*xx	Message has odd number or non-hex characters when sending data as hexadecimal
$TD ERR,BADEXPIRETIME,0*xx	Invalid hold time
$TD ERR,ERR,0*xx	Unspecified error
$TD ERR,HOLDTIMEEXPIRED,<msg_id>*xx	Unable to send within requested hold time
$TD ERR,NODEVICEID,0*xx	The Swarm device ID has not yet been set
$TD ERR,NOCOMMAND,0*xx	**$TD** with no parameters was sent
$TD ERR,NOSPACE,0*xx	No space for message
$TD ERR,NOAPPID,0*xx	The application ID has not yet been set
$TD ERR,BADAPPID,0*xx	The application ID is invalid
$TD ERR,TIMENOTSET,0*xx	Attempt to send message before time set by GPS
$TD ERR,DBXTOHIVEFULL,0*xx	Queue for queued messages is full. Maximum of 2048 messages may be held in the queue.
$TD ERR,TOOLONG,<msg_id>*xx	Message is too large to send

Notes:

The **HD** and **ET** parameters are optional but must occur before the **<data>** portion of the command. Both affect the time when a message is expired no longer considered available to transmit. Expired messages are removed from the outgoing packet database. If neither option is

present, the default hold time of **172800** seconds (48 hours) will be used. If both options are specified, the **<hold_dur>** will be ignored.

<hold_dur> is the number of seconds to hold the message if it has not been sent before expiring it from the database.

Hold Duration Value	Description
1 to **31536000** (one year)	The message will be considered expired if not sent within the specified number of seconds. The maximum duration is one year from the current time.
Any other value	An error message (**$TD ERR,0*xx**) is returned.

<expire_time> is an epoch second date after which the message will be expired if it has not been sent.

Expiration Time Value	Description
Any other value	An error message (**$TD ERR,0*xx**) is returned.
1577836800 to **4102444799** (2020-01-01 00:00:00 to 2099-12-31 23:59:59)	The message will be considered expired if not sent before the specified time. If the specified time is greater than **1577836800** and less than or equal to the current UTC time, the message will not be queued and an expired message **$TD HOLDTIMEEXPIRED,0*xx** will be returned immediately.

<string|data> may be expressed one of two different ways. If all the data to be sent is in the ASCII character range from 0x20 (space) to 0x7e (tilde), then the data may be sent as a string. A string is specified by enclosing the data in double quotes, e.g., "Hello, world". It is permissible for the string to contain double quotes within the string, e.g., "Today is a "new" day". If the data to be sent includes one or more character outside the 0x20 to 0x7e range, then it must be specified as pairs of hex characters ('0'..'9', 'A'..'F', 'a'..'f'), and must be a multiple of 2. Sending 'Hello' as hex would be 48656C6C6F. Illegal characters or an odd number of characters will cause a **BADDATA** message to be returned.

<msg_id> is assigned by the device, and is an unsigned 64-bit value comprised of the device ID, a day of year counter, and a message of day counter. Responses that have a 0 as the message ID indicates the message has not been placed in the queue and therefore has no ID.

The value should be treated as a simple arbitrary number.

Typical messaging flow:

1. User queue message to be sent, with an expiry time of 7200 seconds (2 hours):

$TD HD=7200,“Hello there!”*04

2. Device acknowledges receipt of message, and message enters into device’s internal message database. Message is given the message ID of **5354468575855**. Database has a maximum amount of 2048 messages stored. Database is non-volatile and messages persist through sleep mode and power cycling:

$TD OK,5354468575855*2a

3. If the message has not expired due to time (as it was set to expire 2 hours from when it was entered), when the device hears a satellite pass overhead it attempts to send any messages in its database. Messages are scheduled to be sent in the order they were entered into the device (e.g. first in database, first transmitted). Each message heard by the satellite is individually acknowledged with a **$TD SENT** response - the acknowledged message is referred to by its message ID (**5354468575855**)

$TD SENT,RSSI=-99,SNR=5,FDEV=32,5354468575855*6f

4. Acknowledged message in database is marked for deletion by device. Any unsent messages will be attempted to be sent by the device at a later time.

Examples:

Sending a message from the device in ASCII:

$TD "Hello World!"*31

$TD OK,5354468575916*2c

$TD SENT,RSSI=-104,SNR=-3,FDEV=345,5354468575916*44

Sending a message from the device in ASCII that will expire in 1 hour:

$TD HD=3600,"Hello World!"*29

$TD OK,5354468575917*2d

$TD SENT,RSSI=-103,SNR=2,FDEV=-67,5354468575917*70

Sending a message from the device in ASCII that will expire on 2021-01-01 12:34:56:

$TD ET=1609504496,"Hello World!"*1F

$TD OK,5354468575919*2f

$TD SENT,RSSI=-100,SNR=-3,FDEV=437,5354468575919*4D

Sending a message from the device in HEXASCII:

$TD 5468697320697320696E206865786173636969*65

$TD OK,5354468575916*2c

$TD SENT,RSSI=-107,SNR=3,FDEV=199,5354468575916*69