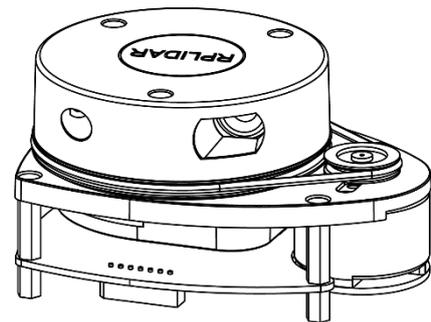
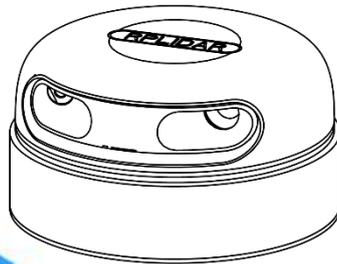


RPLIDAR

Low Cost 360 Degree Laser Range Scanner

Interface Protocol and Application Notes

Applied to RPLIDAR A1 & A2



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1. Overview

The host system communicates with RPLIDAR core system via the TTL UART serial interface. Based on the communication protocol defined in this document, the host system can retrieve the scan data, the device status, the health information etc. and manipulate RPLIDAR's working mode.

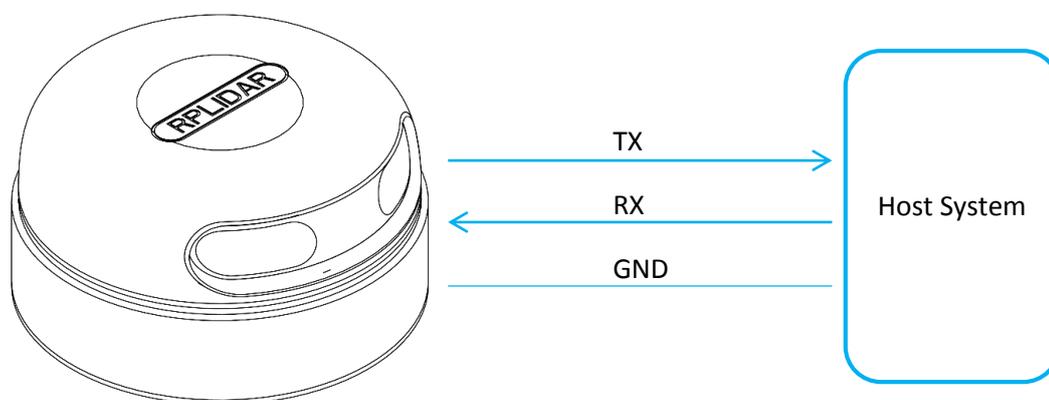


Figure 1-1 The Communication Between RPLIDAR and Host System

Please refer to the RPLIDAR datasheet for information about the bottom layer communication protocol and the electrical level definition of the serial signals used to communicate with RPLIDAR. The communication protocol based on UART serial port and the data transmission format will be introduced in this document.

SDK and Demo Program

SLAMTEC provides open-sourced SDK and demo program for customers to integrate RPLIDAR into their systems quickly. The SDK implements all the communication stacks, driver logics and related data structures described in this document

The SDK supports multiple platforms including Windows, Linux, MacOS and even bare systems without an OS.

Please refer to the SDK manual for details.

Basic Communication Mode

The RPLIDAR uses a non-textual binary data packet based protocol to communicate with host systems. And all the packets transmitted on the interface channel share uniform packet formats.

A communication session is always initialized by a host system, i.e. a MCU, a PC, etc. RPLIDAR itself won't send any data out automatically after powering up.

If a data packet is sent from host systems to RPLIDARs, such a packet is called a **Request**. Once an RPLIAR receives a request, it will reply the host system with a data packet called a **Response**.

RPLIDAR will only start performing related operations required by a host system once after it receives a request. If RPLIDAR should reply to the host system, it will send one or more required response packets.

In order to let an RPLIDAR start scanning operation and send out data, a host system is required to send a pre-defined **Start Scan** request packet to RPLIDAR. RPLIDAR will start scanning operation once after it receives the request and the scan result data is sent out to the host system continuously.

There are three different request/response modes based on the related request types:

Request/Response Modes

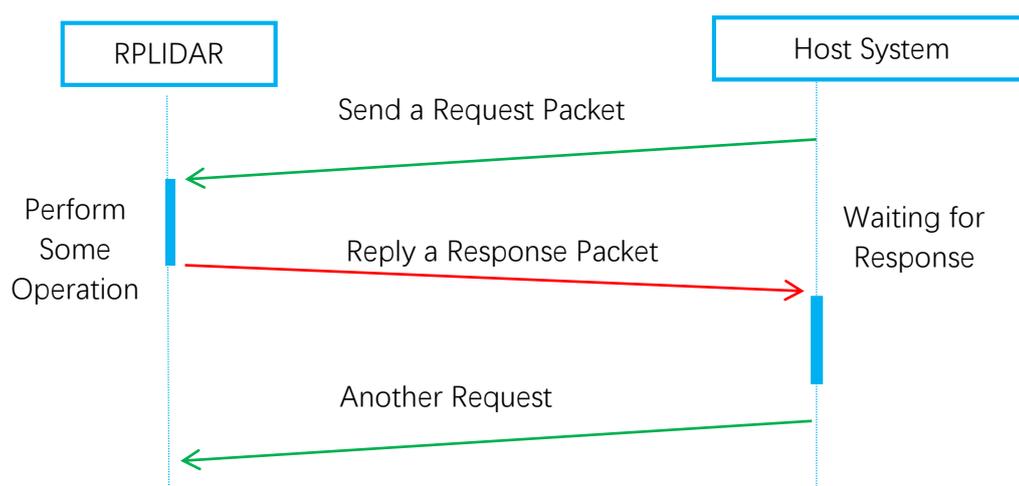


Figure 2-1 RPLIDAR Request/Response Modes

Host system should prevent sending extra request packets if the RPLIDAR is busy with handling the current request and hasn't replied to the host system yet. Otherwise,

these extra request packets will be discarded by the RPLIDAR's protocol stack and the RPLIDAR will not have any chance to handle it.

Single Request-Multiple Response Modes

This mode is used when the RPLIDAR is asked to perform the scan operation. After a host system sending a Start Scan request, RPLIDAR will take distance scan measurement continuously. Once a scan measurement sample is retrieved, its related result data (distance, angle value) will be sent out as individual response packets.

Host systems are only required to send a single request packet with this mode but will receive a continuous response packet stream with multiple response packets.

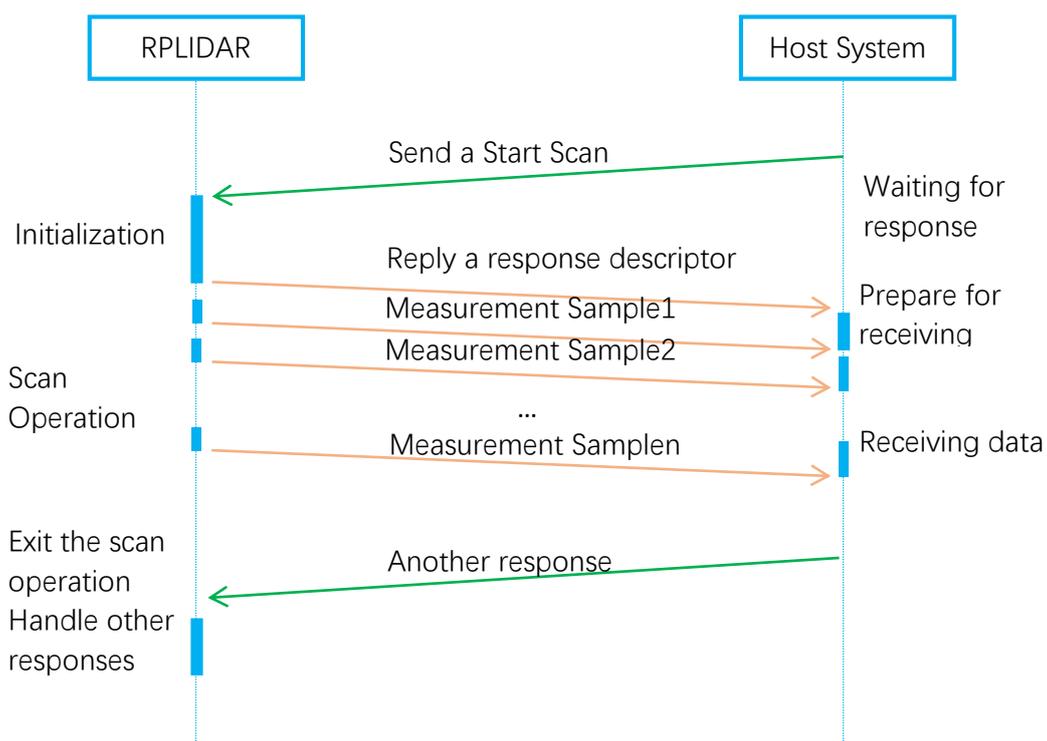


Figure 2-2 RPLIDAR Single Request - Multiple Response Mode

The host system can interrupt RPLIDAR and let it leave the multiple responses mode by sending a STOP request or any request packet. After leaving the multiple

responses mode, the RPLIDAR will continue to handle the request which has interrupted it.

The request packets sent by the host system during the multiple responses mode will be cached by the RPLIDAR's protocol stack. After leaving the multiple responses mode, RPLIDAR will handle the cached request.

Single Request-No Response

For requests like STOP, RESET Core, RPLIDAR uses the single request – no response mode since there is no need to reply to the host system.

Host systems should wait for a period of time before sending another request since RPLIDAR needs time to process the request operation. Otherwise, the request may be discarded by the RPLIDAR's protocol stack.

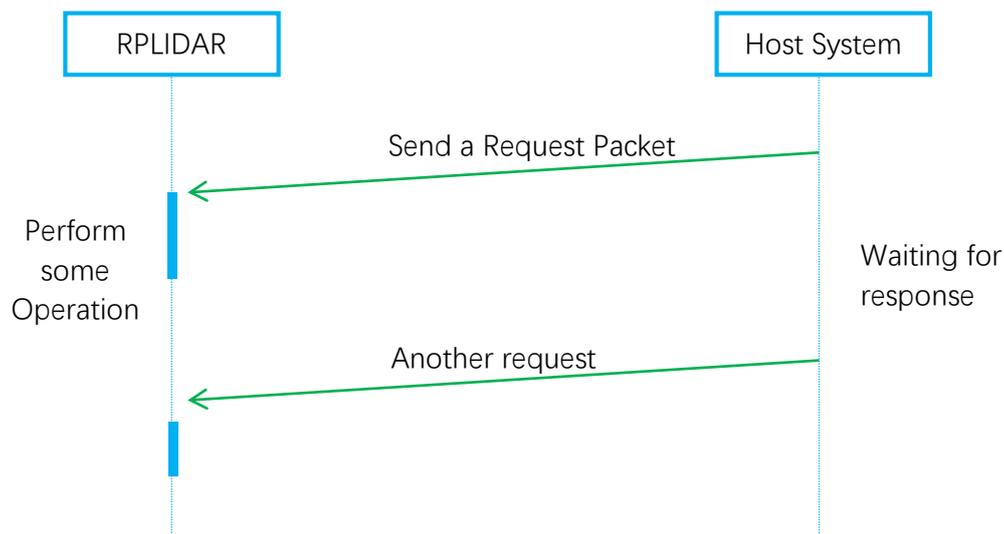


Figure 2-3 RPLIDAR Single Request-No Response Mode

Request Packets' Format

All request packets sent by a host system share the following common format. Little endian byte order is used.

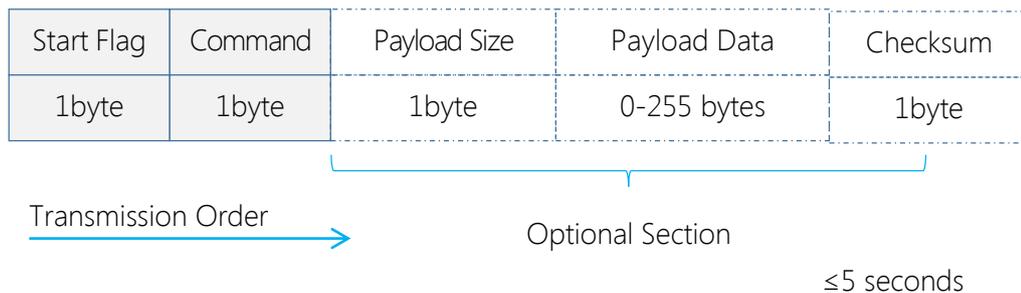


Figure 2-4 RPLIDAR Request Packets' Format

A fixed 0xA5 byte is used for each request packet, RPLIDAR uses this byte as the identification of a new request packet. An 8bit (1byte) command field must follow the start flag byte.

If the current request carries extra payload data, an 8bit (1byte) payload size field is required to be transmitted after sending the command field and then follows the payload data. After the payload data has been transmitted, an 8bit (1byte) checksum field calculated from the previous sent data should be transmitted.

The checksum value can be calculated using the following equation:

$$\text{checksum} = 0 \oplus 0xA5 \oplus \text{CmdType} \oplus \text{PayloadSize} \oplus \text{Payload}[0] \oplus \dots \oplus \text{Payload}[n]$$

Note: Timing Consideration

All bytes within a request packet must be transmitted to RPLIDAR within 5 seconds. Otherwise, the communication stack of RPLIDAR will discard the current request packet.

Response Packets' Format

All the response packets are divided into two classes: **response descriptors** and **data responses**. If the current request received by RPLIDAR requires a response, RPLDAR will always send a response descriptor packet first and then send one or more data response packets based on the type of requests. Only one response descriptor packet will be sent out during a request/response session. The response descriptors carry the information of the incoming data responses. All the response descriptors share a same format.

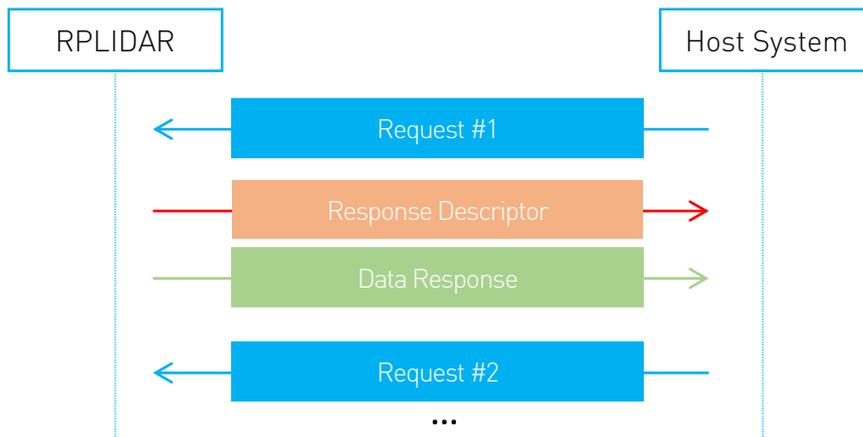


Figure 2-5 Response Packets Sent during a Single Request-Single Response Mode

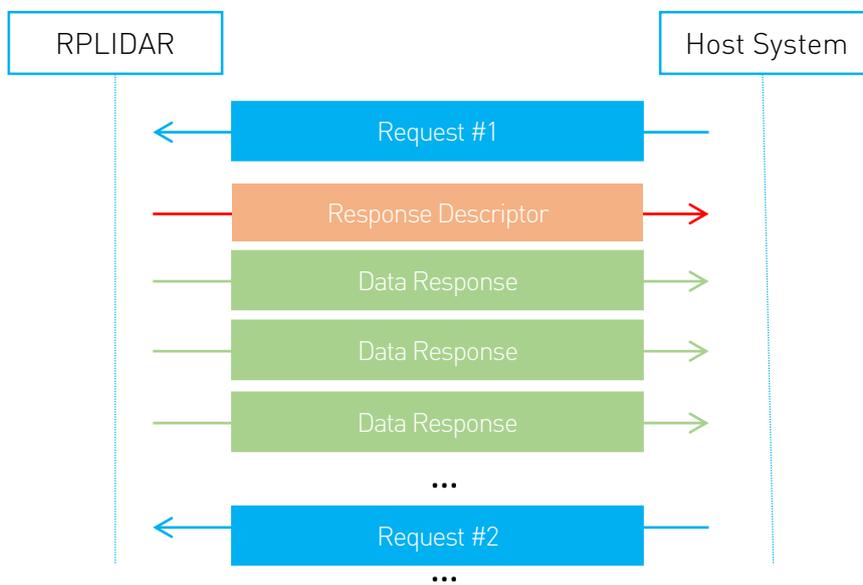


Figure 2-6 Response Packets Sent during a Single Request-Multiple Response Mode

The format of response descriptors is depicted in the following figure.

Start Flag1	Start Flag2	Data Response Length	Send Mode	Data Type
1byte (0xA5)	1byte (0x5A)	30bits	2bits	1byte

Transmission Order

Figure 2-7 RPLIDAR Response Descriptors' Format

A response descriptor uses fixed two bytes' pattern 0xA5 0x5A for the host system to identify the start of a response descriptor. The 30bit Data Response Length field records the size of a **single** incoming data response packet in bytes. (All the incoming data response packets within a request/response session should have the same format and length). The 2bits Send Mode field describes the request/response mode of the current session. Its values are listed below:

Send Mode	Description
0x0	Single Request – Single Response mode, RPLIDAR will send only one data response packet in the current session.
0x1	Single Request – Multiple Response mode, RPLIDAR will continuously send out data response packets with the same format in the current session.
0x2	Reserved for future use
0x3	Reserved for future use

Figure 2-8 RPLIDAR Data Response Packets Value

The 1byte Data Type describes the type of the incoming data response packets. It is related to the type of the request RPLIDAR just received. Host systems can choose different data receiving and handling policy based on this field.

Different from response descriptors, there is no common format used among response data packets. Each type of response data has its own data format and packet length based on its type.

3. Working State and Mechanism

Major Working States and Transition Conditions

RPLIDAR has the following 4 major states: Idle, Scanning, Request Processing and the Protection Stop state.

The transition conditions are depicted in the following figure:

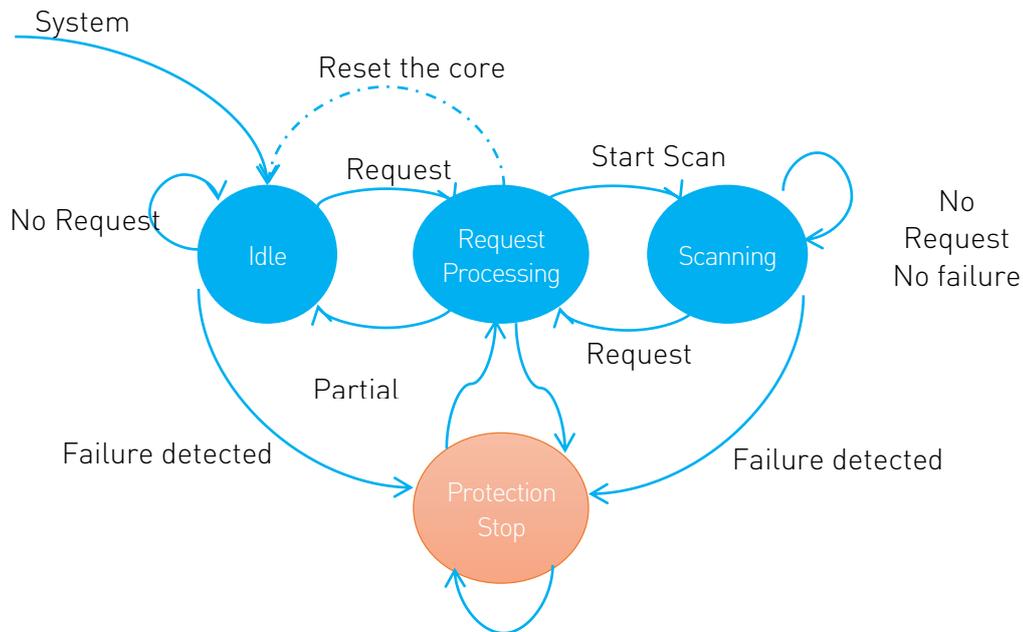


Figure 3-1 RPLIDAR's Major Status Transition

The Idle state is the default state of RPLIDAR which will be entered automatically after powering up or reset. Both the laser diode and the measurement system are disabled in this state, and the whole system is in power saving mode. Once RPLIDAR enters the Scanning state, the laser diode and the measurement system will be enabled and RPLIDAR will start measuring distance and sending the result out continuously.

RPLIDAR will enter the Request Processing state once it receives request packets from the host system. During processing the request, RPLIDAR won't perform the scan operation and won't send any data out. It will only send out response data for request needing a response after the required operation has been finished. After the request has been processed, RPLIDAR will enter other status specified by the request.

Once RPLIDAR detects something wrong with the device hardware, it will stop the current operation and enter the Protection Stop state. A host system can still communicate with an RPLIDAR in the Protection Stop state to query its working

status. But the host system cannot ask the RPLIDAR to perform scan operations unless the host system send a Reset request to reboot the RPLIDAR core system.

Scanning Status

RPLIDAR always checks the motor rotation status when working in the scanning state. Only when the motor rotation speed becomes stable, RPLIDAR will start taking distance measurement and sending out the result data to the host system.

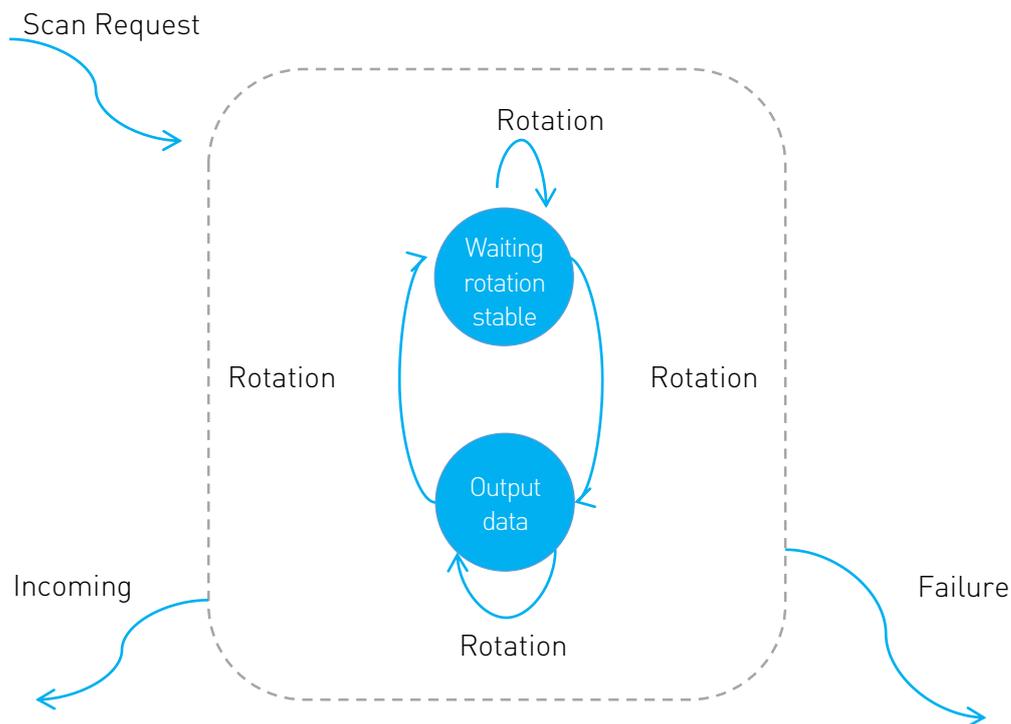


Figure 3-2 RPLIDAR' s Working Mode during Scanning

4. Request and Response Data **SLAMTEC**

Requests Overview

All the available requests are listed in the below table. Their detailed descriptions are given in the following sections.

Request Name	Value	Payload	Response Mode	RPLIDAR Operation
STOP	0x25	N/A	No response	Exit the current state and enter the idle state
RESET	0x40	N/A		Reset(reboot) the RPLIDAR core
SCAN	0x20	N/A		Enter the scanning state
EXPRESS_SCAN	0x82	YES	Multiple response	Enter the scanning state and working at the highest speed
FORCE_SCAN	0x21	N/A		Enter the scanning state and force data output without checking rotation speed
GET_INFO	0x50	N/A	Single response	Send out the device info (e.g. serial number)
GET_HEALTH	0x52	N/A		Send out the device health info
GET_SAMPLERATE	0x59	N/A		Send out single sampling time

Figure 4-1 The Available Requests of RPLIDAR

STOP Request

Request Packet:

A5	25
----	----

RPLIDAR will exit the current scanning state once it receives the Stop (0x25) Request sent by a host system. The laser diode and the measurement system will be disabled and the Idle state will be entered. This request will be ignored when RPLIDAR is in the Idle or Protection Stop state.

Since RPLIDAR won't send response packet for this request, host systems should wait for at least 1 millisecond (ms) before sending another request.



Figure 4-2 The Timing Sequence of a STOP Request

RPLIDAR Core Reset(RESET) Request

Request Packet:

A5	40
----	----

Host systems can make RPLIDAR core to reset (reboot) itself by sending this request. A reset operation will make RPLIDAR revert to a similar state as it has just been powered up. This request is useful when RPLIDAR has entered the Protection Stop state. After a core reset, RPLIDAR will return to the idle state which will accept the start scan request again.

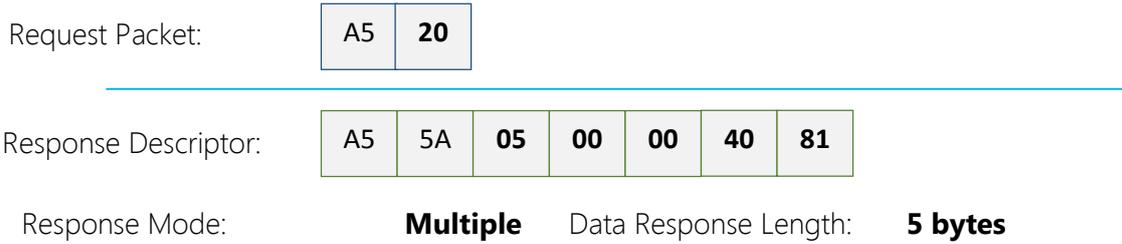
Since RPLIDAR won't send response packet for this request, host systems should wait for at least 2 milliseconds (ms) before sending another request.



Figure 4-3 The Timing Sequence of a RESET Request

Start Scan (SCAN) Request and Response

Note: RPLIDAR A2 and other device **models support** 4khz sampling rate will lower the sampling rate when processing this request. Please use EXPRESS_SCAN for the best performance.



RPLIDAR, except for the RPLIDAR that is in the Protection Stop State, will enter the scanning state once it receives this request from a host system. Each measurement sample result will be sent out using an individual data response packet. If the RPLIDAR has been in scanning state already, it will stop the current measurement sampling and start a new round of scanning. This request will be ignored when RPLIDAR is in the Protection Stop state.

The related response descriptor will be sent out by RPLIDAR immediately once it receives the request and accepts it. The data response packets related to every measurement sample results will be sent out continuously only after the motor rotation becomes stable. RPLIDAR will leave the Scanning state once it receives a new request from the host system or it detects something is wrong.

Format of the Data Response Packets :

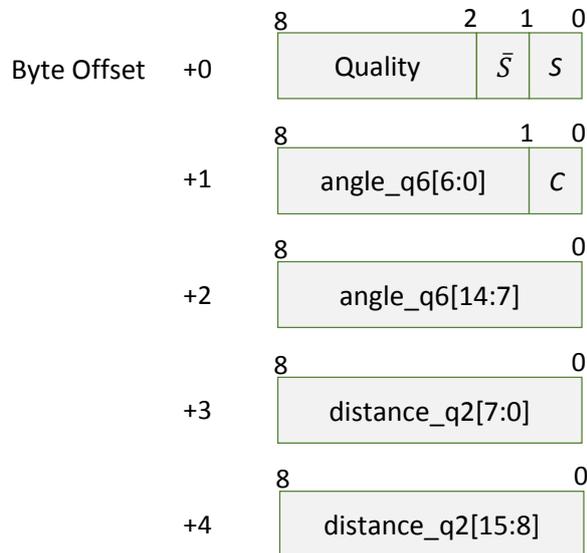


Figure 4-4 Format of a RPLIDAR Measurement Result Data Response Packet

RPLIDAR encapsulates each measurement sample into a data response packet with the format showed in the above figure and send the packet out. The descriptions of every field within the packet are listed in the following table:

Field Name	Description	Examples / Notes
S	Start flag bit of a new scan	When S is set to 1, the current and incoming packets belong to a new 360° scan.
\bar{S}	Inversed start flag bit, always has $\bar{S} = !S$	Can be used as a data check bit.
C	Check bit, constantly set to 1	Can be used as a data check bit.
quality	Quality of the current measurement sample	Related the reflected laser pulse strength.
angle_q6	The measurement heading angle related to RPLIDAR's heading. In degree unit, [0-360] Stored using fix point number.	Refer to the below figure for details. Actual heading = angle_q6/64.0 Degree
distance_q2	Measured object distance related to RPLIDAR's rotation center. In millimeter (mm) unit. Represents using fix point. Set to 0 when the measurement is invalid.	Refer to the below figure for details. Actual Distance = distance_q2/4.0 mm

Figure 4-5 Field Definition of a RPLIDAR Measurement Result Data Response Packet

The geometric definition of the included angle and distance value is shown as below:

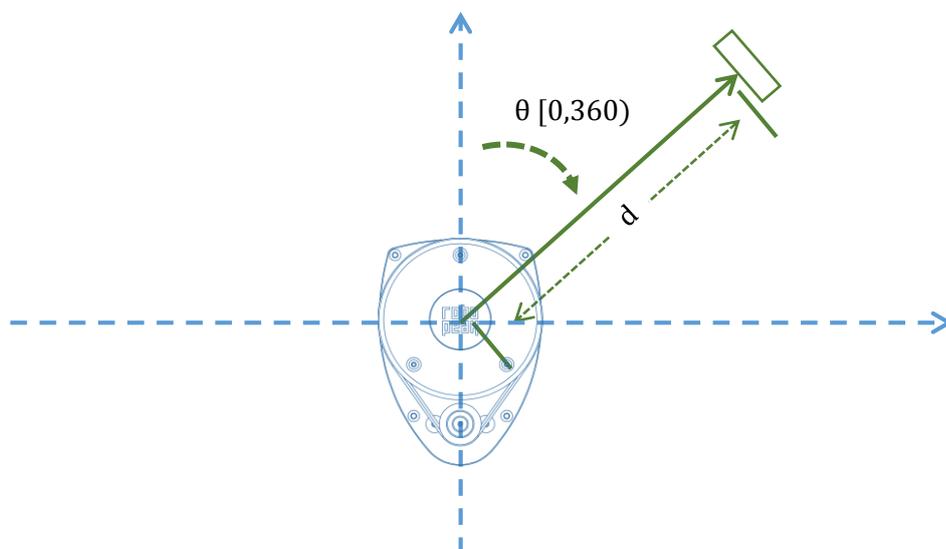


Figure 4-6 Angle and Distance Value Geometric Definition for RPLIDAR A1 series

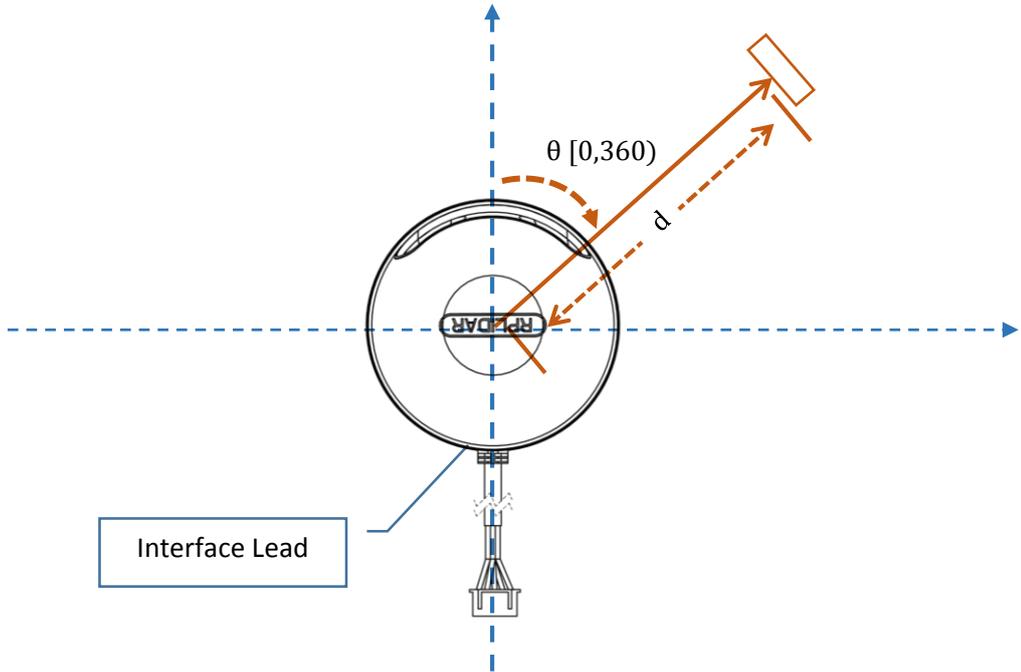


Figure 4-7 Angle and Distance Value Geometric Definition for RPLIDAR A2 series

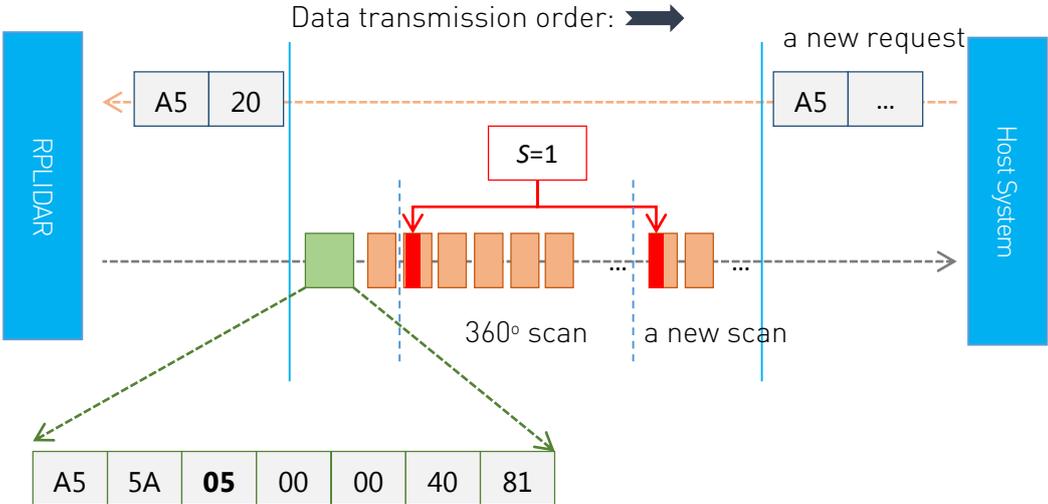


Figure 4-8 The Communication Status after Host System Sending a SCAN Request

Express Scan(EXPRESS_SCAN) Request and Response

Request Packet:

A5	82	05	00	00	00	00	00	22
----	----	----	----	----	----	----	----	----

Response Descriptor:

A5	5A	54	00	00	40	82
----	----	----	----	----	----	----

Response Mode:

MultipleData Response Length: **84 bytes**

RPLIDAR will enter the measurement sampling mode once it receives the express scan(EXPRESS_SCAN) request. Different from the scan(SCAN) request, this request will make RPLIDAR work at the sampling rate as high as it can be. For RPLIDAR A2 and the device models support 4khz sampling rate, the host system is required to send this request to let the RPLIDAR work at 4khz sampling rate and output measurement sample data accordingly; for the device models with the 2khz sample rate (such as RPLIDAR A1 series), this request will implement the same sampling rate as the scan(SCAN) request.

The host system can send the get sample rate(GET_SAMPLERATE) request to get the information about the single measurement sampling time in SCAN mode and EXPRESS_SCAN mode.

RPLIDAR uses the same state machine and processing logic for this request as the one of the scan(SCAN) request, but uses the different response format.

Format of the request packets:

The express scan(EXPRESS_SCAN) request is required to carry the 5 bytes payload data and the data structure is shown as following. This payload data cannot be omitted.

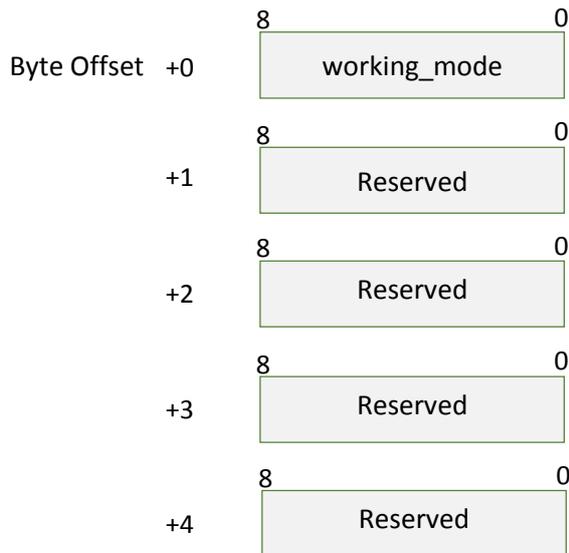


Figure 4-9 Format of a RPLIDAR Express Scan Data Request Packet

The descriptions of every field within the above data are listed in the following table:

Field Name	Description	Examples/Notes
working_mode	The other parameters in the scan mode of RPLIDAR, set to 0.	The field only supports for standard scan mode currently, set to 0.
Reserved	Reserved field, set to 0.	Reserved for future use, set to 0.

Figure 4-10 Field Definition of RPLIDAR Express Scan Data Request Packet

Format of the data response packets :

RPLIDAR uses the following data response packet structure for responding the EXPRESS_SCAN request.

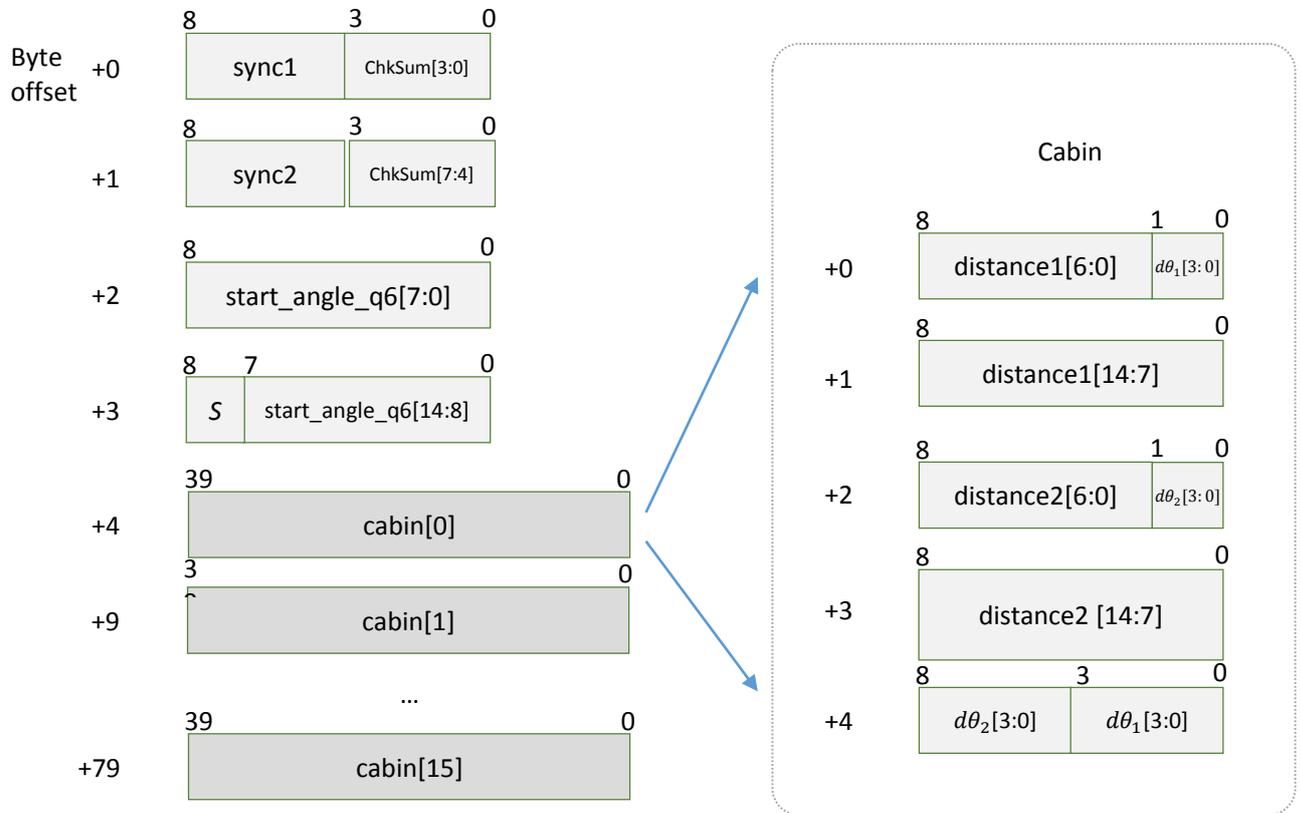


Figure 4-11 Format of a RPLIDAR Express Scan Data Response Packet

When working in express scan mode , RPLIDAR will send the above data packet cyclically to output the measurement data to host system. The packet contains 16 group of substructures called Cabin in the same format. Each Cabin is a 5-byte data body with specific structure corresponding with the angle and distance value of two measurement sampling data sets. Therefore, an express scan data response packet carries 32 measurement sampling data points.

The descriptions of every field within the above packet are listed in the following table:

Field Name	Description	Examples/Notes
sync1	Data packet start sync flag1. Always be 0xA	It is used by host system for identifying the start of a new response packet.
sync2	Data packet start sync flag2. Always be 0x5	It is used by host system for identifying the start of a new response packet.
start_angle_q6	The reference value for the angle data in the current response packet. Stored with fix point number in q6 format and the unit is degree. Range [0-360)	Please refer to the following sections for information about the calculated method of the angle value. It adopts the same coordinate system definition with standard SCAN request. Actual angle =start_angle_q6/64.0 Deg
S	Start flag bit of a new scan	When S is set to 1, the current and incoming packets belong to a new 360° scan.
ChkSum	Obtained by calculating the response data packet using XOR operation to each packet data byte and accumulating them together.	It is used for checking the validity of s response data packet.
cabin	a 5-byte data body with the angle and distance value of two measurement sampling data sets. A data response packet contains 16 group of cabin data.	Please refer to the following table for detailed definition.

Figure 4-12 Field Definition of RPLIDAR Express Scan Data Response Packet

The following table describes the field definition of the Cabin data.

Field Definition	Description	Examples/Notes
distance1 distance2	The distance data for the first and second measurement sampling. The unit is millimeter(mm) When the value is 0, the matched sampling point is invalid.	The first sampling time is before the second.
$d\theta_1$ $d\theta_2$	The angular compensation value for the first and second measurement sampling. It uses fix point number in q3 format and the unit is degree. The top digit is sign bit.	Please refer to the following sections for how to calculate the included angle value of every measurement sampling point.

Figure 4-13 Field Definition of RPLIDAR Express Scan Cabin Data Response Packet

The following figure describes the communication status after the host system sending out the express scan request.

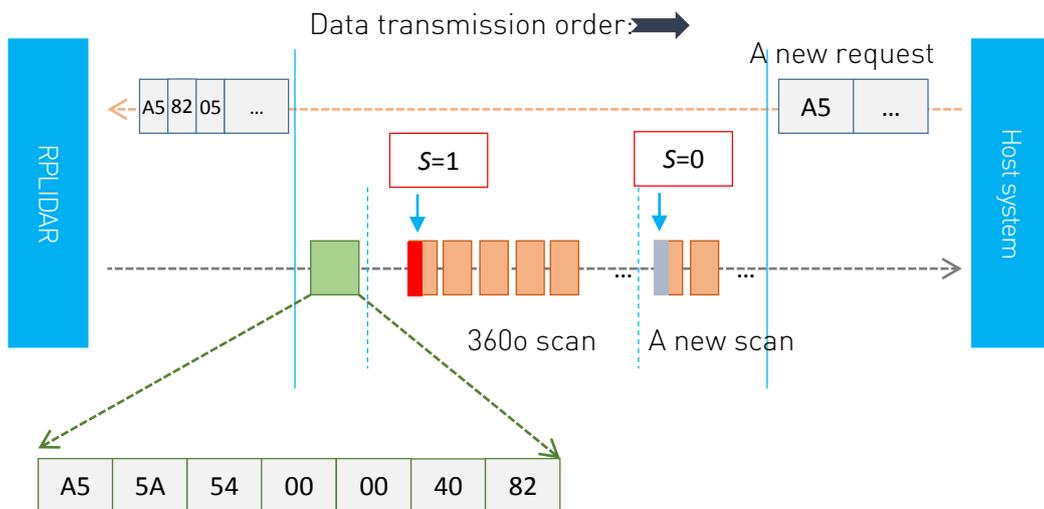


Figure 4-14 The Communication Status Sending Out the Express Scan Request

Data Processing of the Express Scan Data

By compressing the redundant data, the data response packet used in express scan mode makes it possible to send the 4kHz sampling data via the original 115200bps bandwidth communication link. For this reason, the host system needs extra data recovery logic to get valid measurement data.

When working in express scan mode, the measurement sampling data is stored in the cabin structural body with two sets as unit. It includes the distance value(distance1/distance2) and the angular compensation ($d\theta_1$ 、 $d\theta_2$). The distance value is matched with the actual distance measured in this sampling, but the angular compensation value is not the actual angle data between the measured object and RPLIDAR required by the host system. The final angle data can be calculated out with the start_angle_q6 in this request. The detailed calculation method is shown as following:

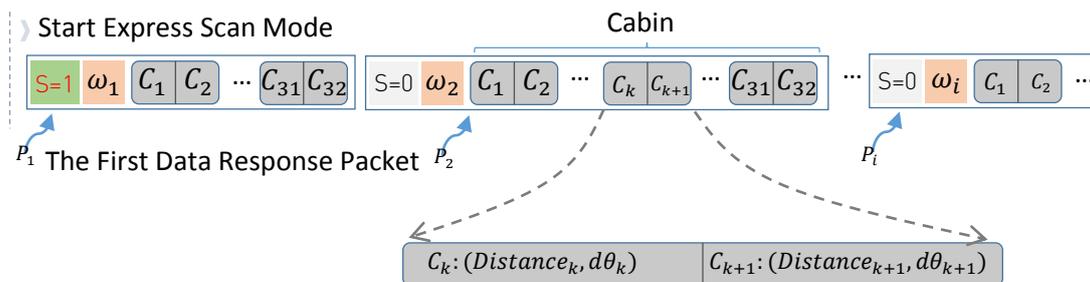


Figure 4-15 The Abstract Description for the Response Data Packet of Express Scan Request

The above figure indicates the data response packet format of RPLIDAR in the express scan mode. For convenience, after RPLIDAR receives the express scan request and enter express scan mode, the first sent data response packet is denoted as P_1 , the second P_2 and the i^{th} P_i . Accordingly, ω_i indicates the actual angular physical quantity corresponded with the start_angle_q6 field of P_i

Since in express scan mode, the corresponding data of measurement sampling is stored respectively and sequentially in the Cabin of each data response packet. In every P_i response data, the data of the k^{th} measurement sampling point is denoted as C_k . It carries the distance value $Distance_k$ and the included angle compensation $d\theta_k$ corresponded with the current measurement sampling point.

The actual included angle θ_k of any measurement sampling point C_k can be calculated out via the following formula:

$$\theta_k = \omega_i + \frac{AngleDiff(\omega_i, \omega_{i+1})}{32} \cdot k - d\theta_k$$

The function $AngleDiff(\omega_i, \omega_{i+1})$ in the above formula is defined as below:

$$AngleDiff(\omega_i, \omega_{i+1}) = \begin{cases} \omega_{i+1} - \omega_i, & \omega_i \leq \omega_{i+1} \\ 360 + \omega_{i+1} - \omega_i, & \omega_i > \omega_{i+1} \end{cases}$$

Response descriptor flag S:

After entering express scan mode, the first sent data response packet always has the S flag set to 1. In the following measuring process, if the angle value cannot be calculated via the above formula due to rotating speed instability or something wrong, RPLIDAR will reset the flag S. Then the host system is supposed to restart the data analysis based on the current response data packet set as flag S.

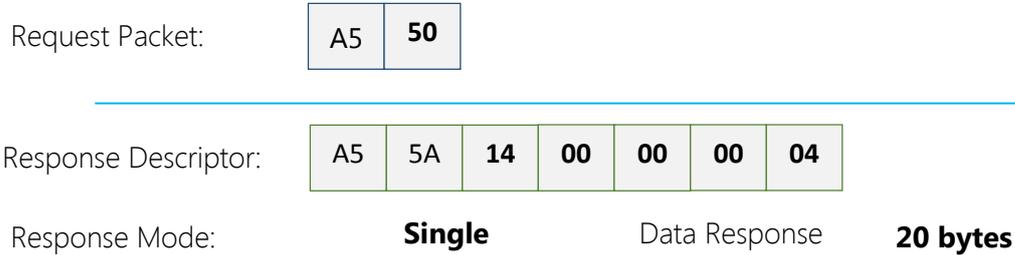
Force Scan(FORCE_SCAN) Request and Response

Request Packet:	<table border="1"><tr><td>A5</td><td>21</td></tr></table>	A5	21					
A5	21							
Response Descriptor:	<table border="1"><tr><td>A5</td><td>5A</td><td>05</td><td>00</td><td>00</td><td>40</td><td>81</td></tr></table>	A5	5A	05	00	00	40	81
A5	5A	05	00	00	40	81		
Response Mode:	Multiple Data Response Length: 5 bytes							

A force scan (FORCE_SCAN) request forces RPLIDAR to start measurement sampling and send out the results immediately once it receives this request. This request is useful for device debugging.

RPLIDAR uses the similar processing logic for this request and the same response format as the one of the scan(SCAN) request, but uses the different response format.

Get Device Info (GET_INFO) Request and Response



RPLIDAR will send out its device information (e.g. serial number, firmware/hardware version) to the host system once it receives this request.

Format of the Device Info Response Packets:

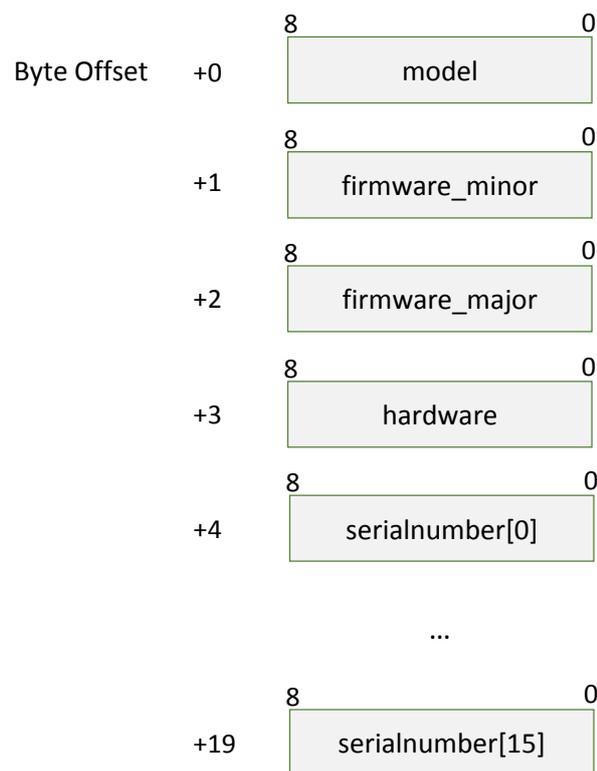


Figure 4-16 Format of a Device Info Data Response Packet

Field Name	Description	Examples / Notes
model	RPLIDAR model ID	The model ID of the RPLIDAR being used
firmware_minor	Firmware version number, the minor value part	The decimal part of the version number
firmware_major	Firmware version number, the major value part	The integer part of the version number
hardware	Hardware version number	
serialnumber[16]	128bit unique serial number	When converting to text in hex, the Least Significant Byte prints first

Figure 4-17 Field Definition of Device Info Data Response Packet

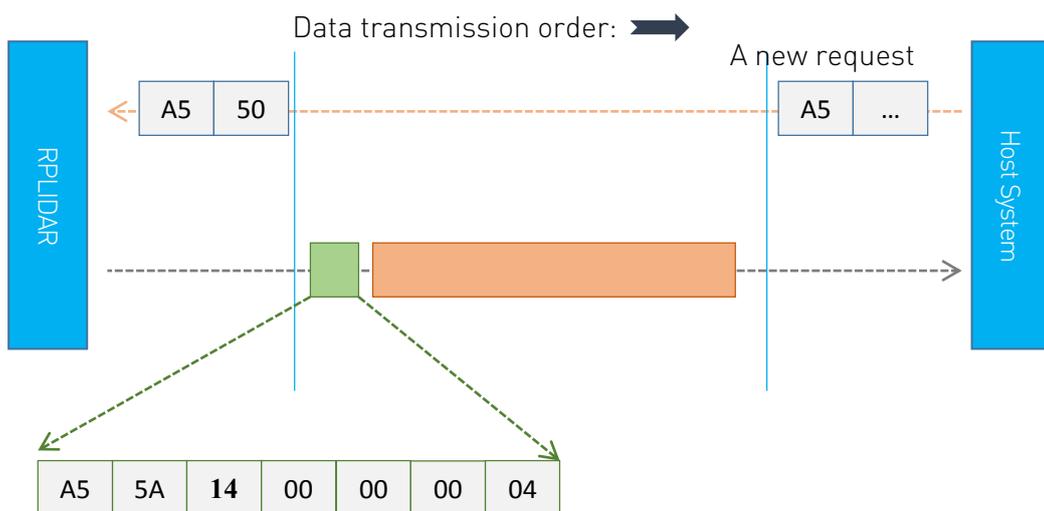


Figure 4-18 The Timing Sequence of a GET_INFO Request

Get Device Health Status (GET_HEALTH) Request and Response

Request Packet:

A5	52
----	----

Response Descriptor:

A5	5A	3	00	00	00	06
----	----	---	----	----	----	----

Response Mode:

Single

Data Response Length:

3 bytes

A host system can send the GET_HEALTH request to query RPLIDAR's health state. If the RPLIDAR has entered the Protection Stop state caused by hardware failure, the related error code of the failure will be sent out.

Format of the Data Response Packets

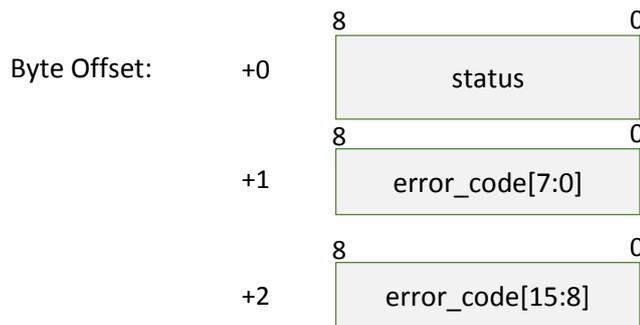


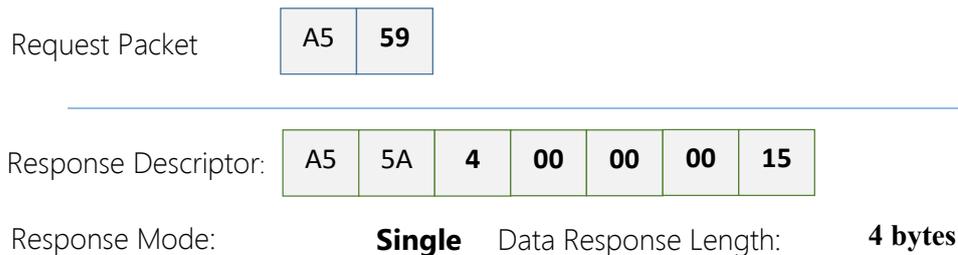
Figure 4-19 Format of a Device Health Data Response Packet

Field Name	Description	Examples / Notes
status	RPLIDAR Health State	Value definition : 0: Good 1: Warning 2: Error When the core system detects some potential risk that may cause hardware failure in the future, the status value will be set to Warning(1). But RPLIDAR can still work as normal. When RPLIDAR is in the Protection Stop state, the status value is set to Error(2).
error_code	The related error code that caused a warning/error.	

Figure 4-20 Field Definition of Device Health Status Data Response Packet

When a host system detects RPLIDAR has entered the Protection Stop state, it can set a RESET request to let RPLIDAR core system reboot to escape the Protection Stop state. However, if RPLIDAR enters the Protection Stop state for several times, this may be a sign of some unrecoverable damage has occurred in RPLIDAR.

Get sample rate(GET_SAMPLERATE) Request



By sending this request, the host system can get the single measurement duration in standard scan mode and express scan mode respectively and calculate the current rotating speed of RPLIDAR accurately.

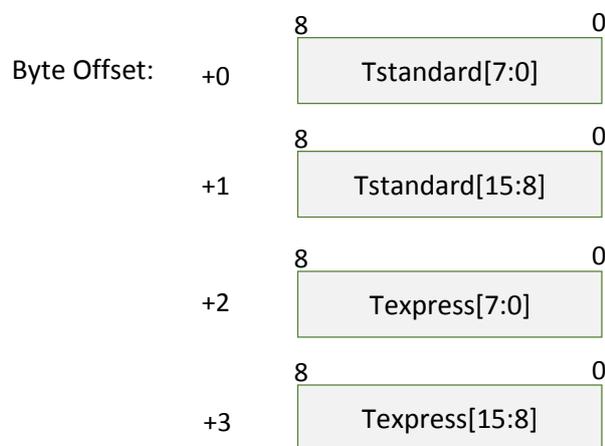


Figure 4-21 Format of a Sample Rate Data Response Packet

The following table describes the field definition of the above packet.

Field Name	Description	Examples/Notes
Tstandard	In scan(SCAN) mode, the time used when RPLIDAR takes a single laser ranging Unit: microsecond(uS)	It can be used for debugging the rotating speed when the RPLIDAR uses the SCAN request.
Texpress	In express scan(EXPRESS_SCAN) mode, the time used when RPLIDAR takes a single laser ranging Unit: microsecond(uS)	It can be used for debugging the rotating speed when the RPLIDAR uses the EXPRESS_SCAN request.

Figure 4-22 Field Definition of Sample Rate Data Response Packet

Retrieving scanning data from an RPLIDAR

It is recommended that a host system always follows the below sequence to enable RPLIDAR's scanning operation and retrieve the scanning data. Before sending a SCAN request, the host system should send a GET_HEALTH request in advance to query the RPLIDAR's health status. In case RPLIDAR is in the Protection Stop state, the host system can send a RESET request to try to escape the Protection Stop state. Please refer to the SDK code for implementation details.

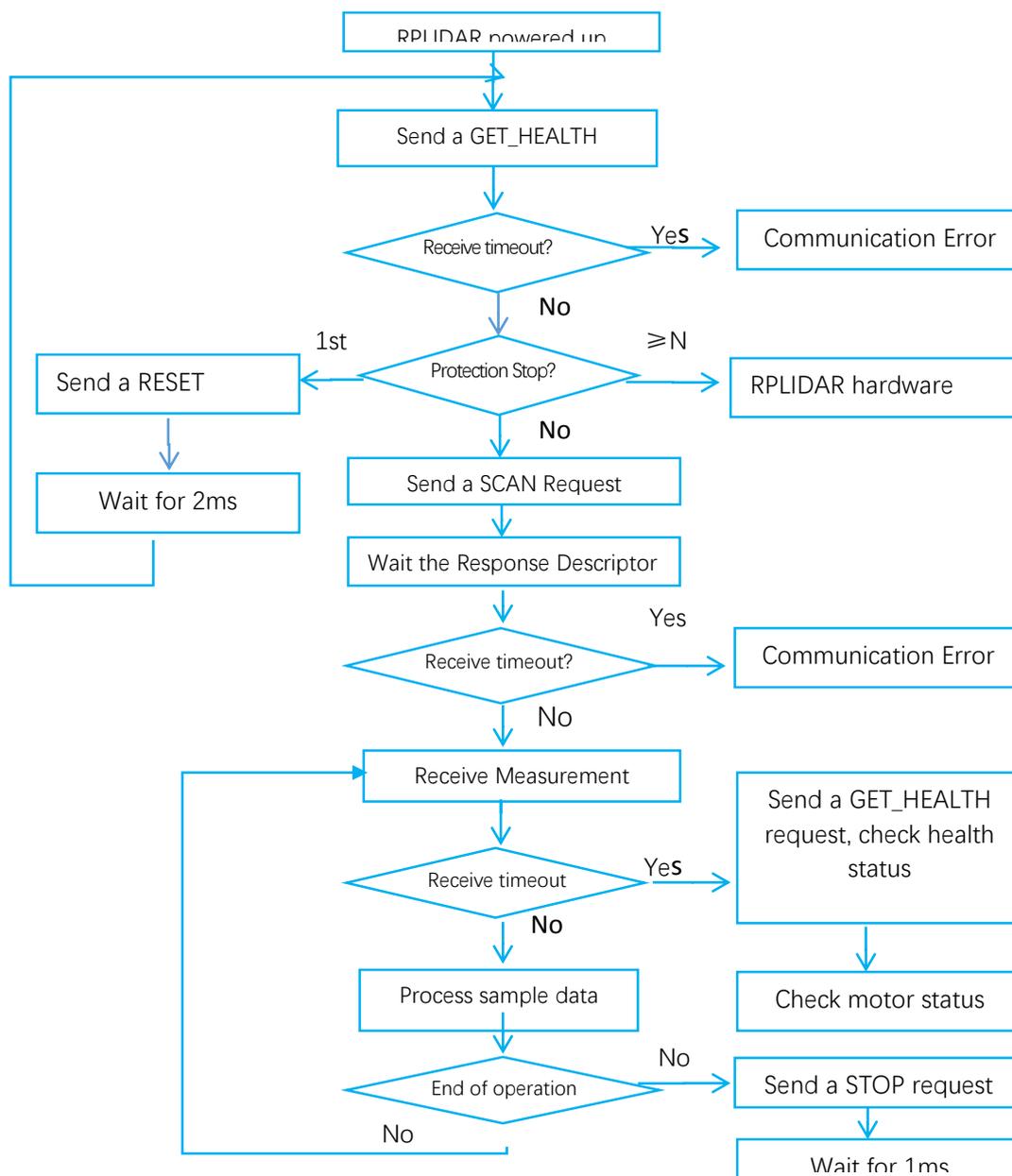


Figure 5-1 Recommendation for Starting RPLIDAR Scanning and Data Retrieving

Calculate RPLIDAR Scanning Speed

In most cases, there is no need for a host system to care about the actual RPLIDAR scanning speed. RPLIDAR ensures the precision of the measurement results using its build-in self-adaptive motor rotation speed detector.

If an RPLIDAR is required to have a fixed scanning speed, the host system can control the motor speed using a PWM driver and based on the speed feedback provided by the algorithm described in this section.

RPLIDAR A1Mx Series

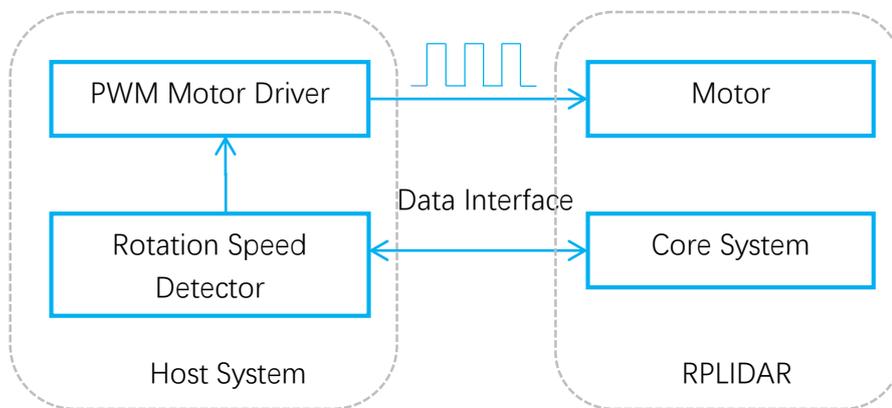


Figure 5-2 Block Diagram of RPLIDAR A1 Speed Detection and Control System

RPLIDAR A2 Mx Series

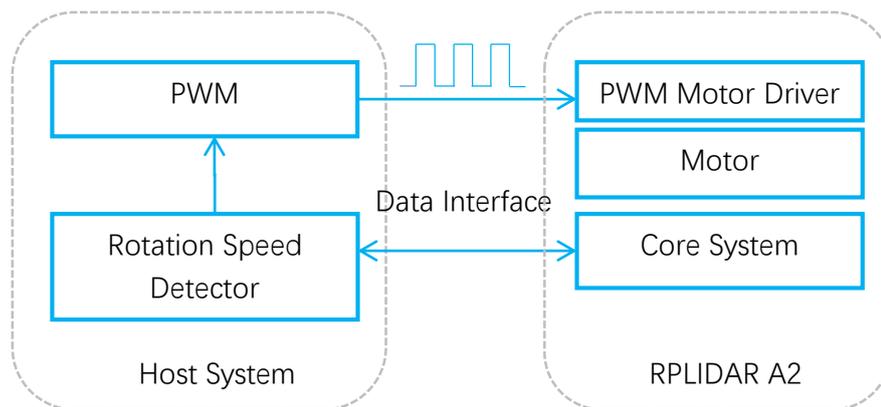


Figure 5-3 Block Diagram of RPLIDAR A2 Speed Detection and Control System

The host system can keep recording the interval time between two adjacent measurement sample data response with the start flag bit S set to 1 (S=1), called

ΔT . The interval time represents how long the RPLIDAR has spent to perform a 360° scan. So the actual scan speed can be calculated using the following equation:

$$\text{RPM} = \frac{1}{\Delta T} * 60$$

The calculated value can be used as a feedback to control the motor speed.

6. Revision History

Date	Description
2013-3-5	Initial vesion
2014-1-25	Modified related descriptions
2014-3-8	Added descriptions about the time requirement of sending request packet.
2015-8-21	Modified the incoherence in the context of GET_HEALTH
2016-4-10	Added descriptions for the RPLIDAR A2 newly added protocol
2016-5-4	Fix a description bug

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