DFR1179 ZL9NSQ

Wireless attitude sensor chip

Datasheet (V1.06)

Index

Image

Table

revision history

Version number	illustrate	date
v1.04	first edition	2024-01-17
v1.05	Update the reflow soldering process parameters	2024-06-07
V1.06	IIC, SPI data blocks 4-byte alignment	2024-06-14

1 Function Description:

ZL9NSQ is a 3D attitude sensing system-in-package that integrates a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer. The chip integrates a 32-bit ARM® Cortex-M4f™+ microprocessor to run the IMU Motion Engine algorithm developed by Zerolab Technology (Shanghai) Co., Ltd., 2.4G wireless transceivers and antenna in package. Zerolab Technology (Shanghai) Co., Ltd. uses advanced signal processing algorithms to process high-speed sampled internal sensor data to provide accurate and reliable 3D attitude information such as quaternion, Euler angle, calibrated acceleration and calibrated angular velocity.

The core of ZL9NSQ is the IMU Motion Engine software developed by Zerolab Technology. IMU Motion Engine software is a complete set of composite data fusion algorithms, including attitude calculation, interference judgment, online calibration and other algorithms and data communication. The data communication software is based on the ZLBUS unified communication protocol of Zerolab Technology to implement power management, parameter configuration, data communication and other functions, users can not only communicate with the system host through the standard debugging software provided by Zerolab Technology to obtain the required 3D attitude information, but also use Python/C++ through the SDK provided by Zerolab Technology to do data exchange and mode config with ZL9NSQ, which significant reduce the work effort of developing 3D attitude applications.

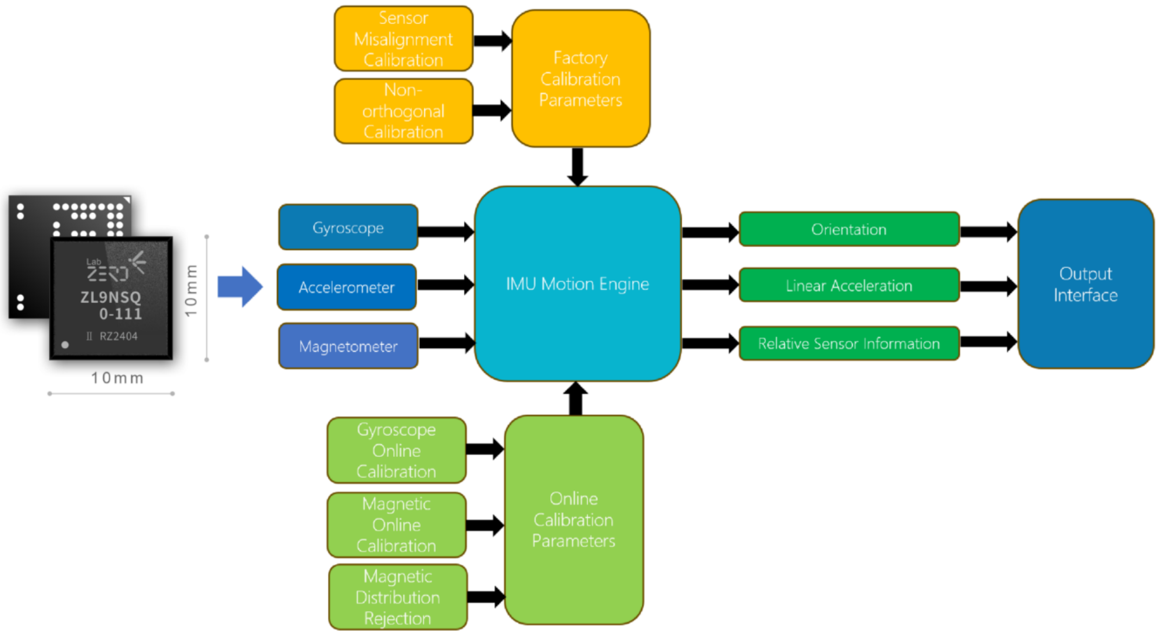
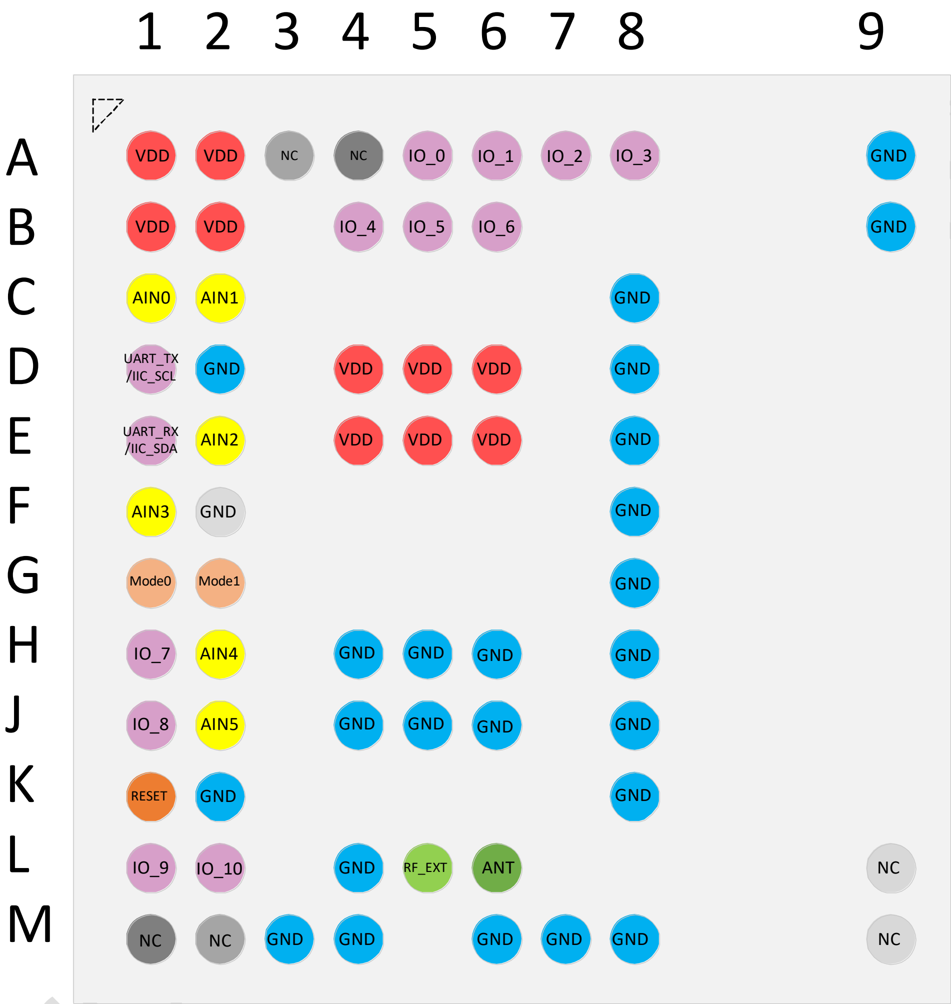


fig1 Functional block diagram of the ZL9NSQ

2. Hardware features:

2.1 ZL9NSQ pins



Top View

fig2 ZL9NSQ pin diagram

2.1.1 Pin Description

Pin IO	name	I/O	description
A1 A2 B1 B2 D4 D5 D6 E4 E5 E6	VDD	Power	Power supply
A9 B9 C8 D2 D8 E8 F8 G8 H4 H5H6 H8 J4 J5 J6 J8 K2 K8 L4 M3 M4 M6 M7 M8	GND	Power	Power Ground
F2	NC	/	There is no internal connection, and GND can be connected externally
A5	IO_0	IO	SPI_MOSI (master)
A6	IO_1	IO	SPI_CS (master)
A7	IO_2	IO	SPI_CLK (master)
A8	IO_3	IO	SPI_MISO (master)
B4	IO_4	IO	RGB_B
B5	IO_5	IO	RGB_G
B6	IO_6	IO	RGB_R
H1	IO_7	IO	Btn_Input
J1	IO_8	IO	Power_En
L1	IO_9	IO	PA_RxEn
L2	IO_10	IO	PA_TxEn
D1	UART_TX / I2C_SCL	IO	I2C Slave
E1	UART_RX / I2C_SDA	IO	I2C Slave
C1	AIN_0	I	Analog input (ADC) (default battery detection IO).
C2	AIN_1	I	Analog Inputs (ADCs)
E2	AIN_2	I	Analog Inputs (ADCs)
F1	AIN_3	I	Analog Inputs (ADCs)
H2	AIN_4	I	Analog Inputs (ADCs)
J2	AIN_5	I	Analog Inputs (ADCs)
G1	Mode_0	I	Hardware mode configuration
G2	Mode_1	I	Hardware mode configuration
K1	RESET	I	Chip Reset
L5	RF_EXT	O	RF antenna PIN output
L6	ANT	I	The internal RF antenna end of the IC
A3 A4 M1 M2 L9 M9	NC	/	The outside must be suspended, and shorting between NCs is prohibited

Table 1 Pin description

2.2 Performance Specifications

parameter	Typical
Pitch/roll accuracy (static)	0.05°
Pitch/roll accuracy (dynamic)	0.1°
Heading accuracy error (magnetometer-assisted)	0.5°
Relative Heading Error (Static)	<1°/hr
Relative Heading Error (Dynamic)	5°/hr
Angular resolution	<0.01°
Angular repeatability	<0.1°
The rate at which the sensor raw data is output	Up to 250 Hz
Navigation data output rate	Up to 250 Hz

Table2 Performance Specifications:

2.3 Sensor Specifications

parameter	accelerometer	gyroscope	magnetometer
Range	±16 g	±2000 °/s	±4900uT
Bias stability	2 mg	5°/hr	20nT
Initial bias	40 mg	0.2°/s	
Scale factor error	±0.06%	±0.05%	±0.09%
nonlinear	±0.1%	±0.1%	±0.3%
Axis alignment error	±0.05°	±0.05°	±0.05°
Noise density	75ug/ √ Hz	0.0028 °/s/√H	0.14 nT/√Hz
bandwidth	260 Hz	256 Hz	200 Hz

Table3 Sensor specifications

2.4 Data interface

The data communication of ZL9NSQ chip follows the ZLBUS communication protocol, and users can implement data communication between ZL9NSQ chip and other devices through Bluetooth BLE, UART, SPI, I^2C interfaces. For details, see Chapter 4 “Data Communication Protocols”.

2.4.1 Wireless data interface

The ZL9NSQ chip is designed with advanced AiP (Antenna In Package) technology with a well matched antenna inside. In the PCB design, the user should carry out the clearance treatment according to the PCB reference design to avoid interference to the internal antenna of the ZL9NSQ chip and impact data transmission performance, and user can add an external antenna if design require long range wireless communication.

The ZL9NSQ factory firmware has implemented the standard Bluetooth BLE5.2 communication protocol software stack, as well as the corresponding Zerolab Universal Service Bluetooth communication service software stack. Users can directly exchange data with ZL9NSQ through computers, mobile phones and other terminal devices which support Bluetooth BLE5.2 without additional development. The ZUS service consists of three data feature attributes, which are used to configure and read ZL9NSQ parameters, read the attitude data stream, chip temperature and status , customer also possible to extend their own custom service.

There is no official connection limitation for the Zerolab Universal Service Bluetooth communication service provided by ZL9NSQ, the maximum number of devices that can be connected at the same time is limited by central BLE devices hardware and operating system. Customer can connect up to 6 ZL9NSQ-based devices for Android, MacOS and Windows platform, and up to 10 ZL9NSQ-based devices for iOS, Linux PC or Raspberry Pi platform. In practice the actual number of devices that can be connected may be less than the theoretical number, or reach the theoretical value with a large amount of packet loss and unstable connection. At this point, users should consider reducing the number of connected devices to improve communication quality or reduce the data sync frequency.

In order to meet the communication needs of large connections and low latency, Zerolab Technology also developed a proprietary wireless communication protocol based on 2.4G transceiver for ZL9NSQ, which realizes functions such as ultra-low latency, multi-devices time synchronization, and high-speed connection of up to 20 devices. This proprietary wireless communication protocol is required to be used with a dedicated wireless data dongle designed by Zerolab Technology. To use this proprietary wireless communication protocol, please consult Zerolab Technology for more information.

ZUS（Zerolab Universal Service）:

- ZUS Service UUID: AEC90000-6E7A-4BC2-9A4C-4CDA7A728F58
- Data eigenvalue: AEC91000-6E7A-4BC2-9A4C-4CDA7A728F58
  - It contains data attribute 1, data attribute 2, and data attribute 3
  - Data attribute 1: AEC91001-6E7A-4BC2-9A4C-4CDA7A728F58
    - Configure ZL9NSQ and read ZL9NSQ configuration parameters
    - Permissions: Write, Notify
  - Data attribute 2: AEC91002-6E7A-4BC2-9A4C-4CDA7A728F58
    - Obtain the attitude data of the ZL9NSQ chip
    - Permissions: Notify
  - Data attribute 3: AEC91003-6E7A-4BC2-9A4C-4CDA7A728F58

- ZL9NSQ custom services, system status, etc
- Permissions: Notify

2.4.2 UART data interface

UART, or Universal Asynchronous Receiver/Transmitter, is a commonly used asynchronous serial communication method with transmission rates of up to 1Mbps. ZL9NSQ provides UART_TX and UART_RX two pins for use, UART pin and I2C pin are functional multiplexing, the default parameter is 115200bps, 8 data bits, 1 stop bit, no parity bits.

When the ZL9NSQ chip uses UART data communication, it follows the ZLBUS communication protocol, and the default baud rate of UART is 115200 bps, and the data format is binary. For the specific configuration of the serial port debugging tool, please refer to Figure 3, by default UART port will display ZL9NSQ chip MAC address and Bluetooth name during power on stage.

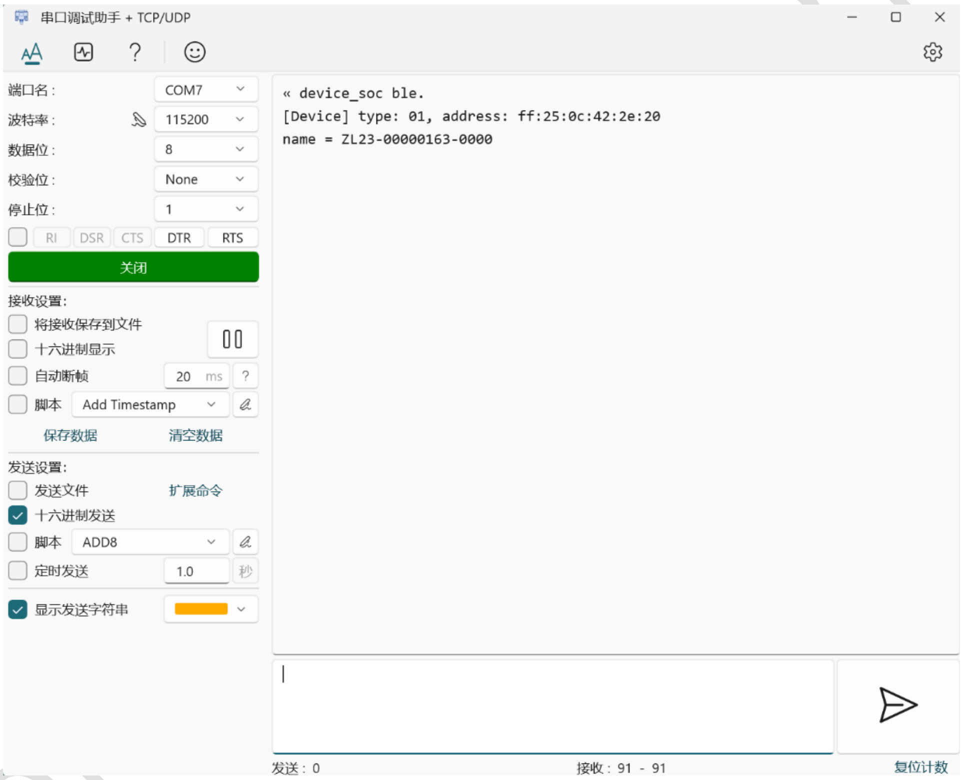


fig3 ZL9NSQ UART configuration

2.4.3 SPI Data Interface

SPI (serial peripheral interface) is an abbreviation for serial peripheral interface, which is a high-speed, full-duplex, synchronous serial communication bus. The ZL9NSQ chip supports master SPI mode, and the data adopts a fixed packet length of 252 bytes, in which the first byte represents the valid data length in the subsequent 251 bytes, in which the invalid data is filled with 0.

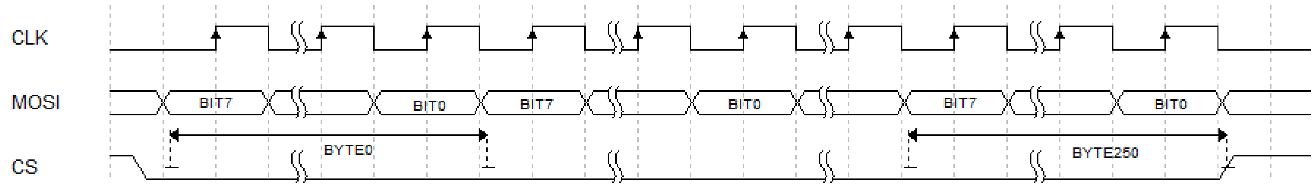


fig4 ZL9NSQ SPI timing diagram

ZL9NSQ chip adopts SPI data communication and follows ZLBUS communication protocol.

2.4.4 I2C data interface

The I2C (Inter-Integrated Circuit) bus is a two-wire serial bus used to connect microcontrollers and their peripherals. It is a serial bus consisting of a data line SDA and a clock line SCL that transmits and receives data. Supports up to 400kH baud rate on I2C bus. The ZL9NSQ chip is used as a slave.

- I2C Slave Address 0x4E (Bit 6 – Bit0)
- I2C is only used for ZL9NSQ configuration, and I2C does not support data stream output
- I2C data interaction uses a fixed packet length of 204 bytes, in which the first byte represents the valid data length in the subsequent 203 bytes, and the invalid data part is filled with 0

2.4.5 Data Interface configuration

Mode0 and Mode1 are the pins configured for the interface (the chip is pulled down to a low level and latched once when the chip is powered on), and the interface mode is defined in the following table. If you need to use other data output interfaces, you can use the ZLBUS protocol to configure them dynamically. The user pulls up and down the level of Mode0 and Mode1 to change the command configuration interface and data output interface.

Mode1	Mode0	Command configuration interface	Data output interface
X	X	UART	RF
Low（default）	Low（default）	UART	RF
Low	High	I2C	RF
High	Low	UART	SPI
High	High	I2C	SPI

Table4 Interface configuration

Note: The UART, SPI, RF interfaces are compatible with both command configuration and data output, and I2C can only be used for command configuration and cannot obtain real-time data streams.

2.5 Installation and alignment

The chip data and attitude data output by the ZL9NSQ are based on the chip coordinate system in Figure 2, and the user should align the chip with the carrier coordinate system as much as possible when using the ZL9NSQ. Proper installation and alignment is essential to achieve good performance, the ZL9NSQ provides eight different coordinate system alignment methods, if it cannot be aligned strictly according to the eight ways provided, the user should manually adjust the coordinate system according to the actual installation method to ensure the accuracy of the output attitude.

2.5.1 Chip coordinate system

The data output of the ZL9NSQ chip is the body coordinate system, and the user needs to adjust the alignment between the shell and the chip according to the chip welding direction.

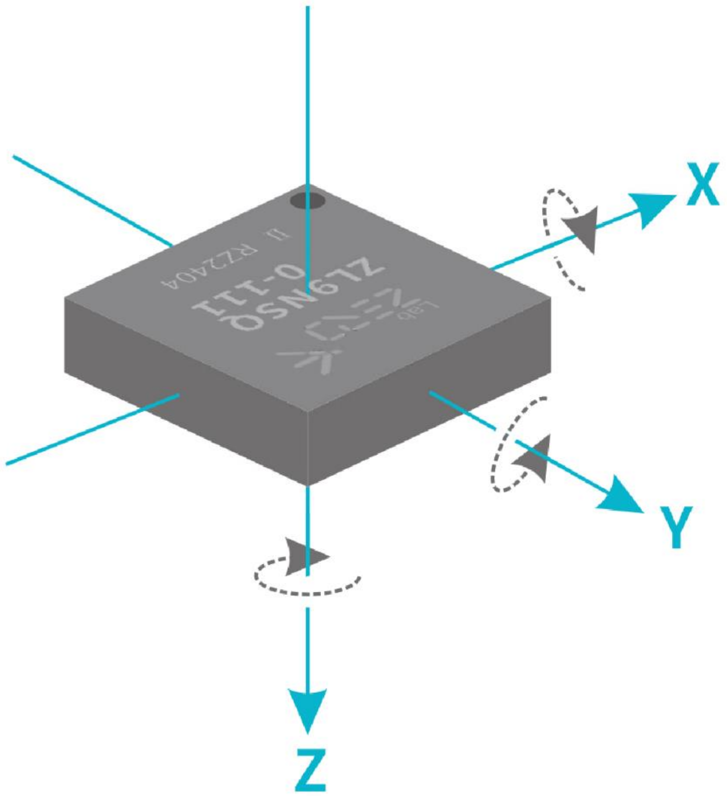


fig5 ZL9NSQ Coordinate System Orientation (Right Hand)

2.5.2 Attitude coordinate system (NED coordinate system).

The NED (North-East) coordinate system, also known as the navigation coordinate system, is often used to describe the position, velocity, and attitude of an object. The origin of the coordinate system can be considered as the current position; From the point of origin, the north axis points to geographic north and is parallel to the line of latitude there; The east axis points perpendicular to the north axis, parallel to the meridian that crosses the point; The Earth's axis points directly down to the center of the Earth. The attitude data output of the ZL9NSQ is based on the standard NED coordinate system, and the output format is quaternion or Euler angle.

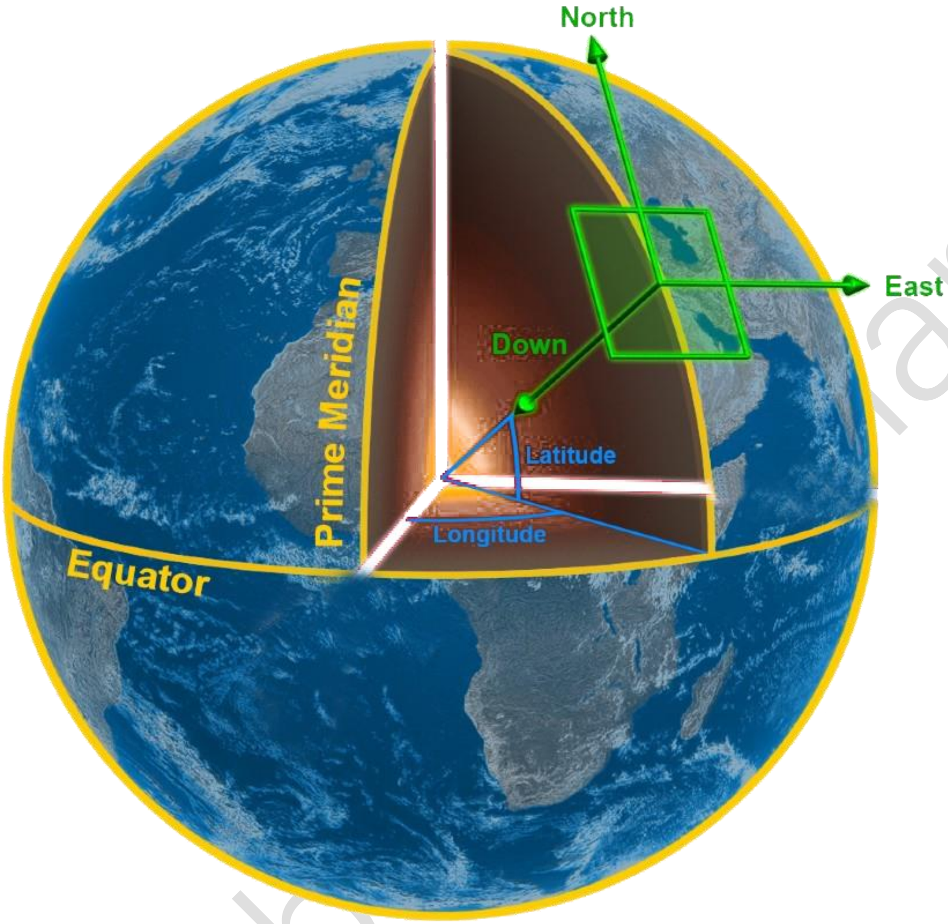


fig6 North-East coordinate system

2.5.3 Installation coordinate system adjustment

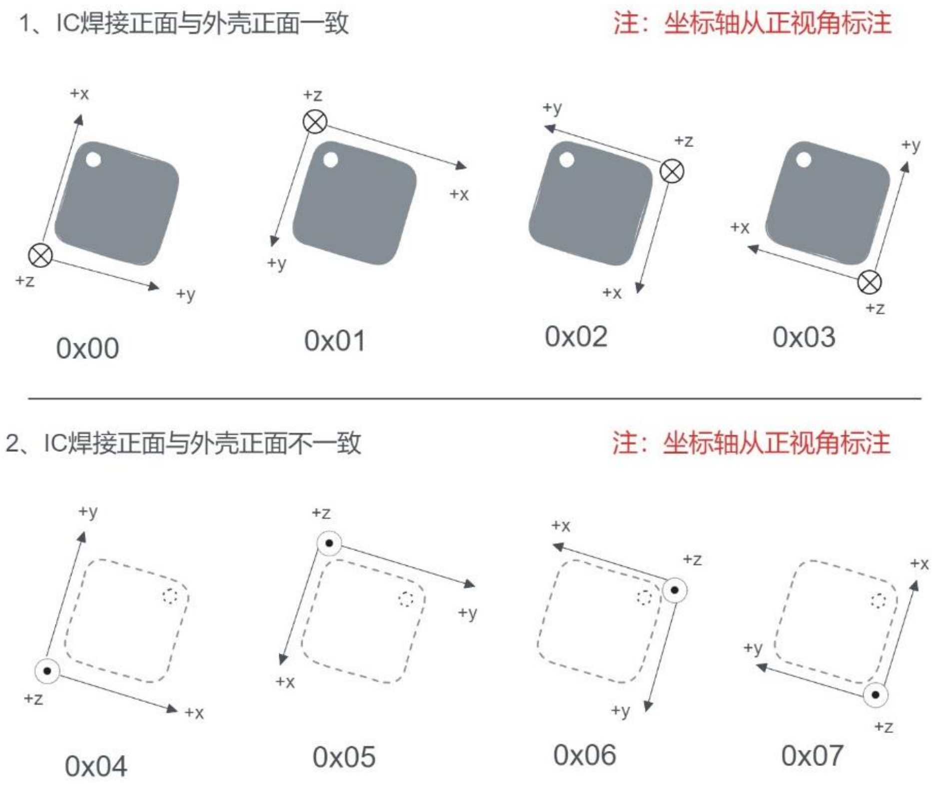


fig7 ZL9NSQ installation coordinates definition

3. Sensor data:

The internal microprocessor of ZL9NSQ collects the raw data of three-axis accelerometer, three-axis gyroscope and three-axis magnetometer at high speed rate, and the online calibration program will automatically calibrate the original data and output the calibrated sensor data. Meanwhile the attitude engine also calculate the calibrated three-axis accelerometer, three-axis gyroscope and three-axis magnetometer data according to the user's configuration to ensure the accuracy of the three-dimensional attitude, all the fusion algorithm run with internal sample rate 250hz and the user-configured attitude data output rate will not affect the accuracy of the three-dimensional attitude.

3.1 Sensor data output

The ZL9NSQ outputs 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer data calibrated by an internal online calibration program, which is based on the ZL9NSQ chip coordinate system. If it is used to adjust the coordinate system according to 2.3.3, the output is the adjusted coordinate system data.

3.1.1 Accelerometer data output

A triaxial accelerometer is used to measure the acceleration of an object (the accelerometer measures the Earth's gravity as an acceleration), and the output of the accelerometer cannot be used to directly describe the acceleration state change of an object due to the presence of the Earth's gravity. The ZL9NSQ separates gravity from the accelerometer data through an attitude fusion algorithm to obtain linear acceleration based on the chip coordinate system, which provides the following acceleration output for the ZL9NSQ:

- Calibrated acceleration data (g)
- Linear acceleration data (g).

Please note that the above data must be enabled via a separate settings request.

3.1.2 Gyroscope angular velocity data output

The three-axis gyroscope is used to measure the rotational angular velocity of the object, and the ZL9NSQ will report the rotation of the X, Y, and Z axes with the device coordinate system, which is the right-hand coordinate system. The ZL9NSQ's internal online calibration program calibrates the gyrometer in real time to ensure the accuracy of the output data, thus providing the following angular velocity output for the ZL9NSQ:

- Calibrated angular velocity data (deg/s).

Please note that the above data must be enabled via a separate settings request.

3.1.3 Magnetic strength data output of magnetometer

Magnetometers measure the ambient magnetic field and are used to determine absolute orientation for fusion filtering with other sensors. Absolute azimuth can be understood as determining the direction of the Earth's magnetic north pole and evaluating the orientation of the sensor relative to the Earth's magnetic north pole.

The complexity of measuring magnetic fields lies in the fact that the ambient magnetic field can be distorted by proximity to ferrous or magnetic materials and electronic devices, which is known as magnetic field distortion, which is particularly severe compared to the magnetic field distortion in the indoor environment of the outdoor environment. Distortion that is usually caused by nearby ferrous or magnetic materials is known as the hard iron effect, while distortion caused by electronic devices is known as the soft iron effect. In order to eliminate the influence of magnetic field distortion on the sensor, the magnetometer needs to be calibrated, ZL9NSQ provides magnetic field calibration instructions, in order to ensure the normal operation of the chip, the magnetometer should be well calibrated before using the magnetometer data, see Chapter 5 "Chip Calibration" for details. The ZL9NSQ offers the following magnetometer outputs:

- Calibrated magnetometer data (uT).
- Uncalibrated magnetometer data (uT).

Please note that the above data must be enabled via a separate settings request.

3.2 Attitude data output

The three-dimensional attitude data is the three-dimensional attitude of the chip calculated by the ZL9NSQ attitude solver program based on the data of the calibrated accelerometer, gyroscope and magnetometer. The methods used to estimate the pose have a long history, and there are many kinds of algorithms, and the ZL9NSQ composite data fusion algorithm provides user configuration instructions, which can flexibly adjust the parameters of the filtering algorithm to meet the needs of different applications.

3.2.1 Magnetically assisted rotation vector mode

The magnetically assisted rotation vector mode provides an attitude output based on the NED coordinate system (navigation coordinate system), which is a rotation vector expressed in quaternion form based on the Earth's magnetic north pole and the Earth's gravity. It consists of the output of an accelerometer, gyroscope, and magnetometer synthesized by a fusion filtering algorithm. Since the magnetometer provides yaw angle correction, the absolute accuracy of the magnetically assisted rotation vector mode is the highest among the modes. (Note: Correct calibration of the magnetometer is a prerequisite for accuracy assurance.))

3.2.2 Rotation vector mode

Unlike the magnetic-assisted rotation vector mode, the rotation vector mode does not use a magnetometer, and because there is no magnetometer, the yaw angle is determined by the attitude of the device at the initial moment, and is a rotation vector expressed in quaternion form. It is synthesized from the output of the accelerometer and gyroscope through a fusion filtering algorithm. Since there is no magnetometer to provide Yaw correction, there will be cumulative drift in the Yaw direction for long periods of use.

3.2.3 Stable rotation vector mode

The magnetically assisted rotation vector mode and rotation vector mode are corrected in real time due to the fusion filtering algorithm, the magnetic north pole of the earth and the gravity of the earth. In turn, there may be abrupt or slow jumps in the output data, which can interfere with (augmented or virtual reality and other human-computer interaction) applications. A typical problem is that the device is already in a stationary state, but the attitude information output by the device is still changing. The Stable Rotation Vector mode only provides corrections while in motion, improving the user experience while maintaining long-term 3D attitude accuracy.

3.3 Pose Output Format

3.3.1 Quaternions

Quaternions were first invented in 1843 by Sir William Rowan Hamilton as an extension of complex numbers. It wasn't until 1985 that quaternions were introduced into computer graphics by Shoemake. Rotation in any three-dimensional space can be represented as a rotation around a specific axis; Given the axis of rotation and the angle of rotation, it is easy to convert other forms of rotation representations to quaternions or from quaternions. At the same time, quaternion can be used for stable, regular rotation and interpolation, which is difficult to achieve in other forms of gesture representation. In view of the above advantages, the default attitude output of the ZL9NSQ is a rotation vector expressed in quaternion form. ,

3.3.2 Euler angles

The magnetically assisted rotation vector mode, rotation vector mode, and stable rotation vector mode can also output attitude descriptions based on Euler angles: yaw angle, pitch angle, roll angle, and rotation vector in the form of quaternions 。Compared with the attitude description of quaternion Euler angles, it is more intuitive, but the rotation order has a non-negligible influence on Euler angles, and the same pose can be described by multiple sets of Euler angles with different rotation sequences, and the rotation of Euler angles also faces the problem of universal deadlock. In practice, it is recommended that the user use the pose represented in quaternion form, while the pose represented in the form of Euler angle is only used for debugging purposes.

4. Data communication protocols

ZLBUS data communication protocol is a unified data communication protocol for Zerolab Technology (Shanghai) Co., Ltd. to read and configure data for ZL 9NSQ with different communication interfaces. Users can choose data communication interface through the Mode0 and Mode1 pins, and use the ZLBUS data communication protocol to implement data exchange with ZL9NSQ.

The ZL9NSQ chip has two communication modes: Streaming Mode and Command Mode. In data stream mode, the ZL9NSQ chip continuously sends data outward at a set rate (the type and format of the data sent can be set). In command mode, it is necessary to communicate with the sensor by sending commands to set the parameters of the ZL9NSQ chip.

4.1 ZLBUS Packet Structure

The structure of each packet of the ZLBUS communication protocol is shown in the following table:

Command Mode packet structure

Send Instructions (Host-> Chip)

byte	name	description
0	Frame header	0xAA
1	Instruction ID	0xD5
2	Data length (low-bit bytes)	A low-bit byte containing the length of the data to be transmitted
3	Data length (bit-bytes)	A high-digit byte containing the length of the data to be transferred
4	Subcommand ID	The ID number of the subinstruction that needs to be written or read
5	RF_ID	0x3F
6	DOT_ID	0xFF
x	Data (n bytes)	Data n is the data length -2
7+n	CheckXor	Xor check digit

Table5 ZLBUS packet structure

The portion of the data in the packet is transmitted in a low-end format, i.e., the low-bit byte comes first, and the high-bit byte comes last.

Send instructions (chip-> host).

byte	name	description
0	Frame header	0xAA
1	Instruction ID	0xD5
2	Data length (low-bit bytes)	A low-bit byte containing the length of the data to be transmitted
3	Data length (bit-bytes)	A high-digit byte containing the length of the data to be transferred
4	Answer ID	The operation is successful, and the response ID = subcommand ID; If the operation is incorrect, the response ID

		= sub-instruction ID + 0x80 (if the operation sub-instruction ID is 0x00, the operation is successful and the 0x00 is returned; The operation fails to return 0x80).
5	RF_ID	0x3F
6	DOT_ID	0xFF
7	Error codes	Only the error code is returned, for example, if the operation is successful, there is no error code field (see the error code table).
8	CheckXor	Xor check digit

Table6 ZLBUS packet structure

Streaming Mode packet structure

byte	name	description
0	Frame header	0xAA
1	Instruction ID	0x10 (IMU and attitude data reporting), 0x11 (status reporting), and 0x14 (battery level reporting).
2	Data length (low-bit bytes)	A low-bit byte containing the length of the data to be transmitted
3	Data length (bit-bytes)	A high-digit byte containing the length of the data to be transferred
4	Subcommand ID	The ID number of the subinstruction that needs to be written or read
5	RF_ID	0x3F
6	DOT_ID	0xFF
7	Serial number	The data sequence number 0-255 loops (default).
x	Data (n bytes)	Data n is the data length -2
8+n	CheckXor	Xor check digit

Table7 ZLBUS packet structure

4.2 List of ZLBUS command mode subcommand IDs

Subcommand ID	name	description
0x00	Set the data upload format	You can select the format of the reported data stream based on your needs
0x01	Read the data upload format	Read the current stream data format
0x02	Set the sampling frequency	sampling frequency of internal accelerometer and gyroscope; The IMU Motion Engine calculates based on the sampling frequency
0x03	Read the sampling frequency setting	Read the sampling frequency of the internal accelerometer and gyroscope
0x04	Set the escalation frequency	Set the frequency of data flow reporting
0x05	Read escalation frequency	Frequency of read data stream reporting
0x06	Start magnetometer calibration	Start magnetometer calibration
0x08	Set the filtering parameters	Set the filtering parameters

0x0A	Clear the filtering parameters	Clear Filter parameter (default).
0x0B	Read the filter parameters	Read filter parameter settings
0x0C	Configure the chip mounting direction	Configure the chip mounting direction
0x0D	Read the chip mounting direction	Read the chip mounting direction
0x0E	Configure the RF device name	Configure the RF device name
0x0F	Read the RF device name	Read the RF device name
0x10	Configure the RF power	Configure the RF power
0x11	Read RF power	Read RF power
0x12	Disconnect the RF	Disconnect the RF
0x14	Enable data output	Enable data output
0x15	Turn off data output	Turn off data output
0x60	Enter LED Interactive	Enter LED Interactive
0x61	Exit the LED interaction	Exit the LED interaction
0x62	Set the LED color	Set the LED color
0x63	Read the LED color	Read the LED color
0x64	Set the baud rate of the serial port	Set the baud rate of the serial port
0x65	Read the baud rate of the serial port	Read the baud rate of the serial port
0x77	Get the MAC address	Get the MAC address
0x79	Obtain the full serial number of the device	Obtain the full serial number of the device
0x7B	Obtain the hardware version number	Obtain the hardware version number
0x7D	Obtain the firmware version number	Obtain the firmware version number
0x7E	Device shutdown (or restart)	The device is powered off
0x7F	Restore factory parameters	Restore factory parameters

Table8 List of ZLBUS command pattern subcommand IDs

4.3 List of ZLBUS traffic pattern subcommand IDs

4.3.1 List of sub-command IDs reported by IMU and attitude data

Subcommand ID	**name**	**description**
0x00	9-axis data	The IC attitude consists of an accelerometer, gyroscope, and magnetometer fusion
0x01	6-axis data	The IC attitude consists of a gyroscope and a magnetometer fused

0x02	6-axis data	The IC attitude consists of an accelerometer and a gyroscope fusion
0x03	3-axis data	The IC attitude consists of gyroscope fusion

Table9 List of IMU and attitude data reporting subcommand IDs

4.3.2 List of battery level reporting subcommand IDs

Subcommand ID	name	description
0x00	Electricity + voltage	Percentage, range 0x00 - 0x64 (0% - 100%), voltage value in mV
0x01	voltage	Voltage value in mv
0x02	Electricity	Percentage, Range 0x00 - 0x64 (0% - 100%)

Table10 List of subcommand IDs for battery level reporting

Note: For specific parameters, please refer to the "ZLBUS Communication Protocol User Manual"

5. Chip calibration

The internal high-performance MCU of the ZL9NSQ reads the sensor data **and calculates it according to the device's kinematic model** to determine the device's spatial attitude. The accuracy of this model depends on the quality of the data provided by the sensor.

Minor defects are inevitable in any type of sensor, and the accelerometer, gyroscope, and magnetometer used in the ZL9NSQ are not immune to these defects. Users need to calibrate the sensor according to the application to ensure that the ZL9NSQ can provide high-quality attitude data that meets the needs of the application. Defects in accelerometers, gyroscopes, and magnetometers are usually manifested as bias, scale, non-orthogonality, Non-linear error (Non-Linear), etc.

There are two types of calibration of sensor data:
- Static calibration
- Dynamic calibration

Static calibration is the parametric correction of the structural error of the sensor, and the static error represents the offset and proportional error that does not change with time or temperature.
The static calibration parameters are referenced as follows:
- Accelerometer (or gyroscope or magnetometer) nonlinearity error
- Accelerometer (or gyroscope or magnetometer) proportional error
- Non-orthogonal error relative to the device frame of reference

Dynamic calibration is a parameter correction for the random error of the sensor, and the dynamic error represents the error

that changes with time or temperature. The ZL9NSQ's internal dynamic calibration algorithm runs continuously during sensor use and adjusts the correction parameters in real time as needed.
The dynamic calibration parameters are referenced as follows:
- Gyroscope zero-rate offset

Magnetic field calibration is an additional feature of the ZL9NSQ. The main purpose of using a magnetometer is to measure the earth's magnetic field, and the magnetic field measured by the magnetometer will cause distortion of the ambient magnetic field due to the presence of ferrous matter, magnetic materials, power supply currents, etc. in the vicinity. These distortions are known as the soft iron effect and the hard iron effect, respectively. The internal dynamic monitoring and calibration algorithm of ZL9NSQ can continuously measure the deviation and distortion of the magnetic field during the movement of the device, and continuously estimate and compensate, so as to eliminate the estimated influence of these distortions on the earth's magnetic field as much as possible. However, due to the complexity of the magnetic field environment in different use scenarios, especially in the indoor environment, it is still the best way to improve the accuracy of the earth's magnetic field estimation by staying away from the interference source.

5.1 Calibration effect

5.1.1 Calibration Instructions

The ZL9NSQ's internal algorithm allows the user to enable or disable dynamic calibration of accelerometers, gyroscopes, and magnetometers via a data communication interface. For specific instructions, please refer to the ZL9NSQ User Instruction Reference Manual.

5.1.2 Accelerometer

The dynamic calibration of the accelerometer is to eliminate the zero offset of the accelerometer, and the acceleration measurement when the accelerometer is stationary should be only gravitational acceleration, and any deviation from the acceleration due to gravity is considered zero gravity offset. This phenomenon is most easily observed when one axis of the accelerometer is perpendicular to the Earth, and the other two axes should read very close to zero. When using the ZL9NSQ as an inclinometer, the dynamic calibration of the accelerometer may affect the accuracy of the inclination measurement, and the dynamic calibration should be turned off with the command and manually calibrated to guarantee the accuracy of the inclination measurement.

5.1.3 Gyroscope

The dynamic calibration of the gyroscope is to eliminate the gyroscope zero offset, and when the accelerometer is stationary, the gyroscope three axes should measure very close to the zero value of 0dps/sec. Any deviation from the zero value is considered as gyroscope zero offset, which is a very important error factor that will cause continuous drift; It is manifested by the device being stationary, but the attitude of the algorithm output is still changing. ZL9NSQ will automatically determine whether the device is in a stationary state and continuously correct the gyroscope zero offset in the stationary state to ensure that the gyroscope zero point offset will not continue to drift in the stationary state.

5.1.4 Magnetometer

A magnetometer can measure the magnetic field around a device, and its typical use is to determine the position of the Earth's magnetic field at the north pole. However, in daily use, the magnetic field around the device is distorted by the magnetic field (soft iron effect) caused by the ferromagnetic effect of speakers, magnets, etc., or other ferrous materials. The ZL9NSQ can dynamically calibrate the readings of the magnetometer to compensate for these distortions.

5.2 Calibration Process

For optimal motion tracking performance, it is recommended to calibrate the ZL9NSQ; Since each MEMS sensor part has different characteristics, each device using the ZL9NSQ must be individually calibrated.

sensor	Calibration process
accelerometer	The device needs to be moved to 6-12 different attitudes and held for 12 seconds to complete the accelerometer calibration
gyroscope	The device needs to be placed on a stationary horizontal surface for 10~20 seconds to complete the gyroscope calibration
magnetometer	The equipment needs to rotate repeatedly along the three coordinate axes of the equipment, and the rotation of each axis is not less than 10 seconds

Table 11 A list of calibration procedures

6. Electrical characteristics

6.1 Limit values

	least	utmost	unit
Operating voltage			
VDD	-0.3	3.9	V
GND		0	V
environment			
Storage temperature	-40	125	℃

Table12 List of limit values

6.2 Recommended working conditions

Symbol	**parameter**	least	typical	utmost	unit
VDD	Operating voltage	3.0	3.3	3.6	V
TA	Operating temperature	-40	25	85	℃

Table13 A list of recommended working conditions

6.3 Power consumption characteristics

parameter	least	typical	utmost	unit
Standby mode		3.3		uA
500hz internal sampling, 250hz SDI calculation, 50hz Bluetooth data reporting, +4dBm		15		mA
250hz internal sampling, 250hz SDI computing, 50hz Bluetooth data reporting, 0 dBm		13		mA
50hz internal sampling, 50hz SDI calculation, 10hz Bluetooth data reporting, -4dBm				mA

Table14 A list of power consumption characteristics

6.4 RF Emission Characteristics

parameter	least	typical	utmost	unit
RF output power	-40	0	4	dBm
Frequency range	2400		2480	mHz

Table15 List of RF emission characteristics

6.5 RF Reception Characteristics

parameter	least	typical	utmost	unit
RF receive sensitivity		-93		dBm
Maximum input signal strength		0	10	dBm

Table16 List of RF emission characteristics

7. Recommended design

7.1 Schematic

If an internal Bluetooth antenna is used, L5and L6 need to be shorted.

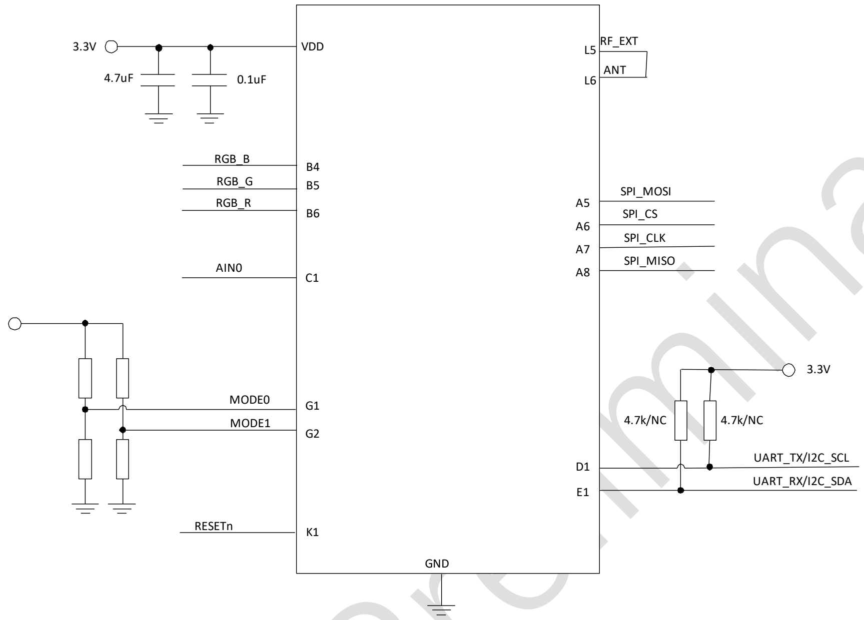


fig8 Schematic diagram of the ZL9NSQ internal antenna

External antenna, internal Bluetooth antenna L6 ANT pin connected GND, the reference schematic diagram is as follows:

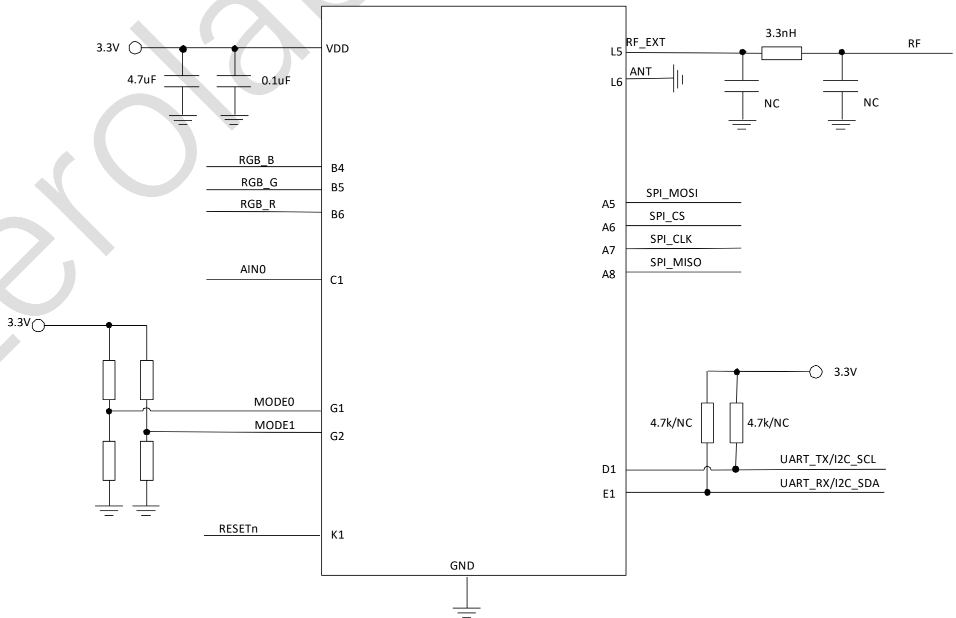


fig9 Schematic diagram of the ZL9NSQ external antenna

For MODE0 and MODE1, the connection method should be to pull up the resistor to 3.3V or pull down the resistor to ground according to the functional requirements.

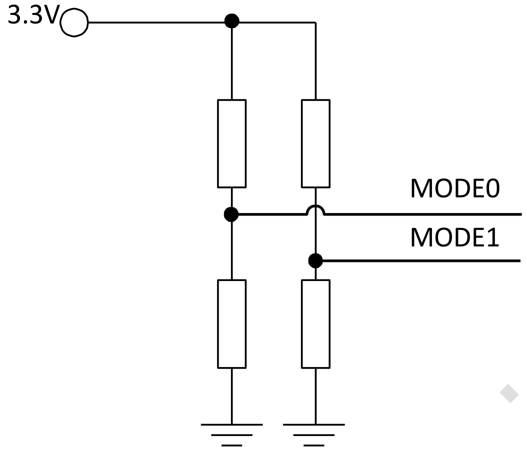


fig10 ZL9NSQ mode configuration schematic

Refer to 2.2.5 Interface Configuration

If an I2C configuration is used, the I2C signal needs to be pulled up by 47K resistor to 3.3V

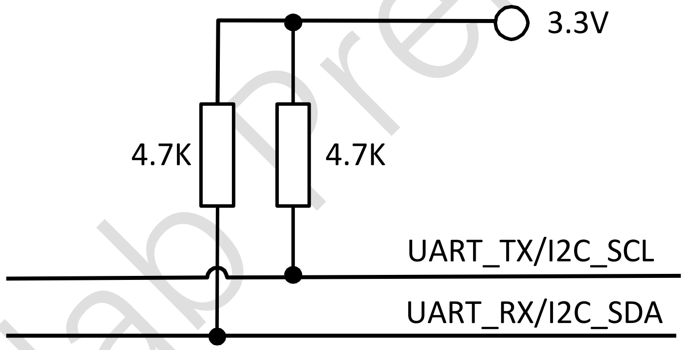


fig11 ZL9NSQ I2C configuration schematic

Reset pin K1, the internal has been pulled up, if not used, can not be connected, direct NC

Bluetooth breathing light reference circuit, with tri-color EDIamp, can flash different colors of light indication as needed:

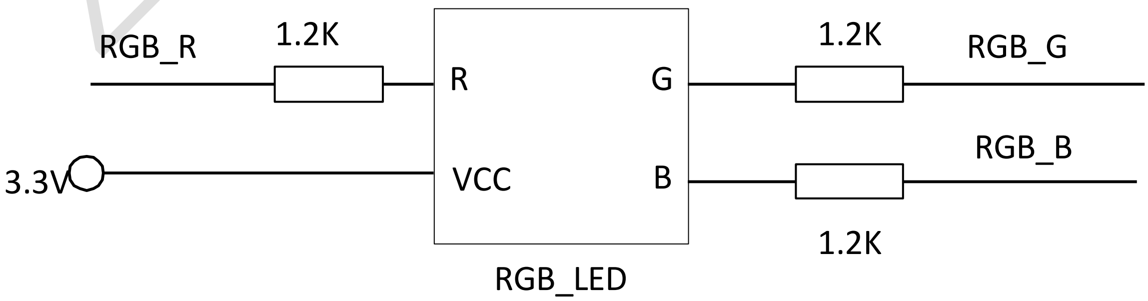


fig12 ZL9NSQ Bluetooth breathing light configuration schematic

Battery detection, if the user uses the battery, the power of the battery needs to be detected, the analog input pin AIN0 can be used, and the battery power is divided by resistance, and the reference circuit is as follows:

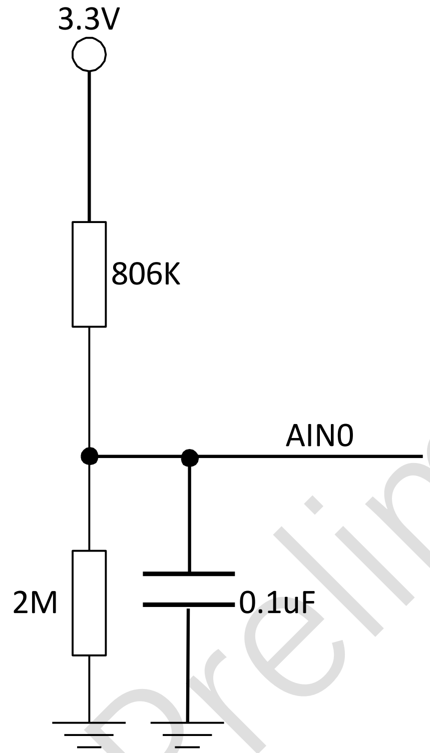


fig13 ZL9NSQ battery level detection schematic

The power supply is 3.3V, and the noise voltage of the recommended power supply of 3.3V is not higher than 50uVrms, and the reference voltage design circuit is as follows:

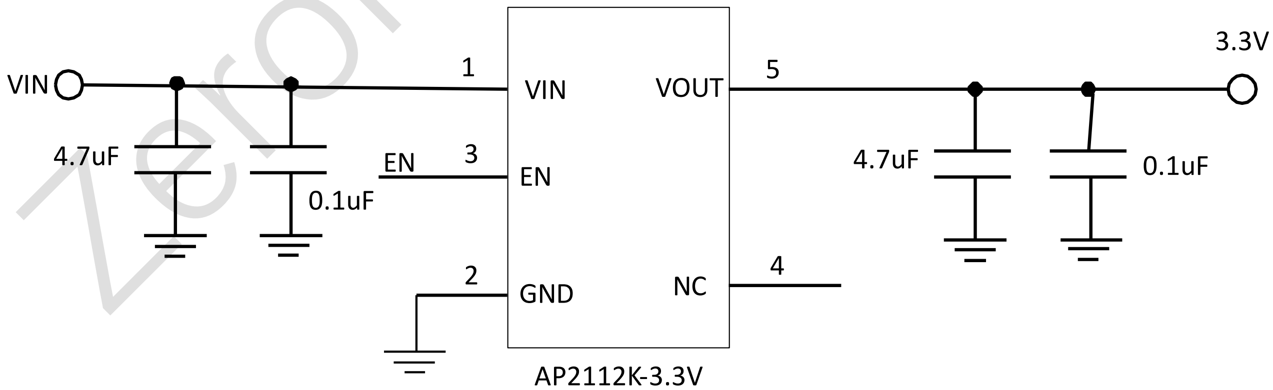
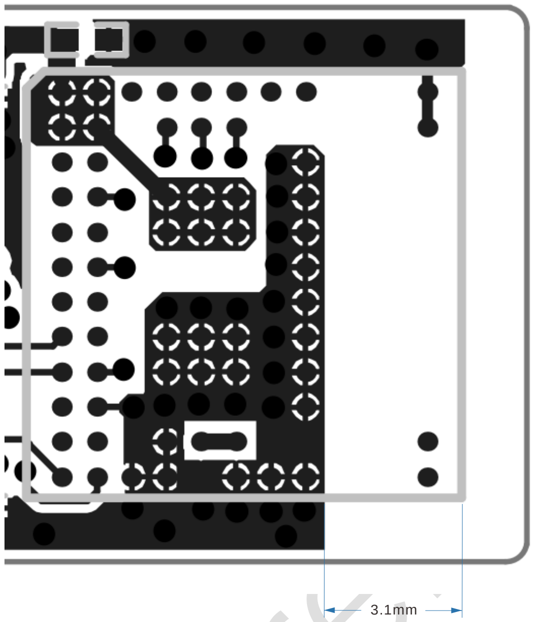


fig14 Schematic diagram of ZL9NSQ regulated power supply

7.2 PCB Layout

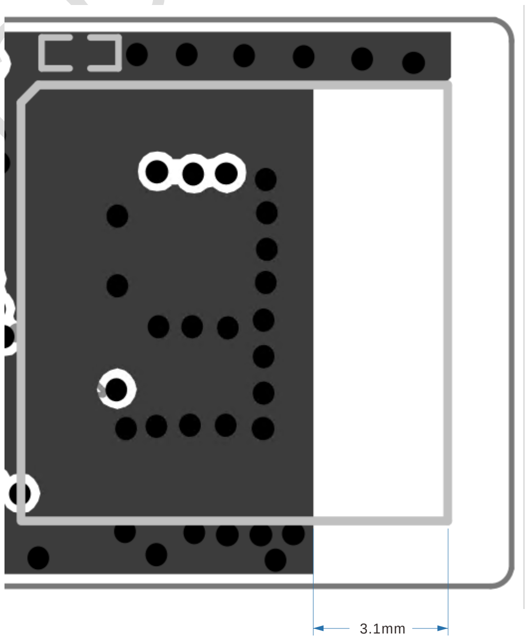
Internal Bluetooth antenna, ZL9NSQ chip needs to be placed on the corner edge of the PCB, PCB Layout refer to the example,



Top Layer

fig15 ZL9NSQ Internal Antenna Reference PCB Design Drawing (Top)

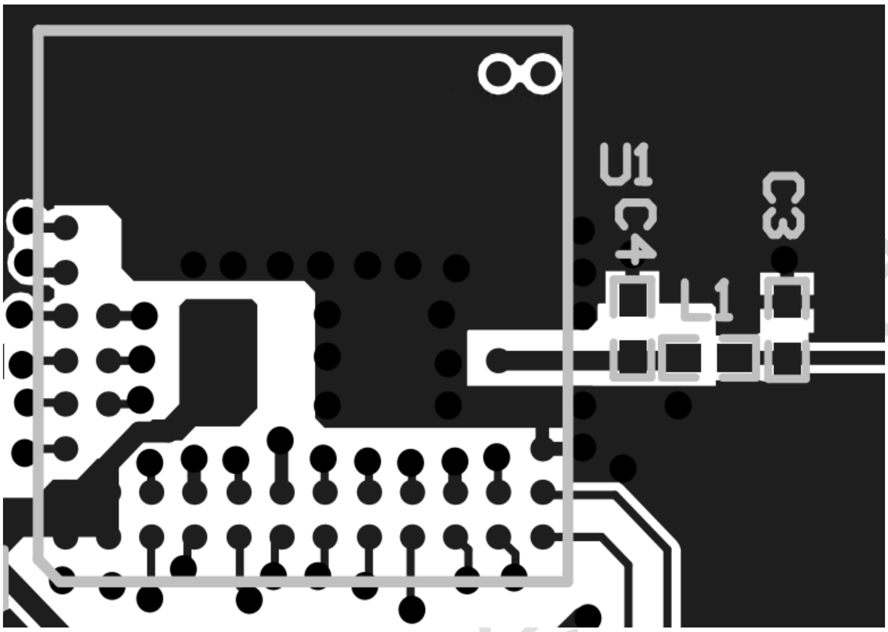
The forbidden area under the internal Bluetooth antenna, as shown in the figure, the distance between the GND ground wire and the bezel of the chip is 3.1mm.



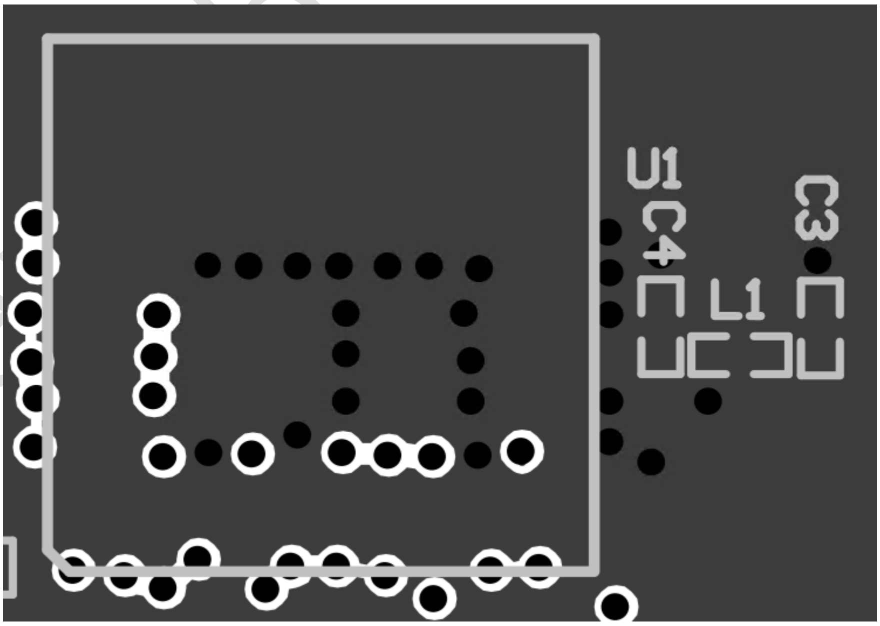
Other Layer

fig16 ZL9NSQ Internal Antenna Reference PCB Design (Bottom)

External Bluetooth antenna, PCB Layout reference example is shown in the figure below, the RF trace after the LC matching circuit needs to ensure a 50 ohm impedance RF trace.



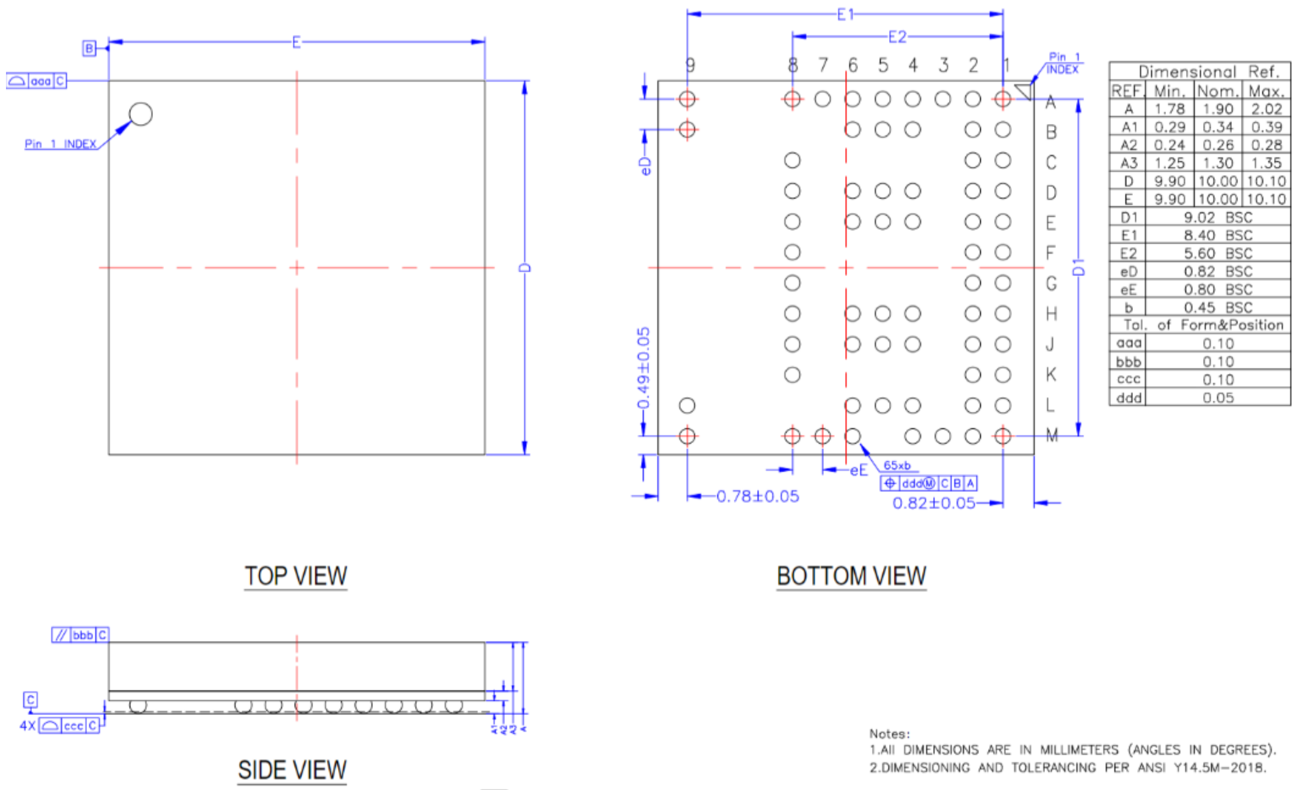
Top Layer
fig17 ZL9NSQ External Antenna Reference PCB Design Drawing (Top)



Other Layer
fig18 ZL9NSQ External Antenna Reference PCB Design (Bottom)

8. Encapsulation Information

8.1 Package Drawing



Dimensional Ref.			
REF.	Min.	Nom.	Max.
A	1.78	1.90	2.02
A1	0.29	0.34	0.39
A2	0.24	0.26	0.28
A3	1.25	1.30	1.35
D	9.90	10.00	10.10
E	9.90	10.00	10.10
D1	9.02 BSC		
E1	8.40 BSC		
E2	5.60 BSC		
eD	0.82 BSC		
eE	0.80 BSC		
b	0.45 BSC		
Tol. of Form&Position			
aaa	0.10		
bbb	0.10		
ccc	0.10		
ddd	0.05		

Notes:
1.All DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).
2.DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-2018.

fig19 ZL9NSQ package dimensions

8.2 Welding Instructions

Process parameter		Unit	Value
Pre-heat	Ramp up rate to T_{sMIN}	℃/s	3
	T_{sMIN}	℃	100
	T_{sMAX}	℃	160
	t_s (from 25℃)	s	110
	t_s (Pre-heat)	s	60 ~ 120
Peak	T_L	℃	185
	t_L (time above T_L)	s	80
	T_p (absolute max)	℃	221
	t_P (time above T_P -5℃)	s	10
Cooling	Ramp-down from T_L	℃/s	4
General	$T_{to\ peak}$	s	285
	Allowed reflow soldering cycles	-	2

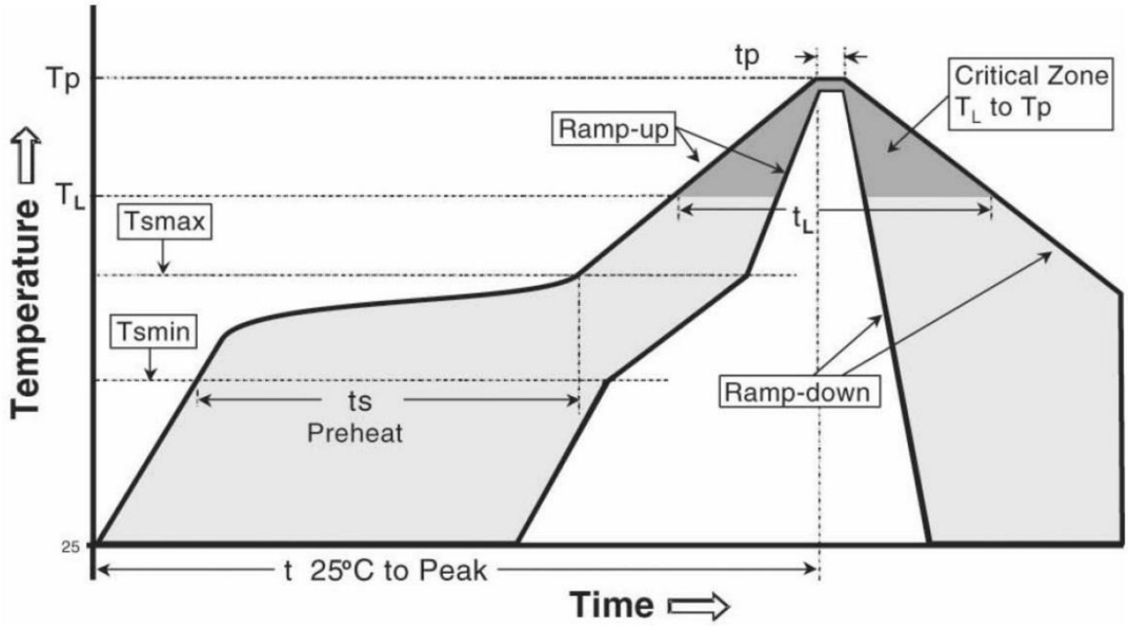


fig20 ZL9NSQ welding guidance diagram

This chapter is a background knowledge for ZL9NSQ or any IMU product first time user. It explains the concepts in simple terms so that people who are not familiar with the IMU technology can quickly ramp up.

INS：

INS stands for Inertial Navigation System: An inertial navigation system can provide a position and speed similar to the GPS Global Positioning System, but there are some big differences. The principle of inertial navigation is to measure acceleration with an accelerometer. This acceleration is then integrated to get the velocity. Then, the velocity is integrated to get the position; At the same time, the gyroscope integrates to obtain the attitude angle, and converts the speed and position obtained in front to the specified coordinate system through the attitude angle. Due to the mixture of noise in the measurement and noise through integration, the error of inertial navigation increases exponentially over time. The relative error of an inertial navigation system is low in a short period of time, but after a long period of time, the error increases significantly.

AHRS：

AHRS stands for Attitude Heading Reference System. An AHRS uses an accelerometer, gyroscope, and magnetometer combined in a mathematical algorithm to provide direction, but not velocity and position. The direction consists of Roll, Pitch and Yaw.

Roll, pitch and yaw:

The direction can be described in terms of the angles of rotation around the three axes: roll, pitch, and yaw, which are called Euler angles. The axes of rotation for roll, pitch and yaw are shown in Figure 1. The roll is the angle around the X-axis, which is zero when the chip is completely horizontal, and the value range is [-Pi, Pi]. Pitch is the angle around the Y-axis, which is zero when the chip is completely horizontal, and the value range is [-Pi/2, Pi/2]. Yaw is the angle around the Z-axis, which is zero when the X-axis points to true north, and the range of values is [0,2Pi].

Rotation Order:

When multiple axes are rotated, to get the final direction, the three rotations must first be performed in order, first yaw, then pitch, and finally roll. To derive the final direction, the chip should first be placed horizontally, with the X-axis pointing north and the Z-axis pointing downward. Yaw is applied first, then pitch, and finally roll, giving the final direction. When using the rotation represented by Euler angles, the same rotation can be represented by different rotation angles in different sequences; Therefore, it should be ensured that the user follows the rotation order defined by the chip when using the chip.

Gimbal deadlock:

Gimbal Lock is a condition in which the system loses degrees of freedom due to the coincident of the axis of rotation in a certain situation when the rotation is defined by the Euler angle.