Design Specification

MASIMU02 Nanosatellite Inertial Measurement Unit Attitude Detection System

Revision A

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System Description

The MASIMU02 is a 6-degree of freedom angular rate and linear acceleration sensor platform. MEMS technology is used in all the gyroscopes and accelerometers in the MASIMU02. Its interface is a RS485 serial protocol.

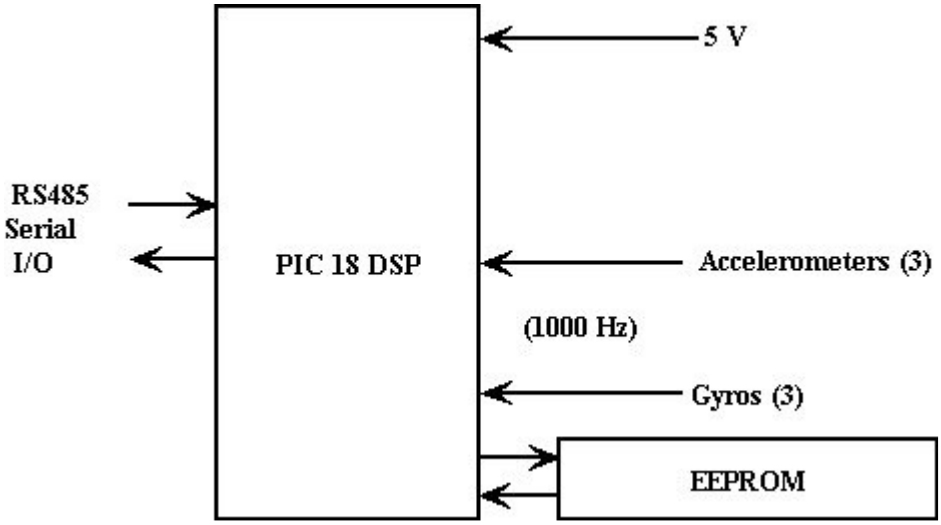

Figure 1 MASIMU02 System Block Diagram

The design illustrated in Figure 1, uses one Analog Devices ADXL150 surface micromachined accelerometer and one ADXL250 accelerometer. These are essentially the same part except that the ADXL250 has two-axis sensitivity. This allows two chips to provide three accelerometer sensor axes. These accelerometers have a full scale of +/- 10g. Each sensor axis is sampled and the output is a voltage is converted by a PIC 18 microcontroller Digital Signal Processor (DSP) at approximately 1000 Hz at 10 bits/sample. The DSP processes and compensates the accelerometer and angular rate data. Data is sent off board at user selectable frequency. The data transmission rate is 115200 bps.

The protocol for the communication system is the MASIMU02 starts up and sends 100 packets of accelerometer and gyro data. It will then wait for a command to determine which mode of data to send back to the external computer. This is in accordance with the command table in the MASIMU02 specifications document. If the MASIMU02 doesn't receive a new command within 10 seconds it will continue outputting data according to the last successfully received command. The MASIMU02 will echo back over the serial connection the command it just received for verification.

The MASIMU02 also requires a 5-12 V power supply. This is connected to the red and black wires coming from the MASIMU02.

Full Scale Range	+/-50 g
Temperature Min/Max	0 C / +70 C
Sensitivity (ratiometric)	38 mV/g
Sensitivity drift (at Min/Max temp)	+/- 0.5 %
Output Bias voltage	2.5 V
Zero g drift due to temperature (at Min/Max temp.)	0.3
Zero-g offset adjustment (voltage gain)	0.5 V/V
Power Supply (Vs)	4.0 – 6.0 V
Noise Density	1 mg/$\sqrt{\text{Hz}}$

Table 1 ADXL150/250 Performance

Analog Devices' ADXRS150 resonator MEMS micro gyroscope is used as the system's angular velocity sensors. Positive output voltage indicates clockwise motion and negative voltage indicates counterclockwise. A high-pass filter is used in conjunction with the sensor to cancel bias drift and the output voltage is measured by the PIC 18 A/D converter. The gyro package provides on-chip voltage reference and temperature sensor for compensation. If higher scale rates are required the ADXRS300 has the same footprint and pinout but has a range of +/-300 deg/sec.

Current consumption	6 mA
Static Output (bias)	2.5 V
Angular Velocity range (deg/s)	+/-150 deg/s
Scale Factor	12.5 mV/deg/sec
Accuracy	0.02 deg
Drift	0.2 deg/min
Operating Temperature	-40 to +85 C

Table 2 Analog Devices ADXRS150 Gyroscope specifications

The gyroscopes will have a drift rate of less than 0.2 deg/min (0.003 deg/sec.) and an accuracy of 0.02 deg.

The RS485 serial protocol is a multi-drop protocol which can be used to communicate with other computer systems. This differs from RS-232 in that as many as 256 nodes can be connected on a bus. The drivers and receivers are inexpensive and require just a single +5V supply (or lower) to generate the required minimum 1.5V difference at the differential outputs. Also, the data rate can be as high as 10 Mbits/sec.

The following three tables give a summary of system mass and power budgets with margins. The tables indicate a mass of 20 grams and a power consumption of 0.59 Watts. The MASIMU02 has on-board current monitoring which resets the unit if it detects an unusual increase in current to guard against latch-up.

Component	**Mass (g)**
Gyroscopes with electronics	5
Accelerometers with electronics	5
PIC controllers with electronics	5
Power supply	3
Margin	2
Total	20

Table 3 IMU System Mass Budget

Component	Power (W)
Gyroscopes with electronics	0.050
Accelerometers with electronics	0.040
PIC controllers with electronics	0.400
Margin	0.1
Total	0.59

Table 4 IMU Power Budget

System Input/Outputs

The MASIMU02 outputs through the RS485 interface the X,Y,Z angular rates and accelerations. These outputs can go to a spacecraft Command and Data handling System board to determine when attitude errors require attitude control actuation devices (e.g. thrusters) to be fired to adjust the spacecraft attitude.

Commands can be sent over the RS485 interface to control the rate of angular rate and acceleration output, to change the bias sensitivity of the system and to write these parameters to the on-board EEPROM of the MASIMU02.

The commands for the MASIMU02 are listed in Table 4 below. The first two characters of each command is the RS485 address of the MASIMU02, set to address 01.

Command	Description
01010000	Resets the IMU
01020000	Send Angular Rate and Acceleration Data, One Time
0103xxxx	Sets Rate to Broadcast Data Over Serial Port where xxxx = data rate 0000 = turn data output off 0001 = 0.1 Hz data 0010 = 1.0 Hz data 0100 = 10 Hz data 1000 = 100 Hz data
0104xxxx	Change accelerometer XY bias x=0001=decrease X accelerometer bias x=0010=increase X accelerometer bias x=0100=decrease Y accelerometer bias x=1000=increase Y accelerometer bias
0105000x	Change accelerometer Z bias x=0=decrease accelerometer bias x=1=increase accelerometer bias
0106000x	Set Output Mode x = 0 = Engineering Units x = 1 = Voltage Units
01070000	Write Configuration to EEPROM
01080000	Re-calibrate

Table 4 MASIMU02 Command Table

Table 5 describes the output data format. There are two formats available, the MASIMU02 can output engineering units where the raw voltages are converted to the proper rates and accelerations. The other mode passes the raw data directly to the user without any conversions. Both data format outputs is a string of 6 10-bit data packets plus a counter which is the packet number since the last command. It can be used to determine when the MASIMU02 will be ready to receive the next command. Table 6 shows when the MASIMU02 will wait for the next command depending on data rate.

Data	Engineering Unit Format	Voltage (raw)Format
Angular Rate X (10 bits)	deg/sec	A/D Voltage
Angular Rate Y (10 bits)	deg/sec	A/D Voltage
Angular Rate Z (10 bits)	deg/sec	A/D Voltage
Acceleration X (10 bits)	G's	A/D Voltage
Acceleration Y (10 bits)	G's	A/D Voltage
Acceleration Z (10 bits)	G's	A/D Voltage

Table 5 MASIMU02 Output Data Format

Data Rate	Data Rate	Count for until next command
0.1 Hz	0.1Hz	1
1	1.5	10
10	13.27	100
100	63.92	100

Table 6 Commanded and Actual Data Rates

Also, the actual rate that data will be sent differs depending on the serial connection and other parameters. This table shows actual data rate for each user selectable rate.

System Testing

The MASIMU02 is shipped with PC control software and a serial converter to convert the RS485 serial I/O to RS232 that is used on the PC. This allows software provided with the MASIMU02 to test and verify the operation of the system. Outputs displayed on the Windows compatible software interface show the X,Y and Z angular rates and accelerations as measured by the MASIMU02. The software also allows the user to change the update rate of the output of the MASIMU02 from 0.1 Hz to 100 Hz (available rates are 0.1, 1.0, 10 and 100 Hz). Calibration of the system is also done through the PC software interface. On-board EEPROM stores system settings and calibrations.

As well as calibration and configuration of the MASIMU02, the PC software provides body co-ordinate rates and accelerations, and Euler angles. Limits and set-points can be put into the software. The system can then be tested standalone or through the PC interface software to verify operation when test platform position changes from the setpoint desired position. For example, the test platform can be placed upon a table top, then rotated by hand and position change can be noted in output display.

For spacecraft design a separate command and data handling system should take the rate and acceleration data to determine difference in actual and desired attitude of spacecraft, to receive updates by Solar cell sun sensor or other update system and to send commands to fire thrusters to change position.

Attitude Update

Attitude updating and aiding could be done using the solar cells on the outer surfaces of the spacecraft as a Sun sensor. The solar cells on the side of the spacecraft facing the Sun will be providing the highest voltage. This can be used to determine the spacecraft's orientation.

All gyroscopes drift over time and require calibration and bias correction. The MASIMU02 program or a terminal emulation program such as hyperterminal can be used to monitor the data output by the MASIMU02. Overtime the zero bias of the accelerometer will drift and has to be corrected for. This is why an external reference such as a Sun sensor is required to provide an external reference. The data from the MASIMU02 should go to an externally provided C&DH monitoring computer on-board

the satellite. The C&DH computer will then take corrective sensor measurements from the Sun sensor or other reference sensor just as on an unmanned aerial vehicle GPS is used for attitude reference updates. A temperature monitor such as a thermal couple can also help the C&DH computer correct for any temperature variations in the calibration constants. The C&DH computer can issue commands to the MASIMU02 to change output modes from deg/sec to voltages if an external calibration is desired. If the platform is stable and at rest the calibration command can be issued to the MASIMU02 to determine the current zero biases.