COMMAND AND DATA HANDLING SUBSYSTEM FOR A NANO-SATELLITE (STUDSAT-2)

Project Report Submitted by

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UNDER THE GUIDANCE OF

Mr. Durga Prasad

Associate Professor, ECE

in partial fulfillment of the requirements for the award of the Degree of

Bachelor of Engineering (ECE)

From

Visvesvaraya Technological University, Belagavi

N.M.A.M. INSTITUTE OF TECHNOLOGY

(An Autonomous Institution under VTU, Belagavi)

(AICTE approved, NBA Accredited, ISO 9001:2008 Certified)

NITTE –574 110, Udupi District, KARNATAKA

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[Project sponsored by Nitte Meenakshi Institute of Technology Bangalore, under Consortium of STUDSAT-2]

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DEPARTMENT OF

ELECTRONICS AND COMMUNICATION ENGINEERING

CERTIFICATE

Certified that the project work entitled

" COMMAND AND DATA HANDLING SUBSYSTEM FOR A NANO-SATELLITE (STUDSAT-2) "

is a bonafide work carried out by

Akash Koyambron	Amith Ferris Prabhu
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Ananth P	Mehboob Mustafa Siyali
(4NM11EC023)	(4NM11EC068)

in partial fulfilment of the requirements for the award of

Bachelor of Engineering Degree *in* ***Electronics and communication Engineering***

prescribed by ***Visvesvaraya Technological University, Belagavi***

during the year 2014-2015.

It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the departmental library.

The project report has been approved as it satisfies the academic requirements in respect of the project work prescribed for the Bachelor of Engineering Degree.

Signature of Guide **Signature of HOD** **Signature of Principal**

<u>Semester End Viva Voce Examination</u>

Name of the Examiners	**Signature with Date**
1. ______________________________	______________________________
2. ______________________________	______________________________

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ABSTRACT

STUDSAT-2 (STUDent SATellite-2) is a Nano-satellite under development with STUDSAT-2 Consortium and Visvesvaraya Technological University (VTU) for proving the concept of Inter-satellite link (ISL). The Twin-Satellites STUDSAT-2A and STUDSAT-2B weighing less than 10 kg (22 lbs) are of dimensions 30×30×20 cm. The main goal of the STUDSAT-2 project is to develop a low-cost small satellite, capable of operating small scientific or technological payloads where real time connectivity is provided by inter-satellite links.

The Command and Data Handling subsystem of the satellite deals with the interfacing of various sensors deployed along with the payload and coordinating between the same. The various sensors deployed in the satellite for normal functioning are magnetometer, gyroscope, GPS, sun sensor, etc.

The sensors that this project will implement are the space grade magnetometer and the gyroscope. These sensors are to be interfaced with the microcontroller (STM32F04). The readings obtained from these sensors need to be stored first .The coordinate values are then obtained from the saved readings.

Thus this project plays a pivotal role in attitude determination of the satellite by providing accurate readings from the gyroscope and the magnetometer obtained after processing through the STM32F04 microcontroller.

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CHAPTER 1

INTRODUCTION

Project STUDSAT-2 takes heritage from STUDSAT-1. It is India‘s First Twin Nano-Satellite Mission which aims to demonstrate Inter-Satellite Communication. STUDSAT-2 hosts two payloads. One is CMOS image sensor for earth imaging. Second is the Inter-Satellite Link (ISL) to demonstrate Inter-Satellite Communication between the two Nano-Satellites in space and increasing temporal resolution for remote sensing applications.

The STUDSAT-2 consists of two Nano-Satellites each weighing appox 10 kg with the dimensions of 30 x 30 x 20 cm. The satellites are in along-the-track constellation architecture with the STUDSAT-2A sending position and velocity data to the STUDSAT-2B through ISL. The two satellites carry CMOS image sensors with ISL facility. The satellite constellation makes it possible to take images of the same place at different intervals of time using Inter satellite communication. Along with these payloads, each satellite hosts an On-Board GPS Receiver, 3-axes attitude stabilization system-magnetic torques, reaction–wheels, efficient power system with deployable solar panels, full duplex communication system using UHF and S-bands, beacon in Morse code, and antenna deployment and various other systems that are required for a successful space mission.

The satellite when ejected to the orbit may tumble in all three axes (roll, pitch and yaw) and in order to stabilize the satellite and point it in the right direction, the satellite employs an Attitude Determination Control System (ADCS) .This project as a part of the Command and Data Handling Subsystem interfaces the space grade magnetometer HMR2300 and a three axis MEMS digital gyroscope ITG3200 with the STM32F04VG microcontroller. These sensors upon integration with sun sensors and GPS provides for effective attitude control of the satellite.

1.1 OBJECTIVES:

1. To understand the architecture of STM32F04VG ARM cortex M4.
2. To interface the space grade magnetometer HMR2300 to STM32F04VG.
3. To interface three axis MEMS gyroscope ITG3200 to STM32F04VG.
4. Visual simulation of the satellite's angular velocity on console.

1.2 METHODOLOGY:

1. The magnetometer (HMR2300) is interfaced to the STM32F04VG using USART interface.
2. The gyroscope (ITG3200) is interfaced to the STM32F04VG using gyroscope interface.
3. The gyroscope (ITG3200) is interfaced with Arduino Mega 2650.
4. The result is displayed visually on the computer using a java code written in Processing.

1.3 ORGANIZATION OF THE CHAPTERS:

The project report has been organized under twelve chapters, which are as follows:

Chapter 1 introduces the main purpose of our project and gives a brief description of our project.

Chapter 2 highlights the literature review.

Chapter 3 deals with the description of the project STUDSAT.

Chapter 4 discusses command and data handling system and the components used.

Chapter 5 discusses the attitude determination aspect of the satellite

Chapter 6 deals with interfacing the magnetometer.

Chapter 7 deals with interfacing the gyroscope.

Chapter 8 discusses the results and conclusion.

CHAPTER 2

LITERATURE SURVEY

In the era of development of space technology, miniaturization plays a vital role in low cost small satellite missions. The versatile application capabilities and low cost of Pico/Nano satellites missions make them attractive for a wide scope of space exploration projects. The paper [1] presented by **Angadi.C** and others outlines the steps involved in design, development and fabrication of a Pico-satellite 'STUDSAT' along with the development of ground station that is capable of communicating with STUDSAT. It elaborates upon the different subsystems in the satellite. This paper gives a clear understanding of the architecture of nano-satellites.

After launch of a spacecraft, the role of the ground station software becomes critically important. The command and data handling software issues telecommands to the spacecraft, and retrieves, displays and stores telemetry from the spacecraft. The key feature of the dynamic design of the software described in the paper[2] ,by **Akthar,S.A** and **Underwood,C.I,** lies in the independence of the software graphical user interface (GUI) from the number of subsystems, telemetry channels and telecommands required at the design time and number of remote users at runtime. This independence enables to software to produce various graphical user interfaces with a unique number of telemetry channels and telecommands for users with different needs, preferences or privileges. The dynamic software layout is definable in the form of a configuration database. The data file is read by software at the time of initialization and user interface is built as defined in the file. Out-of-limit values for every telemetry channel are highlighted as defined in the configuration database. The user interface is powerful enough display a single telemetry channel into multiple units by simply defining different parameters for the channel. The graphical user interface is designed using multiple pages, with a tables of telemetry and telecommands on each page. Every telemetry and telecommand database entry contains page number, row and column of position, caption, unit, channel number, data type, minimum and maximum values and calibration equation for the channel to convert raw digital values to standard units. Security is implemented by privilege assignments to every user account. The paper gives a brief introduction about ground station, followed by the software requirements, architecture, security issues, and dynamic interface implementation. The overall performance, results of the software are described.

A Command and Data Handling (C&DH) system is being developed as part of a series of CubeSat missions being built at the University of Texas at Austin Texas Spacecraft Laboratory (TSL) .This project is described in the paper[3] presented by **Johl, S** and others. With concurrent development of four missions and with more missions planned for the future, the C&DH team is developing a system architecture that can support a variety of mission requirements. The presented research aims to establish a reference for the development of the C&DH system architecture so that it can be reused for future university missions. The C&DH system is designed using a centralized architecture with one main flight computer controlling the actions and the state of the satellite. A commercial off-the-shelf system-onmodule embedded computer running a Linux environment hosted on an interface board designed in-house is used as the platform for the mission software. An integral component of the C&DH system development is the flight software (FSW). The FSW is written in C++ using the Object-oriented architectural style. It is structured as a state machine, controlling the transitioning of the satellite between its operational modes which define its actions and behaviour. The various testing procedures that are performed on the FSW, the C&DH system and the integrated satellite are described. These procedures include traditional software tests such as black box, glass box, and unit testing, as well as formal spacecraft tests such as Command Execution Tests and Day-in-the-Life tests. The design of the flight software and the associated hardware are integral components of the current missions in the TSL which, when flown, will be some of the most operationally complex CubeSat missions attempted to date.

In the paper[4] by **Chul Woo Kang**, robust attitude determination based on the indirect extended Kalman filter is proposed. For the nano-satellite, there are only two vectors of magnetic vector and sun vector for vector measurement without redundant sensors. Accordingly, the three-axis attitude determination using conventional algorithm is impossible when one of the vectors is not available. The proposed attitude determination method uses propagation based on satellite attitude dynamics. The gyro measurements are used for a measurement, and angular rates are estimated by measurements and control inputs. Thus the attitude propagation shows much smaller error than conventional attitude update in the simulation results.

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CHAPTER 3

STUDENT SATELLITE (STUDSAT)

STUDSAT is a satellite designed by students. It was conceptualized and managed by undergraduate students across India.

3.1 STUDSAT-1:

STUDSAT-1 is a Pico satellite, a miniaturized satellite, successfully launched on 12 July 2010 from Satish Dhawan Space Centre into a sun synchronous orbit. The mission's objective was for students to have a hands-on experience with the design, fabrication and realization of a space mission at a minimum cost. The mission life was stated to be six months. The Satellite had all the subsystems which are present in the bigger satellites. The subsystems were:

- Payload
- Structure
- Attitude determination and control (ADC)
- On-board communication
- On-board Command and Data Handling (C&DH)
- Electronic Power System (EPS)
- Ground station

STUDSAT-1 was the first Pico satellite launched by India, as well as the smallest satellite launched indigenously by any Indian organization. The satellite is close to being a cube, of miniature size, when compared with the common satellites, with dimensions of 10 cm x 10 cm x 11.35 cm. It weighs just 950 gm and has a volume of 1.1 litres and hence falls into the category of “Pico Satellites”. The satellite has been launched in a PSLV into a 647 km solar-synchronous orbit. The functional objective of the satellite is to perform remote sensing and capture images of the surface of the earth using it's camera of resolution 95 m.

The Pico Satellite, weighing less than 1 Kg, volume of 1.1 litres is designed to operate in Low Earth Orbit (LEO) at an altitude of 647 Km. The payload of the satellite is a CMOS camera and it is capable of capturing images with a ground resolution of 90 meters. Prototype for STUDSAT-1 and STUDSAT-2 are shown in Fig 3.1 and Fig 3.2 respectively.

Fig 3.1 Prototype for STUDSAT-1

Fig 3.2 Prototype for STUDSAT-2

3.2 STUDSAT-2:

The Team STUDSAT is continued the legacy and building twin Nano-satellite for proving the concept of Inter-satellite link (ISL). The design of the Twin-Satellites STUDSAT-2A and STUDSAT-2B which are of dimensions 30 cm x 30 cm x 20 cm and weighing less than 10 kg. The main goal of the STUDSAT-2 project is to develop a low-cost small satellite, capable of operating small scientific or technological payloads where real time connectivity is provided by inter-satellite links.

STUDSAT-2 is a Nano-satellite under development with STUDSAT-2 Consortium and Visvesvaraya Technological University (VTU) for proving the concept of Inter-satellite link (ISL). The main goal of the STUDSAT-2 project is to develop a low-cost small satellite, capable of operating small scientific or technological payloads where real time connectivity is provided by inter-satellite links. Major goal of the project is to design, develop and launch two Nano-satellites namely STUDSAT-2A & STUDSAT-2B for Inter-Satellite Communication, where one of the satellite is carrying CMOS camera as a payload and other satellite has communication module as a payload to the lower earth orbit. Along with these payloads, the satellites will house an On-Board GPS Receiver, 3-axes Attitude stabilization system, Reaction wheels, efficient power system with deployable Solar panels, full duplex communication system using UHF and S-bands, Beacon in Morse code, Antenna deployment and various other systems that are essential for a successful Space mission. The two satellites will have capabilities to establish communication (Inter-satellite Link) with each other, and also the Master Control Unit (MCU) at ground segment. The mission of the satellite is to capture images of Earth from Lower Earth Orbit (LEO). The satellites are in along-the-track constellation architecture with the STUDSAT-2A sending position and velocity data to the STUDSAT-2B through Inter Satellite Link.

3.3 GROUND STATION:

The ground station is the first and final terrestrial end of a communication link to an object in outer space. Wireless Communication is done with Satellites, hence the ground station serves as the access point on Earth. The Satellite dumps the data to the ground station whenever it passes over that area. Main purpose of the ground stations is to track and receive telemetry and payload data from satellite for health analysis and also to control the satellite by commanding. The Ground Station includes hardware and software elements to transmit and receive information reliably. The system include a computer programmed with orbital-prediction software compatible with the hardware for auto-tracking and a transceiver to transmit and receive command and telemetry data respectively.

The ground station Nitte Amateur Satellite Tracking Center (NASTRAC), is a part of Student Satellite Project located in the campus of Nitte Meenakshi Institute of Technology. It is a satellite tracking facility built by undergraduate students in UHF band to have half duplex communication with STUDSAT -1 in 2010. NASTRAC currently is upgraded for a full duplex system in both UHF and VHF bands for the satellite STUDSAT-2A and STUDSAT-2B [10]. Ground Station setup and software used at NASTRAC for tracking is shown in Fig 3.3.

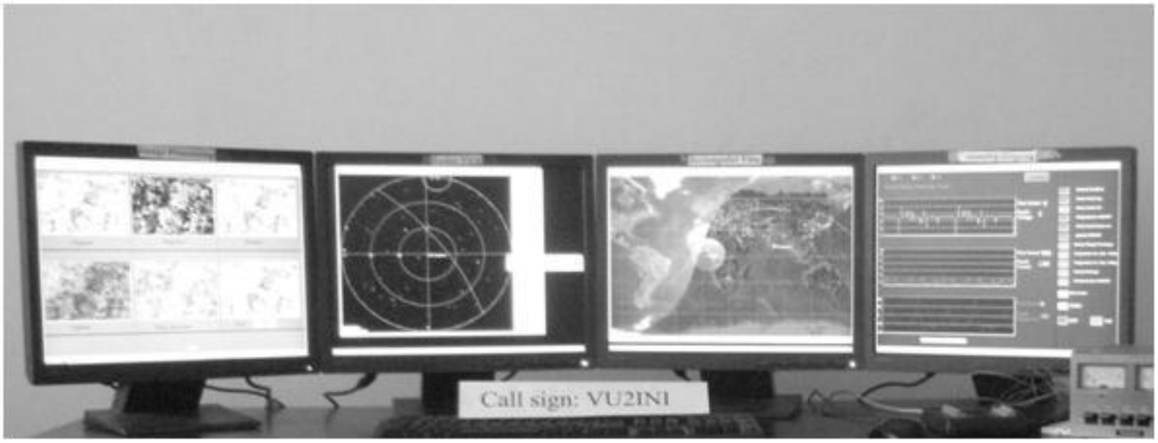

Fig 3.3 Ground station setup and software used at NASTRAC for tracking

3.4 OBJECTIVES OF STUDSAT-2:

3.4.1 Primary Objectives:

- To demonstrate In-Orbit Separation Mechanism for STUDSAT 2A/2B.
- To design, develop and implement Drag Sail technology in STUDSAT 2B for re-orbiting.
- To demonstrate Inter Satellite Communication.
- To demonstrate Solar Panel and Antenna Deployment mechanism in a Nano-satellite.
- To capture images of Earth with a CMOS multispectral camera.

3.4.2 Secondary Objectives:

- To create a modular architecture of small satellite which can be used in future missions.
- To demonstrate satellite development by a team of undergraduate students from seven engineering colleges as consortium.
- To promote space technology in educational institutions and encourage research and development in miniaturized satellites.
- To bridge the gap between academic institutes, research organizations and industries.

CHAPTER 4

COMMAND AND DATA HANDLING

The various peripherals for the C&DH system consist of a set of memories, a microcontroller supervisor IC and temperature sensors at various locations of the satellite. A Read/Write Non-Volatile Radiation Resistant Memory is used for storing the telemetry data. And for storing the images from the CMOS image sensor a fast and lard read/write memory is used. The controller will be supervised by a watchdog timer to catch runaway programs by resetting the controller. The I/O Board provides serial peripheral interface (SPI), I2C, USART, ADC etc. to communicate with sub-modules of other sub-systems. The entire system can be summarized as shown in Fig 4.1 below.

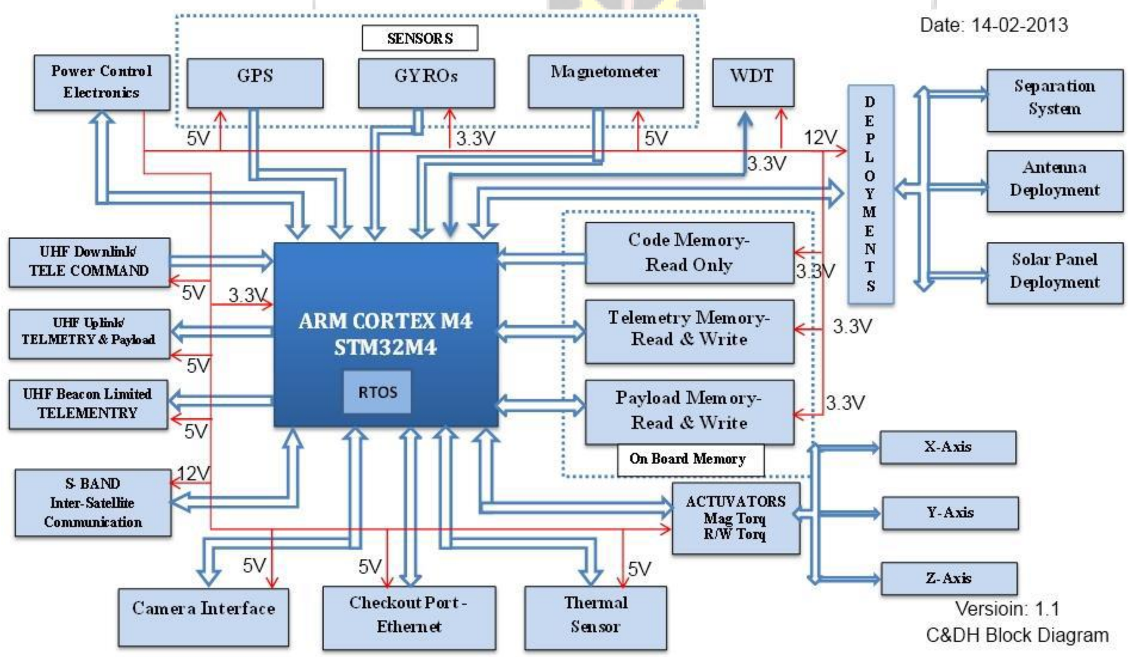

Fig 4.1 Block Diagram of C&DH

The Command and Data Handling (C&DH) System is the brain of the satellite. Its functions are:

- To develop a working hardware prototype of the STUDSAT OBC subsystem
- To perform the house keeping functions which includes logging the telemetry data in the memory periodically
- Implementing the higher layers of the communication protocol

The block diagram of the subsystem developed is as shown in fig 4.2 below.

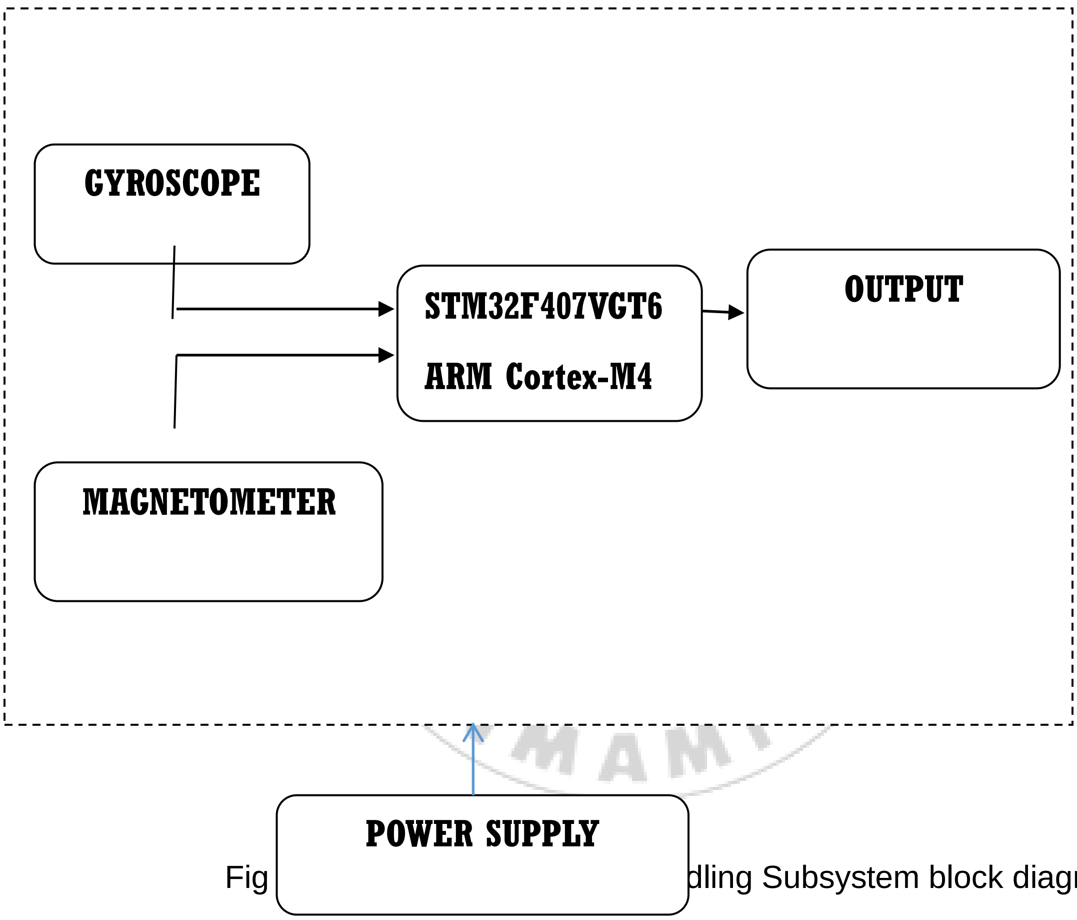

Fig dling Subsystem block diagram

4.1 STM32F4 DISCOVERY

The STM32F407xx family is based on the high-performance ARM® Cortex®-M4 32-bit RISC core operating at a frequency of up to 168 MHz. The Cortex-M4 core features a Floating point unit (FPU) single precision which supports all ARM single precision data-processing instructions and data types. It also implements a full set of DSP instructions and a memory protection unit (MPU) which enhances application security. The

STM32F407xx family incorporates high-speed embedded memories (Flash memory up to 1 Mbyte, up to 192 Kbytes of SRAM), up to 4 Kbytes of backup SRAM, and an extensive range of enhanced I/Os and peripherals connected to two APB buses, three AHB buses and a 32-bit multi-AHB bus matrix. All devices offer three 12-bit ADCs, two DACs, a low-power RTC, twelve general-purpose 16-bit timers including two PWM timers for motor control, two general-purpose 32-bit timers. a true random number generator (RNG). They also feature standard and advanced communication interfaces.

- Up to three I2Cs
- Three SPIs, two I2Ss full duplex. To achieve audio class accuracy, the I2S peripherals can be clocked via a dedicated internal audio PLL or via an external clock to allow synchronization.
- Four USARTs plus two UARTs
- An USB OTG full-speed and a USB OTG high-speed with full-speed capability (with the ULPI),
- Two CANs
- An SDIO/MMC interface
- Ethernet and the camera interface available on STM32F407xx devices only.

New advanced peripherals include an SDIO, an enhanced flexible static memory control (FSMC) interface (for devices offered in packages of 100 pins and more), a camera interface for CMOS sensors. The STM32F405xx and STM32F407xx family operates in the –40 to +105 °C temperature range from a 1.8 to 3.6 V power supply. The supply voltage can drop to 1.7 V when the device operates in the 0 to 70 °C temperature range using an external power supply supervisor. Internal reset OFF.

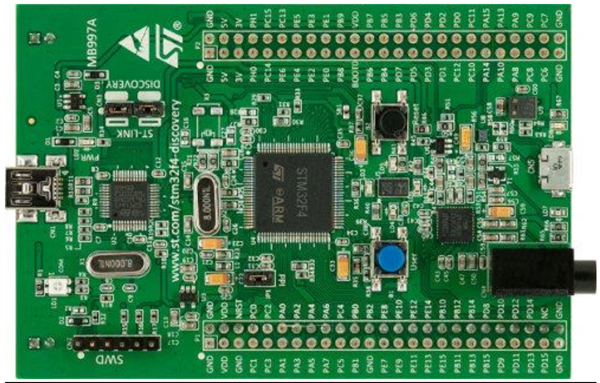

Fig 4.3 STM32F407VGT6

4.2 STM3240G-EVAL Board

The STM3240G-EVAL evaluation board is a complete demonstration and development platform for the STM32 F4 series and includes an STM32F407IGH6 high-performance ARM®Cortex™-M4F 32-bit microcontroller.

STM32F407ZGT6: the STM32F4 microcontroller features are:

- Core: ARM Cortex-M4 32-bit RISC
- Feature: a full set of single-cycle DSP instructions
- Operating frequency: 168MHz, 210 DMIPS/1.25 DMIPS/MHz
- Operating voltage: 1.8V-3.6V
- Package: LQFP144
- Memories: 1024KB Flash, 128+4kB SRAM
- MCU communication interfaces:
    - 3 x SPI, 3 x USART, 2 x UART, 2 x I2S, 3 x I2C
    - 1 x FSMC, 1 x SDIO, 2 x CAN
    - 1 x USB 2.0 high-speed/full-speed device/host/OTG controller.
    - 1 x 10/100 Ethernet MAC
    - 1 x 8 to 14-bit parallel camera interface
- AD & DA converters: 3 x AD (12-bit, 1μs, shares 24 channels); 2 x DA (12-bit)
- Debugging/Programming: supports JTAG/SWD .

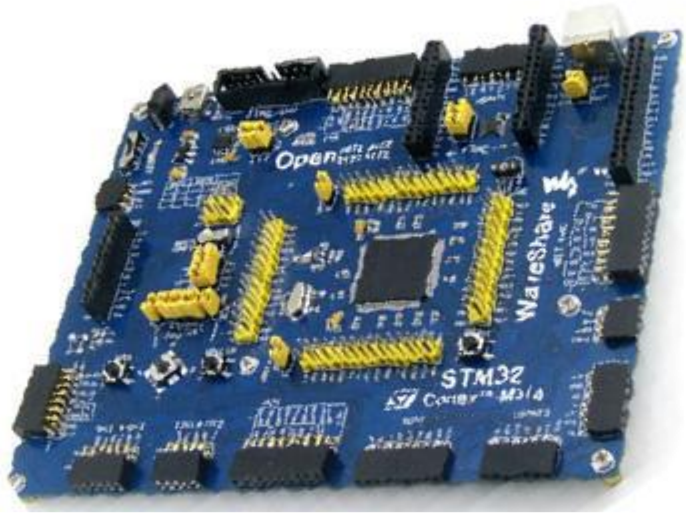

Fig4.4 STM3240G EVAL Board

4.3 GYROSCOPE-ITG3200

The ITG-3200 consists of the following key blocks and functions:

- Three-axis MEMS rate gyroscope sensors with individual 16-bit ADCs and signal conditioning
- I2C serial communications interface
- Clocking
- Sensor Data Registers
- Interrupts
- Digital-Output Temperature Sensor
- Bias and LDO
- Charge Pump

The ITG-3200 consists of three independent vibratory MEMS gyroscopes, which detect rotational rate about the X (roll), Y (pitch), and Z (yaw) axes. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a deflection that is detected by a capacitive pickoff. The resulting signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. This voltage is digitized using individual on-chip 16-bit Analog-to-Digital Converters (ADCs) to sample each axis.

The full-scale range of the gyro sensors is preset to ±2000 degrees per second (°/s). The ADC output rate is programmable up to a maximum of 8,000 samples per second down to 3.9 samples per second, and user-selectable lowpass filters enable a wide range of cut-off frequencies.

Fig 4.5 Gyroscope (ITG3200)

4.4 MAGNETOMETER-HMR2300

The Honeywell HMR2300 is a three-axis smart digital magnetometer to detect the strength and direction of an incident magnetic field. The three of Honeywell's magneto-resistive sensors are oriented in orthogonal directions to measure the X, Y and Z vector components of a magnetic field. These sensor outputs are converted to 16-bit digital values using an internal delta-sigma A/D converter. An onboard EEPROM stores the magnetometer's configuration for consistent operation. The data output is serial full-duplex RS-232 or half-duplex RS-485 with 9600 or 19,200 data rates.

A RS-232 development kit version is available that includes a windows compatible demo program, interface cable, AC adapter, and carrying case.

Honeywell continues to maintain product excellence and performance by introducing innovative solid-state magnetic sensor solutions. These are highly reliable, top performance products that are delivered when promised. Honeywell's magnetic sensor solutions provide real solutions you can count on.

Applications include: Attitude Reference, Compassing & Navigation, Traffic and Vehicle

Detection, Anomaly Detection, Laboratory Instrumentation and Security Systems.

Fig 4.6 Magnetometer (HMR2300)

CHAPTER 5
ATTITUDE DETERMINATION CONTROL SYSTEM

5.1 INTRODUCTION

STUDSAT-2's Attitude Determination and Control System (ADCS) is responsible for maintaining the proper orientation of the satellite during a specified orbit period. Proper orientation of the satellite ensures more accurate pointing for payload (CMOS Camera) and for Inter-satellite communication. Using sun sensor, magnetometer and inertial sensors, the orientation of the satellite can be determined. The STUDSAT-2 satellite will use magnetic torquer coil and reaction wheels as actuators to correct its orientation.

The goal of this configuration is to ensure that the satellite has ADCS that will maintain a sun-synchronous, polar orbit with nadir pointing within +/-10 accuracy. The appropriate sensors and actuators have been studied and chosen to reflect cost and power requirements among other specifications. The MATLAB and Satellite Analysis and Mission Operation Simulation (SAMOS) software package is being used to simulate and analyse the ADCS design.

This design addresses the attitude determination and control methods and hardware required for the different phases of the orbit. These phases of orbit are referred to as detumbling, initial attitude determination, and attitude maintenance. It is important to understand the scope of each phase to be addressed before selecting sensors, actuators, the attitude determination methods and controllers to be used.

After the satellite is released from the launch vehicle into orbit, it will have angular velocities. To have control in its attitude, the satellite must be in a detumble state, which means that the angular velocities of the satellite are controlled to near zero. A controller is required to detumble the satellite so that the initial attitude determination can be performed. The initial attitude determination uses magnetometer and sun sensor to determine the attitude of the satellite just after it has been detumbled. There is no forced change in attitude during this phase and the initial attitude determination gives the existing attitude of the satellite. After the initial attitude of the satellite has been determined, the controller will be used to alter the existing attitude of the satellite to the desired attitude. This controller, along with another attitude determination method, is used to harmoniously ensure that the satellite is at desired attitude throughout the orbit. Figure 3.1 below shows the visual reference of the three phases of the satellite mission.

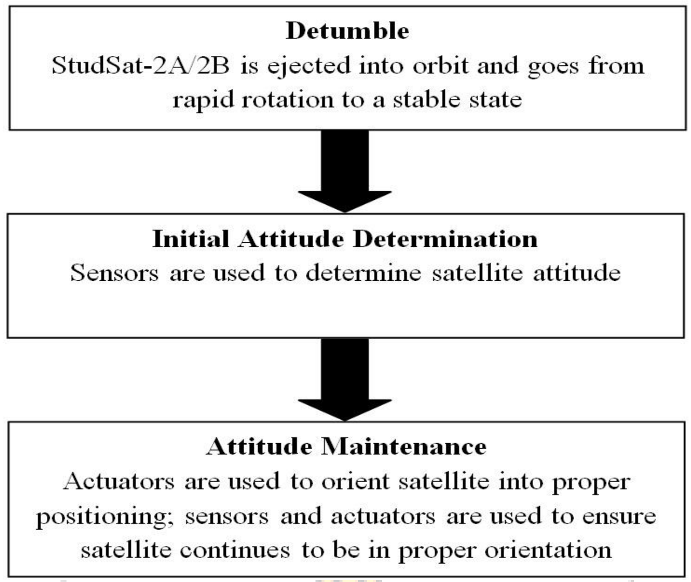

Fig 5.1 Mission Phases of the ADCS

5.2 TWO PHASE DETUMBLING CONTROLLER BASED ON B-DOT

The first and most important attitude control task to be executed, after orbital insertion of the satellite is reducing its angular rate, i.e. detumbling. This procedure should be done by a robust and failsafe system. A very simple method to detumble using magnetic actuation is the B-dot algorithm.

The principle of a B-dot controller is to minimize the derivative of the magnetic field vector measured by a magnetometer. As the spacecraft orbits the Earth, the magnetic field vector in the spacecraft reference frame changes, depending on the position of the spacecraft. However, the dominant rate of change of direction of the field vector is caused by the tumbling of the satellite, as it may tumble with angular rates much larger than the orbital rate (i.e. 30/s to 100/s). Minimizing the change in the measured field vector by magnetic torquing by which angular rate are brought close to the orbital rate.

A novel two stage method of de-tumbling is to be used to detumble STUDSAT-2A/2B. The detumble control will take place post ejection and post solar panel and antenna deployment. At the first phase of detumble mode, the control of magnetic torquer coils of both the satellites (STUDSAT-2A/2B) will be commanded from the controller of master satellite (STUDSAT-2A) considering two satellites as single satellite. Once the connected satellites are detumbled, the satellites will be separated, solar panel and communication antennas will be deployed. The second phase of detumble mode will be executed to null the disturbance caused by separation of satellites.

Figure5.2 below shows the block diagram of detumbling mode.

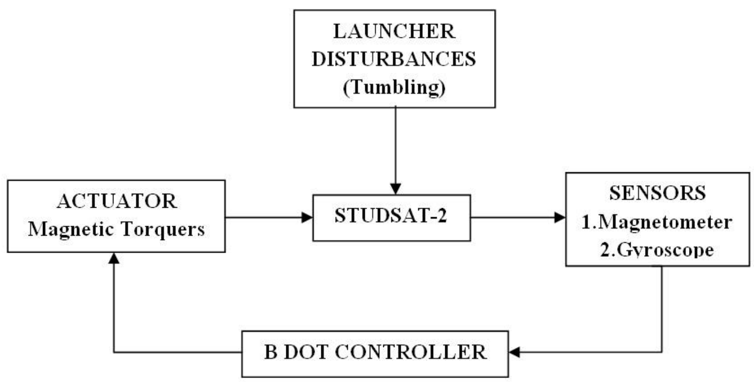

Fig 5.2 Detumbling mode

5.3 PERIODIC MEASUREMENT AND ACTUATION

The B-dot control law described is stated without any constraints to the measured Bfield or the output to the magnetic actuators. However, usage of the actuators while trying to measure the B-field with the magnetometer, causes a disturbance to the measurements, that introduces a feedback in the control loop, which cannot easily be estimated. In order to avoid this potential problem the actuators and the sensor are not used simultaneously but a periodic time-sharing is adopted.

The period of the control/measurement cycle is $T_{cycle} = T_{sensor} + T_{actuator}$. During the period T_{sensor} the sensor readings are fed to the discrete B-dot estimation filter which settles to an estimate of the rate of change of the B-field. During the rest of the time of the cycle period, $T_{actuator}$, the output from the controller is held at a constant value, yielding a constant magnetic dipole moment from the actuators. All readings from the magnetometer are discarded in the actuation period and the input to the estimation filter is held at zero.

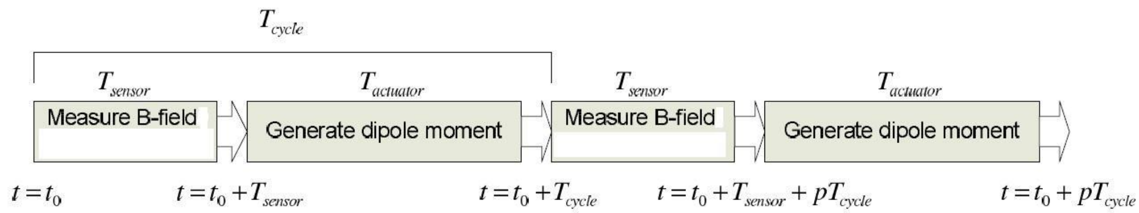

Fig 5.3 Periodic measurement and actuation

5.4 INITIAL ATTITUDE DETERMINATION

The following section provides a description of the attitude determination method that is considered for STUDSAT-2A/2B mission. There are two main types of attitude determination methods. Deterministic methods use the information from sensor readings throughout the mission and compare them to computer models to calculate the current attitude. Recursive estimators (e.g. Kalman filter) are often more convenient, however, as they do not require the data storage of each sensor reading. They process only the current sensor readings and compare them to the last attitude estimate to create a new attitude estimate.

For the initial attitude determination, a deterministic approach is necessary, as a recursive approach would require an initial attitude estimate. There are several different deterministic algorithms for attitude determination. Most require either an intricate sensor or a simple sensor with a complex algorithm. An intricate sensor would be too expensive for our mission. TRIAD algorithm is a good compromise between these two methods.

The TRIAD solution requires two sets of vectors: an observation vector from each of two sensors located on the satellite, and a reference vector for each observation in terms of its inertial direction of reference. STUDSAT-2 will use a sun sensor to determine the direction of the sun from the satellite and a magnetometer to determine the direction of the Earth‘s magnetic field, both measured in terms of the satellite‘s body frame. These sensors would provide the two observation vectors. The two reference vectors would be the direction of the sun from the Earth and the Earth‘s magnetic field, both expressed in terms of the Earth‘s fixed inertial frame. The schematic below provides a flowchart of the TRIAD algorithm.

CHAPTER 6

MAGNETOMETER INTERFACE

6.1 INTRODUCTION

The Honeywell's HMR2300 magnetometer is chosen for StudSat-2 mainly based on its high accuracy, range, low power consumption and ease of implementation. HMR2300 is also flight proven on many satellites such as Proiteres and Radio aurora explorer (RAX) missions. Table 1 presents specifications of HMR2300.

Table: 6.1 Properties of the HMR2300 magnetometer

Type	Three-axis smart digital magnetometer
Range	+/-2 [gauss]
Accuracy	+/-1 [gauss]
Resolution	67µgauss
Interface	RS-232 serial data interfaces
Sampling frequency	10 to 154 samples per second (Selectable)
Supply current	24mA (Vsupply = 9V)
Operating temperature	-40 to +85 [$_0$C]
Weight	98grams (PCB and flanged enclosure)

The Honeywell HMR2300 is a three-axis smart digital magnetometer to detect the strength and direction of an incident magnetic field. The three of Honeywell’s magneto-resistive sensors are oriented in orthogonal directions to measure the X, Y and Z vector components of a magnetic field. These sensor outputs are converted to 16-bit digital values using an internal deltasigma A/D converter. An onboard EEPROM stores the magnetometer’s configuration for consistent operation. The data output is serial full-duplex RS-232 or half-duplex RS-485 with 9600 or 19,200 data rates.

A RS-232 development kit version is available that includes a windows compatible demo program, interface cable, AC adapter, and carrying case.

Honeywell continues to maintain product excellence and performance by introducing innovative solid-state magnetic sensor solutions. These are highly reliable, top performance products that are delivered when promised. Honeywell's magnetic sensor solutions provide real solutions you can count on.

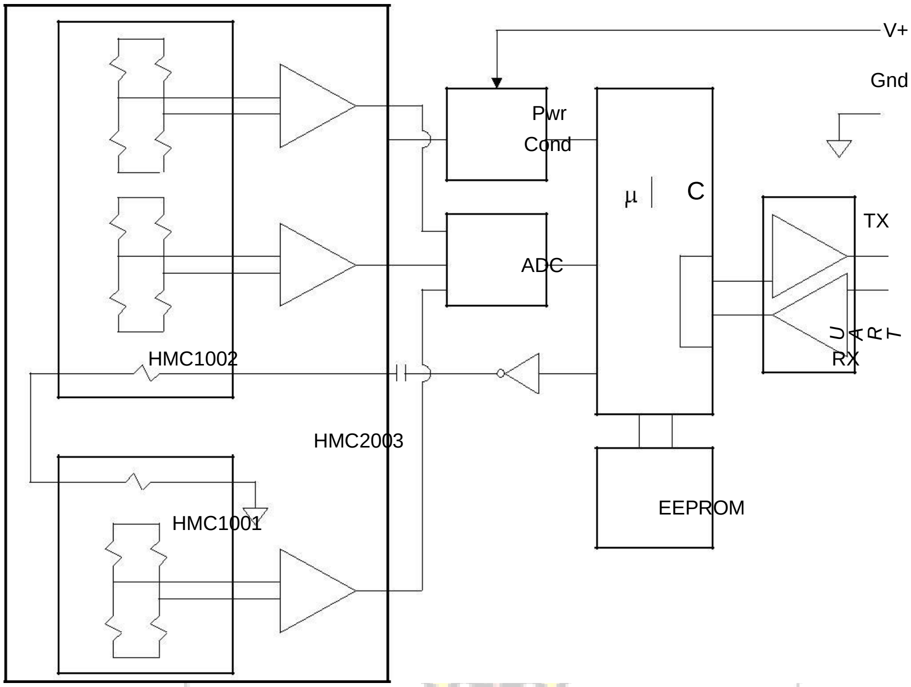

Fig 6.1 Internal block diagram of HMR2300 Magnetometer

Table: 6.2 Pin configurations of magnetometer

Pin Number	Pin Name	Description
1	NC	No Connection
2	TD	Transmit Data, RS-485 (B+)
3	RD	Receive Data, RS-485 (A-)
4	NC	No Connection
5	GND	Power and Signal Ground
6	NC	No User Connection (factory X offset strap +)
7	NC	No User Connection (factory Y offset strap +)
8	NC	No User Connection (factory Z offset strap +)
9	V+	Unregulated Power Input (+6 to +15 VDC)

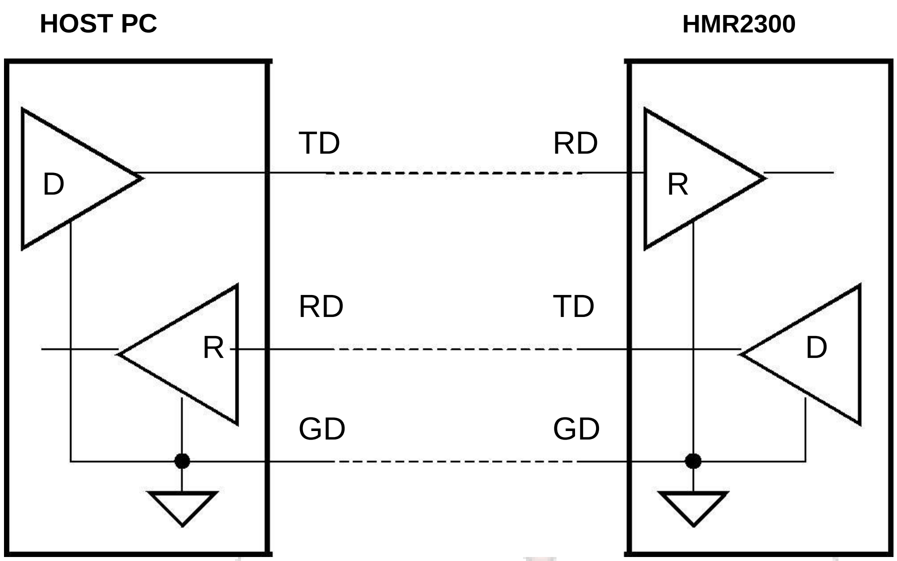

Fig 6.2 RS-232 Unbalanced I/O interconnects

6.2 DATA COMMUNICATIONS

The RS-232 signals are single-ended unidirectional levels that are sent received simultaneously (full duplex). One signal is from the host personal computer (PC) transmit (TD) to the HMR2300 receive (RD) data line, and the other is from the HMR2300 TD to the PC RD data line. When a logic one is sent, either the TD or RD line will drive to about +6 Volts referenced to ground. For a logic zero, the TD or RD line will drive to about –6 Volts below ground. Since the signals are transmitted and dependent on an absolute voltage level, this limits the distance of transmission due to line noise and signal to about 60 feet.

6.3 COMMAND INPUTS

A simple command set is used to communicate with the HMR2300. These commands can be automated; or typed in real-time while running communication software programs, such a windows HyperTerminal.

Table: 6.3 Command signals of the HMR2300 magnetometer

Command	Inputs(1)	Response(2)	Bytes(3)	Description
Format	*ddWE *ddA *ddWE *ddB	ASCII_ON¬ BINARY_ON¬	9 10	ASCII – Output Readings in BCD ASCII Format (Default) Binary – Output Readings in Signed 16-bit Bianary Format
Output	*ddP *ddC Esc	{x, y, z reading} {x, y, z stream} {stream stops}	7 or 28 ... 0	P = Polled – Output a Single Sample (Default) C = Continuous – Output Readings at Sample Rate Escape Key – Stops Continuous Readings
Sample Rate	*ddWE *ddR=nnn	OK¬	3	Set Sample Rate to nnn Where: Nnn = 10, 20, 25, 30, 40, 50, 60, 100, 123, or 154 Samples/sec (Default = 20)
Set/Reset Mode	*ddWE *ddTN *ddWE *ddTF *ddWE *ddT	S/R_ON¬ S/R_OFF¬ {Toggle}	7 8 7 or 8	S/R Mode: TN – ON = Auto S/R Pulses (Default) TF – OFF = Manual S/R Pulses *ddT Toggles Command (Default = On)
Set/Reset Pulse	*dd]S *dd]R *dd]	SET¬ RST¬ {Toggle}	4 4 4	] Character – Single S/R:]S -> SET = Set Pulse]R -> RST = Reset Pulse Toggle Alternates Between Set and Reset Pulse
Device ID	*99ID= *ddWE *ddID=nn	ID=_nn¬ OK¬	7 3	Read Device ID (Default = 00) Set Device ID Where nn = 00 to 98
Baud Rate	*99WE *99!BR=S *99WE *99!BR=F	OK¬ BAUD_9600¬ OK¬ BAUD=_19,200¬	14 14	Set Baud Rate to 9600 bps (Default) Set Baud Rate to 19,200 bps (8 bits, no parity, 1 stop bit)
Zero Reading	*ddWE *ddZN *ddWE *ddZF *ddWE *ddZR	ZERO_ON¬ ZERO_OFF¬ {Toggle}	8 9 8 or 9	Zero Reading Will Store and Use Current as a Negative Offset so That the Output Reads Zero Field *ddZR Toggles Command
Average Readings	*ddWE *ddVN *ddWE *ddVF *ddWE *ddV	AVG_ON¬ AVG_OFF¬ {Toggle}	7 8 7 or 8	The Average Reading for the Current Sample X(N) is: Xavg=X(N)/2 + X(N-1)/4 + X(N-2)/8 + X(N-3)/16 + ... *ddV Toggles Command
Re-Enter Response	*ddWE *ddY *ddWE *ddN	OK¬ OK¬	3 3	Turn the “Re-Enter” Error Response ON (*ddY) or OFF (*ddN). OFF is Recommended for RS-485 (Default = ON)
Query Setup	*ddQ	{See Desc.}	62-72	Read Setup Parameters. Default: ASCII, POLLED, S/R ON, ZERO OFF, AVG OFF, R ON, ID=00, 20 sps
Default Settings	*ddWE *ddD	OK¬ BAUD=_9600¬	14	Change All Command Parameter Settings to Factory Default Values
Restore Settings	*ddWE *ddRST	OK¬ BAUD=_9600¬ *or* BAUD=_19,200¬	 14 16	Change All Command Parameter Settings to the Last User Stored Values in the EEPROM
Serial Number	*dd#	SER#_nnnn¬	22	Output the HMR2300 Serial Number
Software Version	*ddF	S/W_vers:_ nnnn¬	27	Output the HMR2300 Software Version Number
Hardware	*ddH	H/W_vers:_	19	Output the HMR2300 Hardware Version Number

Version		nnnn¬		
Write Enable	*ddWE	OK¬	3	Activate a Write Enable. This is required before commands: Set Device ID, Baud Rate, and Store.
Store Parameters	*ddWE *ddSP	DONE¬ OK¬	8	This writes all parameter settings to EEPROM. These values will be automatically restored upon power-up.
Too Many Characters	Wrong Entry	Re-enter¬	9	A command was not entered properly or 10 characters were typed after an asterisk (*) and before a <cr>.
Missing WE Entry	Write Enable Off	WE_OFF¬	7	This error response indicates that this instruction requires a write enable command immediately before it.

Binary Format: 7 Bytes

X_H | X_L | Y_H | Y_L | Z_H | Z_L | <cr>

X_H = Signed Byte, X axis

X_L = Low Byte, X axis

<cr> = Carriage Return (Enter key), Hex Code = 0D

ASCII Format: 28 Bytes

SN | X1 | X2 | CM | X3 | X4 | X5 | SP | SP | SN | Y1 | Y2 | CM | Y3 | Y4 | Y5 | SP | SP | SN | Z1 | Z2 | CM | Z3 | Z4 | Z5 | SP | SP |<cr>

6.4 APPLICATIONS PRECAUTIONS

Several precautions should be observed when using magnetometers in general:

The presence of ferrous materials, such as nickel, iron, steel, and cobalt near the magnetometer will create disturbances in the earth's magnetic field that will distort the X, Y, and Z field measurements.

The presence of the earth's magnetic field must be taken into account when measuring other magnetic fields.

The variance of the earth's magnetic field must be accounted for in different parts of the world. Differences in the earth's field are quite dramatic between North America, South America and the Equator region.

Perming effects on the HMR2300 circuit board need to be taken into account. If the HMR2300 is exposed to fields greater than 10 gauss, then it is recommended that the enclosure/circuit boards be degaussed for highest sensitivity and resolution. A possible result of perming is a high zero-field output indication that exceeds specification limits.

Degaussing wands are readily available from local electronics tool suppliers and are inexpensive. Severe field offset values could result if not degaussed.

6.5 USART

The universal asynchronous receiver/transmitter (UART) takes bytes of data and transmits the individual bits in a sequential fashion. At the destination, a second UART re-assembles the bits into complete bytes. Each UART contains a shift register, which is the fundamental method of conversion between serial and parallel forms. Serial transmission of digital information (bits) through a single wire or other medium is less costly than parallel transmission through multiple wires.

The UART usually does not directly generate or receive the external signals used between different items of equipment. Separate interface devices are used to convert the logic level signals of the UART to and from the external signalling levels. External signals may be of many different forms. Examples of standards for voltage signaling are RS-232, RS-422 and RS-485 from the EIA.

Communication may be simplex (in one direction only, with no provision for the receiving device to send information back to the transmitting device), full duplex (both devices send and receive at the same time) or half duplex (devices take turns transmitting and receiving).

Thus with the understanding of the protocol and the working of the magnetometer, the interfacing of the magnetometer with ARM may be understood referring to the flow chart shown in Fig 6.3

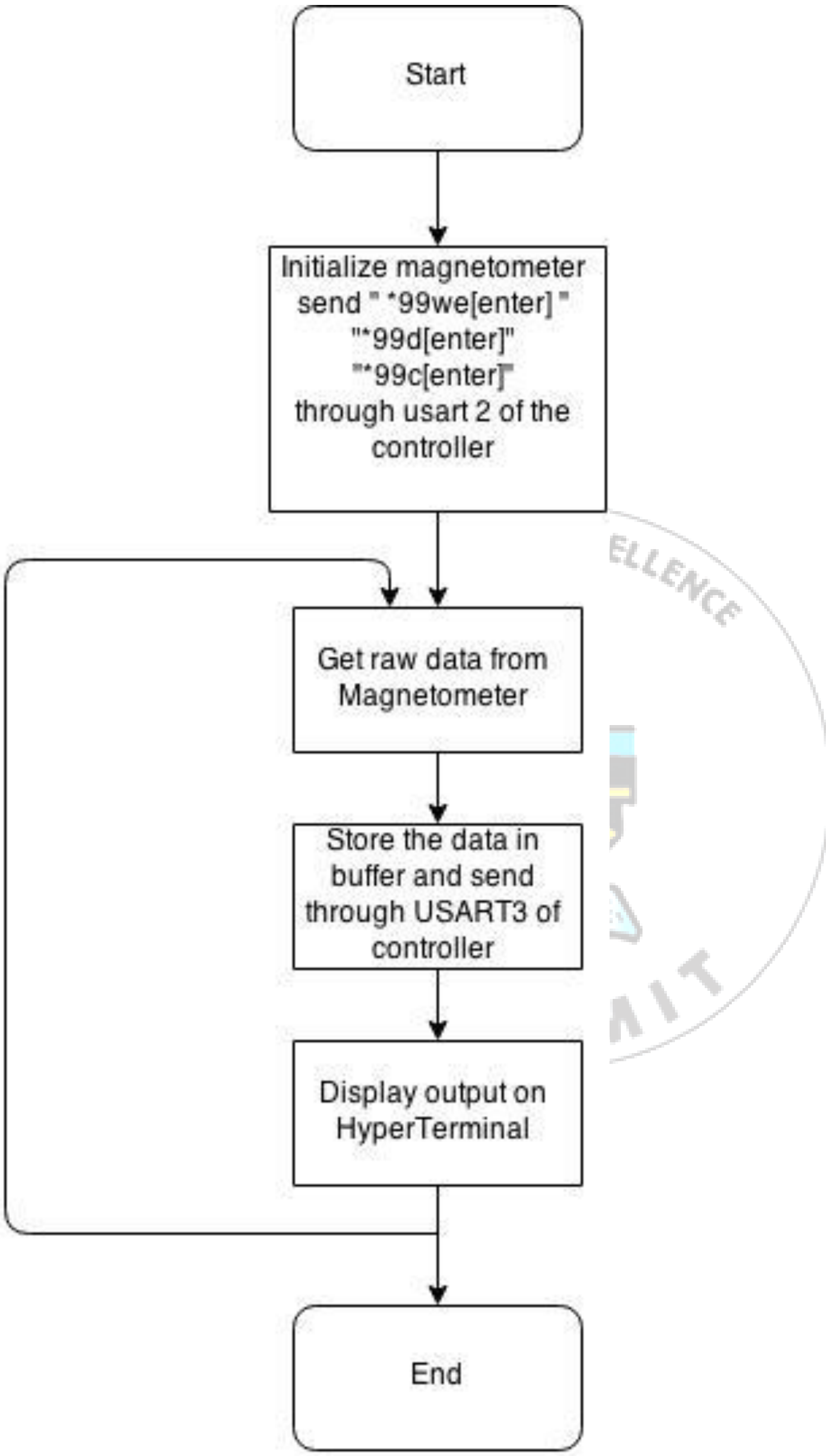

Fig 6.3 Flow chart of magnetometer interface

CHAPTER 7

GYROSCOPE INTERFACE

7.1 INTRODUCTION

An extensive search for inertial sensors that would provide high accuracy attitude knowledge for a satellite was conducted. The InvenSence ITG3200 gyro sensor is chosen for StudSat-2 mainly based on its high sensitivity range, noise performance, size, power consumption and performance. Table presents specifications of ITG3200.

Table: 7.1 Properties of ITG3200 gyroscope

Type	Three-axis MEMS gyro IC
Range	+/-2000 [0/s]
Sensitivity	14.375 LSB [0/s]
Non-linearity	<1% of full scale
Size	4x4x0.9 [mm]
Interface	I2C serial interface
Supply current	6.5mA (Vsupply=3.3V)
Shock tolerance	10,000 [g]
Operating temperature	-30 to +85 [0C]

Table 7.2 Pin out and signal description

Number	Pin	Pin Description
1	CLKIN	Optional external reference clock input. Connect to GND if unused.
8	VLOGIC	Digital IO supply voltage. VLOGIC must be ≤ VDD at all times.
9	AD0	I^2C Slave Address LSB
10	REGOUT	Regulator filter capacitor connection
12	INT	Interrupt digital output (totem pole or open-drain)
13	VDD	Power supply voltage
18	GND	Power supply ground
11	RESV-G	Reserved - Connect to ground.
6, 7, 19, 21, 22	RESV	Reserved. Do not connect.
20	CPOUT	Charge pump capacitor connection
23	SCL	I^2C serial clock
24	SDA	I^2C serial data
2, 3, 4, 5, 14, 15, 16, 17	NC	Not internally connected. May be used for PCB trace routing.

7.2 THREE-AXIS MEMS GYROSCOPE

The ITG-3200 consists of three independent vibratory MEMS gyroscopes, which detect rotational rate about the X (roll), Y (pitch), and Z (yaw) axes. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a deflection that is detected by a capacitive pickoff. The resulting signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. This voltage is digitized using individual on-chip 16-bit Analog-to-Digital Converters (ADCs) to sample each axis.

The full-scale range of the gyro sensors is preset to ±2000 degrees per second (°/s). The ADC output rate is programmable up to a maximum of 8,000 samples per second down to 3.9 samples per second, and user-selectable low-pass filters enable a wide range of cut-off frequencies.

7.3 I2C SERIAL COMMUNICATIONS INTERFACE

The ITG-3200 communicates to a system processor using the I^2C serial interface, and the device always acts as a slave when communicating to the system processor. The logic level for communications to the master is set by the voltage on the VLOGIC pin. The LSB of the of the I^2C slave address is set by pin 9 (AD0).

7.4 CLOCKING

The ITG-3200 has a flexible clocking scheme, allowing for a variety of internal or external clock sources for the internal synchronous circuitry. This synchronous circuitry includes the signal conditioning, ADCs, and various control circuits and registers. An on-chip PLL provides flexibility in the allowable inputs for generating this clock.

Allowable internal sources for generating the internal clock are:

- An internal relaxation oscillator (less accurate)
- Any of the X, Y, or Z gyros' MEMS oscillators (with an accuracy of ±2% over temperature)

Allowable external clocking sources are:

32.768 kHz square wave

19.2MHz square wave

Which source to select for generating the internal synchronous clock depends on the availability of external sources and the requirements for clock accuracy. There are also start-up conditions to consider. When the ITG-3200 first starts up, the device operates off of its internal clock until programmed to operate from another source. This allows the user, for example, to wait for the MEMS oscillators to stabilize before they are selected as the clock source.

7.5 SENSOR DATA REGISTERS

The sensor data registers contain the latest gyro and temperature data. They are read-only registers, and are accessed via the Serial Interface. Data from these registers may be read at any time, however, the interrupt function may be used to determine when new data is available.

7.6 INTERRUPTS

Interrupt functionality is configured via the Interrupt Configuration register. Items that are configurable include the INT pin configuration, the interrupt latching and clearing method, and triggers for the interrupt. Items that can trigger an interrupt are (1) Clock generator locked to new reference oscillator (used when switching clock sources); and (2) new data is available to be read from the Data registers. The interrupt status can be read from the Interrupt Status register.

7.7 DIGITAL-OUTPUT TEMPERTURE SENSOR

An on-chip temperature sensor and ADC are used to measure the ITG-3200 die temperature. The readings from the ADC can be read from the Sensor Data registers.

7.8 BIAS AND LDO

The bias and LDO sections take in an unregulated VDD supply from 2.1V to 3.6V and generate the internal supply and the references voltages and currents required by the ITG-3200. The LDO output is bypassed by a capacitor at REGOUT. Additionally, the part has a VLOGIC reference voltage which sets the logic levels for its I^2C interface.

7.9 CHARGE PUMP

An on-board charge pump generates the high voltage (25V) required to drive the MEMS oscillators. Its output is bypassed by a capacitor at CPOUT

7.10 DIGITAL INTERFACE

7.10.1 I^2C Serial Interface

The internal registers and memory of the ITG-3200 can be accessed using I^2C at up to 400kHz.

Table: 7.3 Serial Interface

Pin Number	Pin Name	Pin Description
8	VLOGIC	Digital IO supply voltage. VLOGIC must be ≤ VDD at all times.
9	AD0	I^2C Slave Address LSB
23	SCL	I^2C serial clock
24	SDA	I^2C serial data

7.10.2 I^2C Interface

I^2C is a two wire interface comprised of the signals serial data (SDA) and serial clock (SCL). In general, the lines are open-drain and bi-directional. In a generalized I^2C interface implementation, attached devices can be a master or a slave. The master device puts the slave address on the bus, and the slave device with the matching address acknowledges the master.

The ITG-3200 always operates as a slave device when communicating to the system processor, which thus acts as the master. SDA and SCL lines typically need pull-up resistors to VDD. The maximum bus speed is 400kHz.

The slave address of the ITG-3200 devices is b110100X which is 7 bits long. The LSB bit of the 7 bit address is determined by the logic level on pin 9. This allows two ITG-3200 devices to be connected to the same I^2C bus. When used in this configuration, the address of the one of the devices should be b1101000 (pin 9 is logic low) and the address of the other should be b1101001 (pin 9 is logic high). The I^2C address is stored in register

0 (WHO_AM_I register).

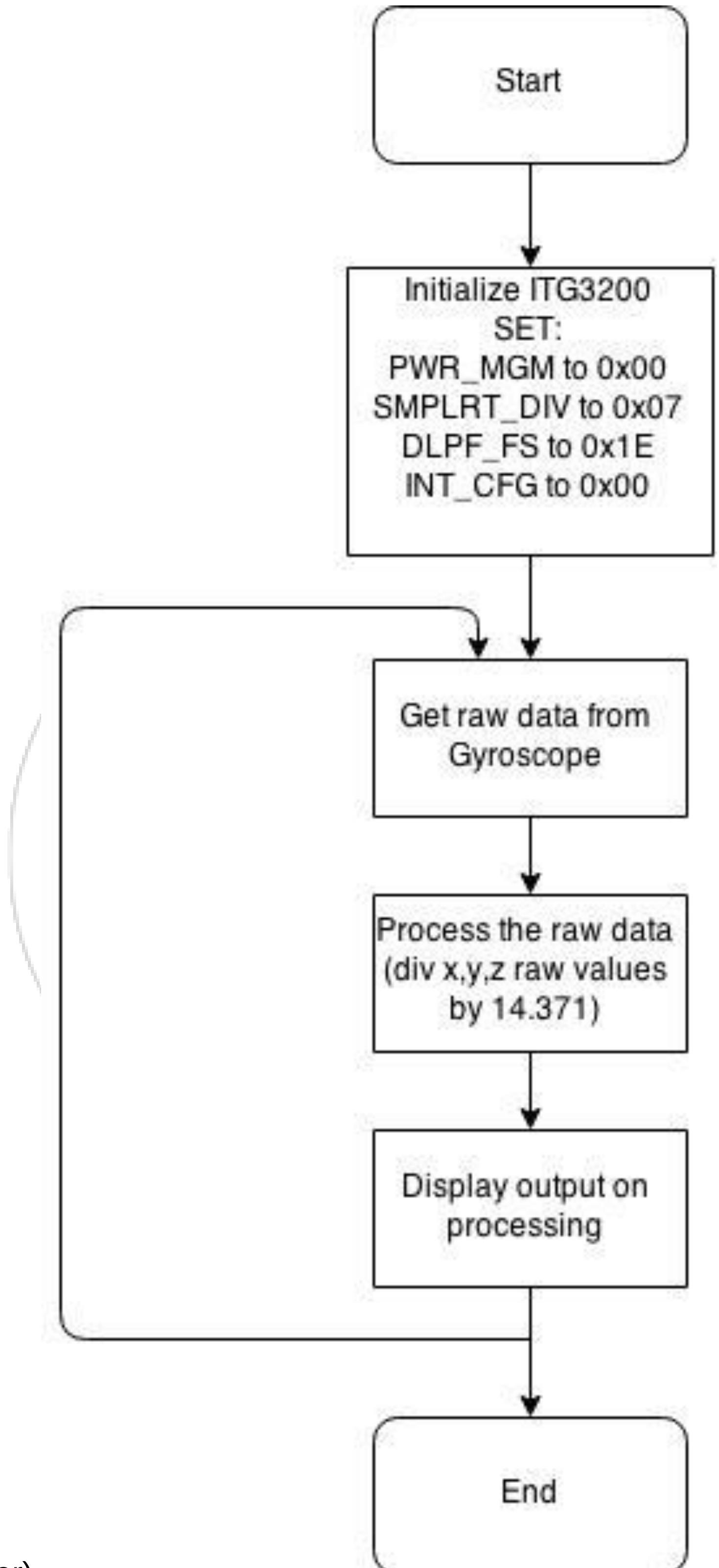

Fig 7.1 Flow chart of gyroscope interface.

CHAPTER 8

RESULTS AND OBSERVATIONS

This chapter deals with results and observations obtained from experiments carried out using various components and devices.

8.1 INTERFACING ITG 3200 GYROSCOPE WITH ARDUINO BOARD

The objectives mentioned earlier have been successfully achieved. The ITG 3200 Gyroscope is successfully interfaced with Arduino Mega2560 board and the output values obtained are analogous to the orientation. The gyroscope returns constant values (0,0,0) as it is kept stable. When it is moved in different directions, the corresponding axis co-ordinate value deviates. The amount of deviation is proportional to the angular velocity with which the Gyroscope is moved. This has been illustrated in figures Fig 8.1, Fig 8.2 and Fig 8.3, and Fig 8.4.

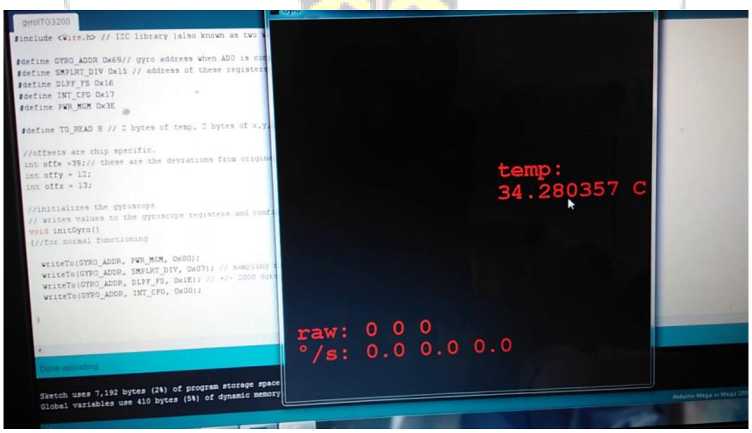

Fig.8.1 Figure showing the processed java output for ITG 3200 in stable conditions

Note: The middle right value is the chip temperature, the first value on the left is the raw output value and the bottom value is the calculated degree per second variation in angular velocity.

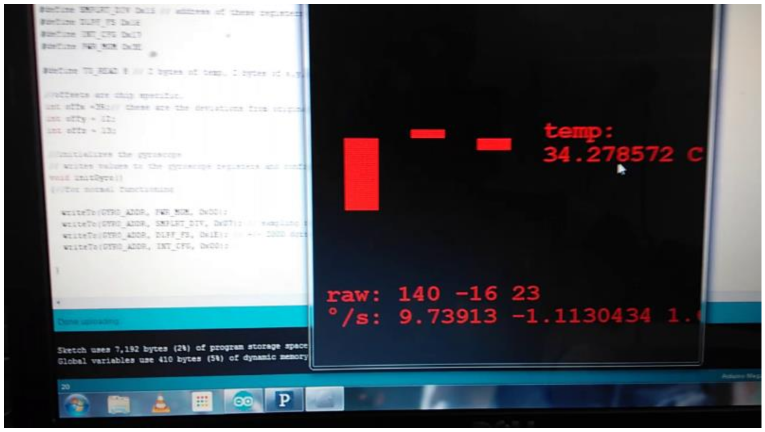

Fig.8.2 Figure showing response to large deviation in x axis and slight deviation in the other two axes

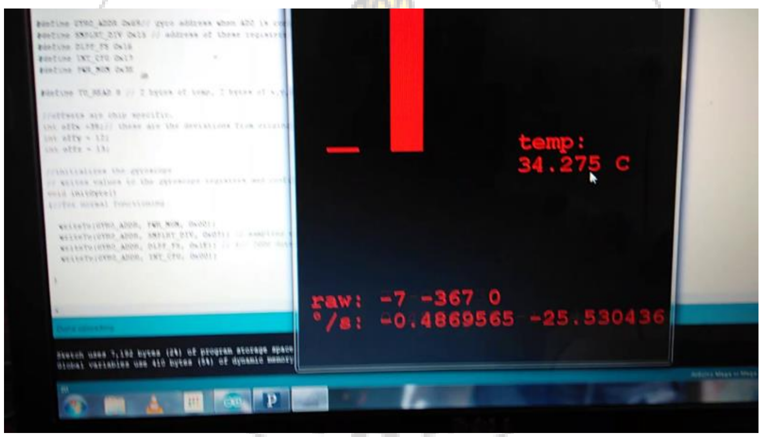

Fig.8.3 Figure showing major deviation in y axis and slight deviation in x axis

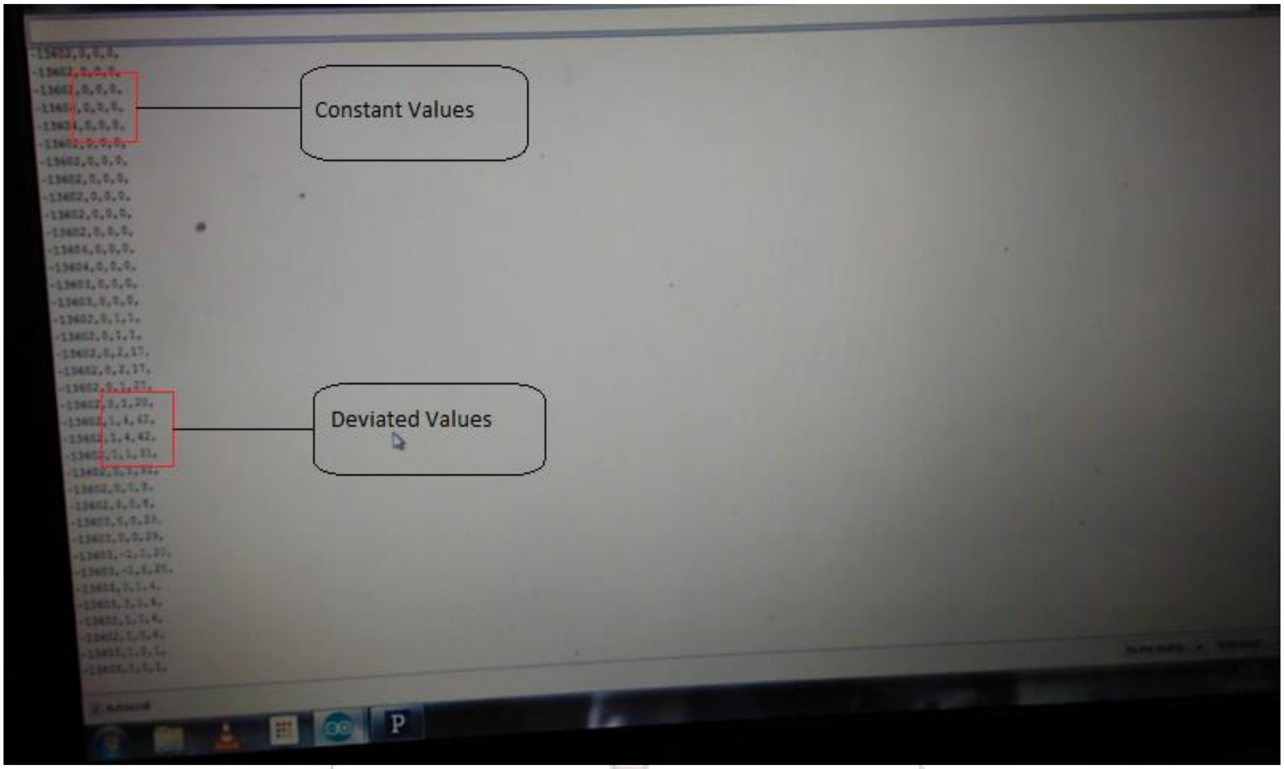

Fig 8.4 Figure showing unprocessed Serial monitor output.

Note: The first value is the raw value for temperature of the chip, the next three values are the raw values depicting the change in angular velocity along the x, y and z axis respectively.

8.2 INTERFACING HMR 2300 WITH STM32F4 DISCOVERY BOARD

The HMR 2300 magnetometer is successfully interfaced with STM32F407VG Discovery. The response changes according to the orientation of the HMR 2300. Initially when the Magnetometer is kept stable and the HyperTerminal is opened, it is seen that three values corresponding to three axis keep are continuously received. As long as the Magnetometer is kept stable, the values remain constant. These are non-calibrated values. As the magnetometer is moved in different directions, the corresponding axis value changes from the initial value. When the Magnetometer is brought back to stable state, the output also shows the initial values. This can be seen in figures Fig 8.5 and Fig 8.6.

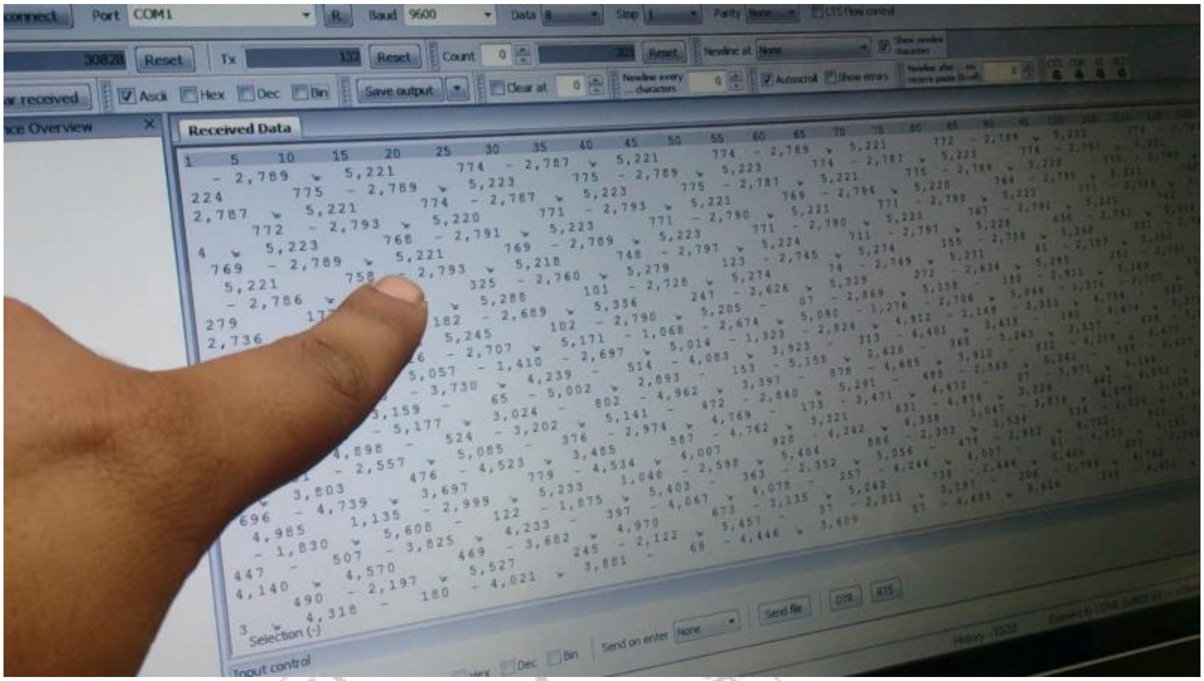

Fig 8.5 Figure pointing to the constant un-calibrated values of the magnetometer readings along the three axes.

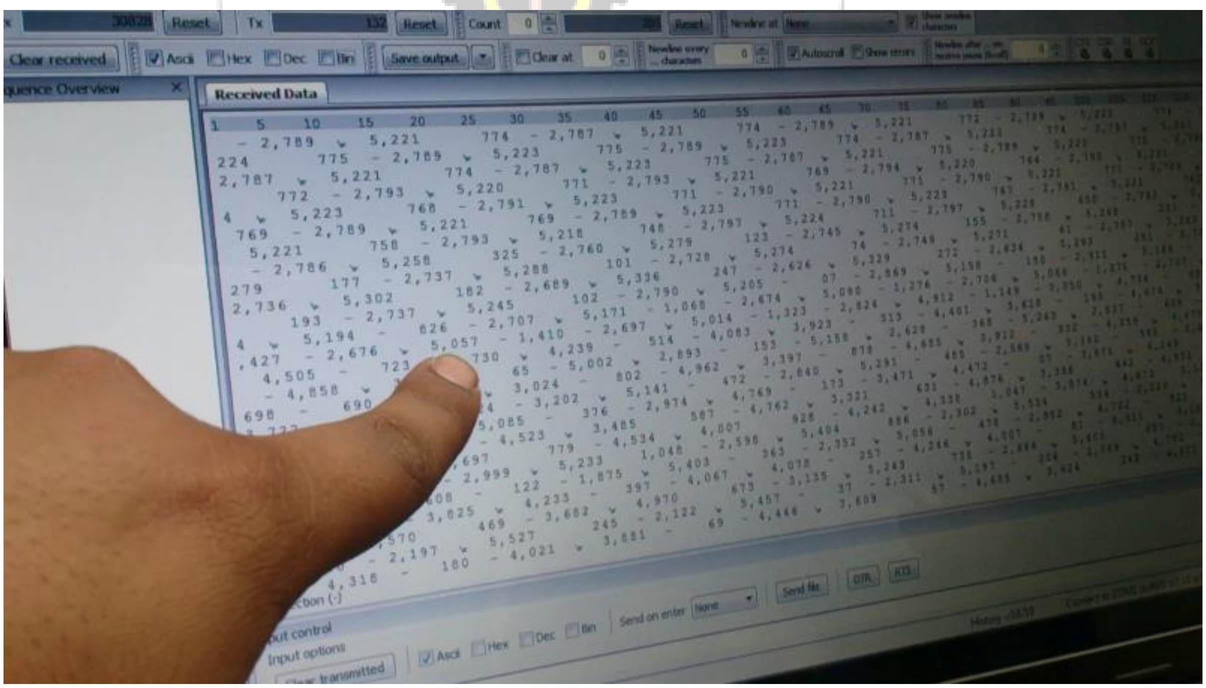

Fig 8.6 Figure pointing to the deviated value due to change in magnetometer orientation.

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APPENDIX A

SATELLITE SPECIFICATION

SPECIFICATIONS OF THE SATELLITE (STUDSAT-2)

General

1. Category: Nano-Satellites
2. Mass: 10kg each
3. Dimension: 30 x 30 x 20 cm3
4. Payload: CMOS Camera, ISL
5. Resolution: 30 m
6. Swath: 48 x 64 km
7. Inter-Satellite Link Frequency: 2.4GHz @ 256Kbps
8. Communication:
    a. Downlink : UHF (434MHz – 437MHz)
    b. Uplink : VHF (144MHz-147MHz)
    c. Beacon : UHF (434MHz – 437MHz)
9. ADCS: 3-Axes Stabilization with nadir pointing accuracy <1degree
2. Sensors: GPS, Sun sensor, Magnetometer, Gyroscope
3. Actuators: Magnetic Torquer Coils and Reaction Wheel
10. Controller: ARM Cortex M-4
11. OS: RTOS
12. Battery: Lithium Ion Battery(5.2Ah)
13. EPS Efficiency: Above 85%
14. Solar Panels: Body mounted and deployed with solar cells of 18% efficiency
15. Mission lifetime: 1 year

Orbital Details

1. Orbit: Sun synchronous polar orbit
2. Altitude: 600 – 700 km (decided by the prime satellite of PSLV)
3. Orbit Period ≈ 98 mins (appx)
4. Inclination ≈ 98° (Assumed)
5. Equatorial Crossing: 9:30 – 10:30 AM (decided by the prime satellite of PSLV)
6. Eccentricity ≈ 0
7. Launcher: PSLV
8. Satellite Separation Rate: 1 km per day = 11.5 mm/s
9. ISL separation: Upto 100 Km

APPENDIX B

STM32407VG DATASHEET

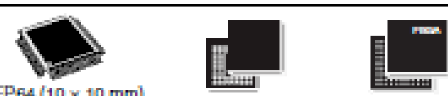
STM32F405xx
STM32F407xx

ARM Cortex-M4 32b MCU+FPU, 210DMIPS, up to 1MB Flash/192+4KB RAM, USB OTG HS/FS, Ethernet, 17 TIMs, 3 ADCs, 15 comm. interfaces & camera

Features

- Core: ARM 32-bit Cortex™-M4 CPU with FPU, Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait state execution from Flash memory, frequency up to 168 MHz, memory protection unit, 210 DMIPS/ 1.25 DMIPS/MHz (Dhrystone 2.1), and DSP instructions
- Memories
  - Up to 1 Mbyte of Flash memory
  - Up to 192+4 Kbytes of SRAM including 64-Kbyte of CCM (core coupled memory) data RAM
  - Flexible static memory controller supporting Compact Flash, SRAM, PSRAM, NOR and NAND memories
- LCD parallel interface, 8080/6800 modes
- Clock, reset and supply management
  - 1.8 V to 3.6 V application supply and I/Os
  - POR, PDR, PVD and BOR
  - 4-to-26 MHz crystal oscillator
  - Internal 16 MHz factory-trimmed RC (1% accuracy)
  - 32 kHz oscillator for RTC with calibration
  - Internal 32 kHz RC with calibration
- Low power
  - Sleep, Stop and Standby modes
  - V_{BAT} supply for RTC, 20x32 bit backup registers + optional 4 KB backup SRAM
- 3×12-bit, 2.4 MSPS A/D converters: up to 24 channels and 7.2 MSPS in triple interleaved mode
- 2×12-bit D/A converters
- General-purpose DMA: 16-stream DMA controller with FIFOs and burst support
- Up to 17 timers: up to twelve 16-bit and two 32-bit timers up to 168 MHz, each with up to 4 IC/OC/PWM or pulse counter and quadrature (incremental) encoder input
- Debug mode
  - Serial wire debug (SWD) & JTAG interfaces
  - Cortex-M4 Embedded Trace Macrocell™

1. The WLCSP90 package will soon be available.



- Up to 140 I/O ports with interrupt capability
  - Up to 136 fast I/Os up to 84 MHz
  - Up to 138 5 V-tolerant I/Os
- Up to 15 communication interfaces
  - Up to 3 × I^2C interfaces (SMBus/PMBus)
  - Up to 4 USARTs/2 UARTs (10.5 Mbit/s, ISO 7816 interface, LIN, IrDA, modem control)
  - Up to 3 SPIs (37.5 Mbits/s), 2 with muxed full-duplex I^2S to achieve audio class accuracy via internal audio PLL or external clock
  - 2 × CAN interfaces (2.0B Active)
  - SDIO interface
- Advanced connectivity
  - USB 2.0 full-speed device/host/OTG controller with on-chip PHY
  - USB 2.0 high-speed/full-speed device/host/OTG controller with dedicated DMA, on-chip full-speed PHY and ULPI
  - 10/100 Ethernet MAC with dedicated DMA: supports IEEE 1588v2 hardware, MII/RMII
- 8- to 14-bit parallel camera interface up to 54 Mbytes/s
- True random number generator
- CRC calculation unit
- 96-bit unique ID
- RTC: subsecond accuracy, hardware calendar

Table 1. Device summary

Reference	Part number
STM32F405xx	STM32F405RG, STM32F405VG, STM32F405ZG
STM32F407xx	STM32F407VG, STM32F407IG, STM32F407ZG, STM32F407VE, STM32F407ZE, STM32F407IE

APPENDIX C

HMR2300 DATASHEET

Honeywell

Magnetic Products

SMART DIGITAL MAGNETOMETER HMR2300

FEATURES

- Microcontroller Based Smart Sensor
- Low Cost and Easy To Use—Just Plug and Read
- Range of ±2 Gauss—<70 µGauss Resolution
- High Accuracy over ±1 Gauss—<0.5%FS
- Output Rate Selectable—10 to 154 Samples/Sec.
- Three-Axis Digital Output—BCD ASCII or Binary
- RS-232 or RS-485 Serial Output—9600 or 19200

APPLICATIONS

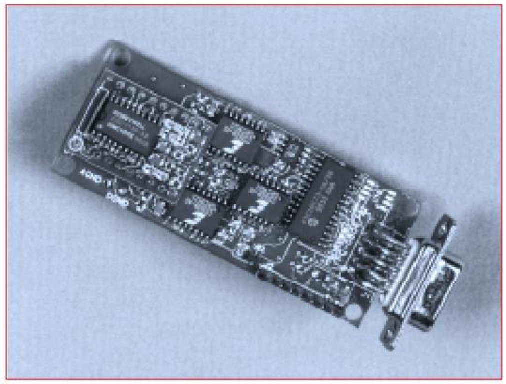
- Compassing—Avionics and Marine
- Remote Vehicle Monitoring (Roll/Pitch/Yaw)
- Process Control
- Laboratory Instrumentation
- Anomaly Detection
- Traffic and Vehicle Detection
- Security Systems

GENERAL DESCRIPTION

Honeywell's three-axis smart digital magnetometer (HMR) detects the strength and direction of a magnetic field and communicates the x, y, and z component directly to a computer. Three independent bridges are oriented to sense the x, y, and z axis of a magnetic field. The bridge outputs are then converted to a 16-bit digital value using an internal delta-sigma A/D converter. A command set is provided (see Table 1) to configure the data sample rate, output format, averaging and zero offset. An on-board EEPROM stores any configuration changes for next time power-up. Other commands perform utility functions like baud rate, device ID and serial number. Also included in the HMR magnetometer is a digital filter with 50/60 Hz rejection to reduce ambient magnetic interference.

A unique switching technique is applied to the permalloy bridge to eliminate the effects of past magnetic history. This technique cancels out the bridge offset as well as any offset introduced by the electronics. The x, y, and z digitized data is sent out as a series of bytes, either after an ID match is received from the control processor, or as a continuous data stream. The data is serially output at either 9,600 or 19,200 baud, using the RS-232 or RS-485 standard, for serial input to most personal computers. The RS-485 standard allows connection of up to 32 devices on a single wire pair up to 4,000 feet in length. An HMR address can be stored in the on-board EEPROM to assign one of thirty-two unique ID codes to allow direct line access. An internal microcontroller handles the magnetic sensing, digital filtering, and all output communications eliminating the need for external trims and adjustments. Standard RS-485 or RS-232 drivers provide compliant electrical signalling.

Honeywell's magnetoresistive magnetometers provide an excellent means of measuring both linear and angular position and displacement. Low cost, high sensitivity, fast response, small size, and reliability are advantages over mechanical or other magnetometer alternatives. With an extremely low magnetic field sensitivity and a user configurable command set, these sensors solve a variety of problems in custom applications. The HMR2300 is available either as a circuit board with an optional 9-pin connector or in an aluminum enclosure with a 9-pin connector. Possible applications include compassing, remote vehicle monitoring, process control, laboratory instrumentation, anomaly detection, traffic and vehicle detection, and retail security systems.



APPENDIX D

ITG3200 DATASHEET

1.2 Purpose and Scope

This document is a preliminary product specification, providing a description, specifications, and design related information for the ITG-3200™. Electrical characteristics are based upon simulation results and limited characterization data of advanced samples only. Specifications are subject to change without notice. Final specifications will be updated based upon characterization of final silicon.

1.3 Product Overview

The ITG-3200 is the world's first single-chip, digital-output, 3-axis MEMS gyro IC optimized for gaming, 3D mice, and 3D remote control applications. The part features enhanced bias and sensitivity temperature stability, reducing the need for user calibration. Low frequency noise is lower than previous generation devices, simplifying application development and making for more-responsive remote controls.

The ITG-3200 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyro outputs, a user-selectable internal low-pass filter bandwidth, and a Fast-Mode I^2C (400kHz) interface. Additional features include an embedded temperature sensor and a 2% accurate internal oscillator. This breakthrough in gyroscope technology provides a dramatic 67% package size reduction, delivers a 50% power reduction, and has inherent cost advantages compared to competing multi-chip gyro solutions.

By leveraging its patented and volume-proven Nasiri-Fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level bonding, InvenSense has driven the ITG-3200 package size down to a revolutionary footprint of 4x4x0.9mm (QFN), while providing the highest performance, lowest noise, and the lowest cost semiconductor packaging required for handheld consumer electronic devices. The part features a robust 10,000g shock tolerance, as required by portable consumer equipment.

For power supply flexibility, the ITG-3200 has a separate VLOGIC reference pin, in addition to its analog supply pin, VDD, which sets the logic levels of its I^2C interface. The VLOGIC voltage may be anywhere from 1.71V min to VDD max.

1.4 Applications

- Motion-enabled game controllers
- Motion-based portable gaming
- Motion-based 3D mice and 3D remote controls
- "No Touch" UI
- Health and sports monitoring