Interdisciplinary Journal of Engineering Sciences Vol.V, No.1 (2017)
http://ijes.pwr.wroc.pl

Electronic flight data acquisition system for remotely piloted aircraft

TOMASZ RUSIECKI, MARCIN SKOWRONEK

Rzeszów University of Technology, Department of Avionics and Control Systems
Powstańców Warszawy 12, 35-959 Rzeszów, Poland

Abstract: *This article presents data acquisition system developed for the use primarily in Remotely Piloted Aircraft Systems. The system consists of several modules which independently function as Air Data Computer, Attitude and Heading Reference System and Flight Data Recorder. Each module works independently from other modules and also provides capability of real time data transmission. The system is capable of wireless data transmission via ZigBee wireless data protocol. The research may be considered as important and valuable due to the fact that it describes innovative concept of "wireless sensors" system. These type of systems are currently only beginning to appear in commercial applications and such wireless systems appear to be a future of metrology in RPAS applications. Features of each module are stated in the article. The prototype device has been tested and confirmed to be operationally functional.*

Keywords: *Air Data Computer, Attitude and Heading Reference System, Data Acquisition System, Wireless Sensor, RPAS.*

1. Introduction

Necessity for acquirement of flight parameters may arise in many situations such as: flight monitoring, flight testing, control model evaluation, flight control applications and potentially in any other areas where accurate flight parameters are required.

Developed data acquisition system is a series of devices used to facilitate gathering flight parameters of a Remotely Piloted Aircraft System (RPAS). The developed system consists of following modules:

- Air Data Computer module (ADC),
- Attitude and Heading Reference System module (AHRS),
- Flight Data Recording module (FDR).

The modules are interconnected with each other using

CANaerospace data bus. Due to versatility of CANaerospace bus other modules may be included in the described system [4]. An example of a prospective extension module is data bus interchange module for MIL-STD-1553B bus functioning as a Remote Terminal (RT), which could share some of or all measured parameters with the devices connected to MIL-STD-1553B bus. Modules are designed in such way that they can exchange measured data with each other providing to the user or to the FDR module the most accurate data as possible. Acquisition system can be considered as a redundant, which is essential in flight control applications.

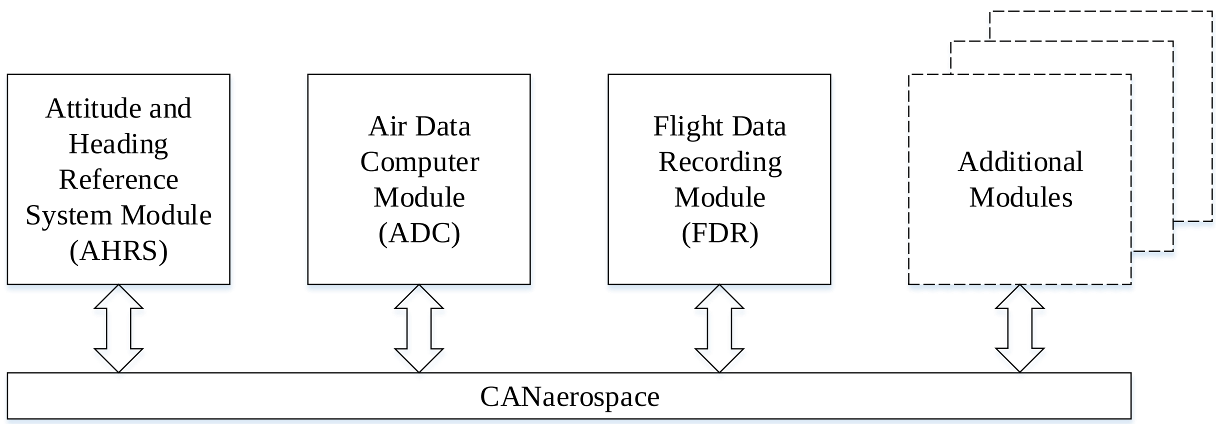


Fig. 1. General structure of the flight data acquisition system [1]

As show on figure 1, the system may be expanded to accommodate growing needs. There's virtually no limit of modules making up the system (number of nodes is limited by the specification of the implemented CAN

transceiver), however there is a requirement that all modules have to implement CANaerospace data bus to enable communication between modules and data recording [4]. The system was invented as an expandable solution, allowing further development of new modules.

2. Design description – device modules

2.1. Air Data Computer Module

An Air Data Computer is a device used to measure these flight parameters which are derived from, in it's most basic form, static pressure, total pressure and total air temperature [3]. Every transport category aircraft and those General Aviation aircraft's with integrated indication systems which combine flight data for presentation on one display (Primary Flight Display), by the means of central computing station, are equipped in ADC [3]. As the market of avionic for General Aviation is growing the development of smaller ADC became more common practice. Nowadays there are many systems designed for even smaller solutions, such as Unnamed Aerial Vehicles (UAV). This presented system was developed as a solution which would be installed in a RPAS.

Air Data Computer calculates most essential parameters such as [3]:

- Barometric altitude,
- Airspeed: IAS (Indicated Airspeed), TAS (True Airspeed),
- Vertical speed.

Additionally the device, while receiving date from the AHRS, can be a source of other information's, such as:

- Wind velocity, wind direction and crab angle,
- Ground speed,
- Temperature: static and total,
- Pressure.

Thanks to the integration between modules additional information can be calculated. Combination of ADC and AHRS result in device called an Air Data/Attitude/Heading Reference System (ADAHRS). In applications where safety of the flight is one of the biggest priorities, several ADAHRS are used to provide redundancy and implement independent measurement of essential data in case of failure of one or more modules.

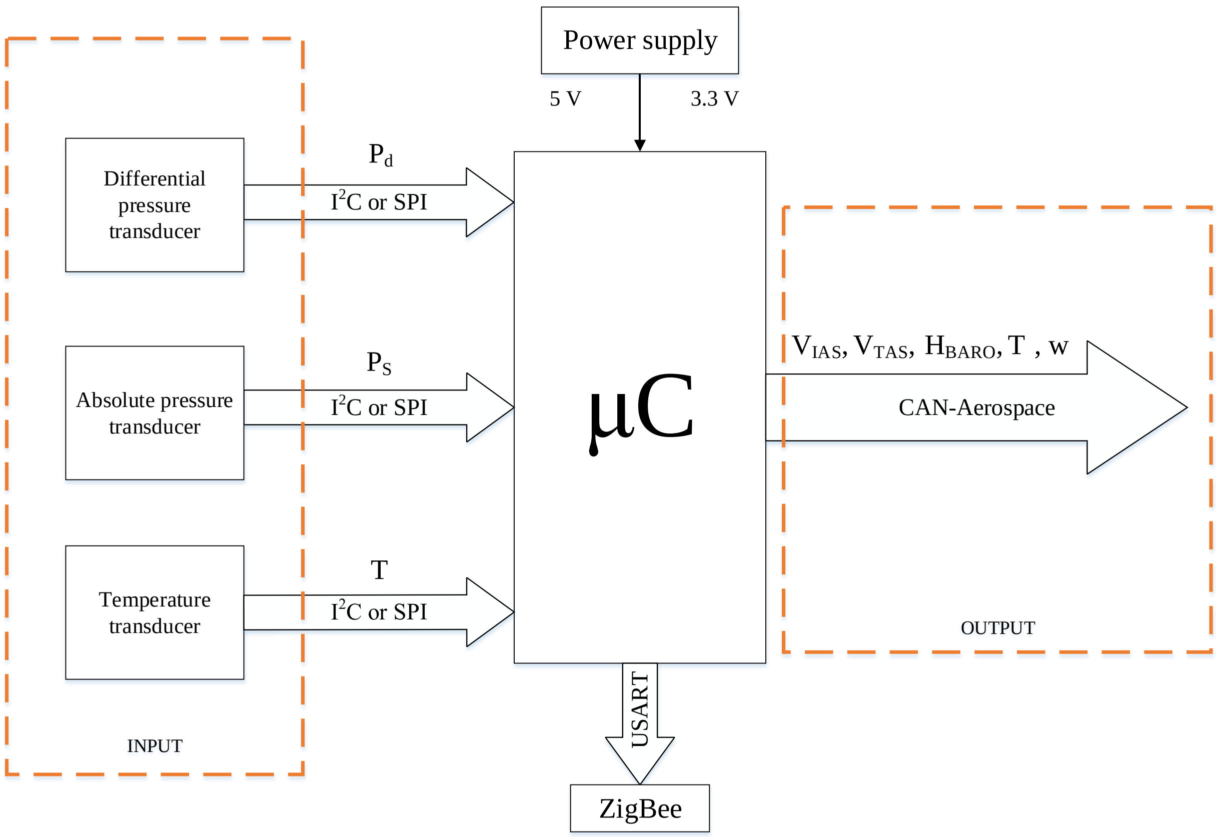


Fig. 2. Structure of the Air Data Computer [1]

The designed Air Data Computer module consists of 3 transducers providing digitized information about actual: absolute pressure, differential pressure and total air temperature. All the data are transferred to a microcontroller using I^2C data bus while usage of SPI bus is also possible. Using sensors with digital outputs eliminate the need for carefully designed analog measurement channels. Additionally the module has an optional wireless output capability (using USART interface) consisting of a ZigBee module [1]. This solutions gives an opportunity to wirelessly transfer real time flight data to ground station. The main output of the module is CANaerospace data bus. However, this data bus may be also considered as input from other devices integrated in the system.

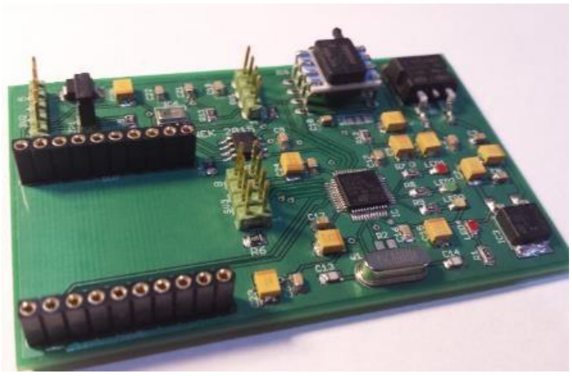


Fig. 3. Prototype PCB of Air Data Computer [1]

The prototype device of the ADC developed for the purpose of electronic flight data acquisition system was made as a compatible device meeting all the requirements that the system must fulfill. The designed and built Printed Circuit Board (PCB) of the ADC was based on the structure shown on figure 2.

The designed Air Data Computer specifications [1]:

- Power input: from 7.4 to 22.2 [V] (battery with 2 to 6 cells),
- Measured altitude: from -100 to 2000 [m],
- Measured velocity: from 50 to 145 [km/h],
- Measured vertical speed: ±6 [m/s],
- Operation temperature range: from –32 to 40 [°C],
- Storage temperature range: from –40 to 80 [°C].

As shown on figure 3 the designed ADC was manufactured with additional mounting spot for ZigBee module. Components are mounted only on one side making the board bigger than it could be, but such design was chosen because of the fact that it was a prototype module. The board designed to be used as an integrated device will have double side mountings allowing to reduce the weight and the dimensions.
Appendix G shows the results from the altimeter test. The test consisted of changing altitude by a constant value and recording the readings from the designed ADC and comparing with other commercial pressure altimeter. The measurement error of the designed module was below 1.5 %, when compared with the commercial pressure sensor [1].

2.2. Attitude and Heading Reference System Module

Attitude and Heading Reference System (AHRS) is used to calculate the orientation angles of an aircraft. It employs a set of acceleration, angular rate and magnetic induction field sensors to obtain necessary measurements. Most modern Attitude and Heading

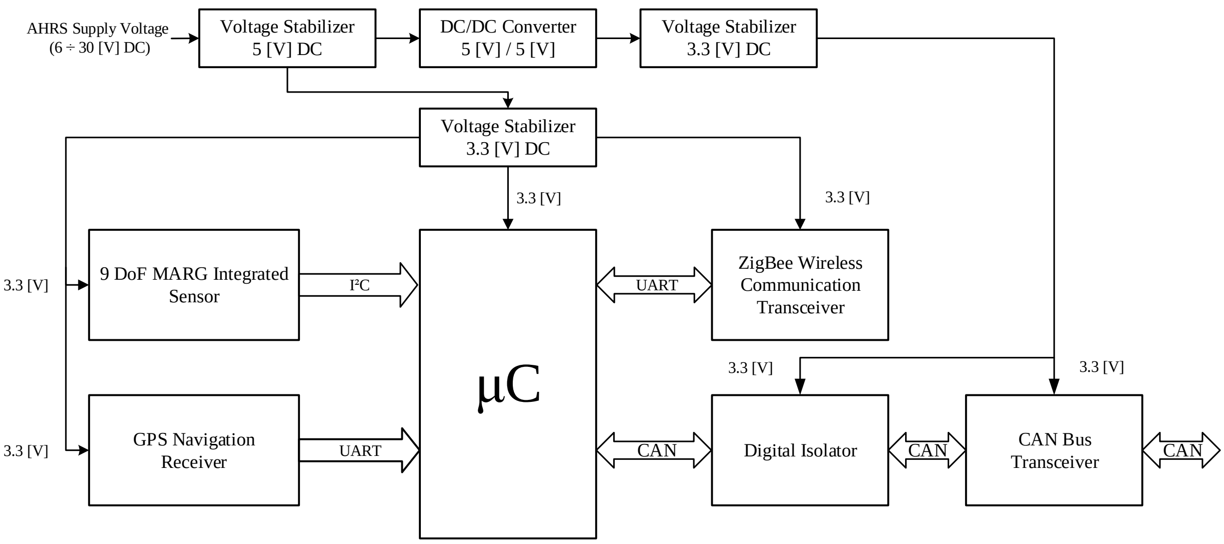


Fig. 4. Structure of Attitude and Heading Reference System [1]

Reference Systems use quaternion based algorithms to calculate body orientation angles which does not have a drawback of singularity problem at pitch angles of ±90 degrees, which is a common problem for conventional algorithms.

The developed AHRS is intended for use on Remotely Piloted Aircraft Systems. To obtain lowest measurement errors, the device should be installed as close as possible to the aircraft center of gravity. As it will be used on RPAS, the AHRS will be exposed to the adverse environmental conditions such as: wide range of atmospheric pressure, high and low temperatures, high air humidity, vibrations induced by propulsion system of the aircraft, impact accelerations caused by air turbulence and careless handling of the device.

Functional characteristics of the implemented AHRS are as follows [1]:

- Device is capable of deriving all aircraft orientation angles (roll, pitch and heading angle) and angular rate measured around of all axis of aircraft related coordinate systems (roll rate, pitch rate and yaw rate).
- Full scope of measured orientation angles (± 180 degrees – roll angle, ± 90 degrees – pitch angle, 0 ÷ 359 degrees – heading angle).
- Accuracy of measured orientation angles (roll rate and pitch rate) is within 1 degree in static conditions.
- Range of measured angular rates is up to 300 degrees per second.
- All measured flight parameters such orientation angles and angular rates are transmitted to other modules using the CANaerospace data bus.
- Refresh rate of the measured parameters is 50 [Hz].
- Device is capable of transmitting measured parameters using ZigBee wireless protocol.
- Satellite navigation receiver allows to calculate difference between magnetic heading and magnetic track and difference between true airspeed and groundspeed which consequently allows to derive wind direction and wind velocity.
- Wide range of supply voltage of 6 ÷ 30 [V] DC (required because of the broad range of voltages used in lithium-polymer battery packs used in unmanned aerial vehicles).

Constructed AHRS module consists of 32-bit microcontroller unit (MCU), 9 Degrees of Freedom (DoF) integrated magnetic, angular rate and gravity sensor, ZigBee protocol transceiver, GPS receiver and CAN transceiver together with digital isolator to provide galvanic separation of the CAN bus from the device. The 9 DoF integrated sensor is connected with the MCU using I^2C bus. GPS receiver and ZigBee protocol transceiver utilize UART interface to

Fig. 5. Assembled Attitude and Heading Reference System [1]

communicate with host MCU [1]. The PCB has been developed and manufactured as double-sided, however components are installed on one side only. To reduce final weight of the module, device is bereft of housing case.

To calculate body orientation angles, the device utilizes Madgwick algorithm, which uses a synthesis of angular rates, linear accelerations and magnetic flux measurements to obtain the most accurate results [2]. The influence of the each measured set (angular rates, accelerations and magnetic flux) on the final result is set by β coefficient [2]. The higher the beta coefficient the calculated orientation angles depend more on the linear accelerations and less on the measured angular rates. Higher β coefficient values will cause the AHRS to provide more stable orientation angle measurements in static condition, but worse results in rapid changing dynamic conditions. Lower β coefficient values result in better accuracy under dynamic conditions [2].

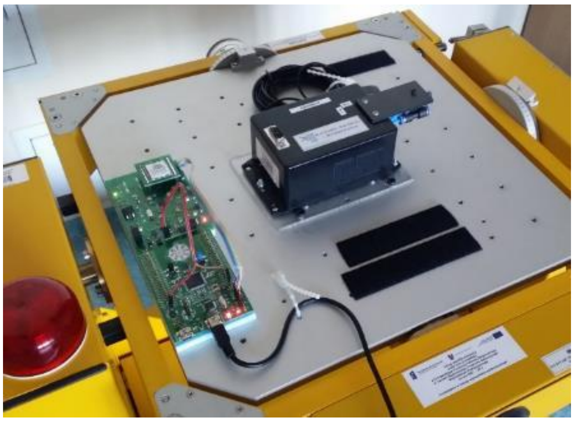


Fig. 6. Tests of the Attitude and Heading Reference System (AHRS) using tilting table [1]

The prototype device was tested using tilting table (fig. 6). The tests showed that measurement accuracy of roll and pitch angle was better than 1 degree in static conditions. Tests in dynamic conditions (in flight testing using a RPAS and reference attitude system) are to be conducted [1].

2.3. Flight Data Recorder Module

The Flight Data Recorder module is responsible for storage of data in non-volatile memory bank. All data received from the CANaerospace bus are written to the Secure Digital (SD) memory card together with a timestamp from Real Time Clock (RTC). Electronic flight data acquisition system may be expanded in future by adding analog and digital input measurement modules, thus the FDR module may be used to record not only parameters related to flight, but also other parameters required by the user (eg. analog voltage). This solution allows to make a fully autonomic flight, and after completing a mission by Remotely Piloted Aircraft System to review all stages of the flight and perform desired diagnostics.

2.4. Wireless data transmission capability

There are many data acquisition solutions available on the market, however virtually none of them incorporates built-in real time data transmission capability. This is applicable both for solutions used in RPAS and General Aviation, as well as systems intended for use in transport category aircraft. The presented flight data acquisition system allows transmission of the measured parameters to the ground monitoring station over ZigBee wireless protocol. The huge advantage of ZigBee protocol is fact that it does not require license or permission to operate from the state authority, as it uses non-restricted 2.4 [GHz] frequency band [5]. Figure 7 shows the received orientation angles using data Telegesis Terminal software [5].

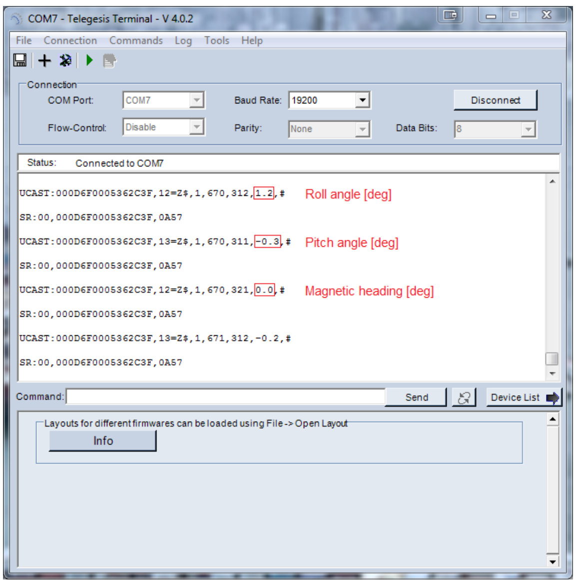


Fig. 7. Preview of the parameters using Telegesis Terminal Software [1, 5]

The developed system is not only limited for use in Remotely Piloted Aircraft Systems, it can be used in any application which requires similar functional capabilities. Due to its modular structure user can choose to only employ modules which are deemed required for current application (eg. if user is not interested in recording measured parameters, as the user only needs real time data preview, the user can choose to not use flight data recorder module by simply not connecting it to measurement systems CANaerospace data bus).

4. Results and discussion

Multiple tests and evaluations of the completed device modules – Air Data Computer and Attitude and Heading Reference System – were conducted in laboratory environment. Modules were tested separately to verify functional characteristics and accuracy of measurements. Integration of the completed modules into complete flight data acquisition system is planned as next steps.

Air Data Computer was tested using calibrated pressure test source to verify correct altitude and speed indications. Results of the altitude indications are shown on Appendix G. Discrepancy between indications of the tested Air Data Computer and reference pressure sensor (BMP180) was found to be below 1.5 % in whole measurement range which can be considered satisfactory taking into account intended applications of the designed Air Data Computer. Vertical speed sensing capability was tested in quality manner rather than quantitative manner, as precise testing of the vertical speed indications exceeded the capabilities of the available testing equipment. Evaluation of the Indicated Airspeed (IAS) capability was conducted similarly to the tests of the altitude sensing accuracy, using calibrated pressure source which was used to set reference values of the Indicated Airspeed (IAS) and measured values were recorded. Indicated Airspeed (IAS) sensing accuracy was tested in pressure range corresponding to the declared Indicated Airspeed (IAS) range (50 ÷ 145 [km/h]). Gathered result which are shown on Appendix H. Mentioned results show that relative Indicated Airspeed (IAS) measurement error decreases with increasing airspeed what was expected. Maximum relative errors were found in the lower range (60 ÷ 90 [km/h]) of declared measured airspeeds and were found to be in the order of 5.0 %. In the high range (110 ÷ 150 [km/h]) of declared measured airspeeds relative errors were found to be in order of 0.4 %. Last stage of device evaluations were tests of the temperature sensor. Measurements were taken at few distinct values of temperature. Reading were found to be within 1 [°C] of the actual temperature which meets the declared accuracy of the used temperature sensor.

Attitude and Heading Reference System was tested only in static conditions using tilting table.

Device was set in multiple orientations and measured orientation angles were recorded and compared with reference orientation angles which were set on the tilting table. Appendices I to M show the results of the tests. It can be observed that accuracy of the measured orientation angles is within 1 [°] of reference values. Testing in dynamic conditions are planned to be conducted in future. To conduct testing in dynamic conditions it is required to obtain reference orientation sensor with proved accuracy and use airborne platform (such as remotely piloted aircraft) to simulate dynamic conditions. Additionally, wireless data transmission capability has been tested and was found to be operating correctly which is shown on figure 7.

As a next major task it is planned to perform integration of the constructed modules into complete flight data acquisition system. Flight Data Recorder module is in last stages of the development process and is expected to be tested in nearby future. After completing and successful testing of the Flight Data Recorder module, it will be required integrate all designed modules into complete measurement system. After successful integration the project would be considered complete.

5. Conclusions

Wireless sensor solutions provide new features for data acquisition applications used in RPAS and General Aviation, giving the opportunity to the user to install modules separately in space constrained environments. The modules can be powered by separate wide range voltage source. Small physical dimensions of the modules allow the user to place them according to his requirements in almost every application. Wireless data transmission implemented in that system continuously sends the measured parameters to the ground monitoring station which can be used to display parameters in real time, perform the real time data analysis and record the data independently from the FDR module. Wireless data transmission capabilities of the developed prototype data acquisition system have been tested and it was proved that it operates as intended in real RPAS application.

This solution is clearly an innovative one, as most of the commercially available devices and systems do not offer wireless data transmission capability and modular structure. The mentioned modular structure gives opportunity for the system to be expanded virtually without limits. As the new technologies become available or user requirements grow, system can be expanded by constructing additional modules designed to perform desired tasks.

References

[1] Authors’ own research, *Rzeszów, Poland, 2016,*

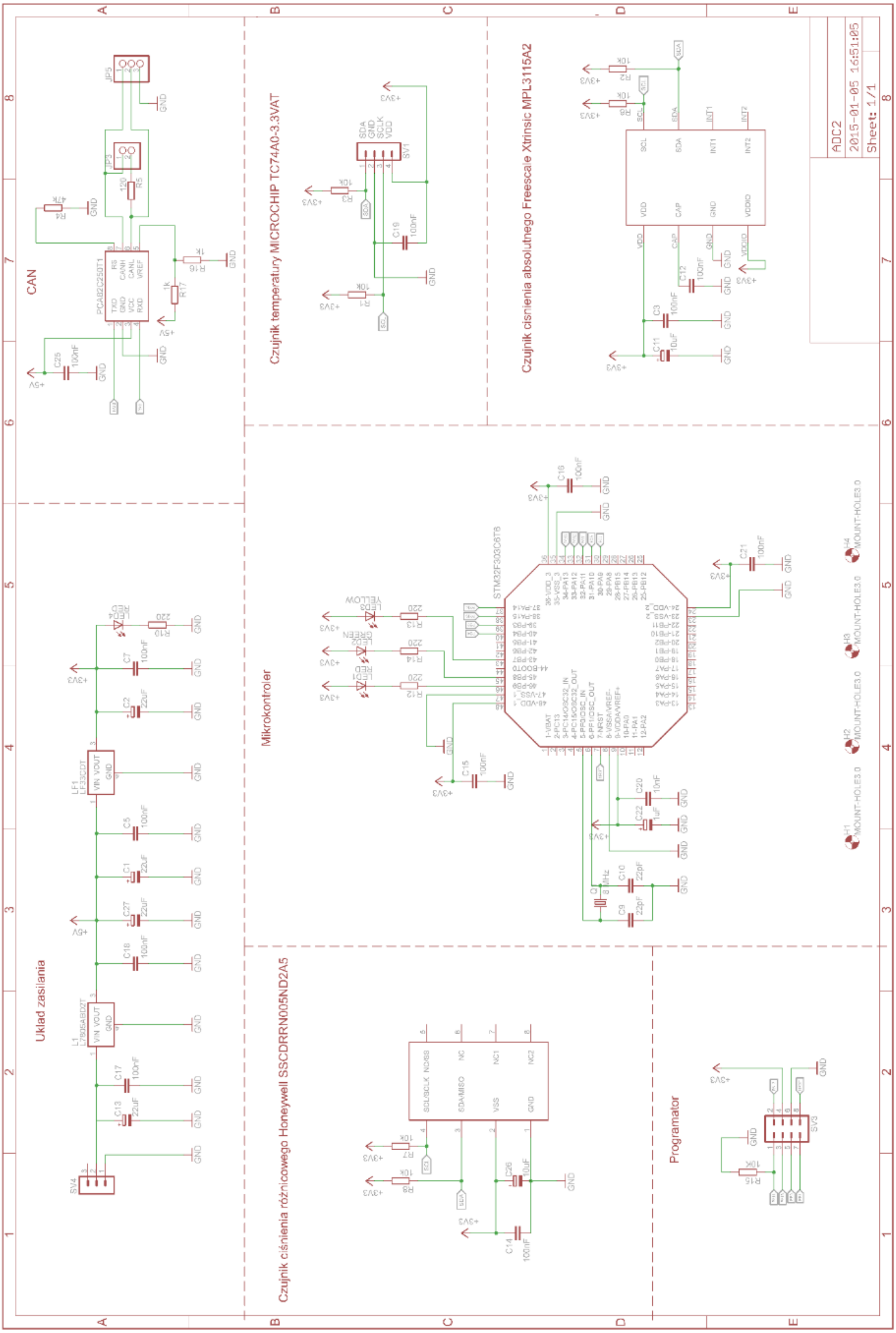
[2] Madgwick S. O. H.: An efficient orientation filter for inertial and inertial/magnetic sensor arrays. *University of Bristol, Bristol, England, United Kingdom, April 2010,*

[3] Pieniążek J., Rogalski T.: The cheap air data computer for aviation applications. Rzeszów *University of Technology, Rzeszów, Poland, 2006,*

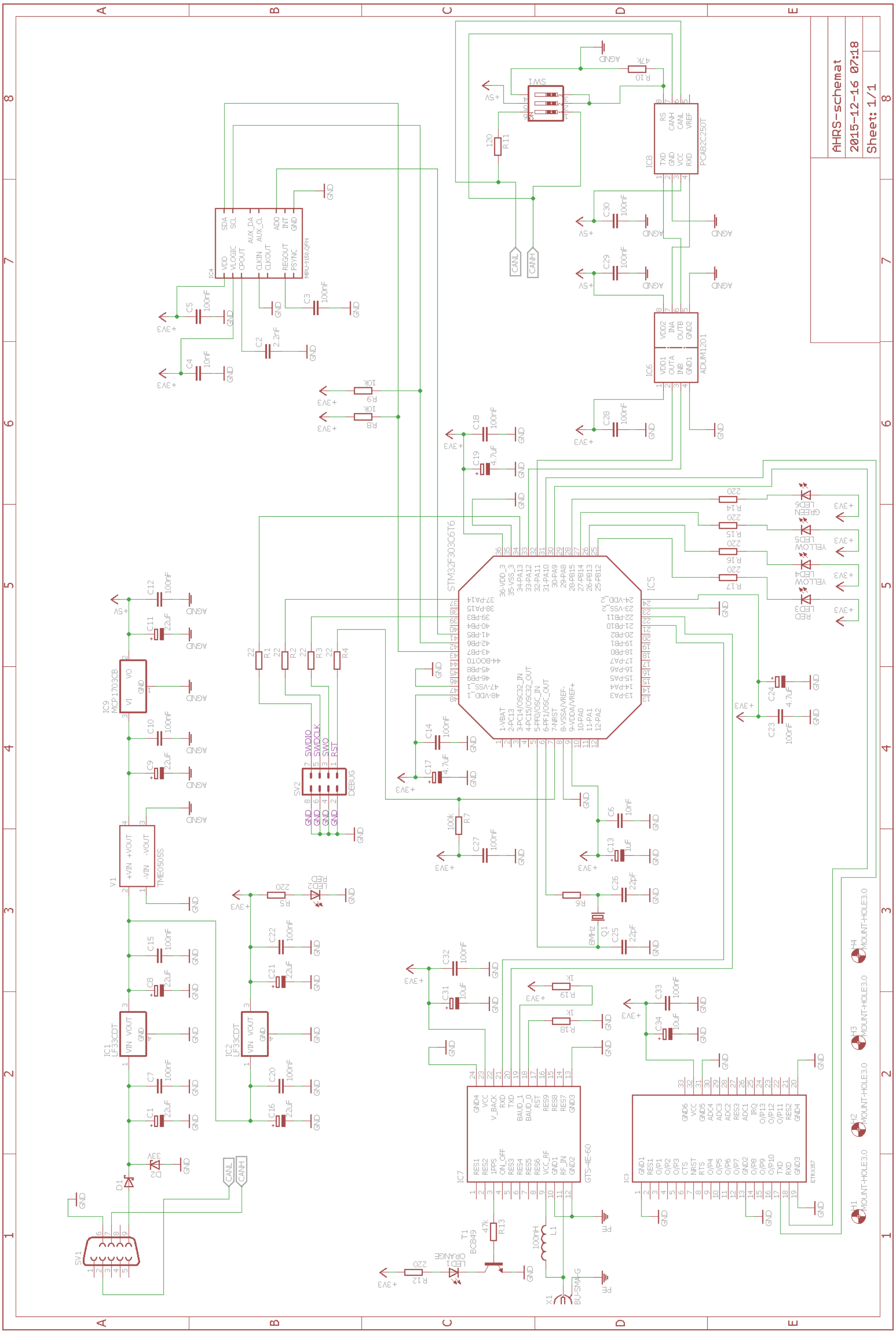
[4] Stock M.: Interface specifications for airborne CAN applications V 1.7. *Stock Flight Systems, Berg/Farchach, Germany, January 2006,*

[5] Telegesis Ltd.: ETRX35X ZigBee Modules Product Manual. *Telegesis (UK) Ltd., High Wycombe, England, United Kingdom, 2015.*

Appendices

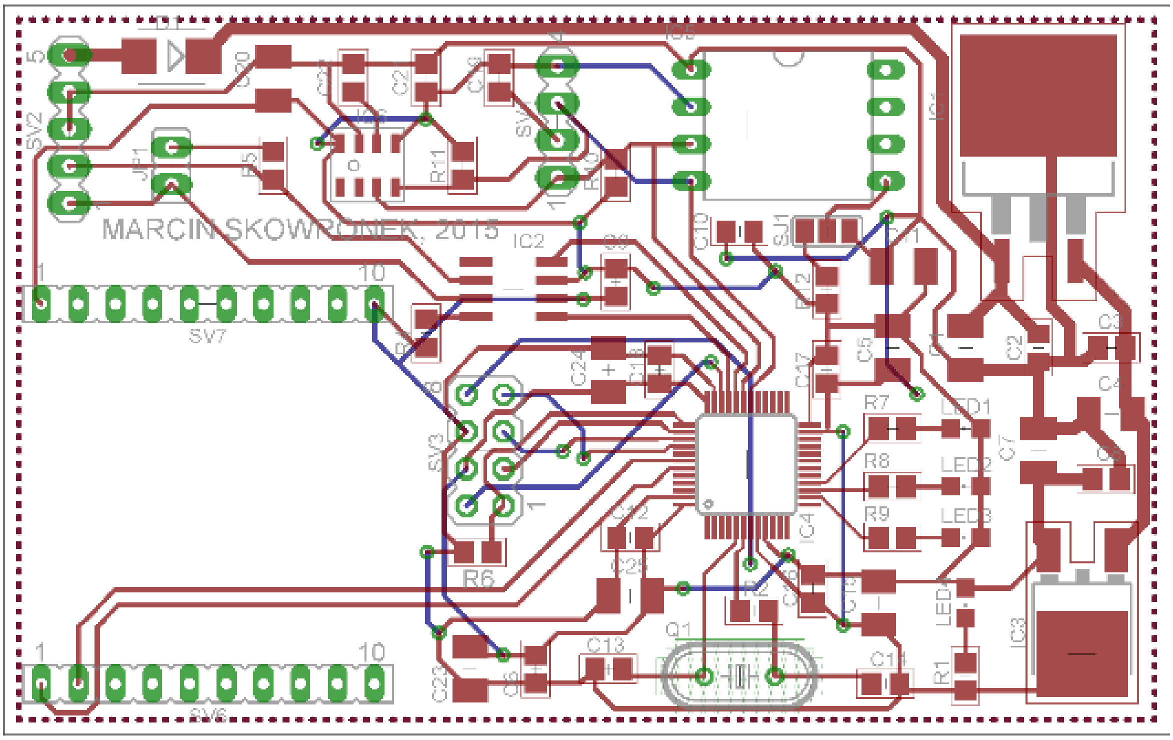


Appendix A. Electrical schematic of the Air Data Computer (ADC)

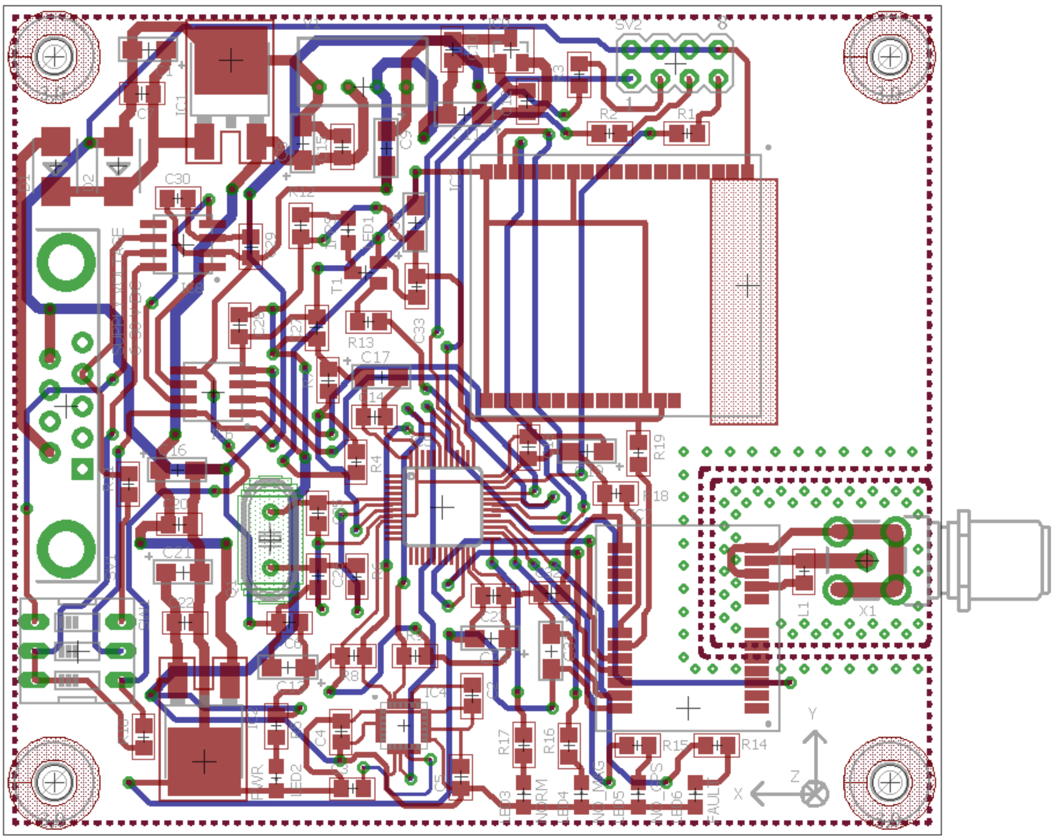


Appendix B. Electrical schematic of the Attitude and Heading Refernce System (AHRS)

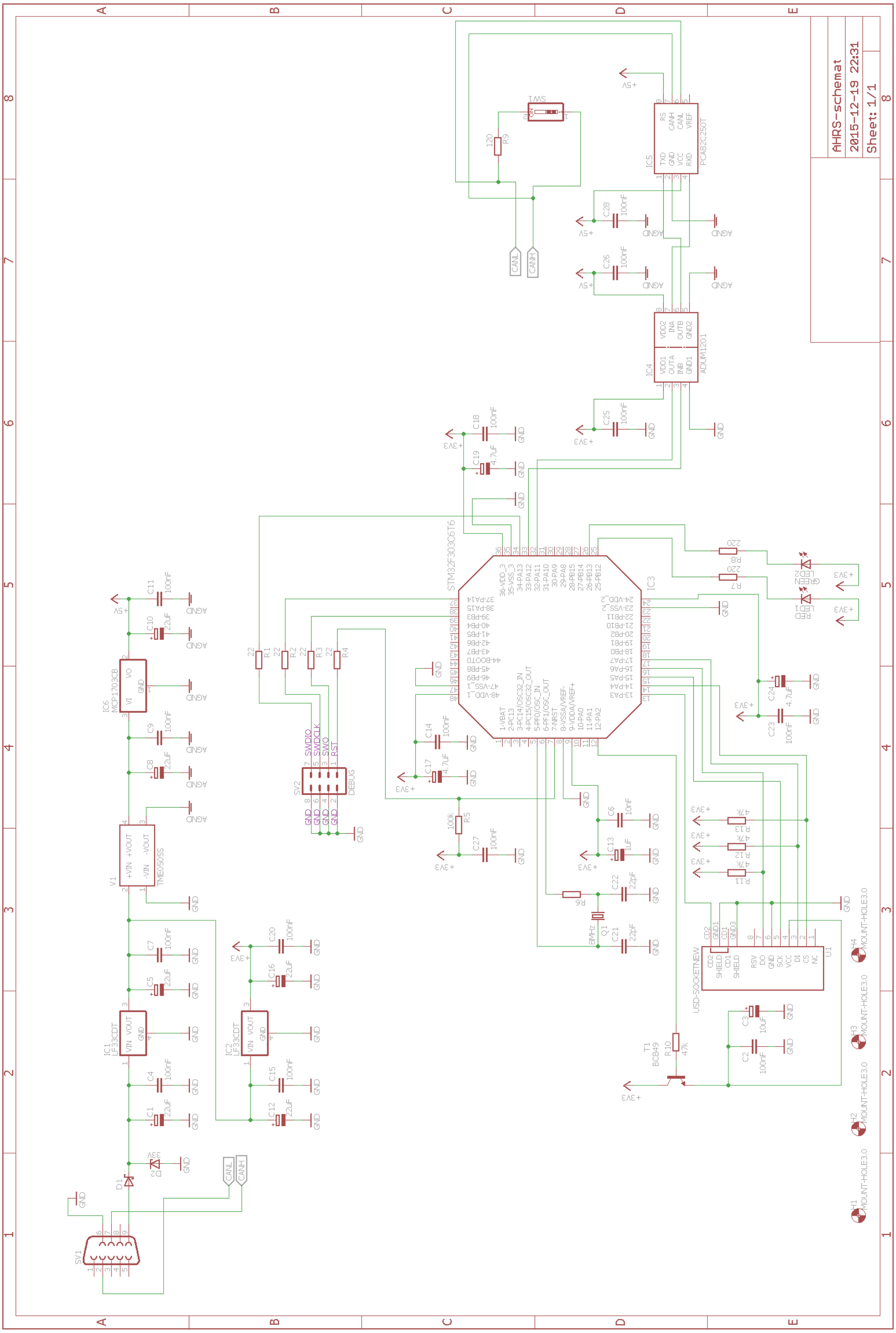
Vol.V, No.1 (2017)



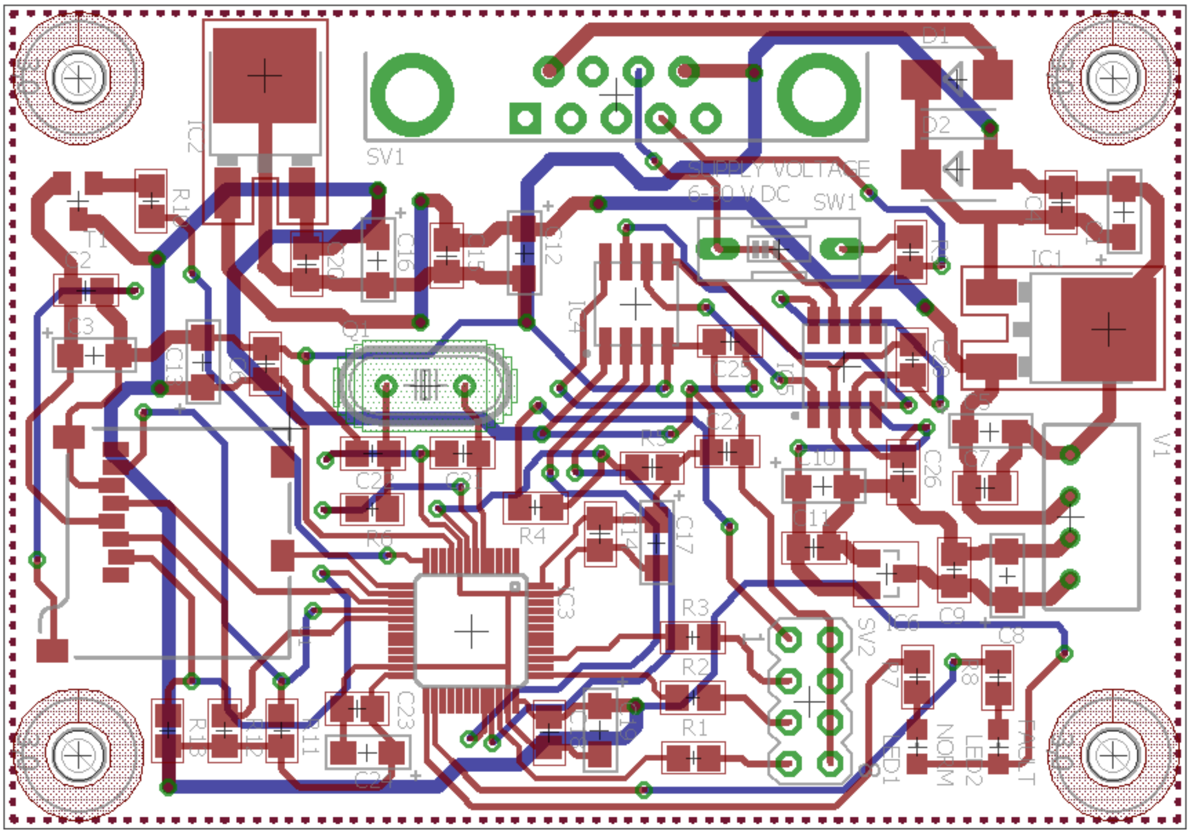
Appendix C. Printed Circuit Board design of the Air Data Computer (ADC)



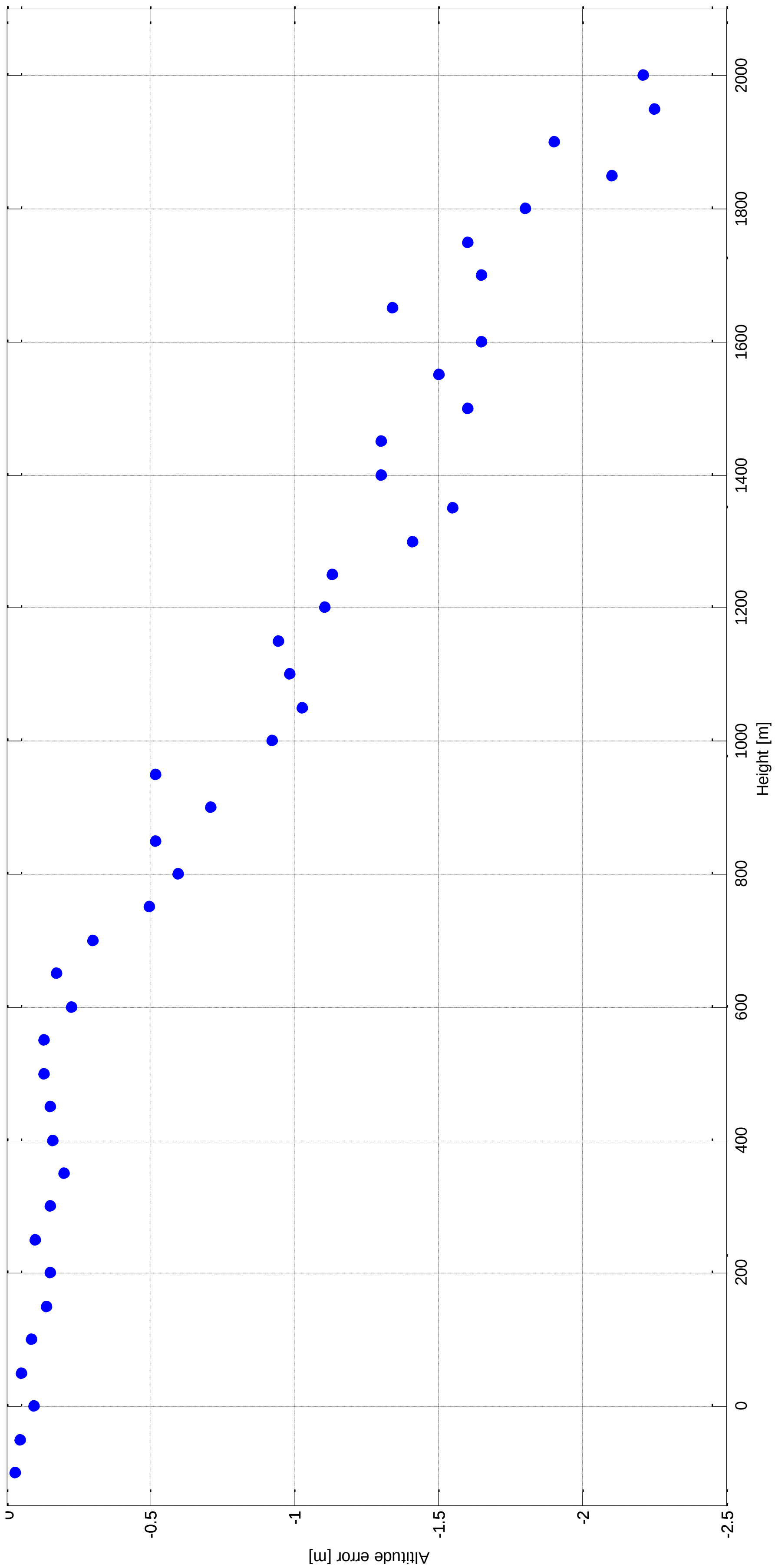
Appendix D. Printed Circuit Board design of the Attitude and Heading Reference System (AHRS)



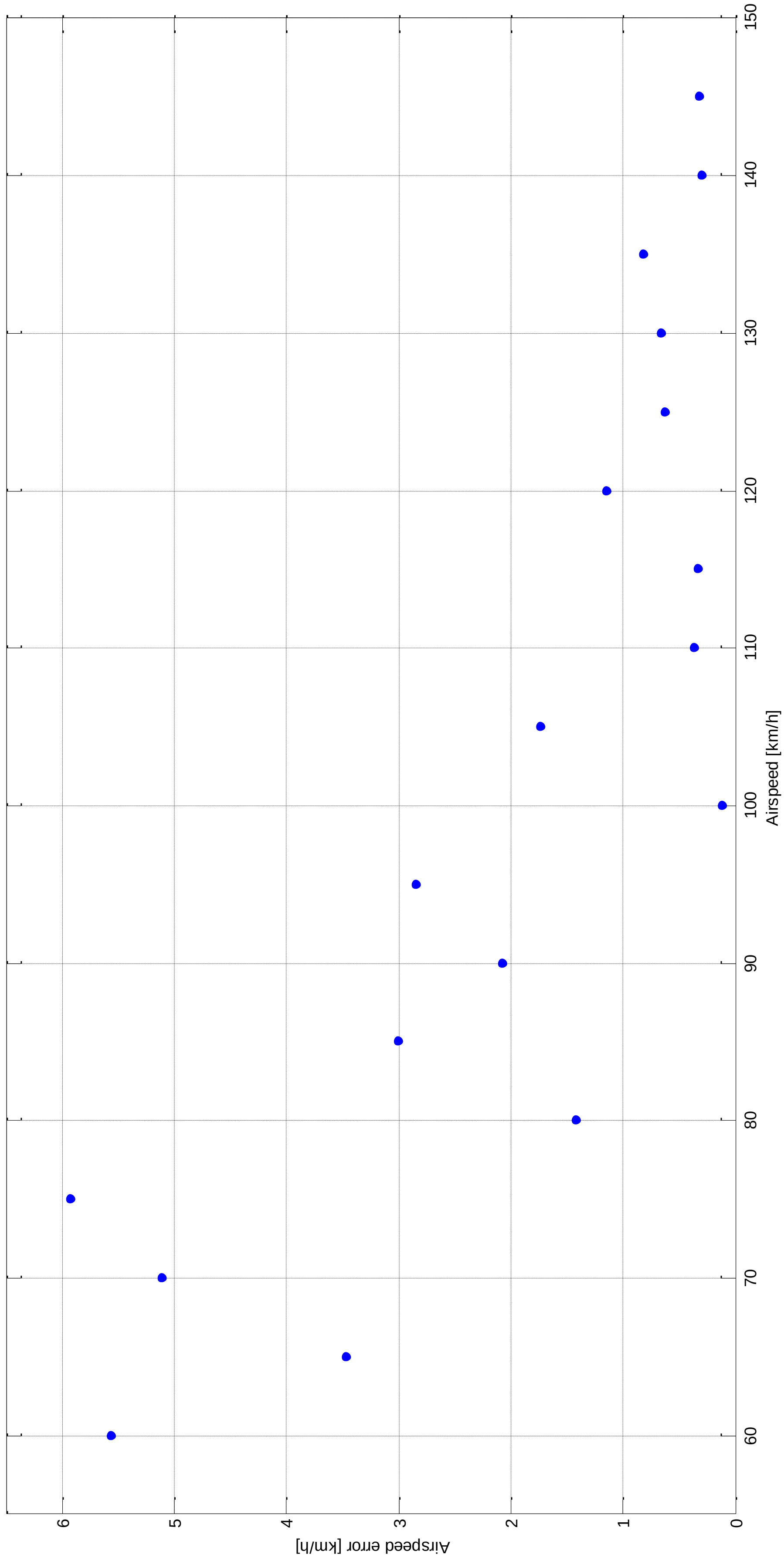
Appendix E. Electrical schematic of the CAN Recorder



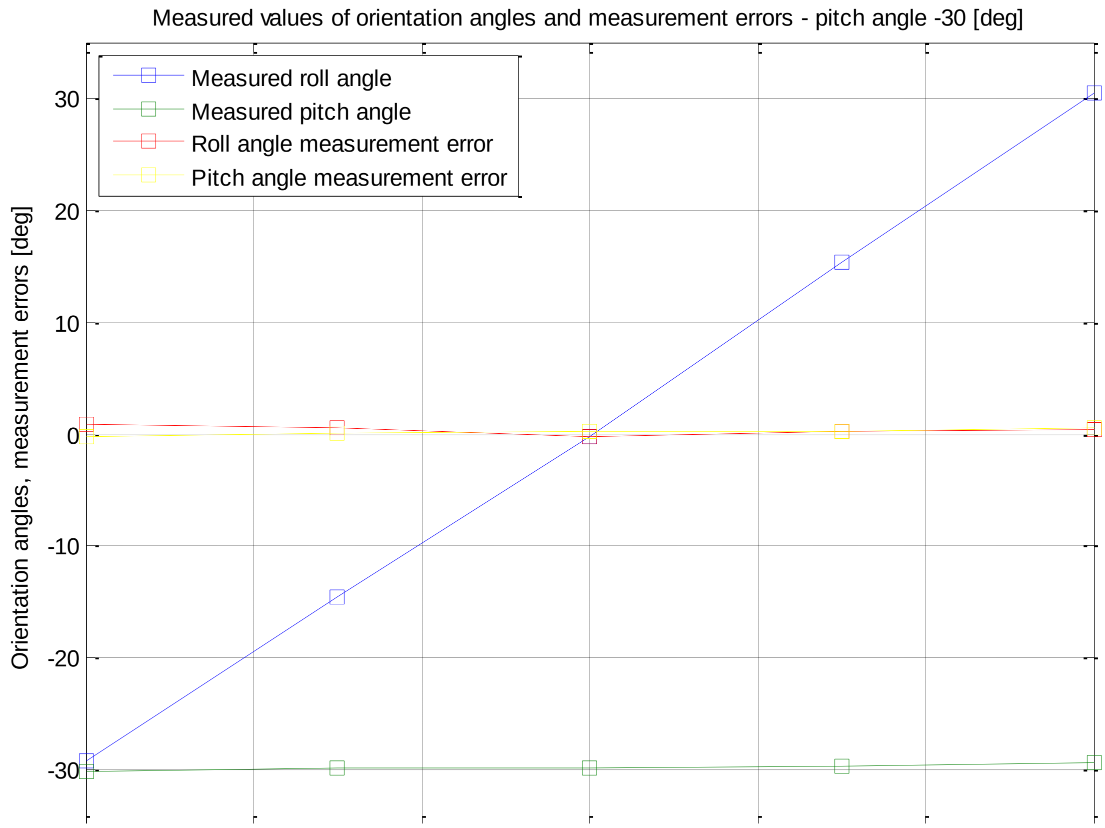
Appendix F. Printed Circuit Board design of the CAN Recorder



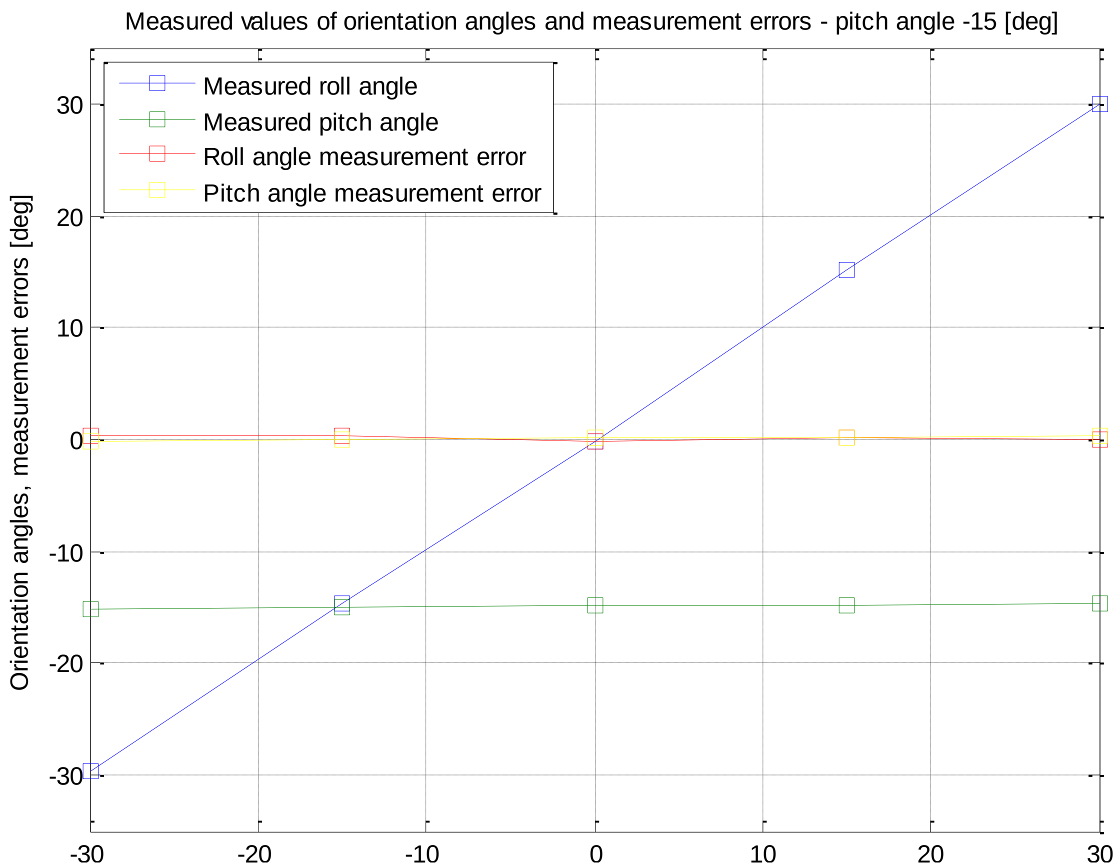
Appendix G. Pressure altitude measurement error chart



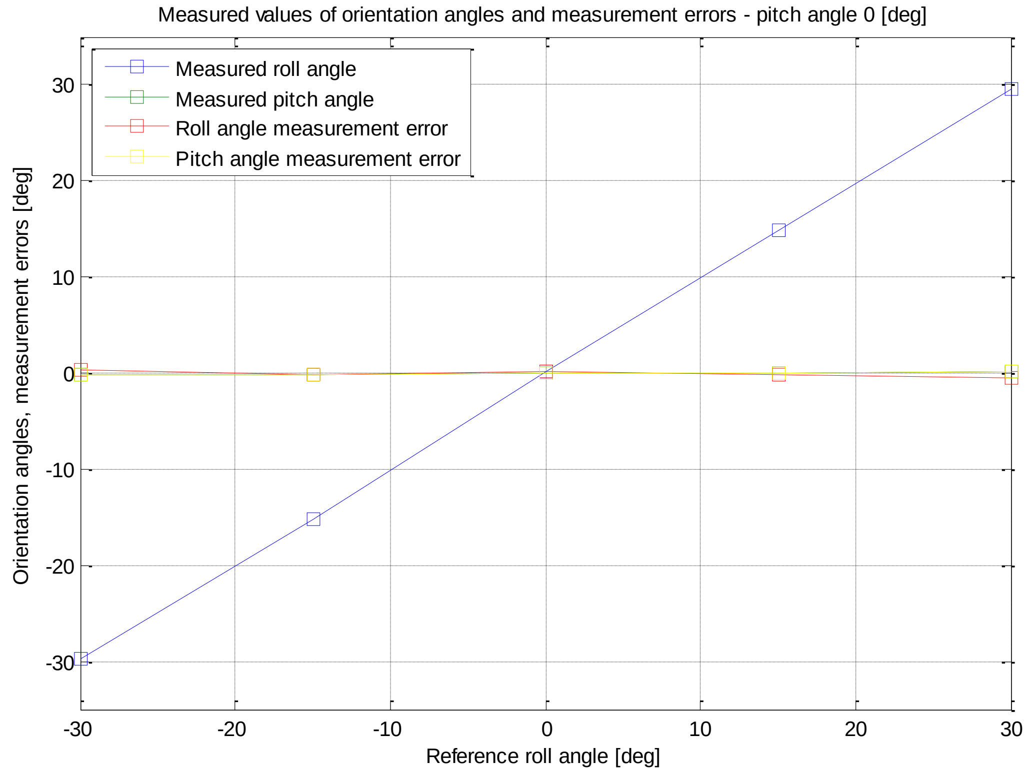
Appendix H. Indicated Airspeed (IAS) measurement error chart



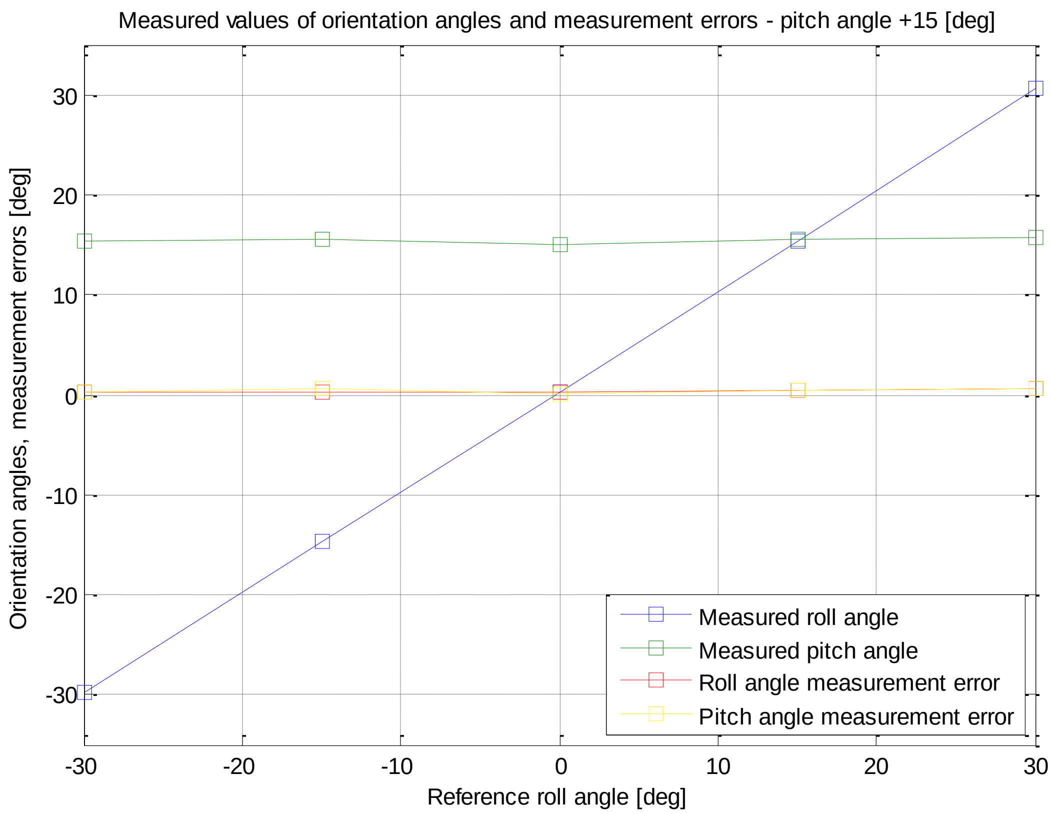
Appendix I. Measured orientation angles (roll angle, pitch angle) and measurement errors chart – constant pitch angle -30 [°]



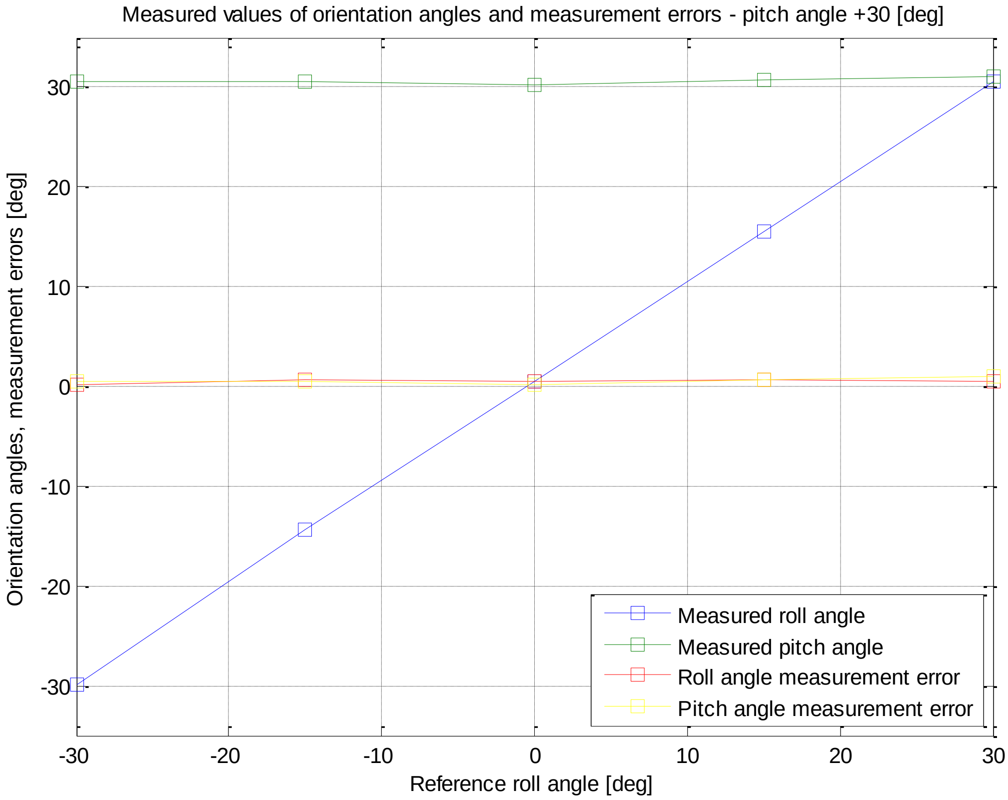
Appendix J. Measured orientation angles (roll angle, pitch angle) and measurement errors chart – constant pitch angle -15 [°]



Appendix K. Measured orientation angles (roll angle, pitch angle) and measurement errors chart – constant pitch angle 0 [°]



Appendix L. Measured orientation angles (roll angle, pitch angle) and measurement errors chart – constant pitch angle +15 [°]



Appendix M. Measured orientation angles (roll angle, pitch angle) and measurement errors chart – constant pitch angle +30 [°]