İstanbul
Bilgi University

Electronic Flight Instrument System (EFIS)

EEEN 102 Embedded Systems Programming Final Project

İbrahim Çağlar YILDIRIM
June 19, 2024

Contents

1 Introduction

Main idea of the project is developing a fully real aviation compilant flight managament / navigation system and electronic flight instrument system (EFIS) for RC airplanes or UAVs. Because currently end user UAV flight controller kits are boring and they have missing features which used in real airplanes.

Currently Air Data Unit and Display Software for ground station is developed. Radio navigation unit, flight management system and auto-flight systems will be developed in future.

This document includes these parts of project:

- Air Data Unit (v1.1)
- Air Data Unit MCU Software (v0.1)
- EFIS Display Software (v0.1.1)

All project files can be found at project's GitHub page:
https://github.com/ibosoftnet/efis

2 Air Data Unit Hardware

2.1 Introduction

Main hardware called as "Air Data Unit" and it reads sensor data and sends the calculated air data to UART output. Air Data Unit consists of a outer case and a electronic board.

Outer case consist of a case and cover, cover has required holes for allowing to making connections to electronic board.

Electronic board is holds all circuit elements and main MCU for operating the Air Data Unit.

2.2 Features and Limitations

- Supply voltage range: 7.5 – 25 V.
- High voltage protection by varistors.
- Low voltage protection by MCU brownout detection.
- Separated supply lines for board and external devices.
- Max 100 mA for main board and max 500 mA for external outputs.
- 100 mA PTC fuses on each power out.
- All I/O pins (except SPI) has serial current limiting resistors.
- ATMega 328P MCU @ 20 MHz
- RTC chip for date and time keeping.
- CR1220 battery for RTC chip.
- Separated I^2C lines via switch for isolating lines from each other when corruption occurs on some of lines.
- Main UART for data transmission and secondary UART for GNSS module.
- UART1 can capable up to 230400 bauds and has flow control pins.
- UART2 can capable up to 38400 bauds.
- SPI port (6 pins AVR ISP).
- 6 configurable general purpose I/O or analog inputs.

2.3 Electronic Board

2.3.1 Circuit Schematic

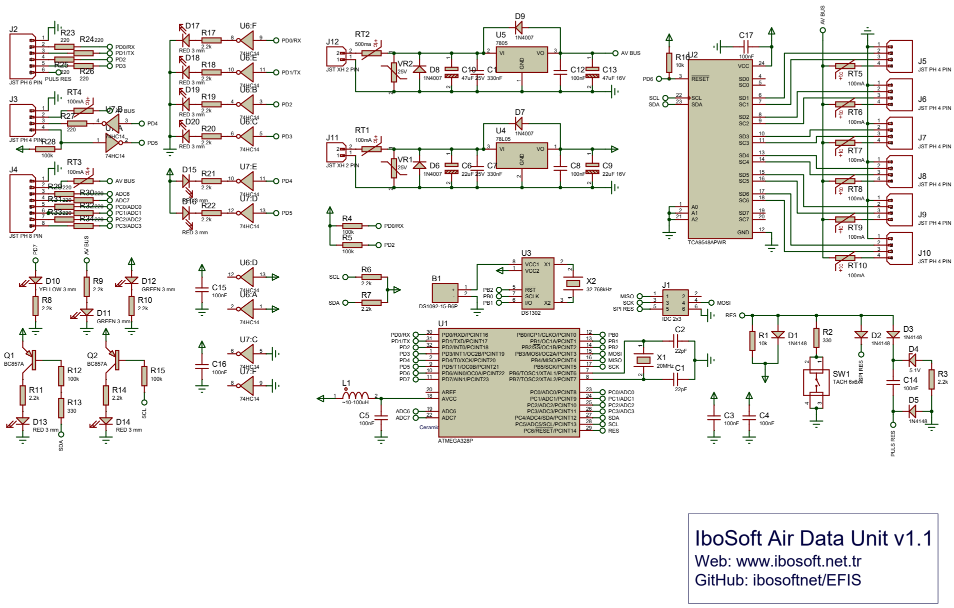

Figure 1: Circuit schematic

2.3.2 Considerations Regarding the Design of the Circuit

- All ICs have 100 nF ceramic de-coupling capacitors connected to supply pins.
- All communication line LEDs isolated from communication lines with NOT gates or BJT transistors for allowing the high speed communication.
- D7, D9, C7, C8, C11, C12 placed according to recommendations mentioned in various 78XX series linear voltage regulator datasheets.
- D6, and D8 prevents from reverse voltage with short circuiting and causing the trip of RT1 or RT2 PTCs.
- C6, C9, C10, C13 placed as bulk capacitor for preventing the supply voltages from dropping low during high peak loadings.
- D2 and D3 placed for protecting connected SPI device from short circuit when reset line goes low during reset output of SPI device is high.

- C14 placed for generating pulse reset signal for generating single reset if programmer pulls the reset pin of UART1 to low continuously.
- D3 diode prevents current wants to travel to MCU if UART1 reset line goes low and after high. Because voltage over C14 will increase in this situation. Normally, reset pin durable the higher voltages due to HVPP mode but other external devices connected to reset line may damaged if voltage exceeds the limit.
- D4, R3 and D5 placed to ensuring the discharge of C14. Otherwise, UART1 device can't reset the MCU anymore after first reset attempt. R3 limits the discharge current for protecting the C14, D4, R3 and D5 from high peak current.
- All UART I/Os have required pull-up or pull down resistors.
- I^2C outputs haven't got pull-up resistors because external I^2C devices may have internal pull-up resistors and this may cause to excessively low equivalent pull-up resistances if pull-up resistors placed to I^2C outputs. If a external I^2C device hasn't got internal pull-up resistors, external pull-up resistors must be connected to related output.
- RX and TX lines of UART2 passed through NOT gates for take advantage of inverted software serial method because it provides greater baud rates than non-inverted software serial.

Most applicable recommendations and limitations have been followed mentioned in *Atmel AVR042: AVR Hardware Design Considerations* guide and Microchip ATmega 328 datasheet:

- All outputs except SPI has current limiting resistors.
- All MCU supplies have 100 nF ceramic de-coupling capacitors.
- Low-pass filter created with L1 and C5 used for filtering the AVCC supply of MCU.
- R2 placed for limiting peak voltage induced by self-inductance of SW1 button.
- External pull-up resistor (R1) placed for guaranteeing high state at reset input.
- D1 placed for ESD protection because reset pin hasn't got internal ESD protection diodes due tı HVPP mode of ATmega MCUs.
- 22 pF ceramic capacitors used for 20 MHz crystal.

2.3.3 PCB Design Rules

- SMD and TH mixed.
- 2 layers used.
- Minimum 9 Thou spacing and trace width used.
- Dimensions are 42 mm × 82 mm.
- Screw holes are M3.

2.3.4 Images of PCB

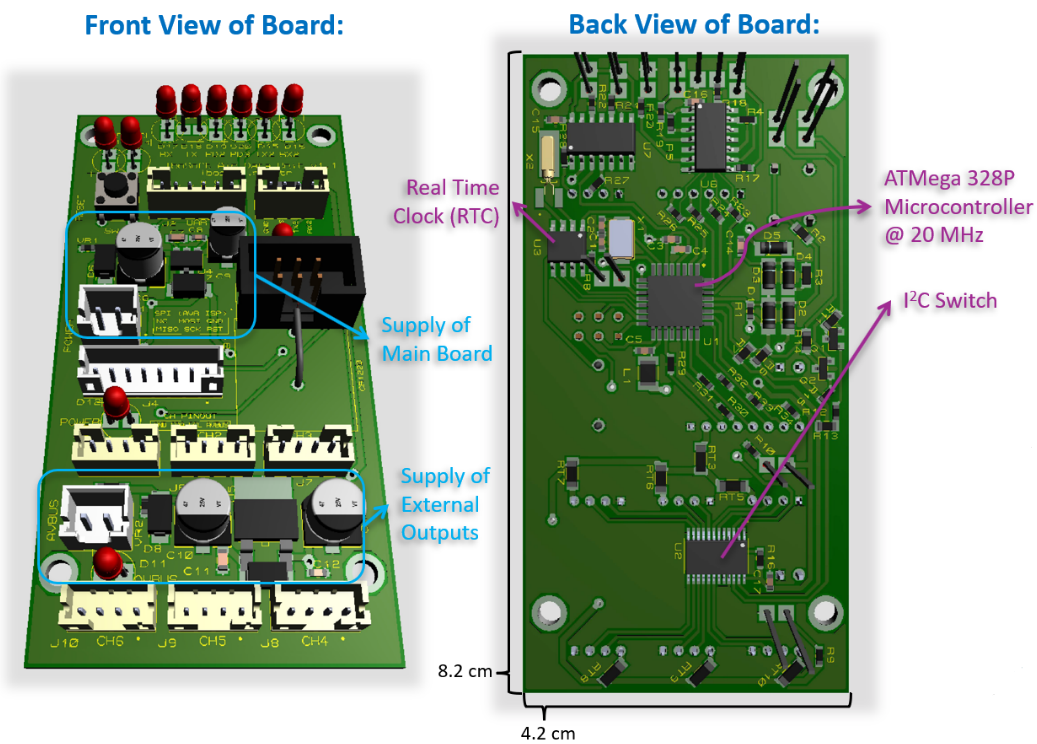

Figure 2: Front and back view of PCB

2.3.5 Block Diagram

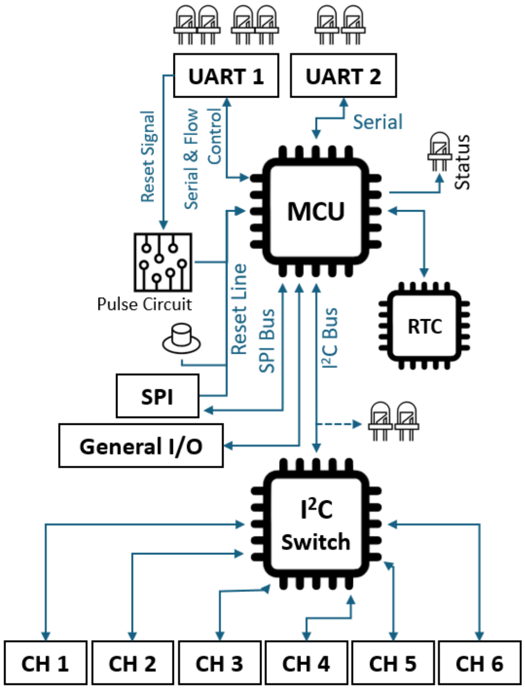

Figure 3: Block diagram of electronic board.

2.4 Entire Unit

2.4.1 Images of Unit

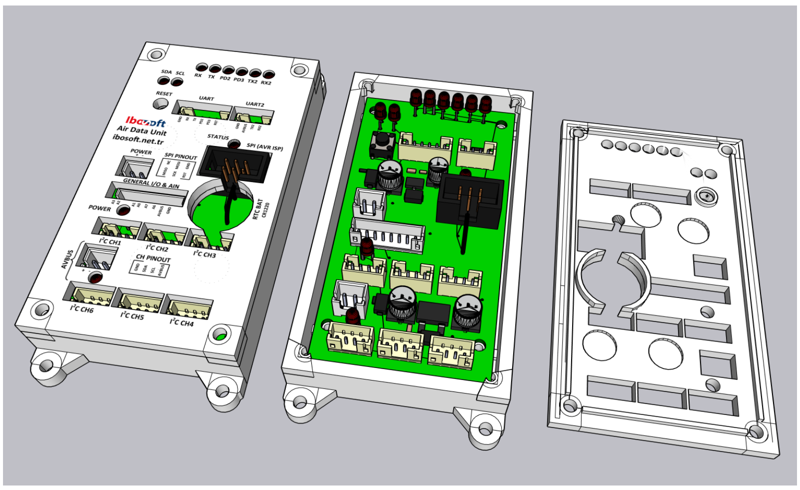

Figure 4: Images of inside and outside of case.

2.4.2 Connection Ports

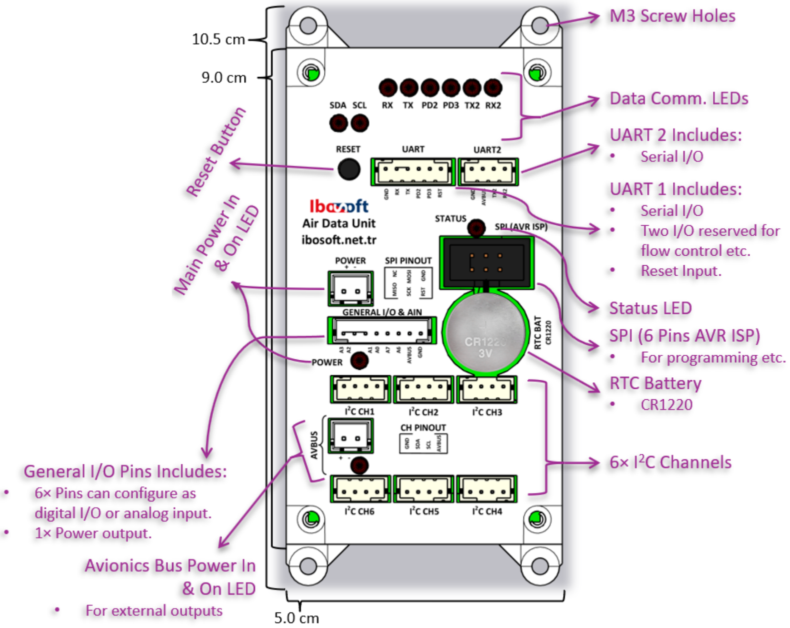

Figure 5: Descriptions of connection ports.

2.4.3 Connection Diagram

- Given sensors selected for demonstration purposes. Different sensors can be used with or without software adjustments.

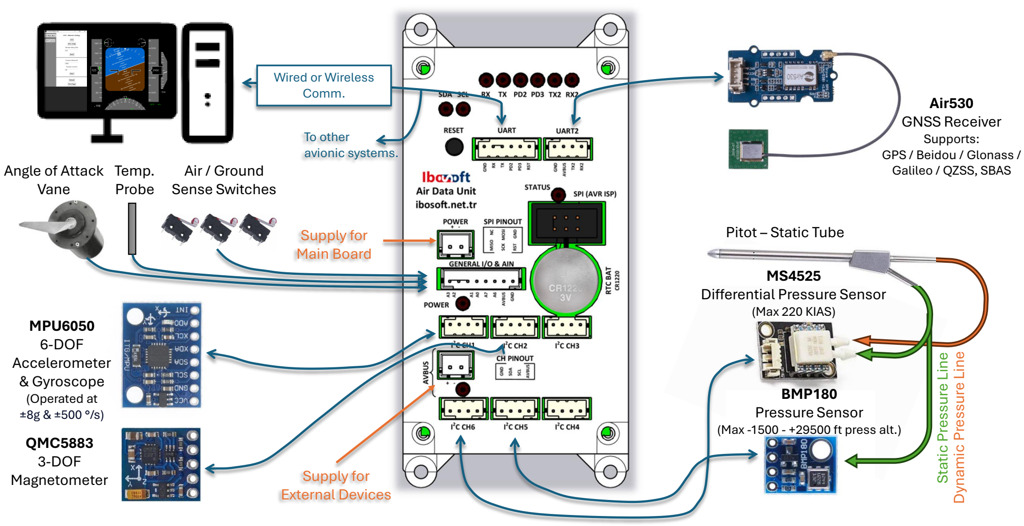

Figure 6: Connection diagram of sensors and communication lines.

3 Air Data Unit MCU Software

Air Data Unit MCU Software reads sensor data and calculates usable air data according to raw sensor datas and send them over UART1 serial output. GNSS data reading and parsing will be integrated in future. Air data calculation derived from *ICAO Doc 7488 - Manual of The ICAO Standard Atmosphere* but detailed air data calculations and software features don't shown in this document.

C/C++ programming language used with AVR-GCC compiler. Main aim is avoiding excessive library use but we couldn't avoid using Arduino libraries because it required by some other libraries. We will eliminate the use of some libraries in the future.

An external header file that stores only the variables was created so that adjustments could be made without editing the main code.

4 EFIS Display Software

4.1 Introduction

EFIS Display Software used for displaying air data and sending commands to Air Data Unit via serial port. Python programming language was used. Display software decodes incoming serial data and shows air data symbology according to incoming data and it capable to show failure flags for related air data if sensor failure sended in incoming data. Also Display Software can capable to detect communication lost. Currently, only primary flight display (PFD) completed, other displays will be developed in future.

Also it provides a control menu for adjusting some settings and sends to changed data to Air Data Unit in every data cycle. "Tkinter" library used for control menu.

Symbology displaying with "Pygame" library. Some symbologies are code-based, while others are created by projecting image files onto the screen. Mathematical algorithms used for positioning the symbols doesn't explained in this document.

Boeing-style symbology was used due to familiarity. Symbologies derived from PDF formatted Boeing 737 Flight Crew Operation Manual (FCOM). As font, original Boeing font didn't use due to copyright issues so OCR-B font selected for displaying texts and numbers.

4.2 PFD - Normal Symbology

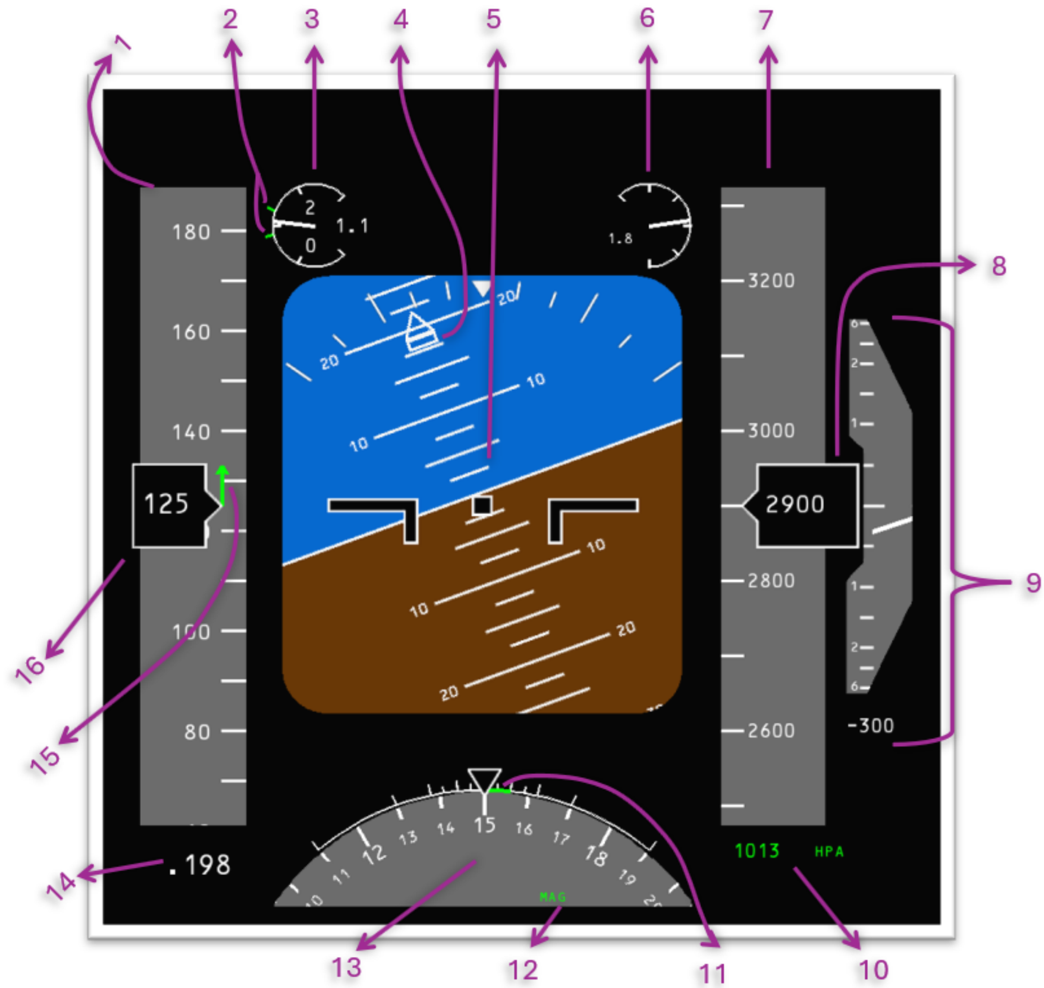

Figure 7: Descriptions of PFD symbology.

1. Airspeed Tape.
2. G Peaks (g): Shows minimum and maximum recorded vertical acceleration in g. Can be resetten from "G Peaks" page.
3. Vertical Acceleration Indicator: Shows vertical acceleration in g.
4. Slip / Skid Indicator: Shows lateral acceleration.
5. Attitude Indicator: Shows pitch and roll angles in degrees (°). Ticks over roll scale are equal to these values in order of: 10°, 20°, 30°, 45°, 60°.
6. Angle of Attack Indicator: Shows angle of attck in degrees (°). Single division is equal to 10°.

7. Altitude Tape.
8. Altitude Indicator: Shows barometric altitude in foot (ft).
9. Vertical Speed Indicator: Shows barometric vertical speed in foot per minute (ft/min).
10. Altimeter Setting Indications: Shows altimeter setting mode and value:
    (a) STD (Green): Standart altimeter setting (1013.25 hPa) selected after climbed above transition altitude.
    (b) STD (Amber): Standart altimeter setting (1013.25 hPa) still selected after descending below transition level.
    (c) xxx HPA (Green) or xxxx HPA (Green): Altimeter setting value set unit of hectopascal (hPa) before climbing above transition altitude or after descended below transition level.
    (d) xxx HPA (Amber) or xxxx HPA (Amber): Altimeter setting value set unit of hectopascal (hPa) after climbed above transition altitude or before descending below transition level.
    (e) xx.xx IN (Green): Altimeter setting value set unit of inch of mercury (inHg) before climbing above transition altitude or after descended below transition level.
    (f) xx.xx IN (Amber): Altimeter setting value set unit of inch of mercury (inHg) after climbed above transition altitude or before descending below transition level.
11. Turn Rate Indication: Shows horizontal turn rate in degrees per second (°/s). Ticks are equal to these values in order of: 1.5 °/s, 3 °/s, 4.5 °/s, 6 °/s, 10 °/s, 20 °/s.
12. Compass Mode Annunciation: Indicates operation mode of compass:
    (a) MAG (Green): Compass is in tilt-compensation mode and shows magnetic heading.
    (b) TRU (Green): Compass is in tilt-compensation and shows true heading.
    (c) UNCORR MAG (Amber): Compass is not in tilt-compensation mode and shows magnetic heading.
    (d) UNCORR TRU (Amber): Compass is not in tilt-compensation mode and shows true heading.
13. Compass.
14. Mach Indicator: Shows mach number. Displaying over 0.1 mach.

15. Speed Trend Arrow: Shows acceleration in aircraft's movement axis.
16. Airspeed Indicator: Shows Indicated airspeed in knot (kt).

4.3 PFD - Failure Flags

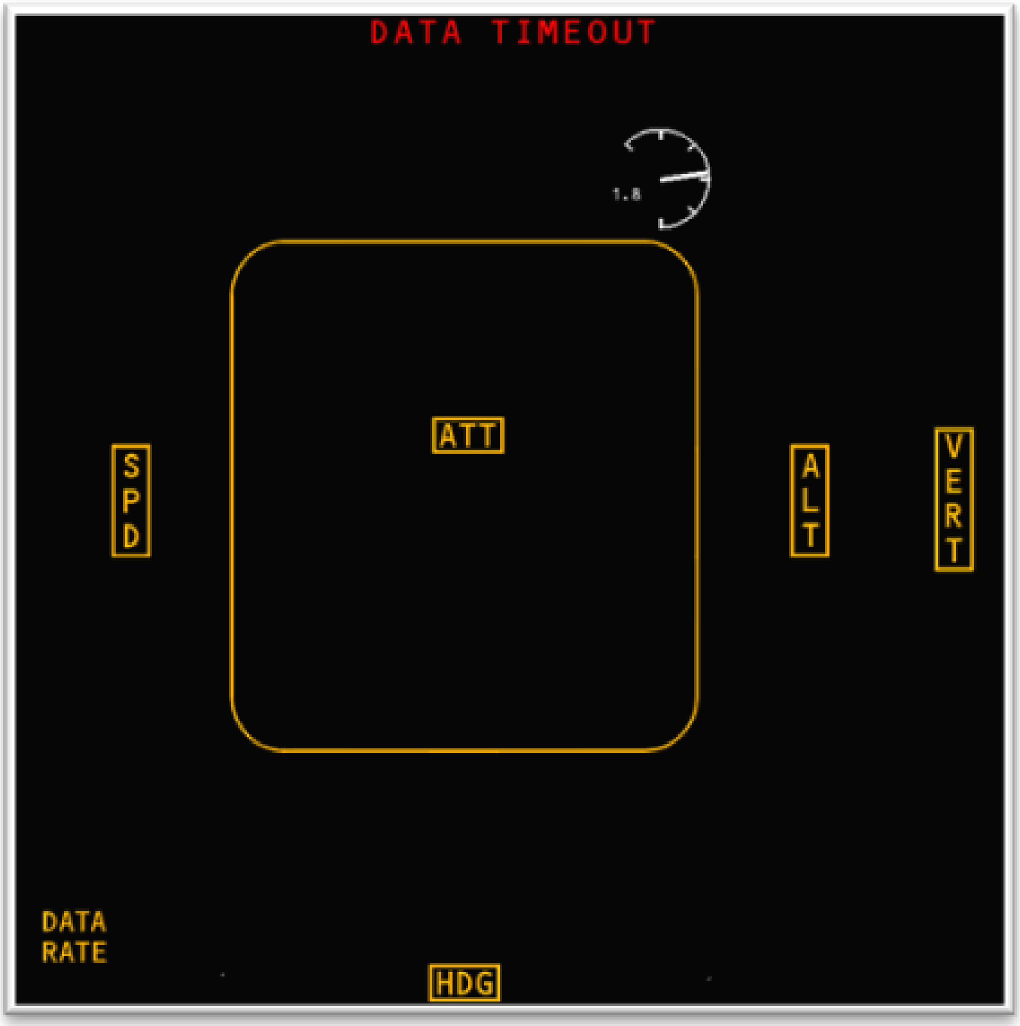

Figure 8: PFD failure flags.

Red flags depented to Display Software. Amber flags send by Air Data Unit.

1. DATA TIMEOUT (Red): Incoming data not available. All shown data freezes.
2. DATA RATE (Amber): Air Data Unit single measurement cycle exceeds the adjusted limit.
3. SPD (Amber): Differential pressure sensor malfunction. Removes airspeed indicator and airspeed tape, mach indicator.
4. ATT: Inertial Measurement Unit (IMU) malfunction. Removes:

(a) Attitude indicator.
(b) Slip / Skid Indicator.
(c) Vertical Acceleration Indicator.
(d) Speed Trend Arrow.
(e) Turn Rate Indication.
(f) Reverts the compass mode to UNCORR MAG or UNCORR TRU automatically according to MAG or TRU selected.

5. ALT: Pressure sensor malfunction. Removes altitude indicator, altitude tape, altimeter setting indications.

6. VERT: vertical speed not available. Removes vertical speed indications

7. HDG: Magnetometer malfunction. Removes compass indications.

4.4 Control Menu

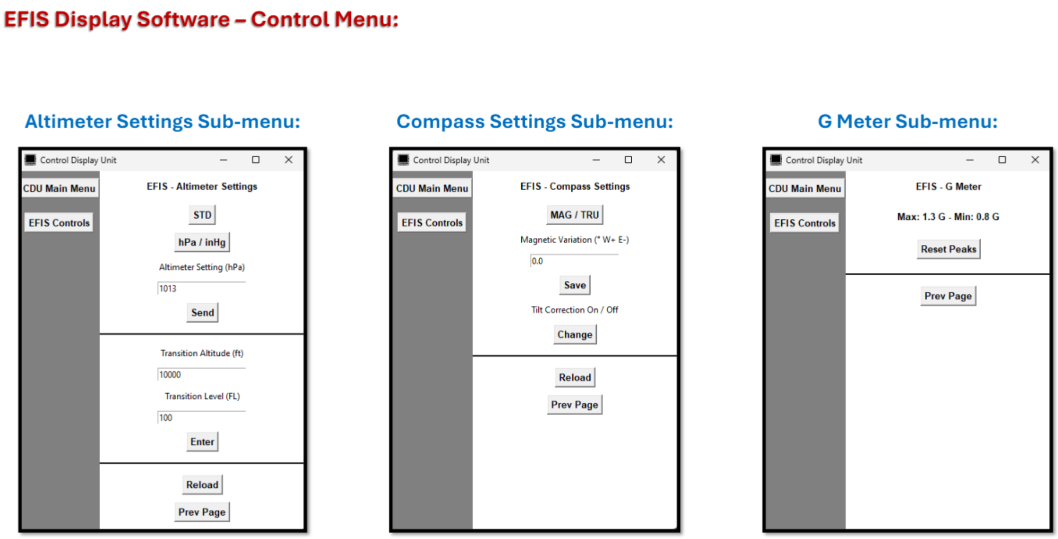

Figure 9: Menu pages of Control Menu

Detailed features currently don't shown in this document.

5 Abbreviations

5.1 Electrical-Electronics Engineering

- AVR - Alf and Vegard's RISC Processor
- CH - Channel
- ESD - Electronic Discharge
- GCC - GNU Compiler Collection
- HVPP - High-Voltage/Parallel Programming
- I/O - Input/Output
- I^2C - Inter-Integrated Circuit
- ISP - In-system Programming
- MCU - Microcontroller Unit
- PTC - Positive Temperature Coefficient
- PCB - Printed Circuit Board
- RC - Radio-controlled
- RTC - Real-time Clock
- RX - Receiver
- SMD - Surface Mount Device
- SPI - Serial Peripheral Interface
- TH - Through Hole
- TX - Transmitter
- UART - Universal Asynchronous Receiver/Transmitter

5.2 International System of Units (SI) For Engineering

- ° - degree
- m - meter
- cm - centimeter
- mm - millimeter

- nF - nanofarad
- pF - picofarad
- A - ampere
- mA - milliampere
- V - volt

5.3 Aviation

5.3.1 ICAO Measurement Units and Quantity Symbols

- ° - degree
- g - Local Acceleration of Free Fall
- hPA - hectopascal
- ft - foot
- kt - knot
- m - metre
- min - minute
- s - second

5.3.2 ICAO Doc 8400 Abbreviations

- EFIS - Electronic Flight Instrument System
- ICAO - International Civil Aviation Organization
- GLONASS - Global Orbiting Navigation Satellite System
- GNSS - Global Navigation Satelite System
- GPS - Global Positioning System
- SBAS - Satellite-based Augmentation System

5.3.3 Other Abbreviations

- inHg - inch of mercury
- PFD - Primary Flight Display
- UAV - Unmanned Aerial Vehicle

6 References

- NIST Special Publication 330 - The International System of units (SI), 2019 Edition
- Atmel AVR042 - AVR Hardware Design Considerations, Revision 2521K-AVR-03/11, 2011
- Microchip ATmega 48A/PA/88A/PA/168A/PA/328/P megaAVR Data Sheet, DS40002061A, 2018
- ICAO Annex 5 - Units of Measurement to be Used in Air and Ground Operations, 5th Edition Amendment 17, July 2010
- ICAO Doc 7488 - Manual of The ICAO Standard Atmosphere, 3rd Edition, 1993
- ICAO Doc 8400 - PANS Abbreviations And Codes, 9th Edition Amendment 33, 8 November 2018
- Boeing 737-600/-700/-800/-900/-900ER Flight Crew Operation Manual (FCOM) The Boeing Company (TBC), Revision 26, 25 March 2010