Do It Yourself
Airborne Proximity Warning Device

Brief outlook on the concept, design and test prototype

Revision: 1.0

Table of contents

(Click on a link to proceed directly to this section)

Idea

Preface

- There is no need to explain any aircraft pilot of how important is in flight to maintain air traffic situational awareness ;
- There are only a few onboard radio-based electronic assistants that help pilots to be aware of other aircrafts in the vicinity ;
- This project is targeted to create yet another, open platform device. Persons should not be highly skilled enthusiasts to build this device by themselves ;
- Greek mythology's hundred-eye giant Argus has given the name to this project.

Goals

- To meet assigned technical specifications (see next slide) ;
- Ensure that no soldering skills are required to build the device ;
- Use only parts that are easily available at local store, e-store, Ebay or Taobao ;
- Ensure that only basic skills are required to install custom firmware(s) ;
- Keep application software to be hardware independent, simple enough to be altered by a user.

Technical specifications

- Operating range:
  - at least within 1.5 kilometers in radius
- Tracking:
  - at least 7 equipped flying objects simultaneously
- «From-Position-to-Mark» latency*:
  - not more than 2-3 seconds

* «From-Position-to-Mark» latency is the time interval between current position of an object and the moment when it will appear on observer's display as a visible mark.

Hardware inter-connectivity

In order to

- meet «no soldering» requirement
- make use a variety of inexpensive mass products available on the market
- to satisfy limited space constraints

decision is to utilize USB Bus as a primary internal hardware interface.

Theory

Radio signal attenuation

Reduction in power of an electromagnetic wave as it propagates through free space can be estimated by:

$$\mathcal{L} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

where

- $\mathcal{L}$ - is free space path loss in decibels,
- λ - is the wavelength,
- d - is transmitter to receiver distance in the same units as the wavelength.

Choices of ISM band radio inter-communication

- «RF Module» (433/868/915 MHz)
- ZigBee (868/915 MHz or 2.4Ghz)
- Wi-Fi (2.4Ghz or 5.8Ghz)
- ADS-B (ES 1090Mhz or UAT 978Mhz)*

* ADS-B is not at ISM band(s). It operates at one of «aviation» frequencies.

Path loss for typical ISM bands

- 868 MHz (EU)

Distance, km	1	2	3	4	5
$\mathcal{L}$, dB	91	97	101	103	105

- 915 MHz (US)

Distance, sm	1	2	3	4	5
$\mathcal{L}$, dB	96	102	105	108	110

- 2.4GHz

Distance, km	1	2	3	4	5
$\mathcal{L}$, dB	100	106	110	112	114

868MHz vs. 2.4GHz

PROS

- Transmitter at 868MHz needs 9dBm less power for the same range, or 3X range for same power than 2.4 GHz transmitter

CONS

- Wavelength at 868MHz is 2.8X longer than at 2.4GHz, so 2.4GHz omnidirectional antenna's gain of the same size is higher

TOTAL

- **System** at 868MHz gives approx. 1.5X (3dB) increase in range at the same power and same antennas size

«RF Module» (433/868/915 MHz)

PROS

- Great «range to power consumption» ratio
- Compact size
- Same band that FLARM* already uses

CONS

- Only a few USB-to-RF dongles are available on the market, most are «short range»
- No common, transparent interface to Linux
- Professional «radio-modems» are rather expensive and bulky

* FLARM® - is a registered trademark of FLARM Technology GmbH.

ZigBee (868/915 MHz or 2.4Ghz)

PROS

- Great «range to power consumption» ratio
- Compact size

CONS

- Only a few USB-to-RF devices are available on the market, most are relatively expensive
- No common, transparent interface to Linux yet

Wi-Fi (2.4Ghz or 5.8Ghz)

PROS

- Good range at reasonable power consumption
- Numerous USB-to-WiFi «extended range» devices are available on the market
- Great unified interface in Linux for data capture/injection (mac80211)
- Low price for «mass products»

CONS

- Some countries apply limitations on transmission power or outdoor use
- Reception noise level can be high near congested areas due to wi-fi hotspots, microwave equipment, etc.

ADS-B (ES 1090Mhz or UAT 978Mhz)

PROS

- Becoming a standard for aviation use within next few years (EU till 2018, US till 2020)

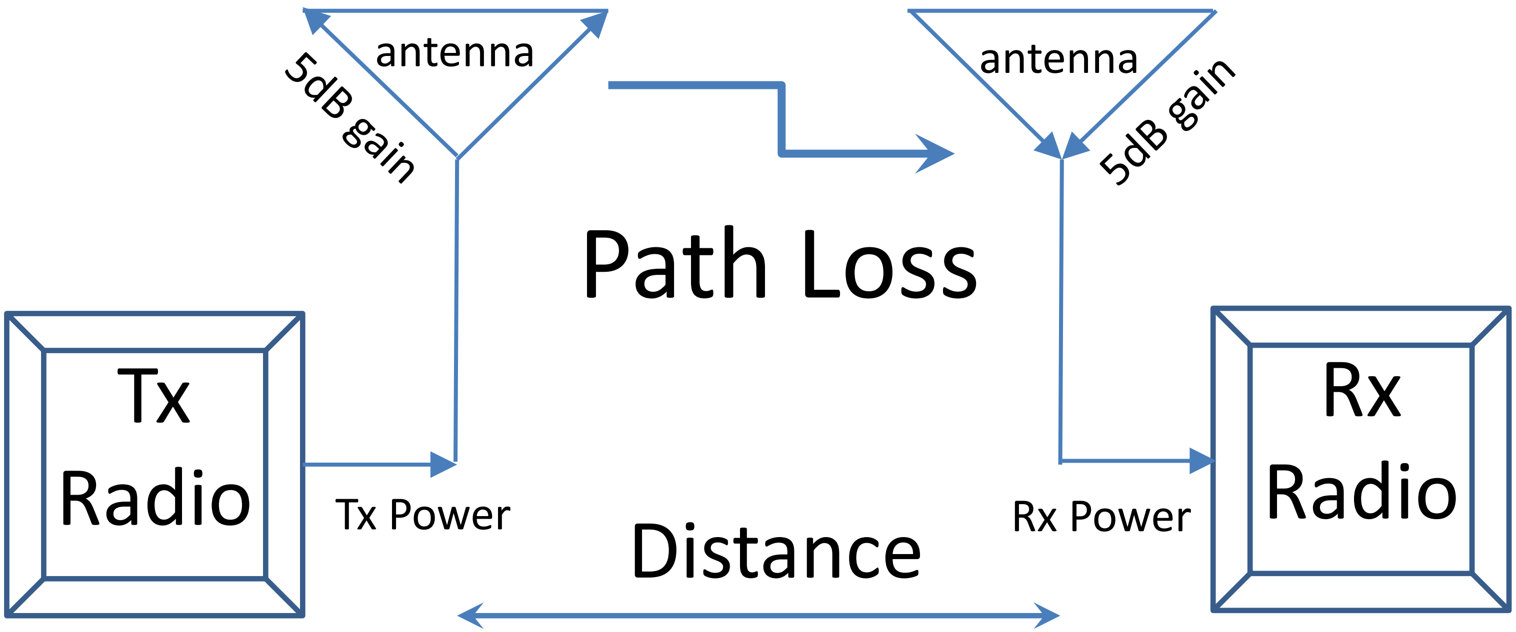
CONS

- No transceivers available on the mass product market yet
- No common, transparent interface to Linux

Decision

- Make use Wi-Fi technology first
- Keep an eye on RF868/915 and ZigBee. System's modular USB design will allow to detach Wi-Fi then attach another RF hardware if necessary
- Think about and try to make few steps toward further transition onto ADS-B (ES 1090)

Wireless Distribution System

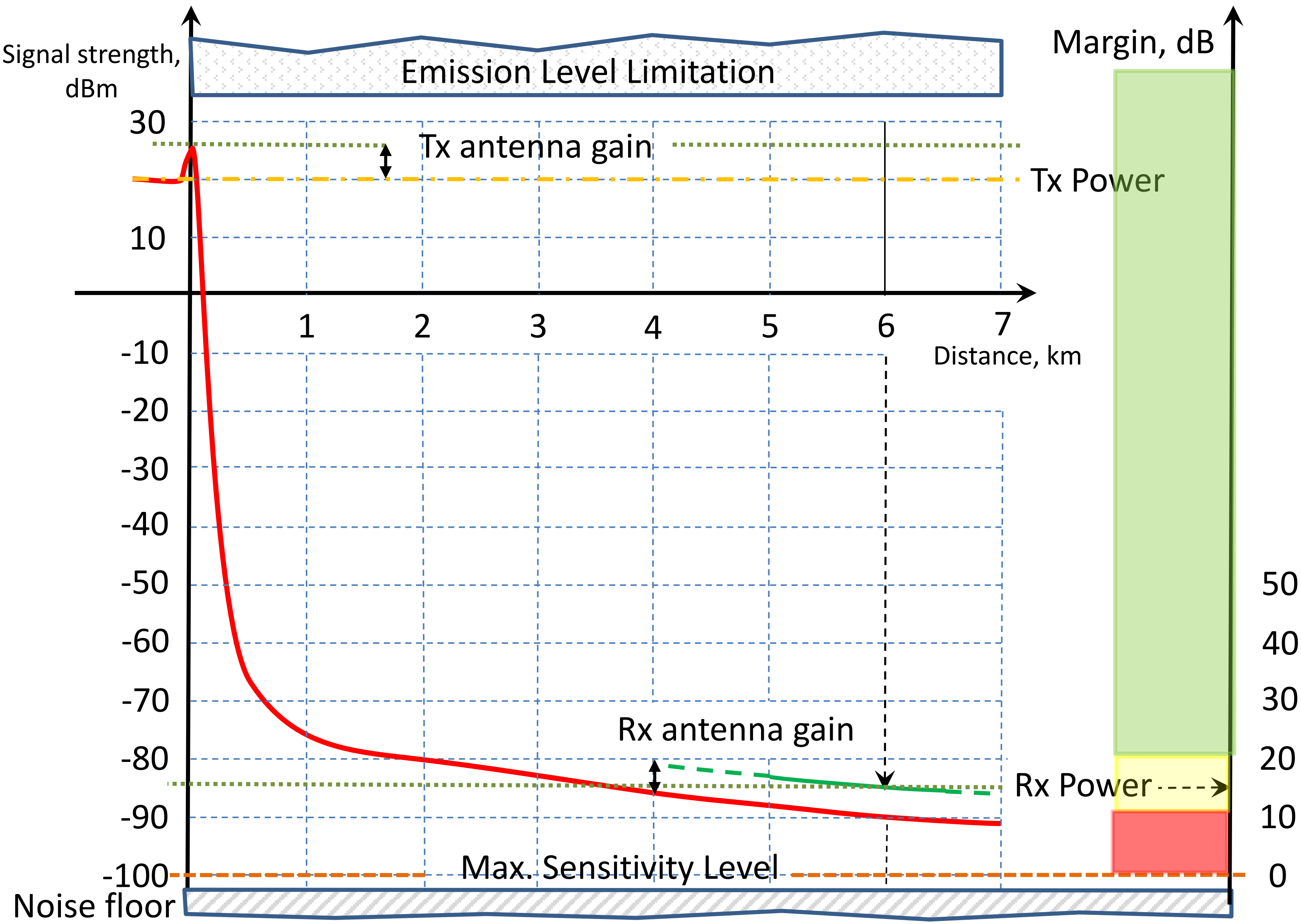


Reception Signal Quality

- Margin – is the ratio by which the Rx signal exceeds the minimum amount for proper operation
- How typical Wi-Fi margin values affect reception quality:

Margin, dB	<10	10-20	>20
Reception quality	*No*	*Poor*	*Good*

Example of graph for Wi-Fi signal attenuation over distance



Examples of regional 2.4GHz emission limitations

IMPORTANT NOTICE!

It is responsibility of the operator of an electronic device to comply with local emission regulations!

EU (ETSI)

- Max EIRP: 20 dBm;

US (FCC)

For Tx antenna gain ≤ 6 dbi:

- Max Tx Power: 30 dBm;
- Max EIRP: 36 dBm;

ETSI range

Provided that Receiver has

- Antenna gain: 5dBi, and
- Sensitivity: -100 dBm, and
- Rx antenna is aligned in parallel with Tx antenna

Distance, km	1	1.6	3	4	5
$\mathcal{L}$, dB	100	104	110	112	114
Rx power, dBm	-75	-79	-85	-87	-89
Margin, dB	25	21	15	13	11

FCC range

Provided that Receiver has

- Antenna gain: 5dBi, and
- Sensitivity: -100 dBm, and
- Rx antenna is aligned in parallel with Tx antenna

Distance, sm	**1**	**3**	**5**	**8**	**10**
$\mathcal{L}$, dB	104	114	118	122	124
Rx power, dBm	-63	-73	-77	-81	-83
Margin, dB	37	27	23	19	17

Hardware

Long range USB Wi-Fi adapter

Alfa Networks AWUS036H

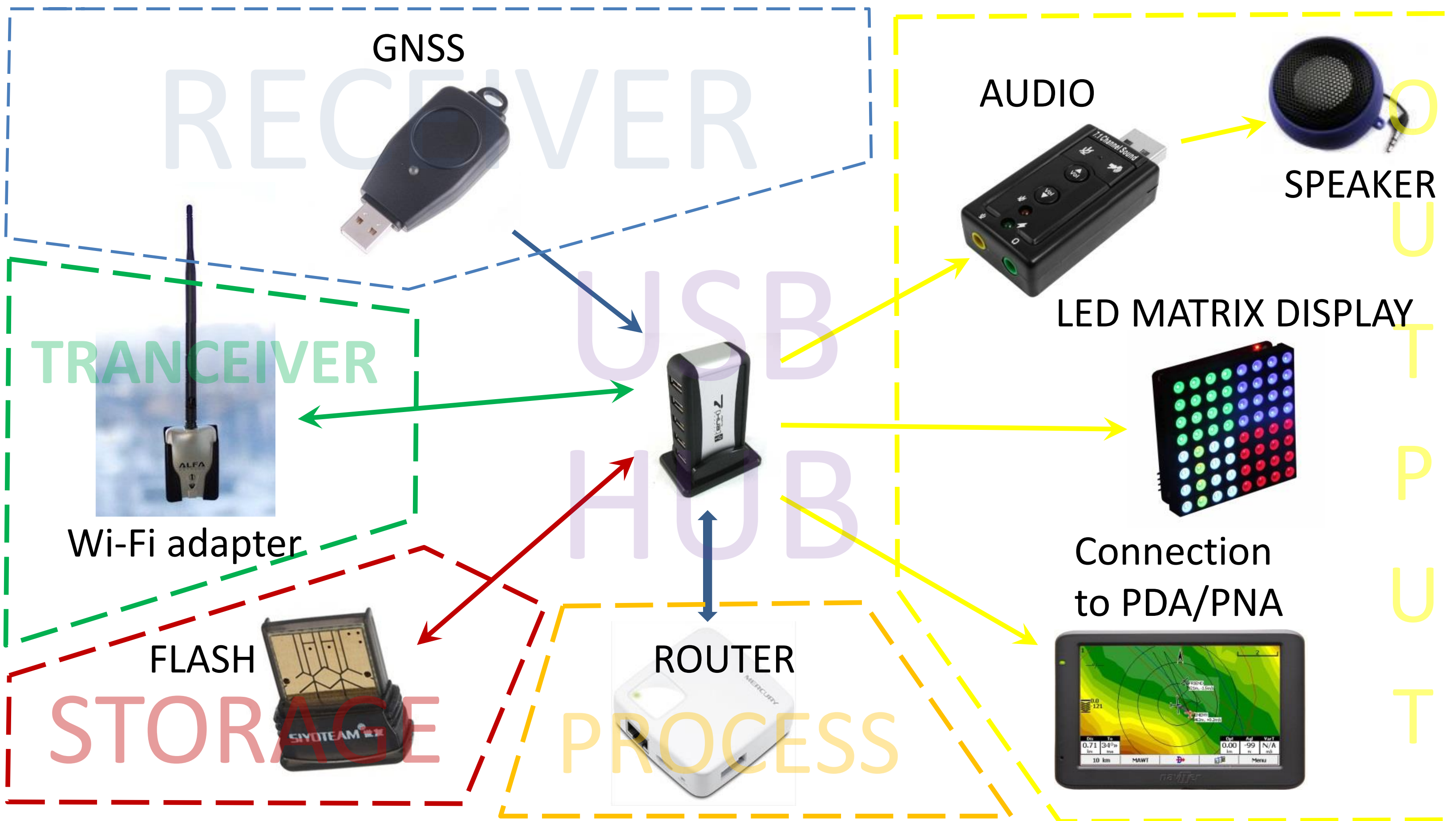
FCC ID: UQ2AWUS036H
Emission Type: DSSS/OFDM
Wireless: IEEE 802.11b/g
Sensitivity 802.11b 1 Mbps (B/QPSK): - 96dBm
typically @PER < 8%
packet size 1024 and
@25ºC + 5ºC
Max. output power: 24.5dBm (by FCC test)
EIRP : 29-30dBm (with 5dBi antenna)
Operating temp.: 0°C ~ +50°C
Linux support:
full-featured “mac80211” open-source
driver with packets capture/injection

Alfa AWUS036H range

- Max Tx Power: 24 dBm by FCC test ;
- Sensitivity: -96 dBm ;
- Tx antenna gain: 5dBi , EIRP: 29 dBm ;
- Rx antenna gain: 5dBi ;

Distance, km sm	1.6 1	2.9 1.8	4.8 3	8 5	12.8 8
$\mathcal{L}$, dB	104	109	114	118	122
Rx power, dBm	-70	-75	-80	-84	-88
Margin, dB	26	21	16	12	8

Standard components overview



Processing module

Brand
- TP-Link

Model
- TL-WR703N

Features
- Atheros AR7240 32-bit CPU (MIPS) @400Mhz
- Atheros integrated wireless 802.11 b/g/n
- 4 MB flash memory
- 32 MB RAM
- USB 2.0 port
- Tiny form factor: 5.7cm x 5.7cm x 1.8cm
- 0.5W power consumption (average)
- Supported by OpenWrt (Linux) project

Equivalents of WR703N available on other markets

Mercury MW151RM-3G

Fast FWR171-3G

TP-Link MR3020

Storage module

The router being used as a processing module has limited internal storage size.

Software pack that manages the system requires 50-100 Mbytes of permanent memory to store programs and data.

USB-Drive provides enough memory to meet this requirement.

GNSS module

There are numerous USB GPS or GLONASS «dongles» available on the consumer’s market.

Standard Linux GPSd software is employed in this system to receive geo-positional data from the device.
This gives opportunity to support almost any of these «dongles».

Bus interconnect

Since the system consists of several devices, all of them need to be electrically connected.

Minimum 7-port USB hub is required.

Power to the system is supplied through the hub.

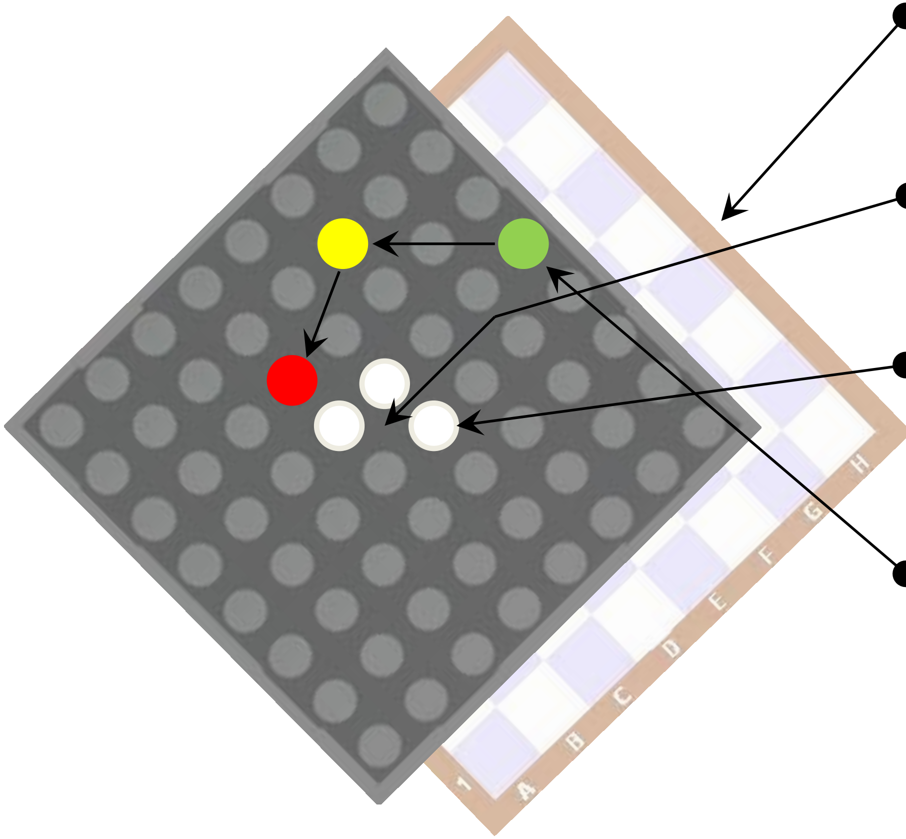
USB Display

The display consists of:
- 60x60mm 8x8 RGB LED matrix (on top) ;
- USB LED display controller (on the bottom) ;

The controller is either:
- «*Rainbowduino*» by Seeed Studio, or ;
- «*Colorduino*» by Itead Studio ;

\- both are supported.

LED display purpose



- The display depicts a «chess board» been rotated at 45° ;
- Position of the observer is in the center of the «board» ;
- Three white colored LEDs in the center of display depicts an «arrow» in the direction of motion (or «north-up») ;
- Red, yellow and green LEDs depict a traffic in the vicinity of observer ;

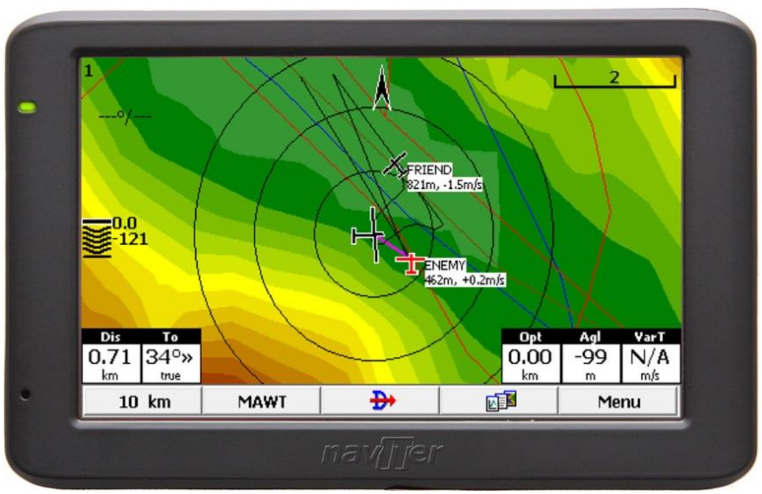
«Closer to center» means «closer to observer», warning level is color-encoded ;

Audio module

USB Sound Card is employed to provide voice and audio traffic alerts for sailplane pilots with no necessity to look at the instrument panel.

The speaker delivers these alerts from device to the pilot’s ears.

Output to external gadget



The system is capable to provide output of traffic positions and proximity alerts to external «Personal Assistants» such as PDA, PNA, PGA and other.

To transfer this information to an «Assistant» a USB cable or USB Bluetooth dongle can be used.

ADS-B module (optional)

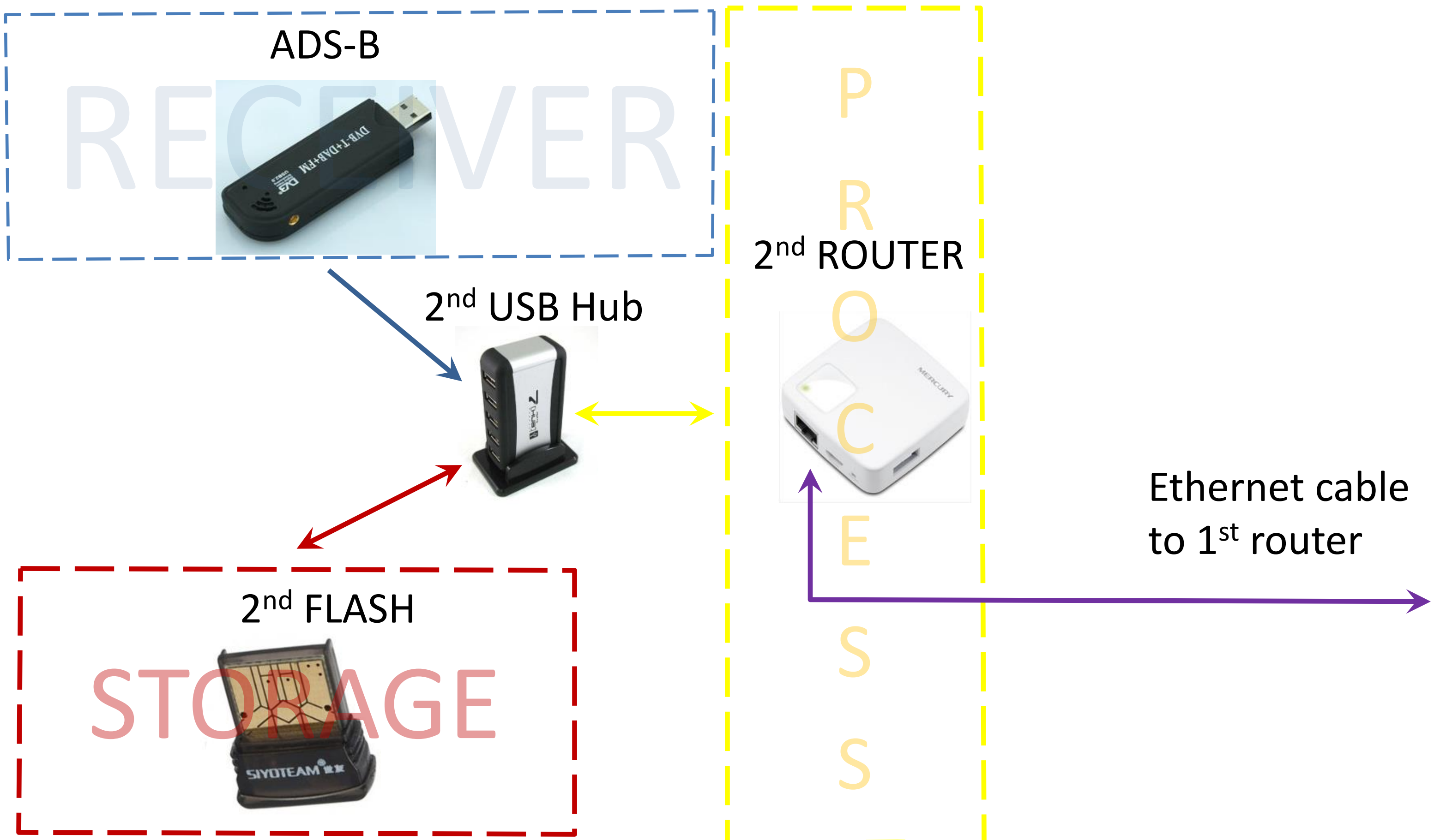
In the areas where the volume of airlines traffic is high it could make sense to receive alerts on proximity of these heavy jets.

There are few USB DVB-T TV sticks available on the market that are known to receive ADS-B signals (1090 MHz), filter them out of noise, amplify, digitize then deliver to a computer for processing.

This system employs the device as an optional source of traffic information. Receive-only, no transmission is available.

Due to high CPU power and RAM memory consumption necessary for decoding of ADS-B an additional processing module is in use.

ADS-B subsystem overview



Software

Overview

Application software:

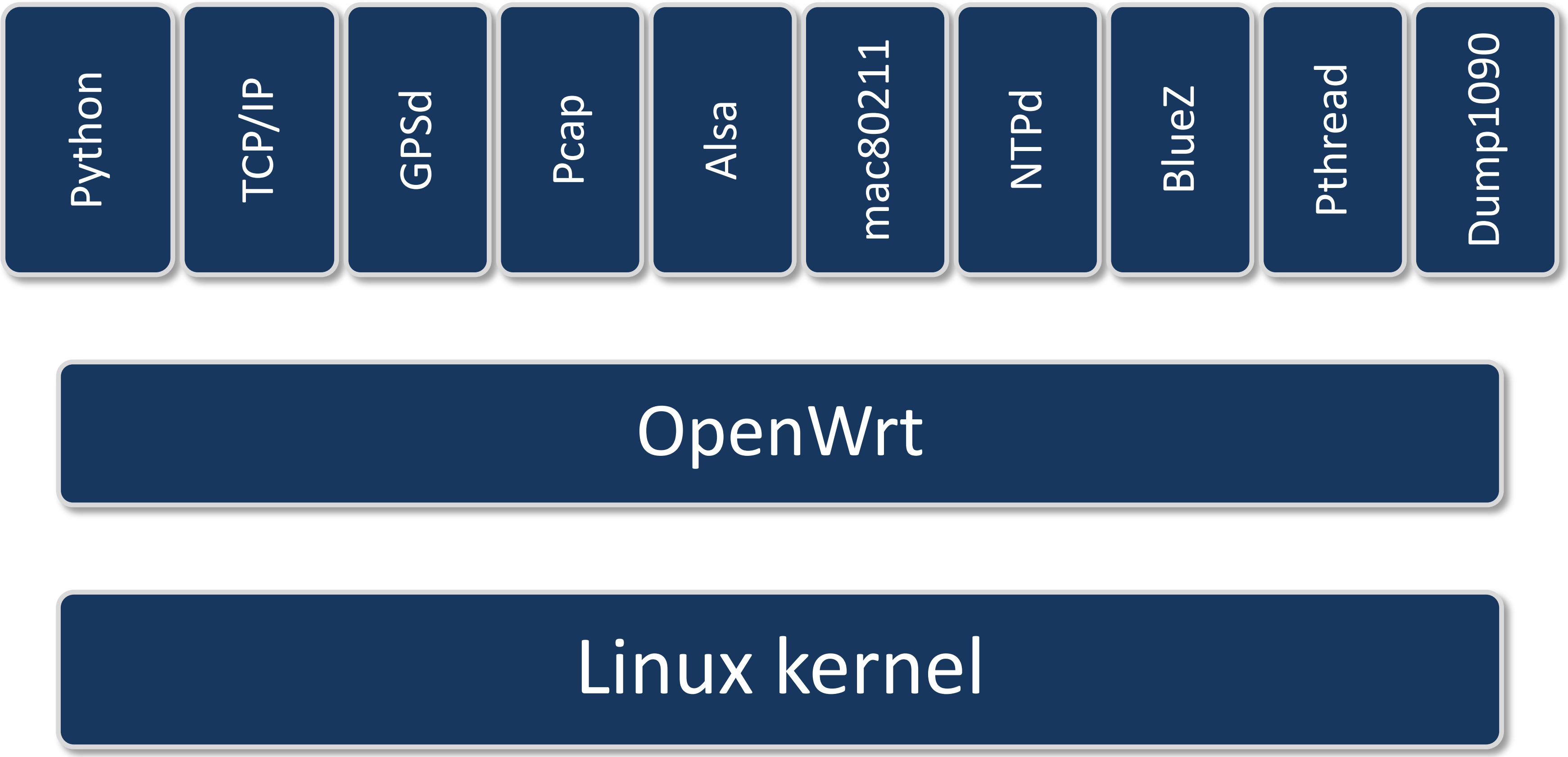
- This software drives the system components to perform the specified task;
- It is mostly developed by the author of this presentation ;
- It is written in Python programming language ;

System software consists of:

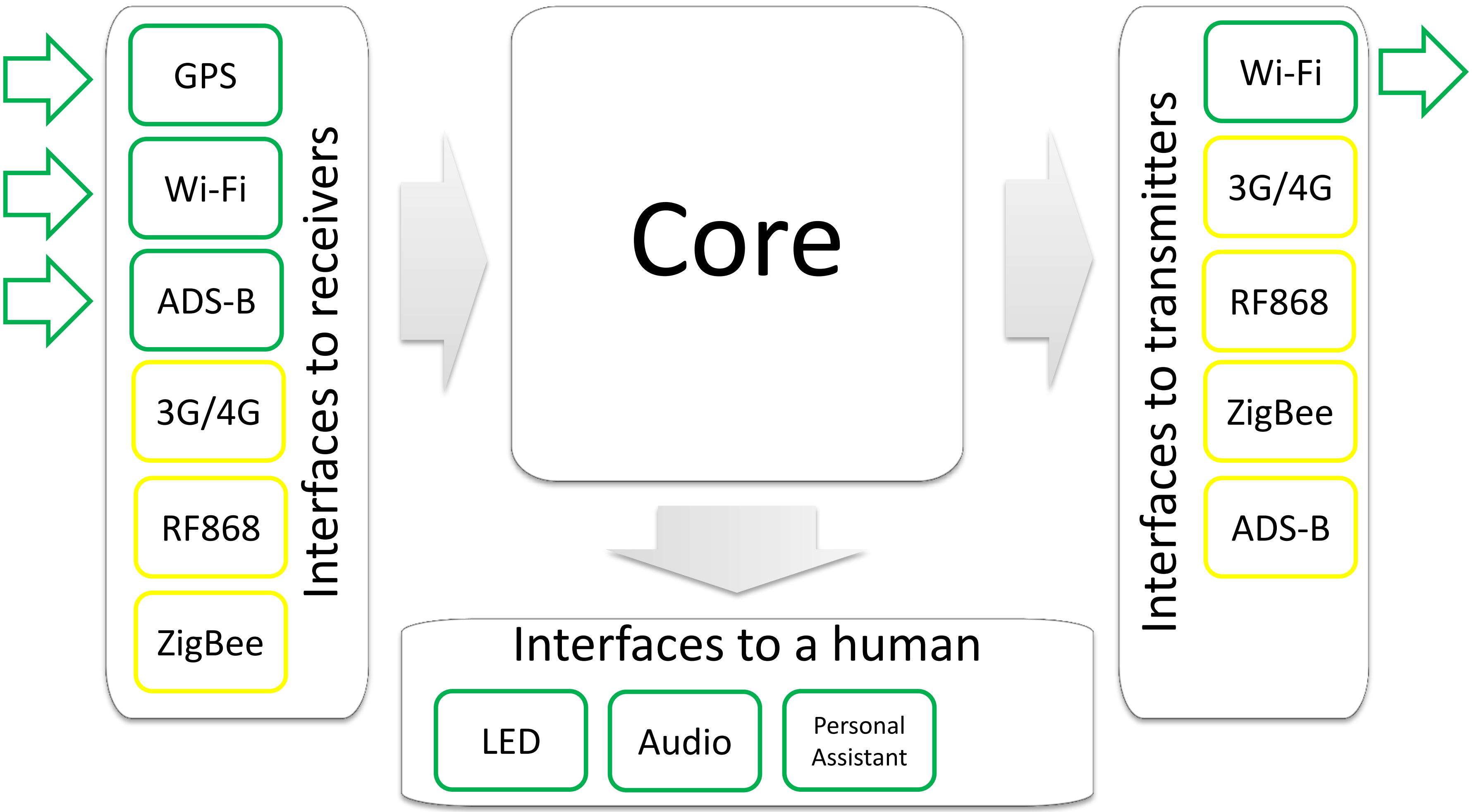
- Firmware for processing module ;
- Operating System extension for processing module ;
- Firmware for LED display module ;

System software is primarily developed by Linux/OpenWrt and Arduino communities.

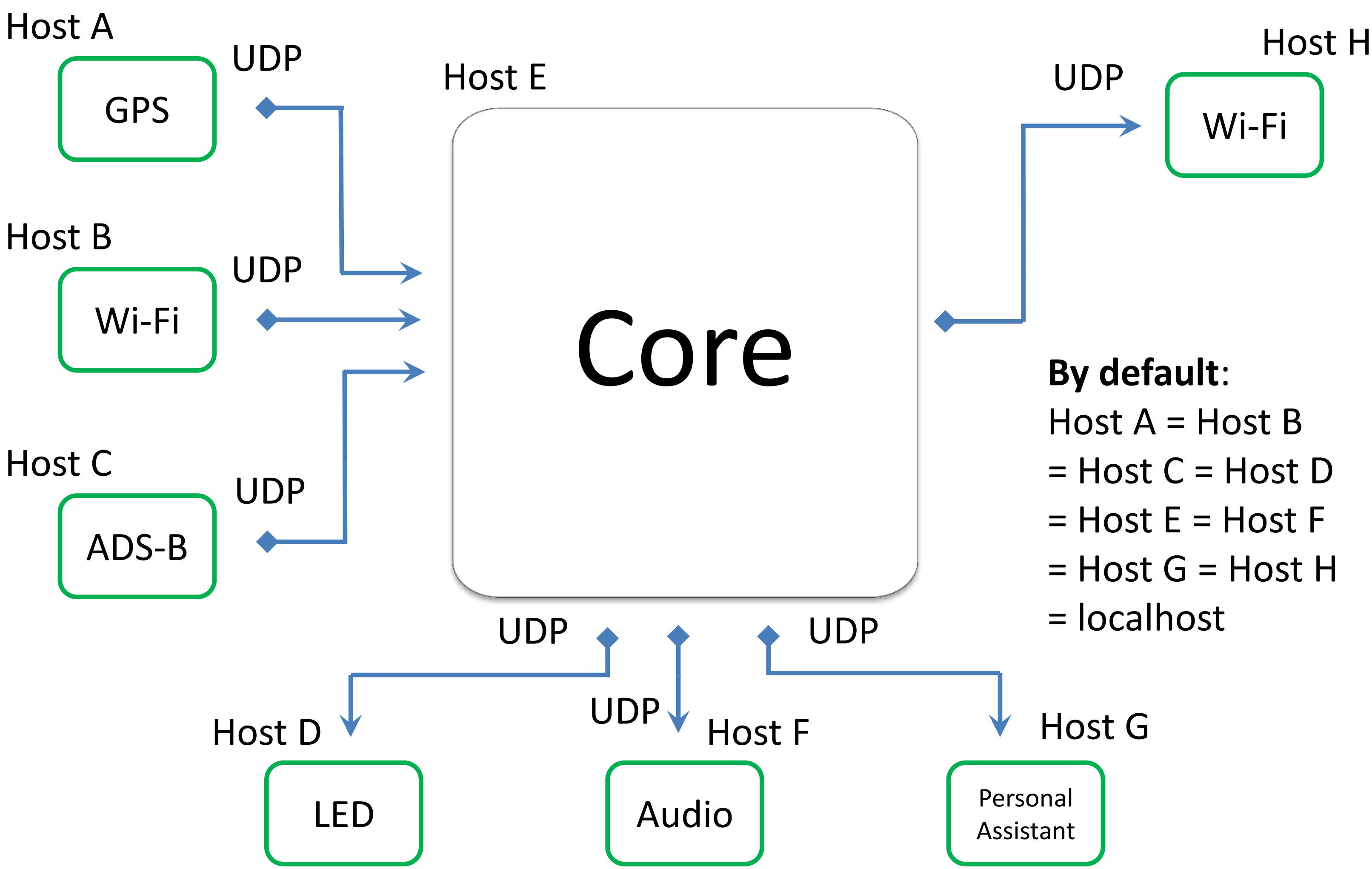
System software



Application software



Distributed software net



Core overview

Flight Progress «Strips Board»

«Vectors Board»

Strips board

Time (UTC)	A/C ID	Position	Alt.	…
15:25:01.5	RA	N52.885201 E036.206278	1510	
15:25:01.7	OY	N52.887855 E036.213337	1743	
15:25:02.1	ZK	N52.88726 E036.192649	1476	
15:25:02.5	CY	N52.878196 E036.197327	1822	

- The «strips board» represents most recent flight progress information about all the traffic in the vicinity of observer, one «strip» per one aircraft ;
- Observer's aircraft (if any) is also represented in the list ;
- The board is updated on a regular basis by new information coming from receiving sources ;
- Core submits full content of the board to transmitters for radio broadcasting at a given rate per second.

Vectors board

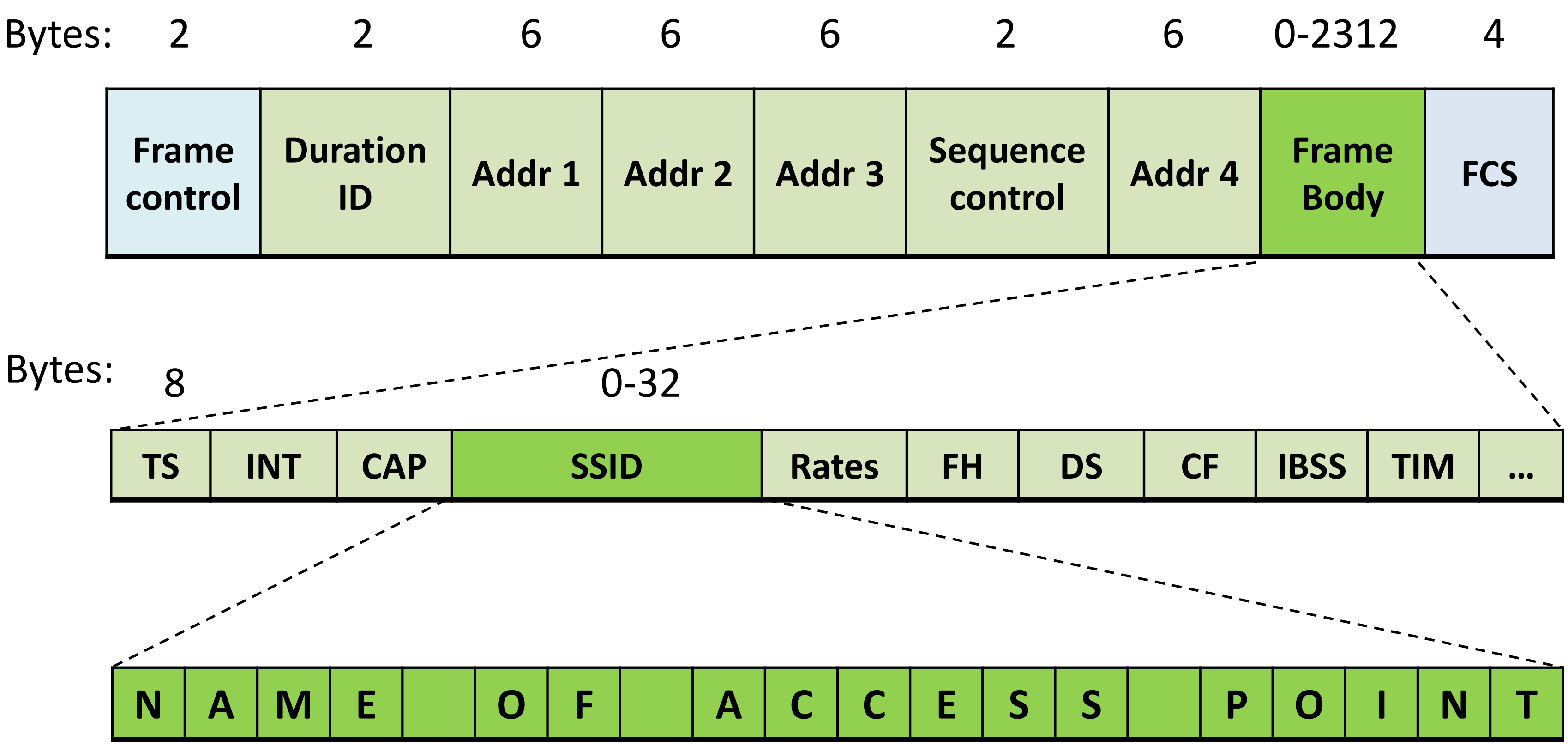
Distance	Bearing	Elevation	A/C ID	…
331	47°	-114	DJ	
486	153°	671	ME	
2333	314°	229	PW	

- This «board» provides vectors pointing to all the traffic in the vicinity of observer ;
- The data is represented in relation to position of the observer’s aircraft.

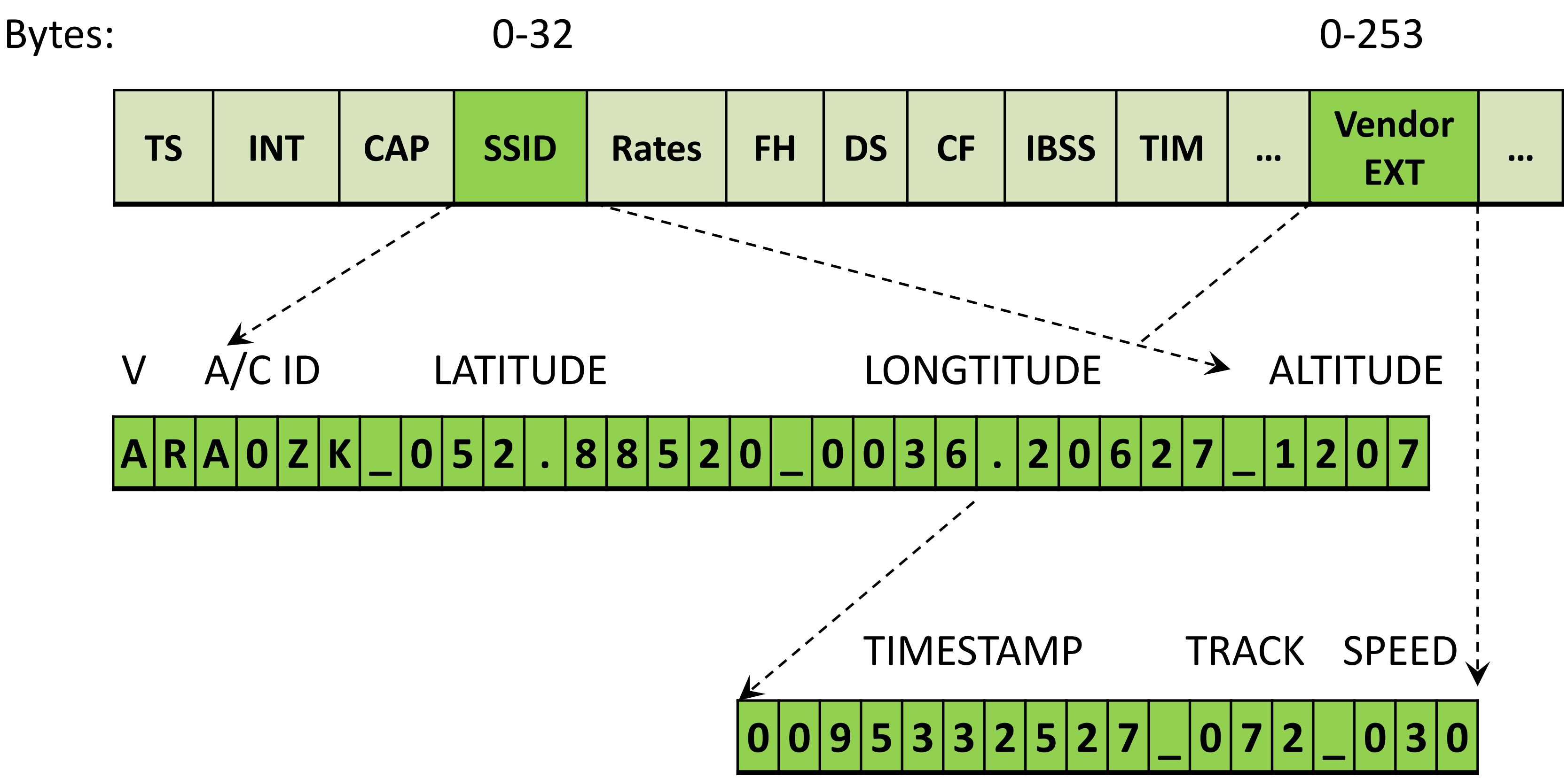
Interface to Wi-Fi

- This system uses Linux «radiotap» API to achieve direct 802.11 frame injection and reception ;
- Within variety of all 802.11 features only beacon-type management frames are employed ;
- Beacons are broadcasted repeatedly at a certain time interval ;
- While in a traditional Wi-Fi network the beacon's content is relatively constant, in this system the beacons are dynamic ;
- To achieve maximum operating range the beacons are emitted at the maximum allowed power setting and at the minimum data rate.

802.11 beacon frame format



Advanced use of 802.11 beacon frame



Operating range update

- The technical specification for the long-range Wi-Fi adapter states that :

  Sensitivity is - 96dBm typically @PER < 8%

  and packet size 1024

- Since this system uses beacon frames of only 100 bytes in length or less, the equivalent sensitivity will be few decibels higher ;
- Thus a slight increase in actual operating range is expected.

GPS subsystem

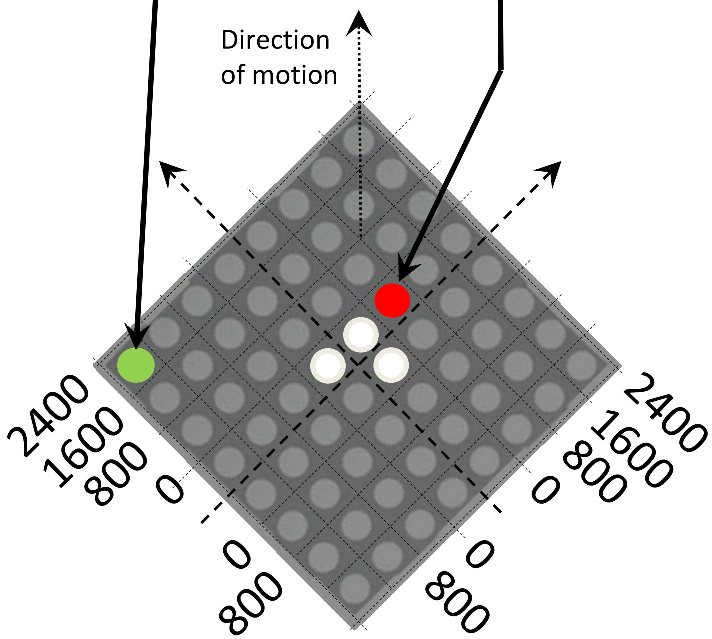
- The software module maintains TCP connection with local or remote GPSd system service;
- At a certain time interval it takes a data from the GPSd, such as:
  - High accuracy current timestamp ;
  - Geo-positional fix (latitude, longitude, altitude) ;
  - Misc. data (ground track course, ground speed, etc.) ;
- It complements the information with locally stored observer's aircraft ID ;
- The module fills this data into an UDP packet then emits the packet in the direction of «Core».

ADS-B subsystem

- This software module keeps persistent connection with local or remote DUMP1090 system service ;
- DUMP1090 utilizes SBS protocol to serve clients. Only «*MSG3*» type of the protocol messages are currently recognized ;
- Information which is contained in the SBS packet’s data is sufficient to convert it into an equivalent «core’s» record ;
- Since autonomous ADS-B hardware module may not have internal reliable real-time clock source, the timestamp field is omitted ;
- The module fills this data into an UDP packet then emits the packet in the direction of «Core».

LED display subsystem

Distance	Bearing	Elevation	A/C ID	…
582	31°	622	OW	
3133	275°	291	VR	



- For each record in the «vectors table» this module allocates a «traffic point» in a 2D scalar field ;
- The center of this field does match the location of observer and both axis are tilted at 45° relative to direction of motion ;
- The field is mapped into a grid. Dimensions of a grid element are 800m x 800m. Grid size is 8 elements in each direction ;
- Every «traffic point» located outside of the grid is ignored ;
- After all the «points» are located, the module draws them in a frame buffer. Then it submits the frame to USB LED display for actual visualization.

Audio subsystem

Distance	Bearing	Elevation	A/C ID	…
486	153°	671	CP	

«Traffic» <Bearing / 30> «o'clock»,
sign(Elevation) ? «high» : «low»,
<Distance / 100> «hundred», <A/C ID>

PLAY traffic.wav, five.wav, oclock.wav,
high.wav , four.wav, hundred.wav,
charlie.wav, papa.wav

- The module receives most critical traffic alerts from the «vectors board»;
- A verbal sentence is created based on the alert's data ;
- Next step is conversion of the sentence into a voice message.

Interface to a «Personal Assistant»

Distance	Bearing	Elevation	A/C ID	…
486	153°	671	CP	

$**PDIYU**,1,1,1,1,<Bearing>,2,<Elevation>,
<Distance>,<A/C ID>*<CheckSum>
$**PDIYA**,2,<ΔX>,< ΔY>,<Elevation>,2,
<A/C ID>,,,,,1*<CheckSum>

- This module receives «vectors» from the «core» first. Then it converts each vector into two NMEA messages ;
- By means of Bluetooth or USB cable connection these messages are to be delivered to «Assistant's» software (such as **XCSoar**) for visualization.

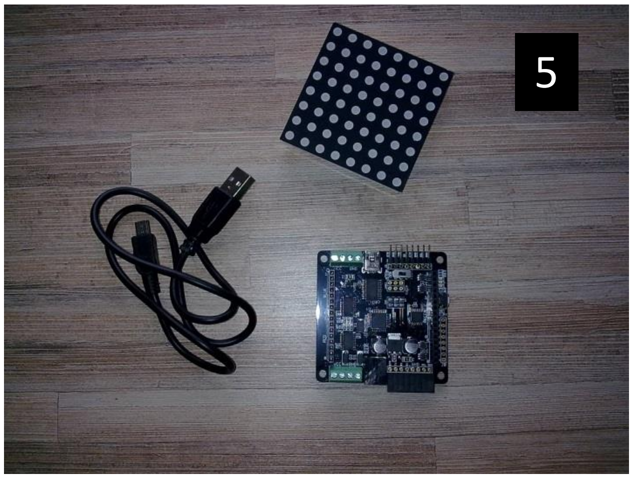
Prototype

Purpose and description

- The purpose of the prototype is to prove the concept, undergo test procedures, verify compliance with tech specs, estimate reliability, locate weaknesses ;
- Prototype consists of two instances of the device;
- Devices should be self-contained, self-powered and robust enough to withstand outdoor environment and casual handling manner.

Assembly procedure

Assembly procedure (cont.)



Assembly procedure (cont.)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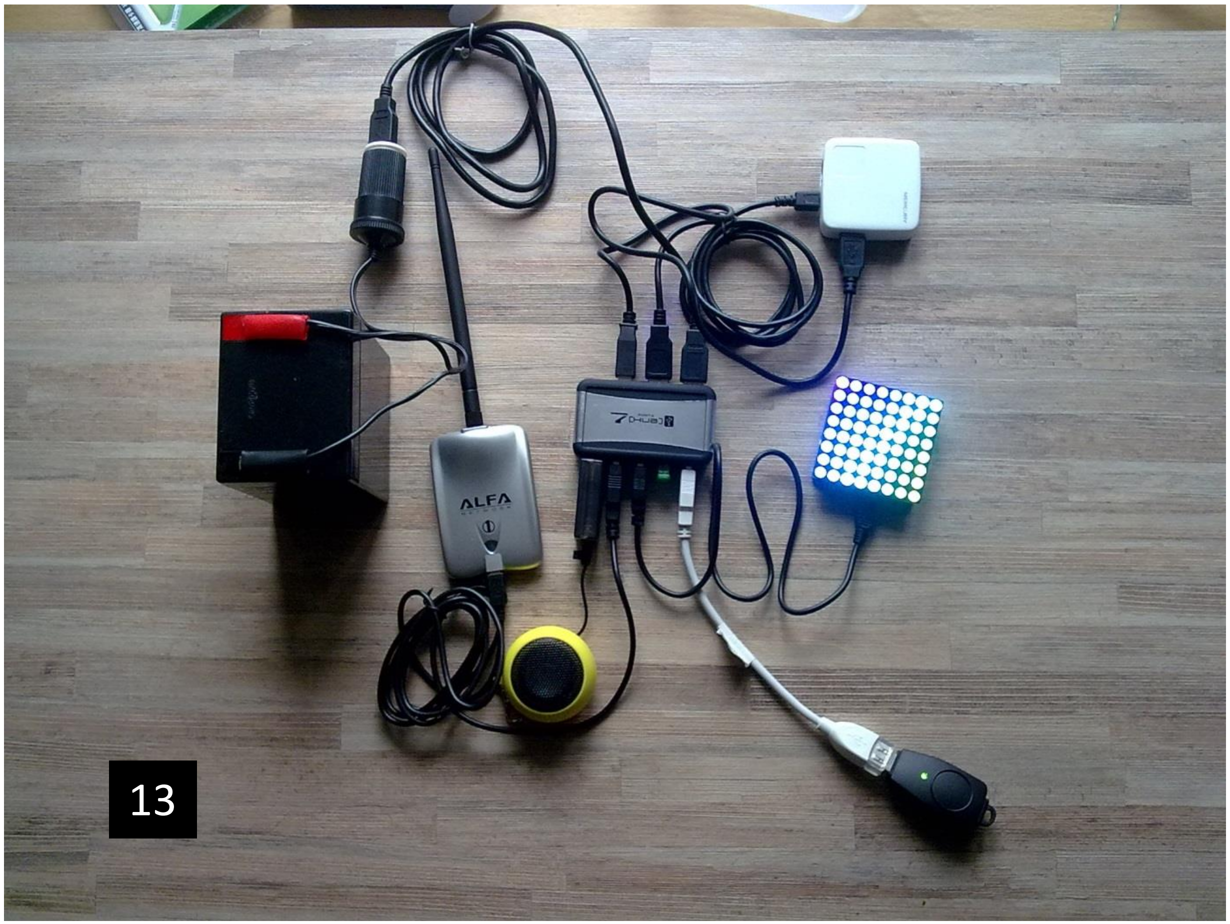
10

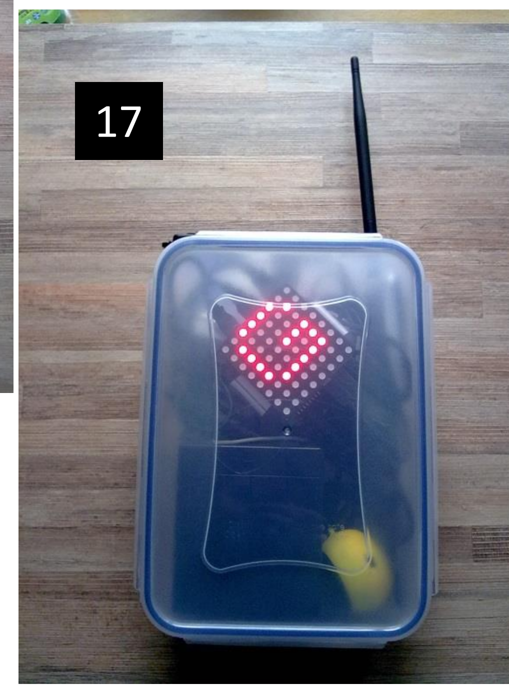

11


12

Assembly procedure (cont.)



Assembly procedure (cont.)



Assembly is completed

ADS-B extension assembly

Tests

Load testing

- **Conditions**:
  - The test is carried out indoor ;
  - 9 simulated GPS sources of NMEA messages are submitting positional data to the prototype ;
  - One of these sources is providing observer’s own location and motion. Other eight are providing information on «virtual» aircraft’s traffic around. Each «flying object» has its own «flight path» ;
- **Result**:

  During normal system operation cycle average CPU load value of the processing module did not exceed 80%.

Ground test of practical operating range (distance)

- **Conditions**:
  - The test is carried out outdoor ;
  - Wi-Fi transceiver module is in use ;
  - One of the prototype devices is stationary and being elevated at few meters above the ground. Another device is in motion and being transferred by a pedestrian or a car;
  - The mobile device is positioned distant from stationary one at 900, 1600, 3300 meters consequently ;
  - No obstructions for straight-line visibility between these two devices are allowed ;
- **Result**:

  Reliable signal reception level and stable rate of position reports were observed in every of these three cases. Practical ground operating range of 3.3km (2 statute miles) was achieved.

Test of ADS-B operating distance

- **Conditions**:
  - The test is carried out outdoor ;
  - ADS-B «receive-only» subsystem is in use ;
  - The receiver is being elevated at approx. 15 meters above the ground ;
  - «Stock» 15 cm antenna is connected to the USB DVB-T hardware ;
- **Result**:

  Reception of numerous ADS-B data packets coming out from airlines traffic was achieved. Some of that traffic was located at more than 60 kilometers away from the test point.

Flight test. Conditions.

- One of the prototype devices is stationary on the ground. Another device is in motion ;
- Mobile device is consequently carried onboard and being hold in the cockpit of these three aircrafts:
  - PZL-104 («Wilga») ;
  - LET L-13 («Blanik») ;
  - SZD 48-3 («Jantar 3 Std») ;
- Both «Wilga» and «Blanik» are doing a traffic pattern work within 1-2 km range from the stationary device at altitudes equal or less than 300 meters AGL;
- «Jantar» is doing local area flight within 5 km range from the stationary device at altitudes equal or less than 900 meters AGL.

Flight test. Results.

- The test performed with one device been hold in the cockpit of «Wilga» has failed. The GPS satellite signal reception was lost soon. Most likely reason of that is: open sky view was shielded by metal structures of the aircraft ;
- The test performed when the device had been flown by «Blanik» was successful ;
- The test performed when the device had been flown by «Jantar» was successful. Test partner was depicted on the LED display throughout all the maneuvers. Full scale display's operating range (2300 – 3400 meters) was achieved.

Tests that still need to be done

- Measure <u>maximum</u> operating distance:
  - at factory default Tx power setting ;
  - when EIRP is set to ETSI (EU) limit ;
- Measure «From-Position-to-Mark» latency ;
- Measure temperature of PM’s CPU under heavy load.

Thank you for your attention!

For more details on the topics presented in this slideshow, please, visit:

< URL is to be determined later >

For software source code, please, visit:

https://github.com/lyusupov/Argus

Acknowledgements

I would like to express my appreciation to:

- Andrey Kalachov, who has made a detailed review of these slides before first public release;
- Alexey Starikovskiy, whose feedback were useful for author to make this document more comprehensive;
- Sergey Antipov, who has offered his assistance in flight testing of the device in Vilga's cockpit.

History of changes

Revision	Date	Author	Comments
0.9	23 Nov 2013	Linar Yusupov	Pre-release.
1.0	8 Dec 2013	Linar Yusupov	Feedback from reviewers were admitted. First public release.