Features and Applications of the Adaptable Flexiband USB3.0 Front-end

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Introduction
Motivation and Applications for a USB Front-end

- Even a software receiver needs some hardware!
  - A front-end is required
  - USB is the most common standard PC interface

- Wide field of applications:
  - Get collection of real-world events to have controlled and reproducible data
  - Interference monitoring and detection
  - Array processing: beamforming / null-steering
  - Reflectometry applications
  - Multipath monitoring
  - Antenna comparisons
Introduction
Fraunhofer USB Front-ends

- L125 Triband USB Front-end (2006)
  - GPS L1/L2/L5
  - Two USB 2.0 data streams
  - Powered over USB

- RTKIII USB Front-end (2010)
  - Lower band: 1145-1310 MHz
  - Upper band: 1545-1630 MHz
  - 2x 410 MSPS ADCs
  - Flexible signal conditioning using an FPGA
  - Three USB 2.0 data streams
Introduction
Fraunhofer USB Front-ends

- "Flexiband" (2012)
- ION GNSS 2012
- Features
  - Portable
  - USB 3.0, USB2.0
  - Powered via USB
  - Futureproof (support all GNSS signals)
  - Flexibility for the user
  - Synchronization between different units
  - Multi antenna support
  - User friendly control GUI and API

Introduction

Fraunhofer Flexiband ⇄ TeleOrbit GTEC RFFE

- Since 2012, distributed via TeleOrbit
- ION GNSS+ 2014
  - At the booth of NavXperience
  - Flexiband together with Fraunhofer’s 3G+C Antenna
Flexiband Hardware
Overview

- System architecture comprises four blocks:
  - RF modules
  - Baseband Unit
  - Interface Unit
  - Housing
- Integration
  - 188 x 125 x 50 mm$^3$
  - 0.8 kg weight
  - USB powered
  - Perfectly suited for mobile recording campaigns
Flexiband Hardware
RF Modules and Base Unit

- Carries up to 3 RF modules
  - 80 MHz RF bandwidth
  - Different filter types available
- Three Dual-Channel ADCs
  - Up to 80 Msps@8 bit I/Q
  - Coherent sampling
- FPGA
  - Digital filtering, mixing, multiplexing
  - Synchronization between different units
  - Embedding an error detection protocol
  - 67 GPIOs to e.g. embed digital sensor data in received raw GNSS data stream
- Clock generation and distribution unit
  - Onboard TCXO, External clock
Flexiband Hardware
USB3.0 Interface, Parallel Port

- USB 2.0 discontinued
- USB 3.0
  - Cypress EZ-USB FX3 controller
  - SuperSpeed USB3.0 – 5 Gbits/s
  - Power supply via 1x USB 3.0
  - Possibility to upgrade USB controller, microcontroller and FPGA firmware

- Parallel port interface
  - 24 bit data, 1 clk
  - LVCMOS 3.3V

*Figure 2: Honda connector layout (commonly used for SCSI-bus systems)*
## Flexiband Software Architecture

- **Flexiband software components**
  - USB-driver
  - Application programming interface (API)
  - Visualization and recording software (Qt) ➔ **FlexibandGUI**
  - Console Version ➔ **FlexibandCLI**
  - Available for Windows and Linux
Flexiband Software
Flexiband GUI – Recording tab

- Manual / Automatic Gain Control (AGC)
- Error visualization
- Recording modes
  - Original samples
  - 8 bits/sample
  - Matlab
- Recording methods
  - Direct recording
  - RAM buffered
  - Round robing (infinite recording time, overwrites oldes files)
Flexiband Software
Flexiband GUI – Analyze tab

- Manual / Automatic Gain Control (AGC)
- Error visualization
- Complex Spectrum visualization of selected band
  - Identify e.g. CW-interference
- ADC histogram view
  - Check antenna and gain settings
Flexiband Software

Flexiband GUI – Hardware Information/Configuration

- "Expert control"
- Board revisions
- Status of Firmware
  - USB
  - Microcontroller
  - FGPA
- Settings of RFICs
  - Analog bandwidth
  - Analog local oscillator
- Compensation of ADC DC-offset
Flexiband Software

Flexiband CLI

- All configuration parameters are stored in config.ini file
- Usage:
  FrontendCLI [-i INI_FILE] [--help|-h]
- Default ini-file:

Advantages
- No user interaction to configure/start recording necessary
- Suited for automatic recordings e.g. from triggered events
Project Examples
Recording with Flexible Configurations

- Once the analog front-end hardware is chosen the digital signal conditioning on the FPGA can be used to realize flexible settings
- FPGA development kit for experienced users
  - Generate own bit-files for FPGA to
    - Configurable, complex FIR filter
    - Sampling rate decimation (80MSPS / n with configurable n)
    - Configurable digital mixer for IF setting
- Different FPGA configurations
  - Changing the signal selection and conditioning „on-the-fly“
  - From a single band to a triple band with one mouse click
### Project Examples

#### Recording with Flexible Configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Bandwidth [MHz]</th>
<th>Center frequency [MHz]</th>
<th>Intermediate frequency [MHz]</th>
<th>Sampling rate [MHz]</th>
<th>Sample bit width</th>
<th>USB data rate [MBit/s]</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>Single-band frontend</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I.1a</td>
<td>18</td>
<td>L1/E1 (Galileo)</td>
<td>L5/E5/B2</td>
<td>1.192,500</td>
<td>2x4 (complex)</td>
<td>L5/E5a: -16,050</td>
<td>Monitoring</td>
</tr>
<tr>
<td>I.1b</td>
<td>18</td>
<td>L1/E1bc</td>
<td>L5/E5/B2</td>
<td>1.192,500</td>
<td>2x2 (complex)</td>
<td>G1: 17,000</td>
<td>Monitoring</td>
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<td>L1/E1bc</td>
<td>1.575,420</td>
<td>2x4 (complex)</td>
<td>L1: -11,58</td>
<td>Monitoring</td>
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<tr>
<td>I.1d</td>
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<td>L1/E1abc/B1</td>
<td>L5/E5/B2</td>
<td>1.191,795</td>
<td>2x8 (complex)</td>
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<td></td>
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<td></td>
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<tr>
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<td>G2</td>
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<td></td>
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<td></td>
<td>Monitoring</td>
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<tr>
<td>I.3b</td>
<td>38</td>
<td>E5b/B2</td>
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<td>2x4 (complex)</td>
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<td>L1/E1abc/B1</td>
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<td>2x4 (complex)</td>
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<td>Monitoring</td>
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<td>L1/E1abc/B1</td>
<td></td>
<td></td>
<td>2x4 (complex)</td>
<td></td>
<td>Monitoring</td>
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<tr>
<td>I.6b</td>
<td>18</td>
<td>L1/E1abc/B1</td>
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<td>2x4 (complex)</td>
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<td>2x4 (complex)</td>
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<td>Monitoring</td>
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<tr>
<td>I.7b</td>
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<td>L1/E1abc/B1</td>
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<td>2x4 (complex)</td>
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<td></td>
<td>2x4 (complex)</td>
<td></td>
<td>Monitoring</td>
</tr>
</tbody>
</table>

### From single-band to triple-band
- From 320 to 1280 Mbit/s [40 to 160 Mbyte/s]

### Over 43 defined configurations available
- Customized configurations available, too

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Project Examples
Recording with Flexible Configurations

- Select Configuration FPGA bit-File
- From a triple band III-b:
  - L1 20Msps@4bit I/Q
  - L2 20Msps@4bit I/Q
  - L5 40Msps@4bit I/Q
- With overall 640 Mbit/s (80 Mbyte/s)
Project Examples
Recording with Flexible Configurations

- To a new single band configuration I-1c:
  - L1 20Msps@8bit I/Q
  - With overall 320 Mbit/s (40 Mbyte/s)
Project Examples
Recording with Flexible Configurations

- Or to an extended triple band configuration III-4b:
  - E1 40Msp@4bit I/Q
  - E6 40Msp@4bit I/Q
  - E5 80Msp@4bit I/Q
- With overall 1280 Mbit/s (160 Mbyte/s)
Project Examples
Interference Monitoring at German Reference Station

GPS L1 C/A code

GPS L2P code

GPS L1 C/A carrier

GPS L2P carrier
Project Examples
Interference Monitoring at German Reference Station

- HAM Radio FM-Relais, 1242.650 MHz with approx. 9 Watt output power
- Even a power reduction to 300 mW is clearly visible (not shown here)
- Flexiband with antenna splitter at reference station
Project Examples
Interference Monitoring at German Reference Station

- HAM Radio FM-Relais, 1242.650 MHz with approx. 9 Watt output power
- Even a power reduction to 300 mW is clearly visible (not shown here)
- Flexiband with antenna splitter at reference station

Relative to L2 freq. of 1227.6 MHz

Relative to L2 freq. of 1227.6 MHz
Project Examples
Interference Monitoring at German Reference Station

**NAVSTAR-GPS**
- L5: BPSK(10) 1176.45 MHz
- M-Code BOC(10,5) 1217.60 MHz
- L2: PPS BPSK(10) 1575.42 MHz
- L1 C-I BOC(1,1) 1575.42 MHz
- L1 PPS BPSK(10) 1575.42 MHz
- L1 M-Code BOC(10,5) 1575.42 MHz
- L1 E5a BPSK(10) 1176.45 MHz
- L1 E5b BPSK(10) 1207.14 MHz
- E5 ALTBOC(15,10) 1191.795 MHz

**GLONASS**
- L3C: BPSK(10) 1202.025 MHz
- L2 C BPSK(0.511) 1598.0625 MHz
- L1 SPS BPSK(1) 1575.42 MHz
- L1 C-G TMBOC(6,1,4/33) 1598.0625 MHz
- L1 E6b BPSK(5) 1251.5875 MHz
- L1 E6c BPSK(5.11) 1242.9375 MHz

**Galileo**
- E5a - BPSK(10) 1176.45 MHz
- E5b BPSK(10) 1207.14 MHz
- E5 ARBOC(15,10) 1191.795 MHz
- E11 CBOC(6,1,1/11) 1575.42 MHz
- E11 E11b CBOC(6,1,4/33) 1609.3125 MHz

**L1/E1 Band:** ARNS and RNSS
- L2/E6 Band: RNSS only
- L5/E5 Band: ARNS and RNSS

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Project Examples
Interference Monitoring at Airport Graz, Austria

- GNSS Airport Interference Monitoring System (GAIMS)* using the Flexiband

- 2014-08-19 – 11:18 – Graz – Vicinity of Airport Graz Thalerhof

- Jammer at E1/L1 center frequency

* Provided by TeleConsult Austria GmbH

P. Berglez and S. Hinteregger
Several Flexiband units can be synchronized

Sharing the same reference clock (internal one or external)

Synchronization link necessary
  - Wired OR-connection: all units stay in reset till recording is triggered on all units
  - Used for asynchronous FPGA reset (and its counter values)
  - Preamble and counters guarantee data sync
Project Examples
Mobile Array Recording Platform

- Recording of the array antenna elements for offline data analysis and beamforming / nullsteering
- With coupling two Flexiband units up to 6 antenna inputs possible

Advantages
- Not external power supply necessary (power via USB)
- On-field selection of different recording configurations, e.g.
  - 6x L1/E1, 18 MHz BW, 20 MSPS I/Q, 8 bit = 960 Mbit/s per unit
  - 6x L1/E1, 8 MHz BW, 10 MSPS I/Q, 8 bit = 480 Mbit/s per unit
Project Examples

Mobile Array Recording Platform

6x L1 Front-end input Signals
Project Examples
Mobile Array Recording Platform

Power Minimisation Technique (Minimum Variance Beamforming)

Blue: one input signal with interference
Red: output signal after MMSE
Conclusion

- Flexiband provides a future proof, flexible, portable and user friendly GNSS recording solution
  - Powerful Flexiband recording software
  - USB 3.0 is current baseline interface, Parallel port, USB2.0 also available
  - Powered via USB → perfectly suited for mobile recording campaigns
  - User changeable sampling rate, resolution and IF with different FPGA configurations
  - Synchronization of different units
  - Multi antenna support
- Digital replay solution planned for 2015
- User feedback, new feature suggestions, ideas welcome!
Questions?
alexander.ruegamer@iis.fraunhofer.de
Backup

Flexiband GUI – Script tab

- Scripting language ECMAScript
- Similar to JavaScript
- User can easily implement his own functions
- E.g. user defined automatic gain control (AGC) could implemented here
## Backup

### Flexiband technical parameters

<table>
<thead>
<tr>
<th>Feature</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (length<em>width</em>height) [mm]</td>
<td>188<em>125</em>50</td>
</tr>
<tr>
<td>Power supply</td>
<td>5V / 900 mA via 1x USB 3.0</td>
</tr>
<tr>
<td>Max. RF input power</td>
<td>0 dBm</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>0-55°</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>0-95 %</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>-55° to 125°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band</th>
<th>Nominal Centre Frequency [MHz]</th>
<th>Digital IF [MHz]</th>
<th>RF-Band-width [MHz]</th>
<th>Comple x signal</th>
<th>IF spectrum orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1/E1</td>
<td>1,575.420</td>
<td>0</td>
<td>up to 60</td>
<td>Yes</td>
<td>non flipped</td>
</tr>
<tr>
<td>L2/L2C</td>
<td>1,227.600</td>
<td>0</td>
<td>up to 50</td>
<td>Yes</td>
<td>non flipped</td>
</tr>
<tr>
<td>E6/B3</td>
<td>1,278.750</td>
<td>0</td>
<td>up to 50</td>
<td>Yes</td>
<td>non flipped</td>
</tr>
<tr>
<td>L5/E5</td>
<td>1,176.450</td>
<td>0</td>
<td>up to 68</td>
<td>Yes</td>
<td>non flipped</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Label</th>
<th>Con.-Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>SMA</td>
<td>antenna connector (1 to 3 possible)</td>
</tr>
<tr>
<td>10 MHz in</td>
<td>SMB</td>
<td>input for an external reference clock, signal</td>
</tr>
<tr>
<td>10 MHz out</td>
<td>SMB</td>
<td>sinusoidal output of the internal 10MHz reference clock</td>
</tr>
<tr>
<td>USB</td>
<td>USB 3.0 Micro-B</td>
<td>data interface to the PC and power supply</td>
</tr>
<tr>
<td>Digital output</td>
<td>Honda E68-LFD</td>
<td>optional parallel output of the data stream</td>
</tr>
<tr>
<td>Sync</td>
<td>SMB</td>
<td>optional connector for synchronization of two front ends</td>
</tr>
</tbody>
</table>
Backup
Multiplexer Example for different triple band config

- **III-1a**: L1 20MSPS@2bit I/Q; L2 20MSPS@2bit I/Q; L5 20MSPS@4bit I/Q
- **III-1b**: L1 20MSPS@4bit I/Q; L2 20MSPS@4bit I/Q; L5 40MSPS@4bit I/Q
- **III-6**: L1 20MSPS@4bit I/Q; L5 20MSPS@4bit I/Q; E5b 20MSPS@4bit I/Q
- **I-1b**: L1 20MSPS@2bit I/Q; L2 20MSPS@2bit I/Q; L5 40MSPS@4bit I/Q
- **III-4a**: L1 20MSPS@2bit I/Q; L2 20MSPS@2bit I/Q; L5 40MSPS@4bit I/Q

| Word | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | ...
<table>
<thead>
<tr>
<th></th>
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<td>6</td>
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<td>8</td>
<td>9</td>
<td>...</td>
</tr>
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<td>Bit15</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
</tr>
</tbody>
</table>

**PREAMBLE** | **COUNTER** | **DATA** |
---|---|---|
0x55 | 0xAA | 0x00000000 - 0xFFFFFFFF |
0 | 1 | 2 | 3 | ...

---|---|---|
**DATA** | **CRC** |
---|---|
0x00000000 - 0xFFFFFFFF | 0xDE 0xAD 0xBE 0xEF |
0 | 1 | 2 | 3 | ...

---|---|---|
**CRC** | **CRC** |
---|---|
0xDE 0xAD 0xBE 0xEF | 0x0E 0x0D 0x0C 0x0B |
0 | 1 | 2 | 3 | ...