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

ION GNSS+ 2014
September 8-12, 2014, Tampa Convention Center, Florida

Session A6: Simulation and Testing

Alexander Rügamer, Frank Förster, Manuel Stahl, Günter Rohmer
alexander.ruegamer@iis.fraunhofer.de
Fraunhofer IIS, Nuremberg, Germany
Contents

- Introduction
- Flexiband Hardware and Software
- Project Examples
  - Recording with Flexible Configurations
  - Interference Monitoring at German Reference Station
  - Interference Monitoring at Airport Graz, Austria
  - Array Post-Processing
- Conclusion
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 mm³
  - 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>Frequency band</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>USB type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>US3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Single band front end**

- **Type**
  - US3.0

**Extended L1/L2/L5; GPS + GLONASS**

- **Type**
  - Extended L1/L2/L5

**GPS + GLONASS**

- **Type**
  - GPS + GLONASS

**Recording with Flexible Configurations**

- **Type**
  - Recording with Flexible Configurations

**Customized configurations available, too**

- **Type**
  - Customized configurations available, too

## Over 43 defined configurations available

- **Type**
  - Over 43 defined configurations available

- **Type**
  - Over 43 defined configurations available

- **Type**
  - Over 43 defined configurations available

- **Type**
  - Over 43 defined configurations available

**From single-band to triple-band**

- **Type**
  - From single-band to triple-band

**From 320 to 1280 Mbit/s [40 to 160 Mbyte/s]**

- **Type**
  - From 320 to 1280 Mbit/s [40 to 160 Mbyte/s]
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 20Msp@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 40Mmps@4bit I/Q
  - E6 40Mmps@4bit I/Q
  - E5 80Mmps@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

Relative to L2 freq. of 1227.6 MHz
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
Project Examples

Interference Monitoring at German Reference Station

NAVSTAR-GPS

GLONASS

Galileo

L5/E5 Band: ARNS and RNSS

L2 / E6 Band: RNSS only

L1/E1 Band: ARNS and RNSS
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

© Fraunhofer IIS
P. Berglez and S. Hinteregger
Project Examples
Mobile Array Recording Platform

- 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°C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>0-95 %</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>-55°C to 125°C</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>Complete 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

### III-1a: L1 20MSPS@2bit I/Q; L2 20MSPS@2bit I/Q; L5 20MSPS@4bit I/Q

<table>
<thead>
<tr>
<th>Word</th>
<th>Byte</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>1014</td>
<td>1015</td>
<td>1016</td>
<td>1017</td>
<td>1018</td>
<td>1019</td>
<td>1020</td>
<td>1021</td>
<td>1022</td>
<td>1023</td>
</tr>
</tbody>
</table>

### III-1b: L1 20MSPS@4bit I/Q; L2 20MSPS@4bit I/Q; L5 40MSPS@4bit I/Q

<table>
<thead>
<tr>
<th>Byte</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1009</td>
<td>1010</td>
<td>1011</td>
<td>1012</td>
<td>1013</td>
<td>1014</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### III-6: L1 20MSPS@4bit I/Q; L5 20MSPS@4bit I/Q; E5b 20MSPS@4bit I/Q

<table>
<thead>
<tr>
<th>Byte</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<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>0</td>
</tr>
<tr>
<td>0xDE</td>
<td>0xAD</td>
<td>0xBE</td>
<td>0xEF</td>
<td>0x0</td>
<td>0x0</td>
<td>0x0</td>
<td>0x0</td>
<td>0x0</td>
</tr>
</tbody>
</table>

### I-1b: L1 20MSPS@2bit I/Q; L2 20MSPS@2bit I/Q; L5 40MSPS@4bit I/Q

<table>
<thead>
<tr>
<th>Byte</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<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>0</td>
</tr>
</tbody>
</table>

### III-4a: L1 20MSPS@2bit I/Q; L2 20MSPS@2bit I/Q; L5 40MSPS@4bit I/Q

<table>
<thead>
<tr>
<th>Byte</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<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>0</td>
</tr>
</tbody>
</table>

© Fraunhofer IIS