NetTimeLogic GMBH

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Wireless IEEE1588 over an Infrared Interface

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Wireless communication
Introduction

- **Most common wireless technologies**
  - Radio
  - Optical
  - Sonic
  - Electromagnetic induction
- **Differentiation**
  - Bandwidth
  - Distance
  - Disturbance resistance
- **Suitability depends heavily on the requirements**
  - But, same link for synchronization and data

Wireless communication

PTP and wireless communication

- **A timely deterministic link is best suited for PTP**
  - Time from transmission to reception shall be constant for a link of a specific length
    - Delay will of course change with a distance change
  - Otherwise a lot of statistics and processing power is needed
  - Fast reaction on delay changes due to distance changes is hard to achieve otherwise

Wireless communication

PTP and wireless communication

- **Most common negative influences on timely determinism**
  - Changing distance
  - Multipath transmission and reception
  - Retransmission
  - Encoding and decoding

Wireless communication

PTP and wireless communication

- **Comparison of the two widely used technologies**

Influence Factor	Radio Frequency Technology (RF)	Free-Space Optical Technology (FSO)
Changing distance	yes	yes
Multipath transmission and reception	yes	no, if narrow angle receivers or senders are used
Retransmission	yes, often	no, normally handled by higher layers
Encoding and decoding	yes, often complex	no, simple

Wireless communication

PTP and wireless communication

- **Free-space optical technology is simple and therefore suffers of only a few of the typical factors which negatively influence the timely determinism of a wireless link**
  - But it has other drawbacks
    - Requirement for a line-of-sight
    - Outdoors sun, rain or fog can be an issue
    - Often low-range and/or low-bandwidth

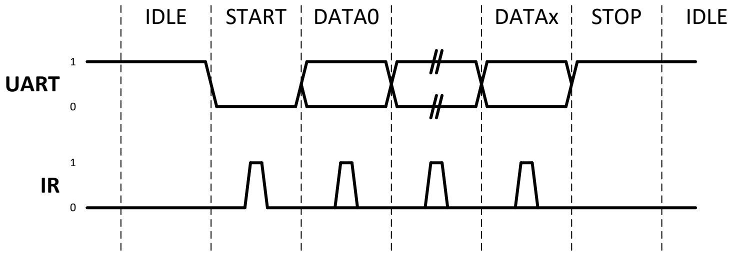
Infrared interface
SIR Introduction

- **Why serial infrared (SIR)?**
  - Quite timely deterministic
  - Simple
  - Low power
  - Cheap (1.5$ per transceiver)

  - Hasn't been used for PTP yet ☺

Infrared interface
SIR Introduction

- **Serial infrared (SIR)**
  - Is one of the widely used low-range, low-bandwidth standardized FSO technologies (IrPHY 0 of IrDA)
  - UART like interface, Point to Point, Half duplex
    - 9.6 - 115.2 Kbit/s, 1 start bit, 8 data bits, 1 optional parity bit followed by a stop bit
  - Return to Zero Inverted (RZI) encoded with 3/16 pulse length, light emission only on logical zeros



Infrared interface

Challenges with SIR when using PTP

- **Challenges with SIR when using PTP**
  - Not frame based, no mapping for Ethernet frames to SIR defined (there is IrLAN but this is out of the scope due to its higher complexity)
  - No timestamping point defined
  - Half duplex, shared media (Air)
  - No off-the-shelf "UART to IR" ASICs available that have a timely very deterministic behavior or can timestamp data
  - Low bandwidth

Infrared interface

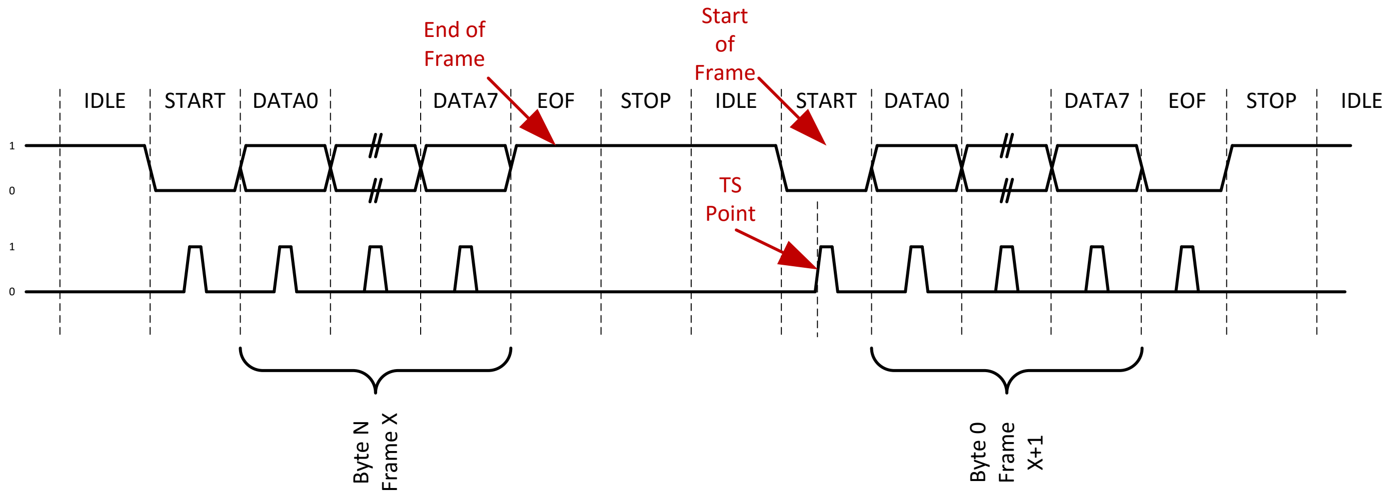
Solutions for the Challenges with SIR

- **Not frame based, no mapping for Ethernet frames to SIR defined**
  - Use of an additional End-Of-Frame (EOF) bit per 8bit transfer, this is re-using the position of the parity bit in a normal UART (but with a different meaning)
  - Ethernet frames are sent in 8bit portions
  - No preamble and Start-Of-Frame (SFD) delimiter
  - No interframe gap
  - CRC32 is used the same way as in Ethernet

Infrared interface

Solutions for the Challenges with SIR

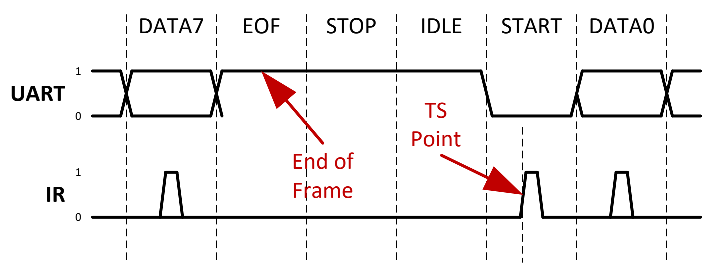
- **Not frame based, no mapping for Ethernet frames to SIR defined cont.**
  - Also a special encoding like 8b/9b could have been used for SOF or EOF, but this was compatible with a normal UART (which ignores the parity)



Infrared interface

Solutions for the Challenges with SIR

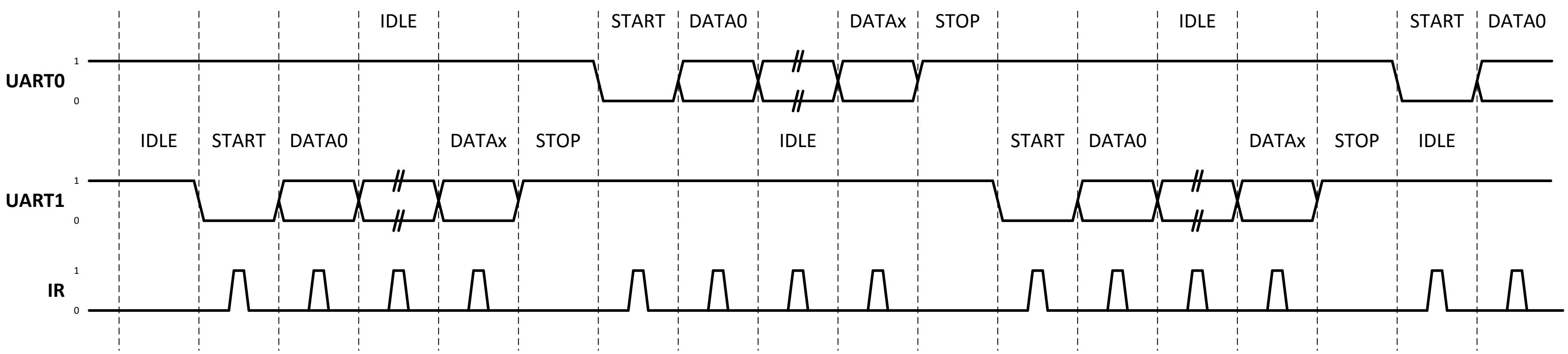
- **No timestamp point defined**
  - A timestamp point similar to the Ethernet mapping had to be defined
  - No Preamble and SFD is sent for bandwidth reasons
  - Deterministic in the relationship to the start of the frame and as close to the media (air) as possible
  - Rising edge of first IR pulse (START bit) after EOF was set



Infrared interface

Solutions for the Challenges with SIR

- **Half duplex**
  - A simple TDMA algorithm was implemented to allow interleaving of frames on a byte level
  - Other starts in idle cycle of the last, before starting next data, check for activity
  - Error detection but no retransmission



Infrared interface

Solutions for the Challenges with SIR

- **No UART to IR ASICs available that have a timely very deterministic behavior or can timestamp data**
  - A simple UART to IR converter had to be implemented in a FPGA which detects the timestamp condition defined and generates an event

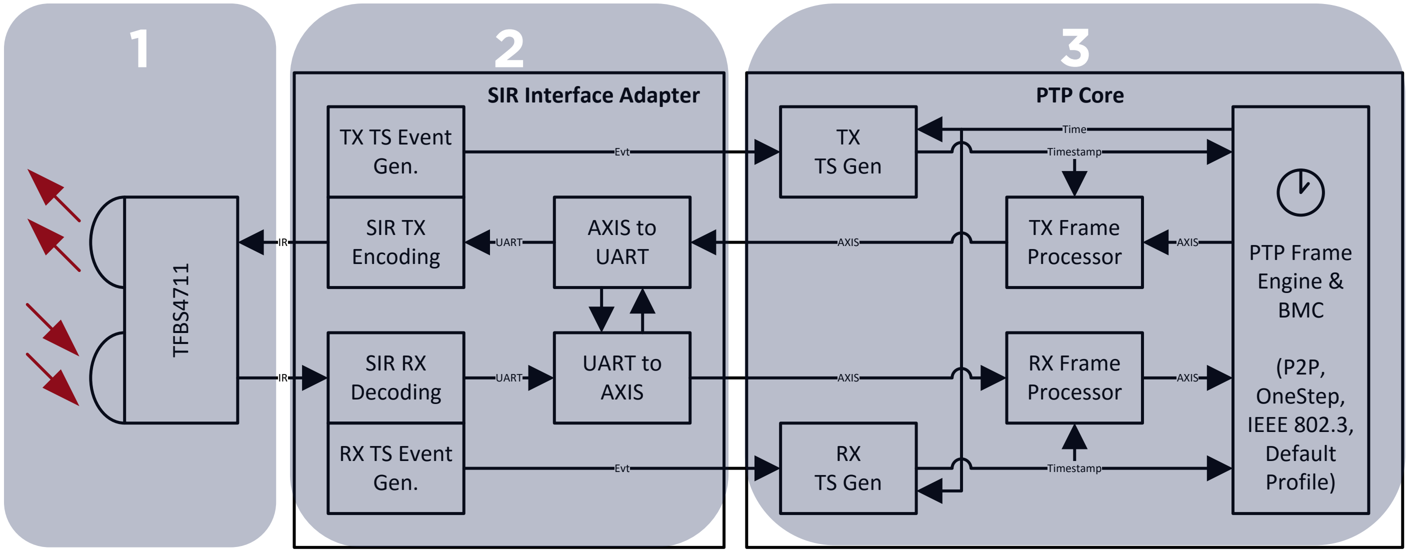
Infrared interface

Solutions for the Challenges with SIR

- **Low bandwidth**
  - Interframe gap, preamble and SFD are skipped
  - Min frame size of 64bytes is reduced to 19bytes
    - 12byte Dst/Src MAC, 2byte Ethertype, 1byte Data, 4byte CRC
  - PTP message rates of 1/s are used with one-step handling, to have a good compromise between bandwidth usage for synchronization and accuracy
    - Bandwidth usage for PTP in that case is around 4%

Prototype implementation
Overview

- **FPGA based implementation with external SIR transceiver (1) as a prove-of-concept**
- **FPGA part consists of two main parts**
  - SIR Interface Adapter (2)
  - PTP Ordinary Clock (3)



Prototype implementation
SIR Transceiver

- **Infrared Transceiver ICs (Vishay® TFBS4711)**
  - Emitter Diode wavelength 850-900nm
  - Photodiode
  - Amplifier
  - Comparator/Integrator
  - Power Control
- **Electrical/Optical conversion**
  - TX path is loop backed to RX
  - On a collision RX path is not equal TX path
  - No clock

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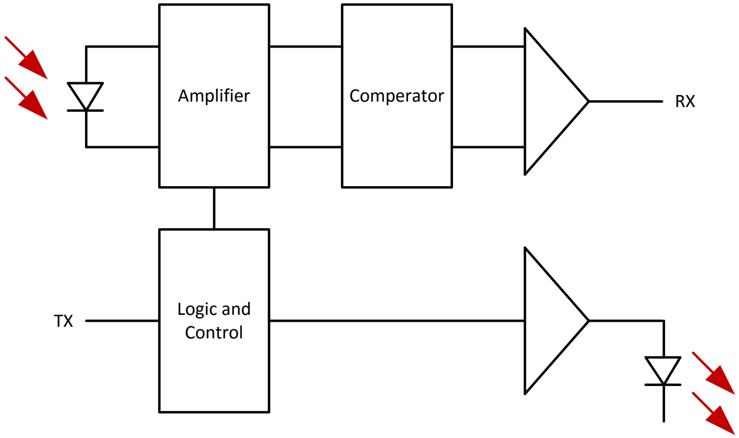
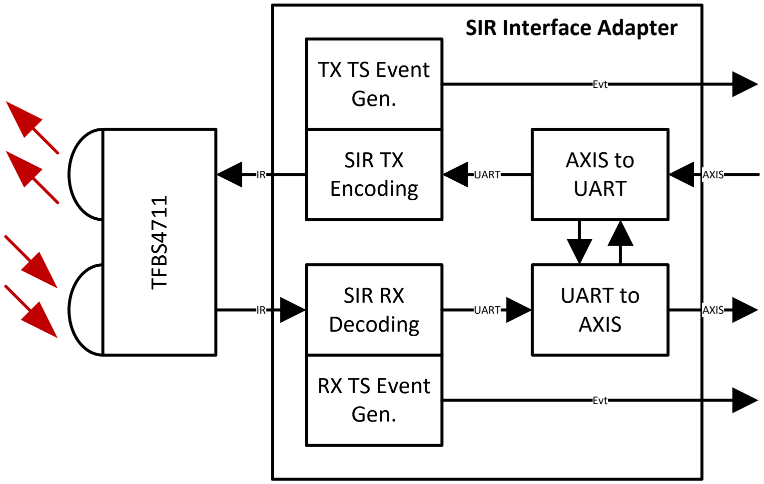


Prototype implementation

SIR Interface Adapter

- **SIR Interface Adapter**
  - Internal FPGA Data bus is ARM® AMBA4® AXI Stream (AXIS), 32bit wide, LAST flag matches EOF
  - AXIS to UART serializer & UART to AXIS deserializer
  - TDMA handler in TX path with RX info
  - SIR TX encoder & SIR RX decoder
  - Echo canceling
  - RX & TX SIR start-of-frame detector and event generator as close to the transceiver as possible
  - 115.2 KBits/s



Prototype implementation
PTP Ordinary Clock

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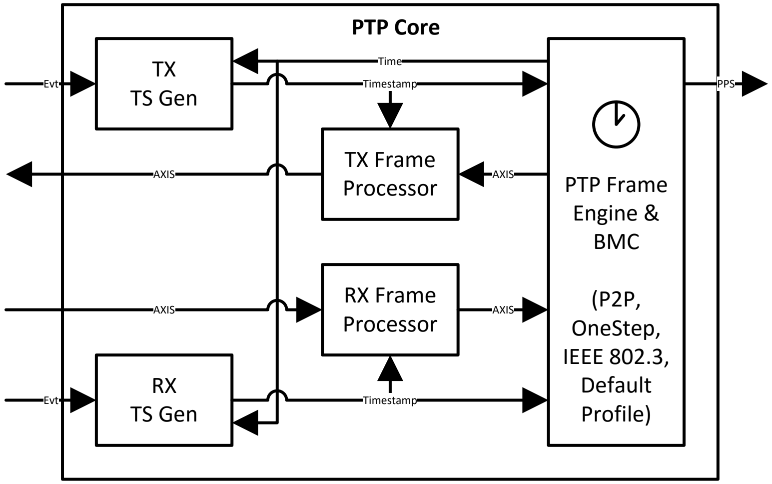
- **PTP Ordinary Clock**
  - Reuse of NetTimeLogic's plain FPGA solution (no CPU) of a PTP OC, with PPS
  - Configuration: P2P Delay measurement, one-step, IEEE 802.3 mapping and Default profile
  - All algorithms (E.g. BMC) message handling and calculations as well as PI servo loops are realized completely in FPGA logic
  - Also uses 32bit wide AXIS to/from the Interface



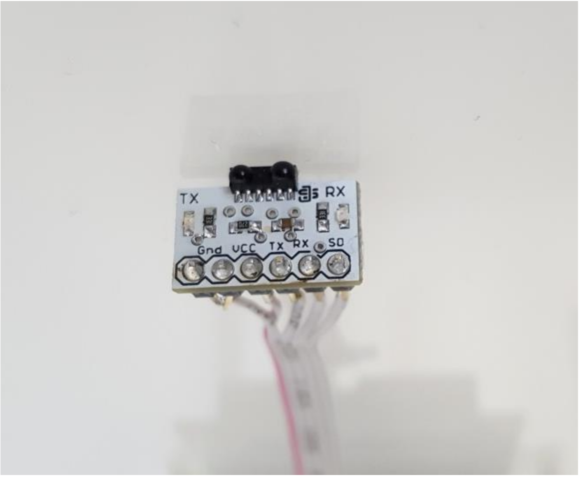
Prototype implementation
Why AXIS?

- **Why AXIS?**
  - AXIS is the most commonly used on chip streaming data bus nowadays (especially on FPGAs)
  - Handshaking on data bus so source and sink can slow down data traffic
    - This was important for this prototype, since the core was made to run at much higher data rates (gbits/s) but the interface adapters can slow down the whole data chain to 115.2kbits/s in both directions: to and from the core
    - No special handling in the PTP OC for lower data rates was required

Test setup and measurements

Hardware

- **Two identical Altera® SocKit FPGA development boards with Vishay® TFBS4711 IR transceivers**



TFBS4711, 115.2kbit/s, 850-900nm wavelength, 24° half intensity angle, SIR transceiver

Test setup and measurements

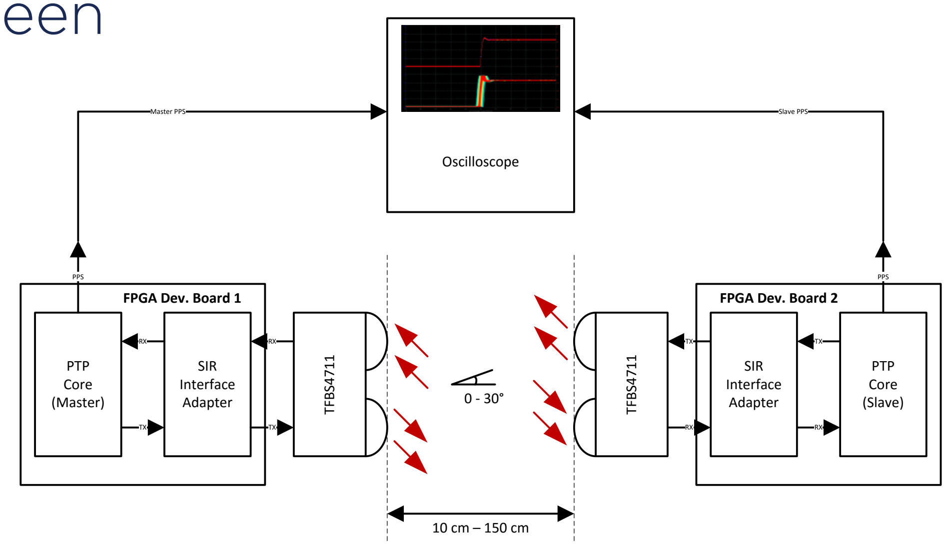
Measurement Parameters

- **PTP Parameters**
  - Default Profile IEEE 802.3 mapping
  - P2P Delay measurement
  - Message rates of 1/s for Sync-, Announce- and PDelay-messages
  - One-step message handling
  - BMC decides on MAC addresses which board will become master because of identical nodes

Test setup and measurements

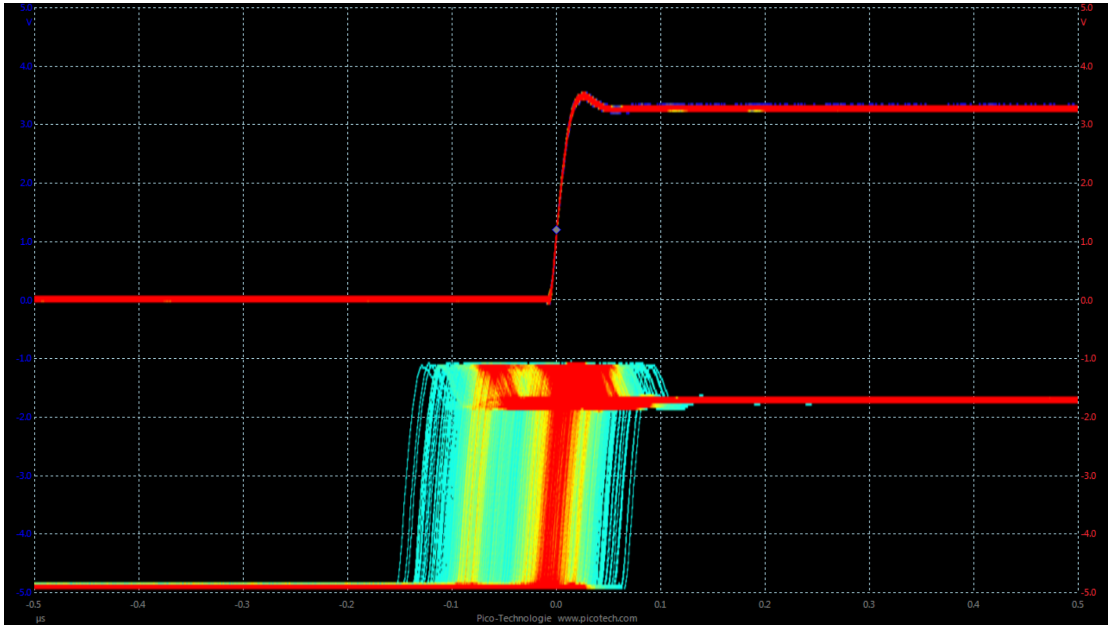
Measurements

- **Measurements**
  - Measurements of delay and jitter at distances between 10cm and 150cm in 10cm steps
  - 3600 measurement points (1h) per distance
  - Measurements at 0°, 10°, 20° and 30° horizontal angels between transceivers at 10cm and 100cm, others 0°
  - Calculation of standard deviation



Test setup and measurements
Measurements

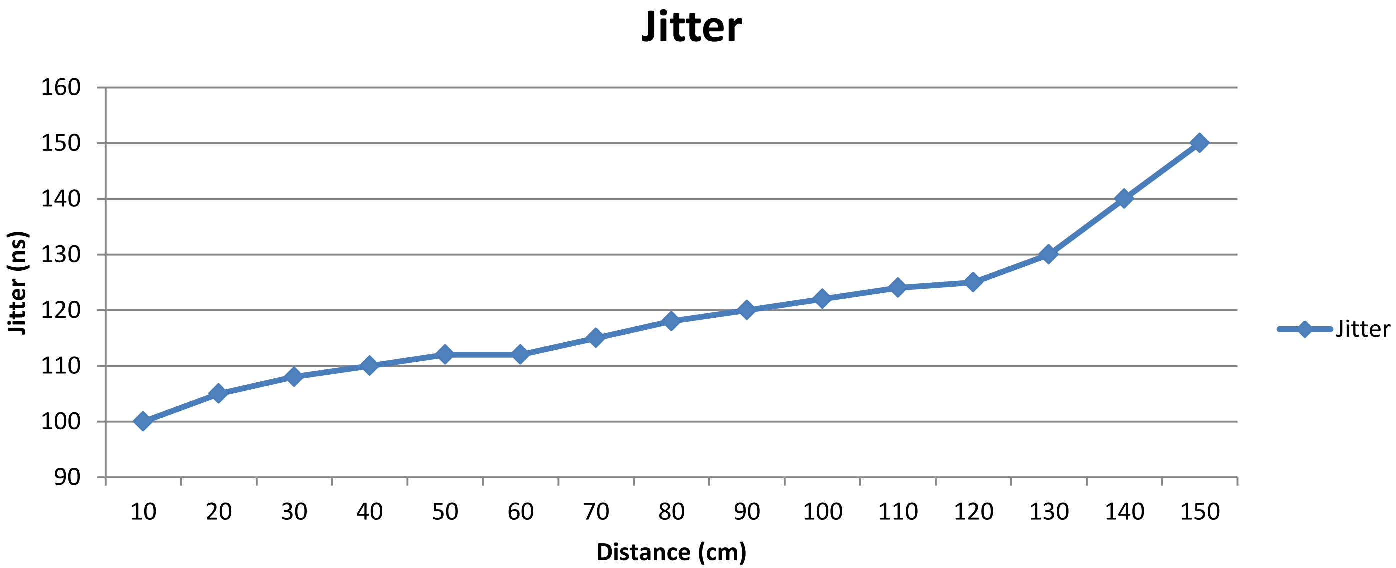
- **Oscilloscope picture at 20cm distance after one hour of measurement with infinite persistence**
  - PPS Master is the trigger
  - 100ns per division



Test setup and measurements

Measurement results

- **Jitter**
  - Max jitter, peak to peak divided by 2 in nanoseconds
  - Standard deviation is almost constant (+/-5ns) at around 55ns over the whole norm distance of 10cm to 100cm



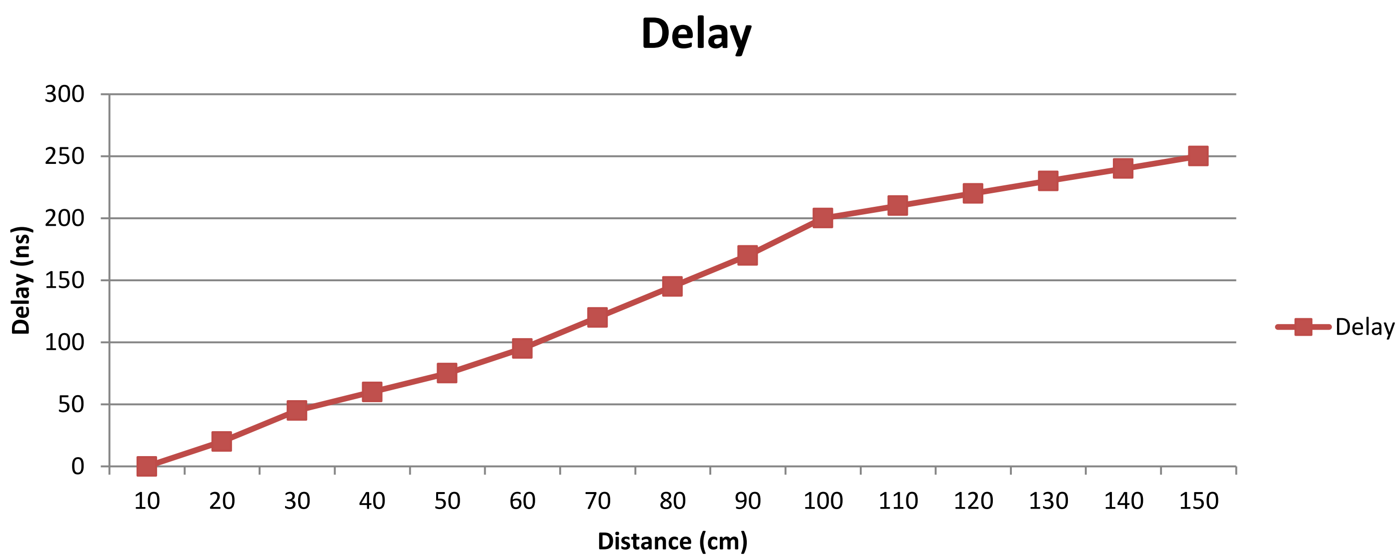
Test setup and measurements

Measurement results

- **Jitter**
  - Longer distances introduce more scattered measurements
  - Jitter increase after the norm max distance (100cm) is not linear anymore (exponential?)
  - System stops working because of bit errors at about 180cm, which is almost double the norm max distance

Test setup and measurements
Measurement results

- **Delay**
  - Mean Delay (always averaged over the last 4 delay measurements), 10cm = 0ns
  - Delay increase is quite linear over the whole norm distance of 10cm to 100cm (~0 - ~200ns)



Test setup and measurements

Measurement results

- **Delay**
  - Delay increase is mostly not due to the longer time that the light needs to travel in air since this is only about 3.5ns for 100cm
    - Delay comes mostly from the IR sensor which needs much longer for the detection and conversion because of less light immission
  - Angles >0° have the same effect as larger distances between the transceivers
    - At 24° the receiver gets half the intensity then with 0° e.g The delay at 40cm with a 0° angle is equal to the delay at 20cm with a 24° angle

Conclusion

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- **Accuracy**
  - Combining wireless data communication and synchronization with sub-microsecond accuracy can be achieved with free-space optical communication via serial infrared
  - Even if the communication nodes are not stationary (moving along the line of sight or within the angle of the transceiver receiver overlap) and the path delays are constantly changing due to distance changes sub-microsecond accuracy can be achieved

Conclusion

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- **General**
  - Free-space optical communication is a separate but equally useful approach to perform time transfer over a wireless link as e.g. RF
    - For applications with low-bandwidth and short-range requirements (e.g. autonomous battery powered sensors) PTP over SIR could be a suitable solution
    - No real use-case yet

  - For a real-world solution a couple of things still would have to be standardized in order to allow interoperability

Questions?

Thank you!

Visit us at our sponsoring table at ISPCS 2016 and see PTP over infrared live

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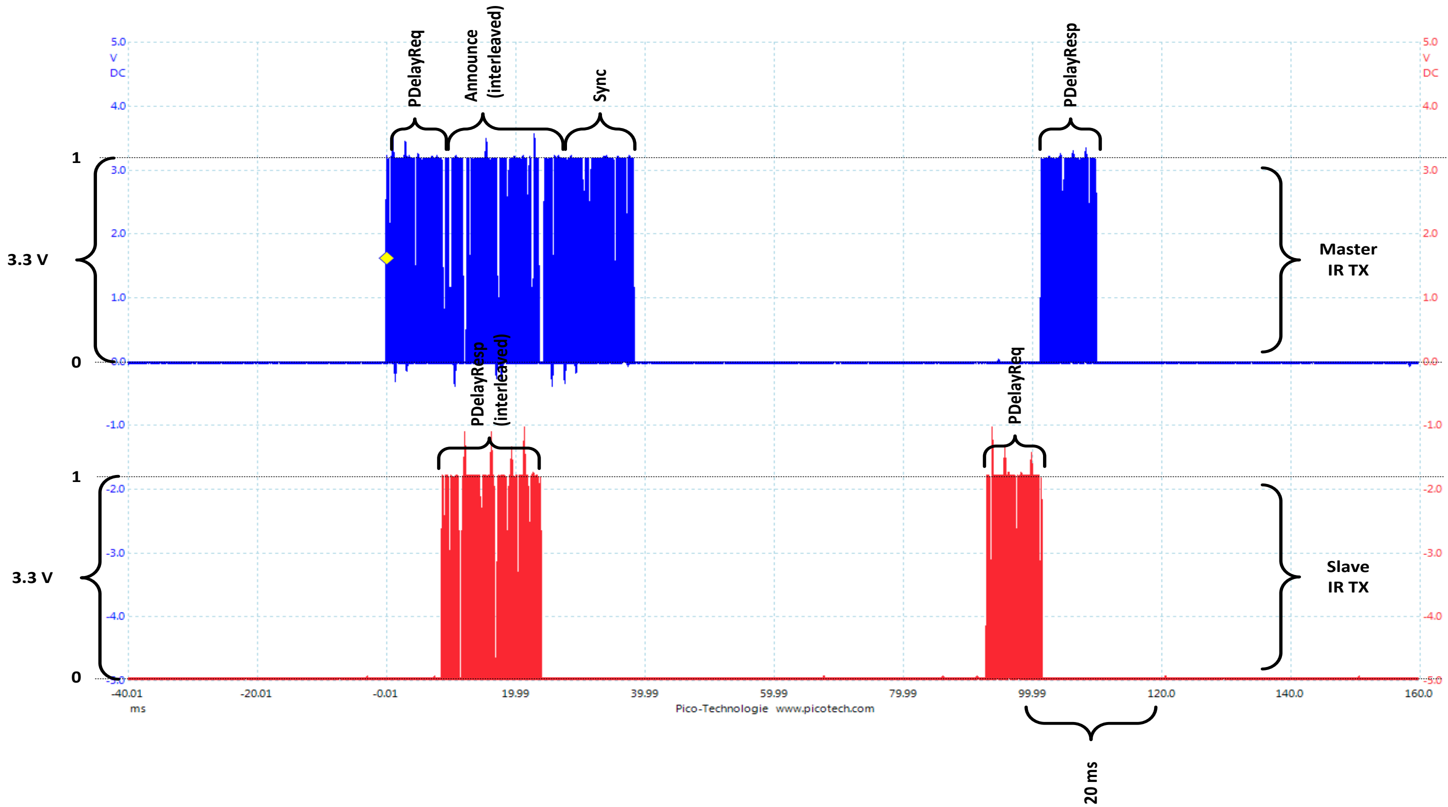
Test setup and measurements
Communication Snapshot

- TX path to IR transceivers within one second



Test setup and measurements

Communication Snapshot

- **Interleaving of Announce from Master with PDelayResp from Slave**