1.6 Gbit/s Synchronous Optical QPSK Transmission with Standard DFB Lasers in Realtime

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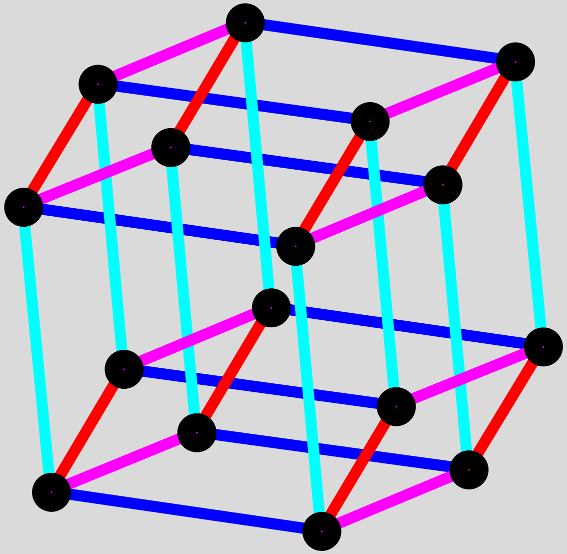
Outline

- Properties of synchronous optical QPSK
- Mathematical Description of Receiver
- Measurement Results
- Conclusions



Properties of synchronous optical QPSK

- **4 bit/symbol** (with added polarization division multiplex)
  ► lower cost per bit
- Symbol rate: 40 Gbaud may suffer from nonlinear phase noise. 10 Gbaud (= 4 x 10 Gbit/s) is perfect for **evolutionary retrofitting of 40 Gbit/s transponders into existing 10 Gbit/s WDM systems**.
- Electrical received signals are proportional to optical fields: „**Optical equalization of CD and PMD in the electrical domain**“ becomes possible.
- **DFB lasers** are a must, since external cavity lasers are too costly and space-consuming.
  ► Possible for synchronous QPSK with feed-forward carrier recovery

Mathematical description

Demodulation of the QPSK signal

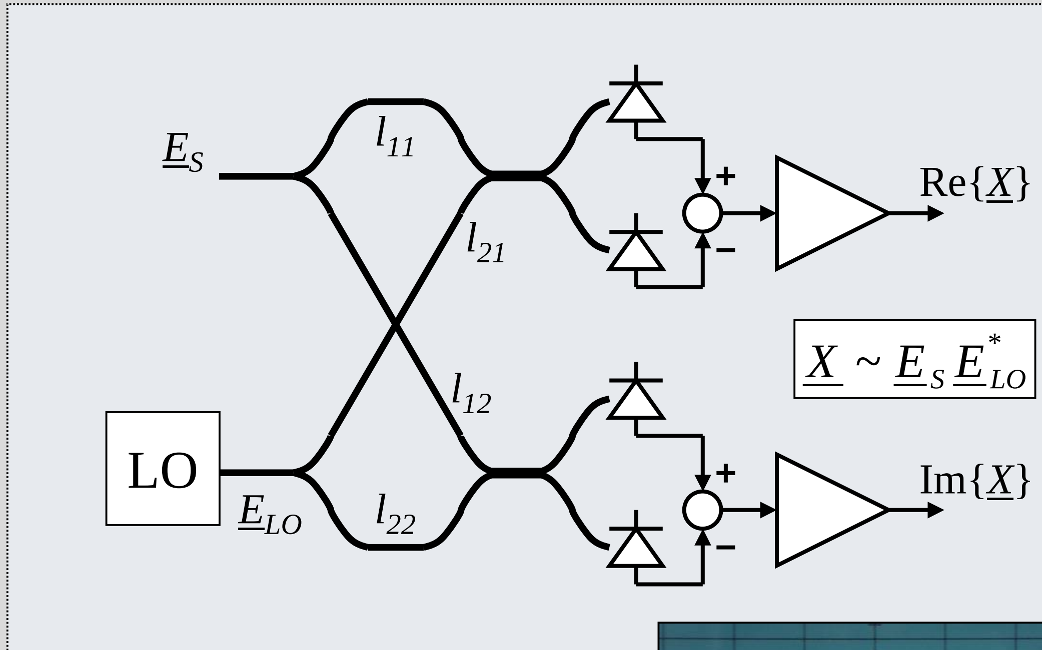
$$\underline{E}_S \propto \underline{c} e^{j(\omega_S t + \varphi_S)}$$

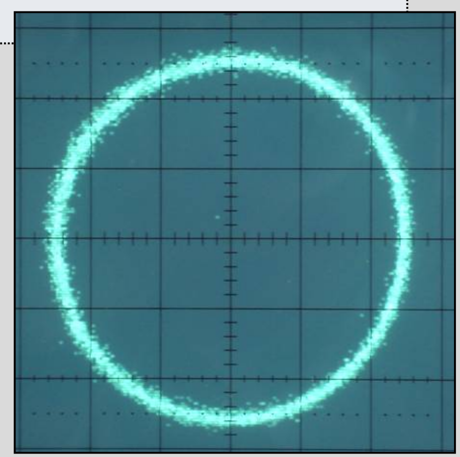
$$\underline{E}_{LO} \propto e^{j(\omega_{LO} t + \varphi_{LO})}$$

Setting of 90° hybrid:

$$(l_{11} - l_{21}) - (l_{12} - l_{22}) = \frac{\lambda}{4}$$

$$\underline{X} = \mathrm{Re}\{\underline{X}\} + j\,\mathrm{Im}\{\underline{X}\} = \underline{c} e^{j\varphi'}$$



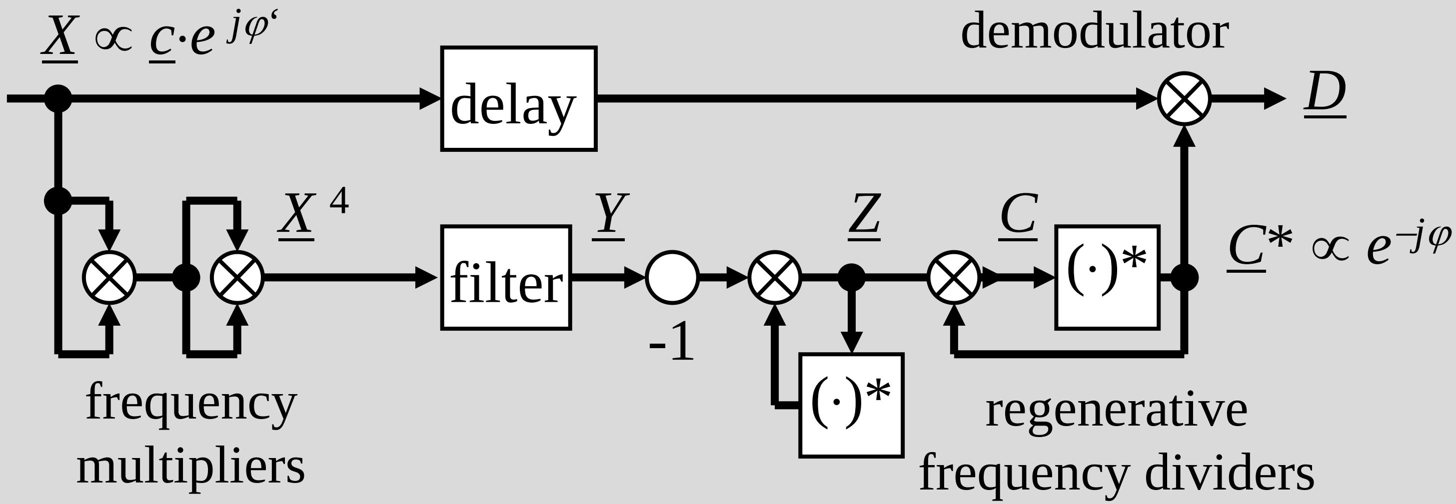


$$\varphi' = (\omega_S - \omega_{LO})t + (\varphi_S - \varphi_{LO})$$

Automatic frequency control & carrier recovery needed!

Mathematical description

Analog carrier recovery



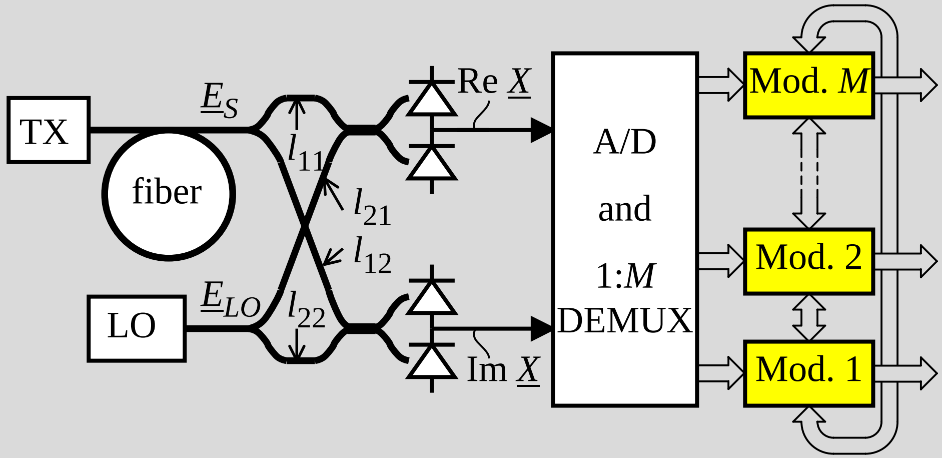
- All signals are complex!
- General complex multiplier requires 4 real multipliers (Gilbert cells) and 2 adders/subtractors
- Frequency multiplication by a factor of 4 removes QPSK modulation
- Lowpass filtering of frequency-quadrupled carrier
- Frequency division of baseband intradyne signals by a factor of 4, using two regenerative frequency dividers: $e^{j\omega t} = e^{j2\omega t} \cdot e^{-j\omega t}$

Mathematical description

Digital carrier recovery

Functionally identical with analog scheme

Differential encoding of angle quadrant number in transmitter

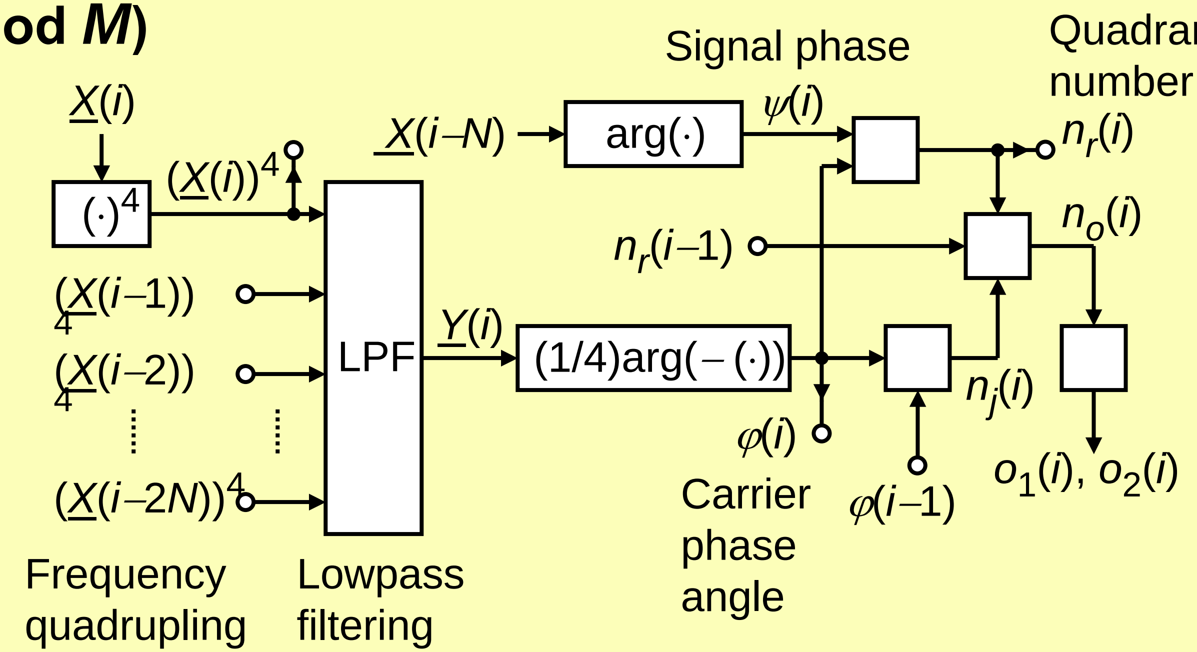


demultiplexed output data bits o_1, o_2

$\underline{X} \sim \underline{E}_{TX} \underline{E}_{LO}^*$

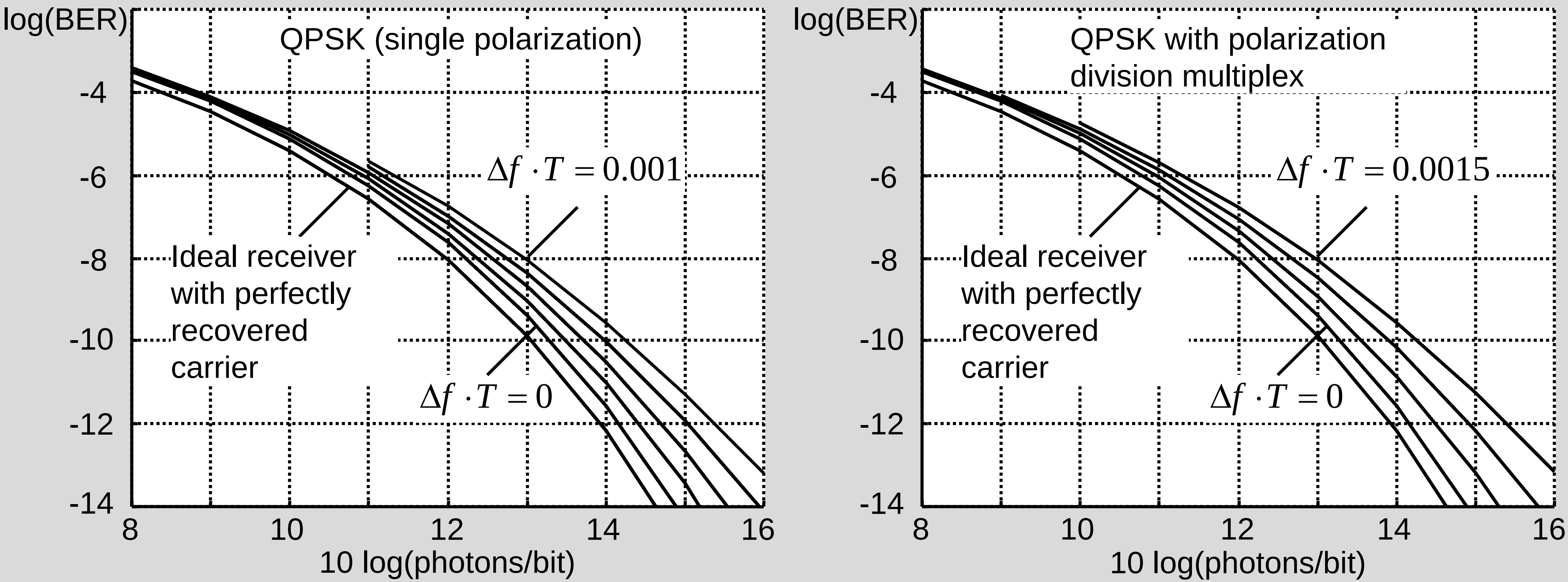
Module (i mod M)

All signals it needs from neighbor modules are already available.



Differential decoding of quadrant phase number, taking carrier phase jumps into account

Laser linewidth tolerance of QPSK feedforward carrier recovery



- For single/dual polarization QPSK, $\Delta f \cdot T \approx 0.0005$ or 0.001 is tolerable. Dual polarizations double carrier recovery SNR and allow to double filter bandwidth.
- Distribution of residual phase error $\Delta\varphi$ is determined by simulation of $5 \cdot 10^5$ symbols. Resulting decision errors are found by evaluating an analytical BER($\Delta\varphi$) formula. Decision errors yield double bit errors due to differential encoding.
- Additional cycle slips of frequency divider contribute single bit errors due to differential angle encoding/decoding.

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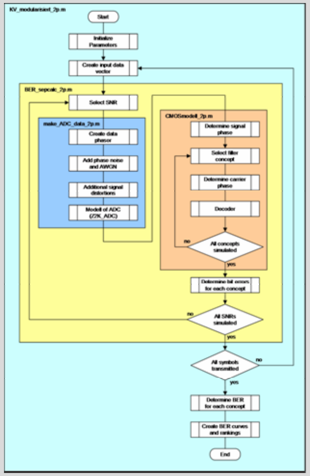
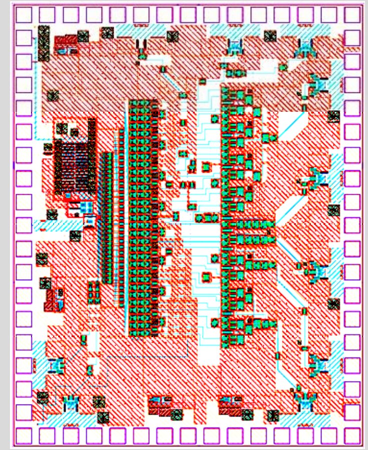
Signal processing component development

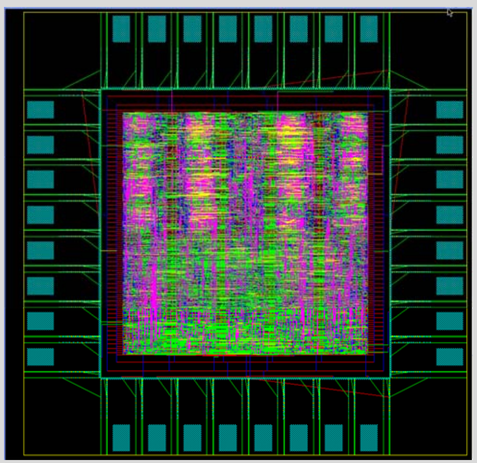


- Development of advanced carrier recovery algorithms
- System level component simulation



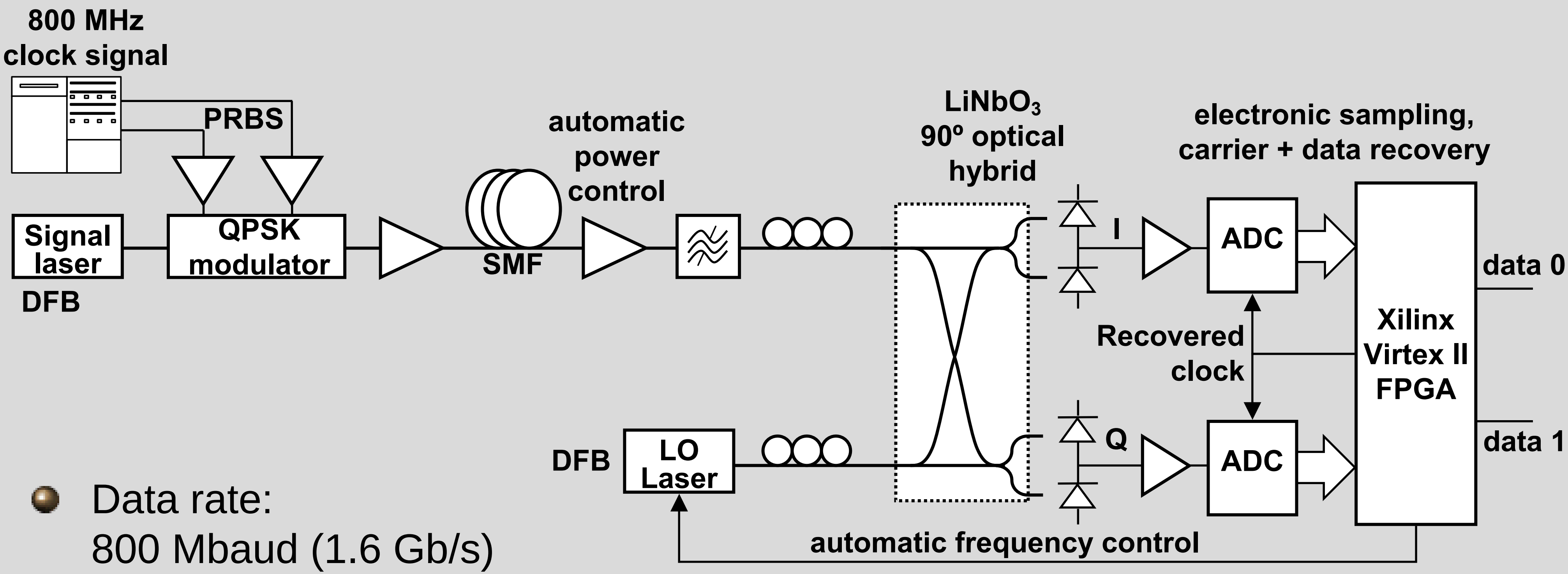
- 10 Gsps analog digital converter
- 0.25µm SiGe technology
- 5 bit Gray coded differential outputs

- Carrier & data recovery realized in CMOS
- 1:16 Demultiplexer
- CMOS clock: 625 MHz



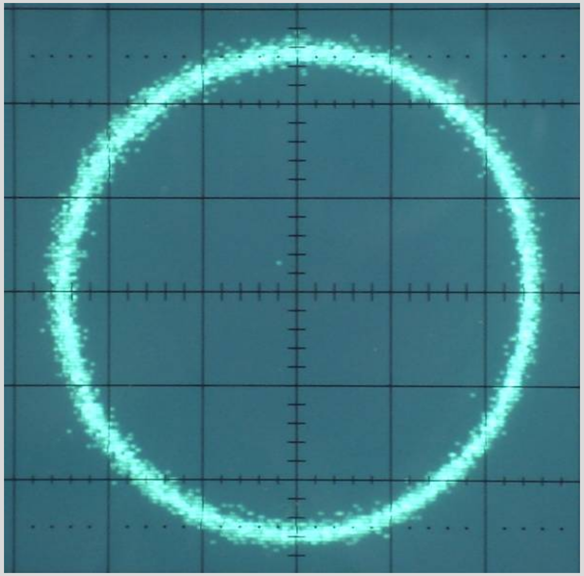
Sebastian Hoffmann, Timo Pfau, Olaf Adamczyk, Ralf Peveling, Mario Porrmann, Reinhold Noé: **Hardware Efficient and Phase Noise Tolerant Digital Synchronous QPSK Receiver Concept**, Proc. OAA/COTA2006, CThC6, June 25-30, 2006, Whistler, Canada.

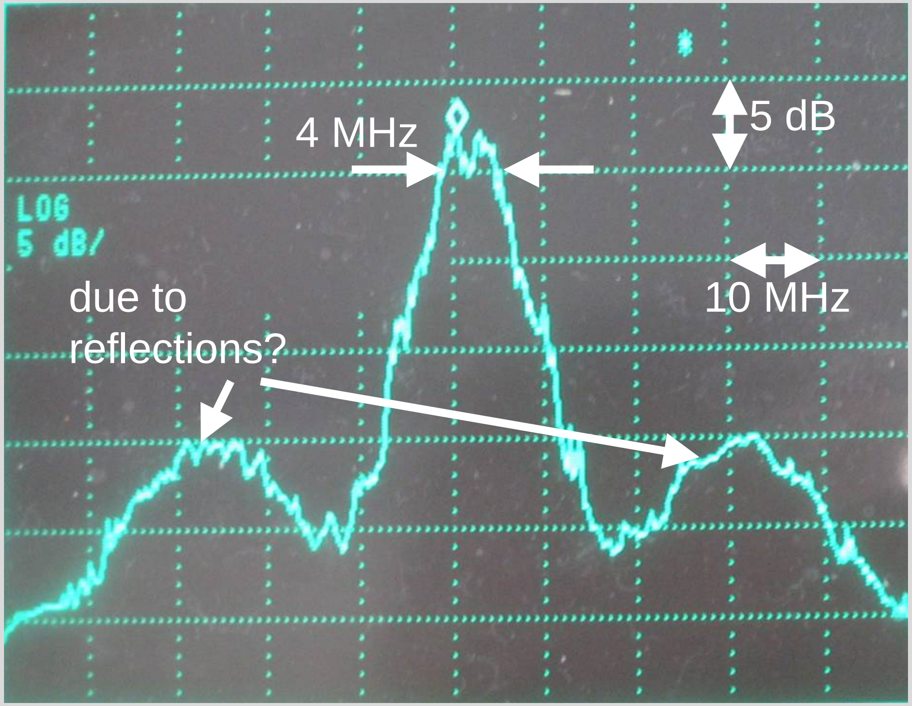
Realtime digital synchronous intradyne QPSK transmission setup



- Data rate:
  800 Mbaud (1.6 Gb/s)
- Manual polarization control
- Commercial 5 bit ADCs, clocked at 800 MHz
- Clock recovery in the receiver
- Automatic LO frequency control implemented
- Noisy optical front ends, much too wide optical filter (~20 GHz)

Results obtained with unmodulated DFB lasers



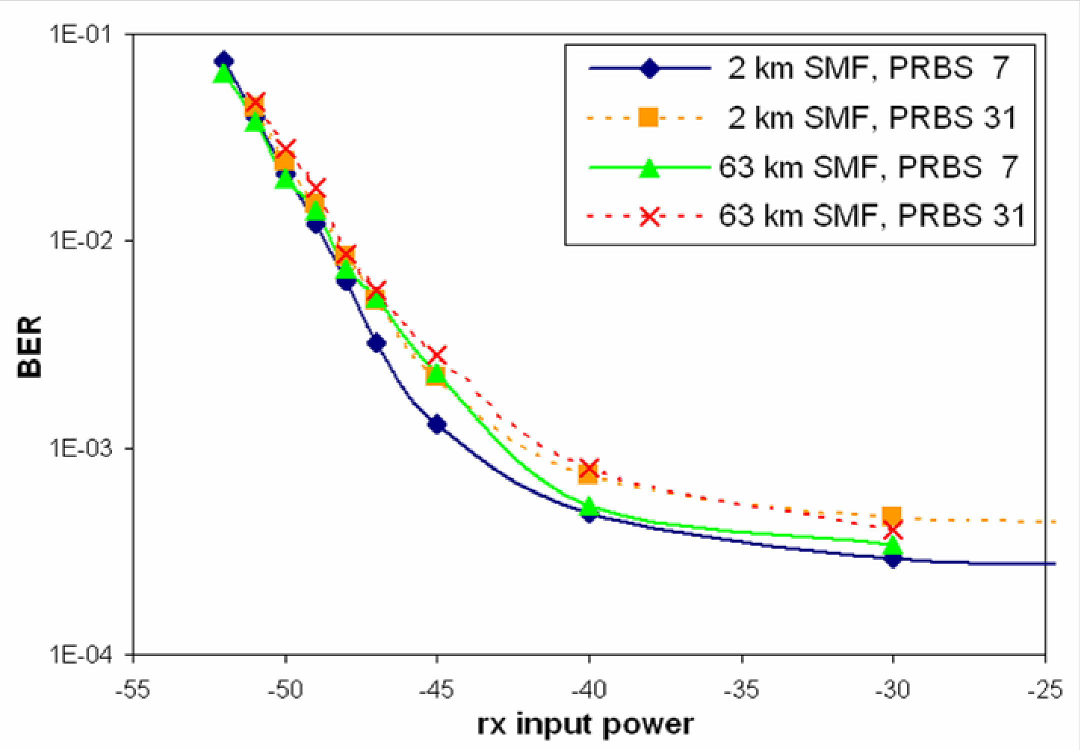


Intradyne (I & Q) phasor in the complex plane, measured after 90° hybrid and photodetection

IF spectrum, here stabilized at 400 MHz rather than 0 MHz.

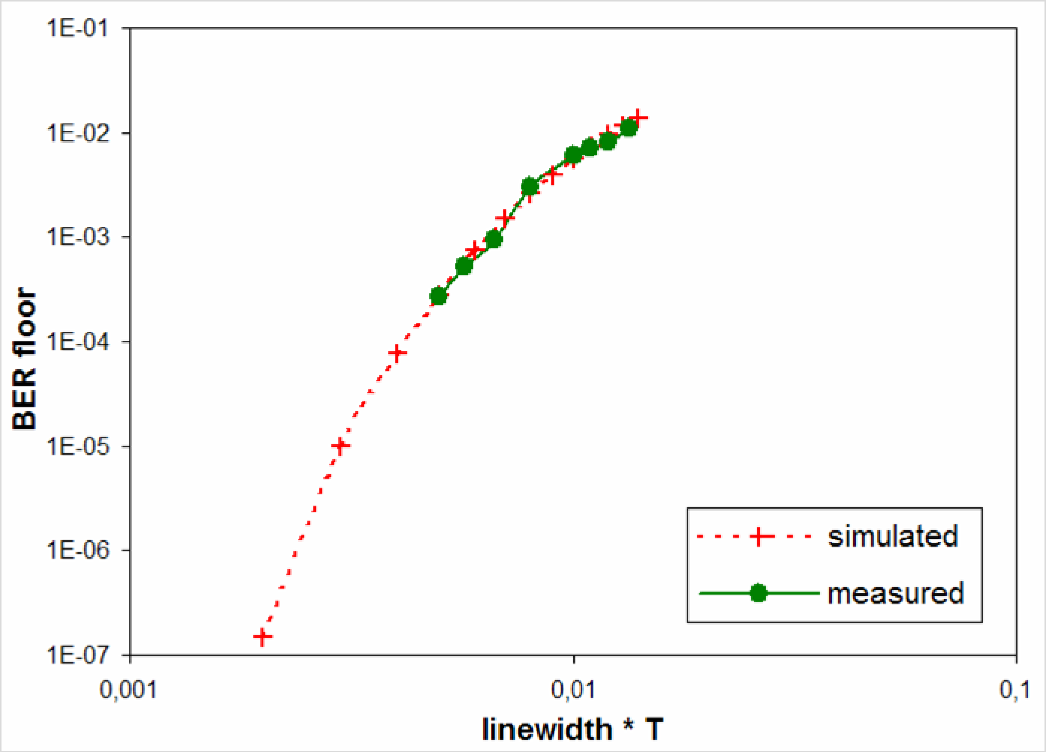
Spectrum looks the same when the IF was stabilized at 0 MHz.

Intradyne transmission results, using DFB lasers



- 800 Mbaud BER floors: $2.7 \cdot 10^{-4}$ (2^7-1, 2 km), $3.4 \cdot 10^{-4}$ ($2^{31}-1$, 2 km).
- Increased BER over 63 km may be due to lack of clock recovery combined with a noisy clock source.
- All BER floors within capability of FEC (7%) $\Rightarrow$ 1.5 Gb/s net data rate

Bit error ratio floor vs. linewidth times symbol duration product



- Unproblematic operation is expected at 10 Gbaud.
- Additional phase noise tolerance (factor 2) applies for polarization division multiplex.

Conclusions

- **First realtime synchronous QPSK transmission with DFB lasers**
- FEC-compatible performance at 800 Mbaud (1.6 Gb/s)
- Phase noise should be unproblematic at 10 Gbaud.
- 4×10 Gb/s synchronous QPSK transmission systems with polarization division multiplex can be developed, using DFB lasers.

Acknowledgement

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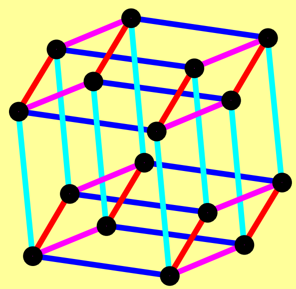
http://ont.upb.de/synQPSK



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