The digital coherent revolution

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Workshop presentation..

- The brief...
  - Talks should only be about “8-minutes” long
  - Should stimulate lots of discussion among the panelists and workshop attendees
  - Where appropriate point at controversial and/or yet unsolved issues

- This talk
  - Will briefly chart the digital coherent revolution
  - Outlining the salient features of a coherent system
  - Discuss the future challenges.

Revolutions take a while

- First “digital coherent receiver” @ 100 Mbit/s
- OPTICAL QPSK TRANSMISSION SYSTEM WITH NOVEL DIGITAL RECEIVER CONCEPT
  F. Derr, Elect. Lett. 7th Nov. 1991 Vol. 27 No. 23 (extended in a 1992 JLT)

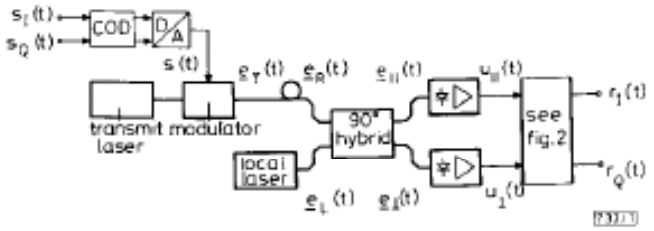


Fig. 1 *Block diagram of optical QPSK intradyne system*

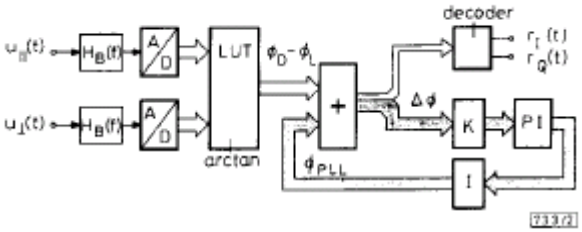
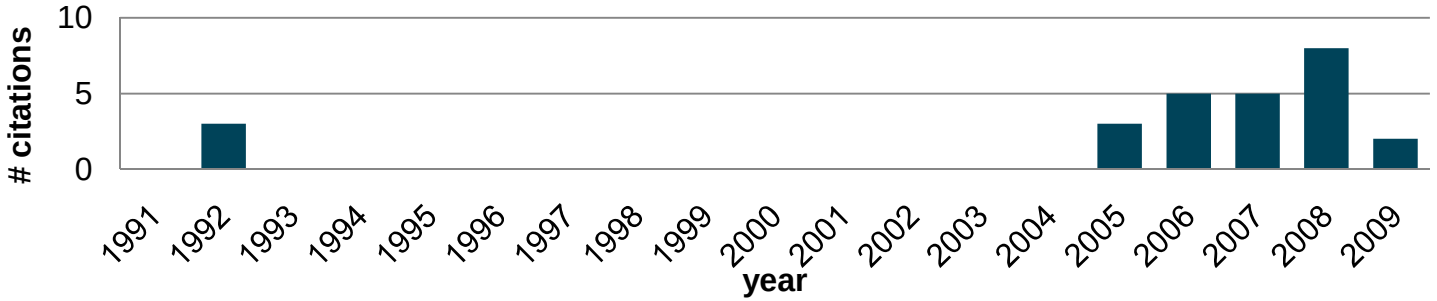


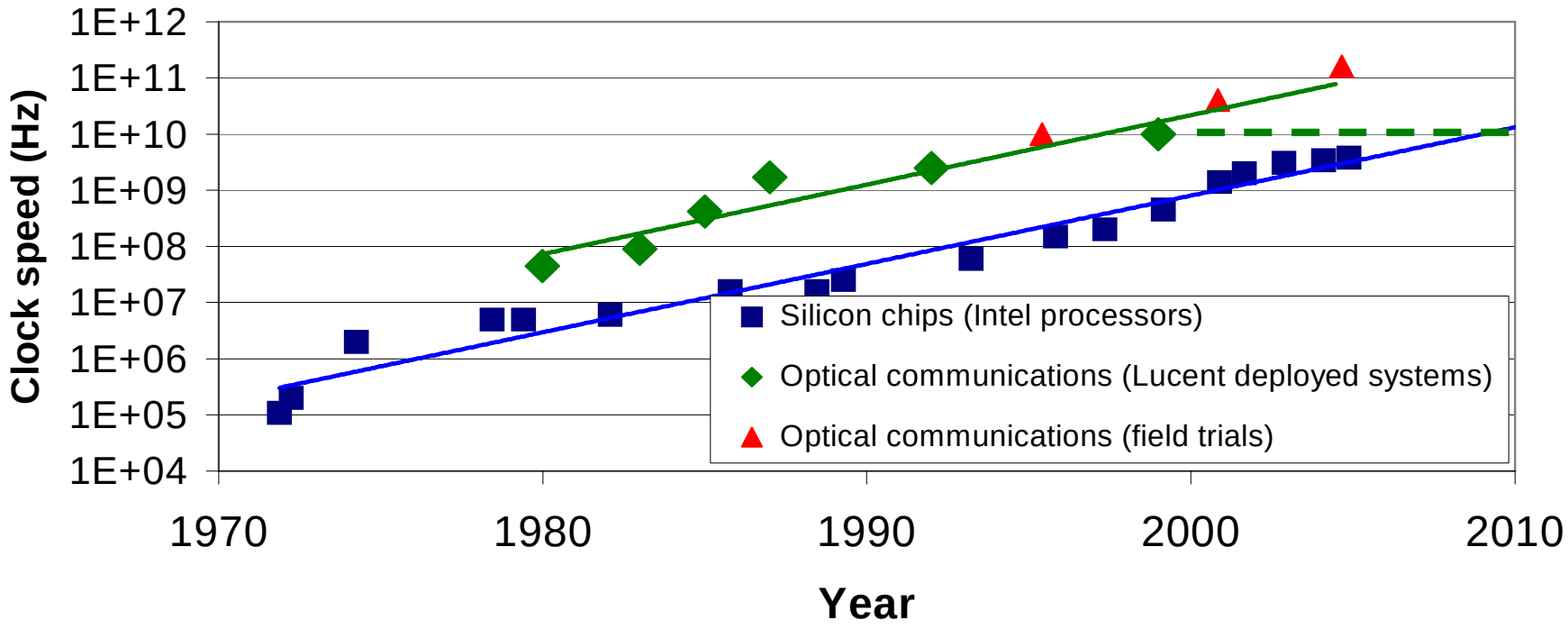
Fig. 2 *Block diagram of digital intradyne receiver*



- Failed to impact the 2.5 Gbit/s systems of the day

The discontinuity

- Silicon and optical data rates have evolved at the same rate, albeit with a lag of ~ 12 years (x4 every 5 years)



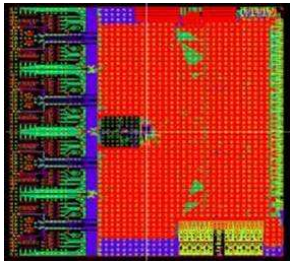
- The delayed deployment of 40Gbit/s, allowed DSP to catch up with current 10Gbit/s optical line rates

Some key developments (many omissions!)

Year	Technological development
2003	20GSa/s, 8 bit ADC demonstrated using time-interleaving in 180nm CMOS Soon afterwards Taylor and Noé independently propose digital carrier recovery
2005	Tsukamoto demonstrates PDM-QPSK transmission over 200km
2006	Long haul transmission of PDM-QPSK with digital polarization tracking
2007	Long haul transmission of 111Gbit/s PDM-QPSK by Fludger et al.
2007	20GS/s 20M gate 90nm CMOS ASIC with 4 integrated ADCs
2008	112Gbit/s PDM-16QAM demonstrated by Winzer and Gnauck
2009	56GSa/s 8 bit ADC appear

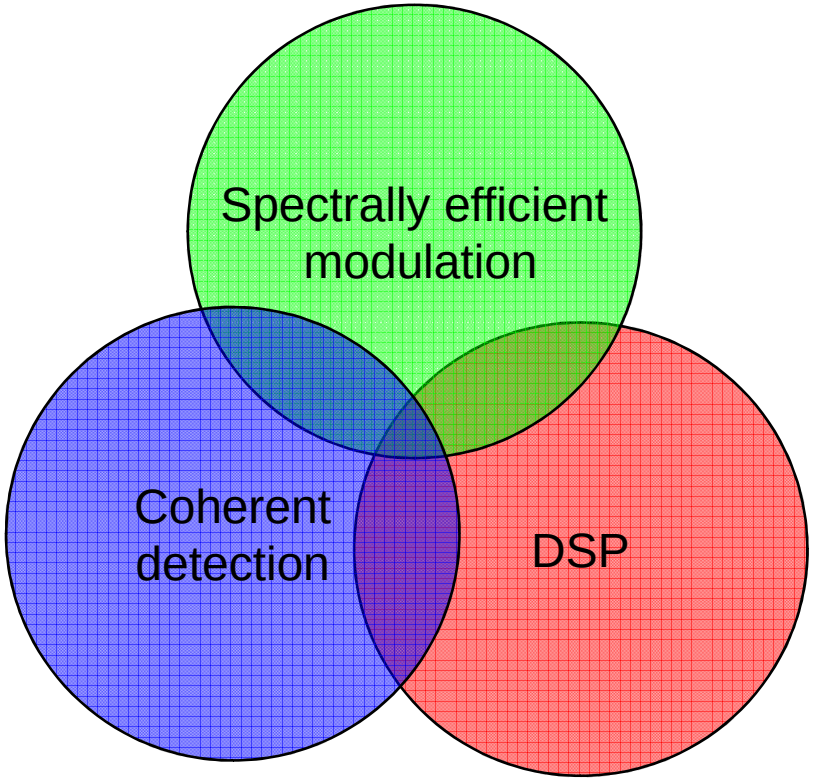
Digital coherent systems have allowed both digital compensation of CD & PMD and spectrally efficient modulation formats & OFDM

This alone has caused a revolution in system design



Three elements of a digital coherent system

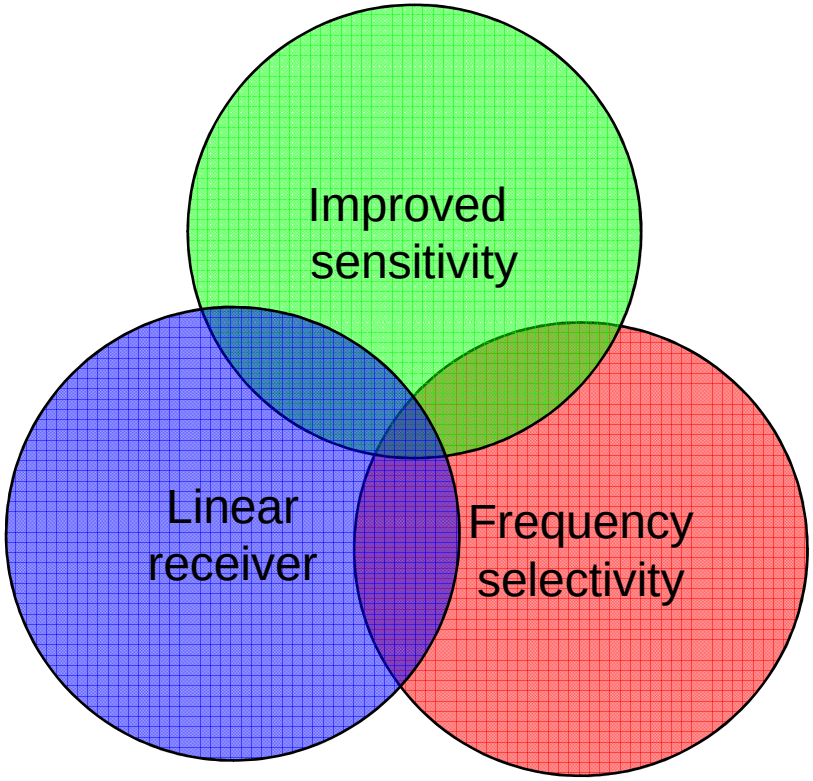
- The combination of spectrally efficient modulation, coherent detection and DSP is a symbiotic relationship
- Coherent detection maximises efficacy of DSP, and permits use of spectrally efficient modulation
- DSP simplifies the coherent receiver, removing need for optical phase and polarisation tracking
- Spectrally efficient modulation formats maximises the benefits afforded by digital coherent receivers



This combination is greater than the sum

Salient features of a digital coherent system

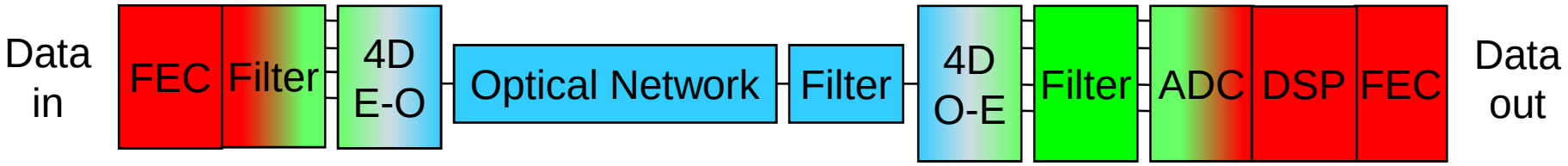
- Improved sensitivity
  - E.g. For Coherently detected DQPSK ~ 2.5dB improvement c.f. directly detected DQPSK
  - Traditional motivator for coherent detection, where photons per bit was minimised
- Linear receiver
  - Maps entire optical field into digital domain
  - Complexity moved from optical to digital domain (e.g. Pol tracking)
  - Enables equalisation of linear impairments (no DCF required)
  - Current motivator for coherent detection
- Frequency selectivity
  - Enables resolution of two 14Gbaud carriers separated by ~ 20GHz



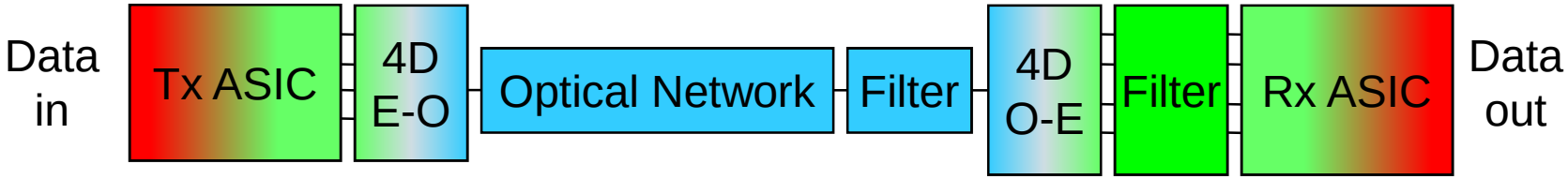
Future digital coherent systems will use all three features

Digital Coherent Modems

- Moving from Digital Coherent Receivers



- To Digital Coherent Modems



- DSP could become software defined
  - Could trade off power consumption versus performance
  - Modulation format chosen according to situation
  - Tends towards embedded system based transceivers

Key challenges

- Optical fibre communication channel is a nonlinear MIMO system, with memory
- Current complexity dominated by channel memory due to dispersion (scales quadratically with symbol rate)
  - 2007 - 20M gates in 90nm CMOS demonstrated
  - Moore's law -> 40-50M gates should be possible now, but...
  - We will need all these extra gates to cope with increase channel memory, as we increase from 10.7Gbaud to 28 Gbaud
- Need low complexity nonlinear compensation
  - Nonlinear compensation currently offers 1-2 dB improvement
  - Soft decision coding may be more hardware efficient means of getting same improvement

Discussion points

- Coherent everywhere, from access to core
  - Direct detection for quantum communications and multimode fibre
- Case for OFDM versus single carrier not clear
  - OFDM well suited to non-flat channels...
    - E.g. Multimode fibre
    - Systems using ROADMs
  - But since coherent detection gives frequency selectivity, can drastically change ROADM architecture (50 GHz filters obsolete?)
- Designing a hybrid 100G PDM-QPSK coherent and 10G IM/DD system is a dead-end
  - Upgrade offers x10 improvement in speed
  - As speeds increase infrastructure changes (lessons from road transport).
- We will remove the DCF, if this gives better performance

Thank you for listening

Questions?