Fraunhofer
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Opportunities and Challenges for High-Speed Optical-Wireless Links

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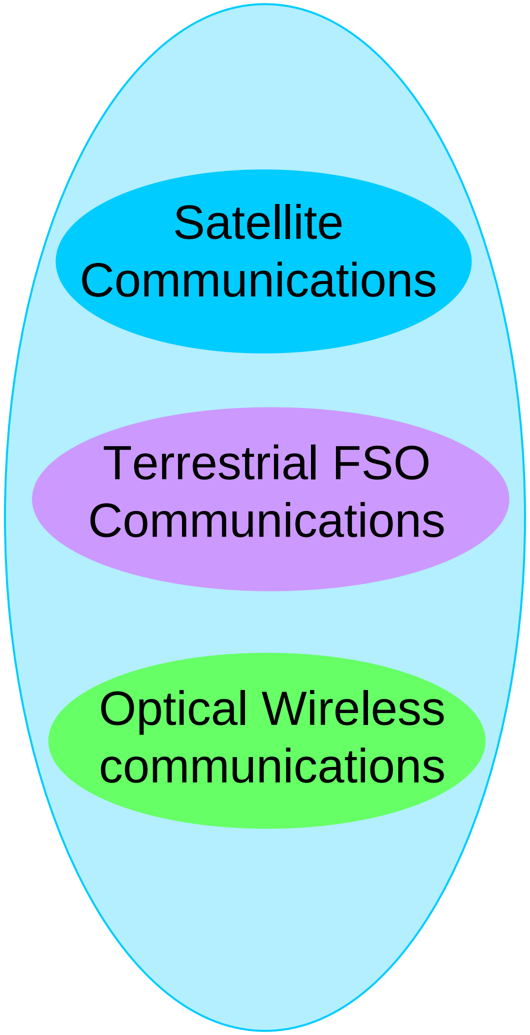
Outline

- Introduction to Optical Wireless Communications
  - Motivation and Domains of Application
- Infrared Links
  - Main Features and Recent Efforts
- Visible Light Links
  - Main Features and Recent Efforts
- Summary and Conclusions

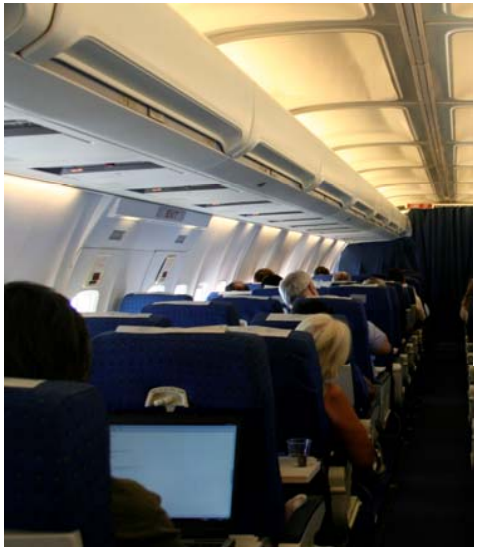
Domains of Wireless Communication via Light

- Satellite communications
  - Inter-satellite, satellite-to-earth links, ~10 000 km
  - P-t-P, line-of-sight (LOS), < 1 Gbit/s
- Terrestrial free-space optics (FSO)
  - LOS city links (between building rooftops)
  - P-t-P, relaying, ~ km range, ~ Gbit/s range
- **Optical wireless (OW) communications**
  - **Indoor applications in ~ m range**
  - **P-t-P, P-t-MP links (LOS and/ or reflections)**
  - **10 … 1000 Mbit/s**



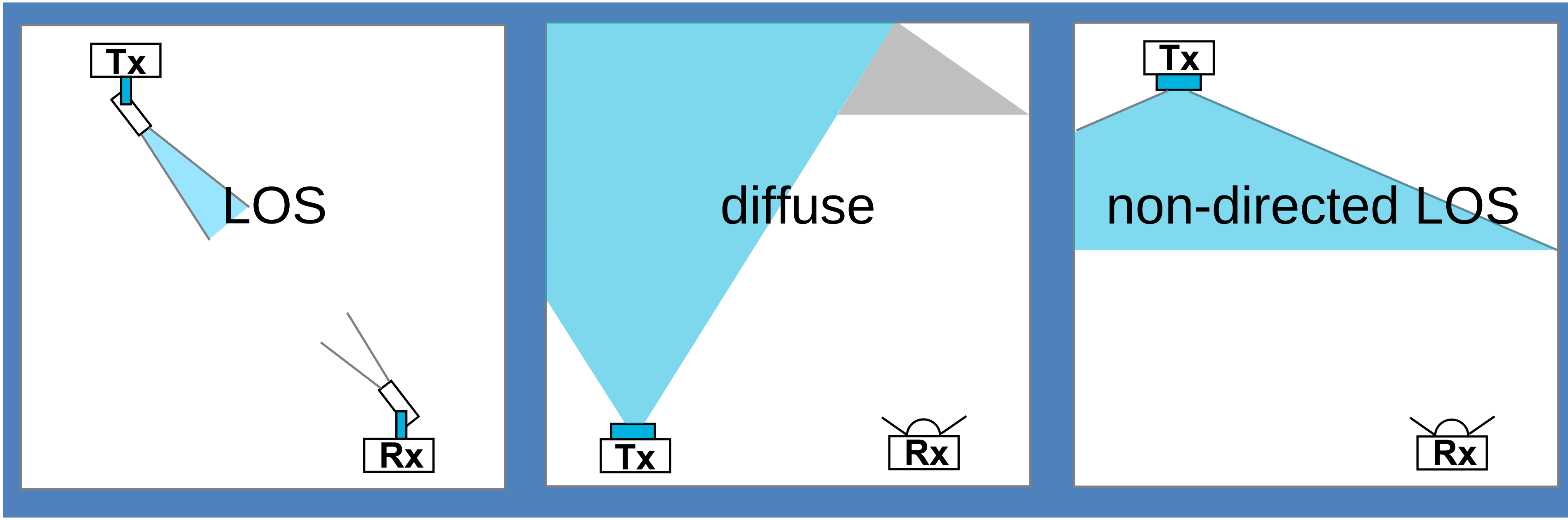
Optical Wireless Communications

- No EMI with radio systems, no “e-smog”
- Available and unregulated spectrum
- Simple shielding by opaque surfaces → easily obtainable privacy
- Complementary to radio for wireless access



Basic Types of OW Links

directed | non-directed



- LOS
- High data rates
- Sensitive to blocking

- Reflections
- High coverage
- High path loss

- LOS + diffuse
- High coverage + potentially high data rates

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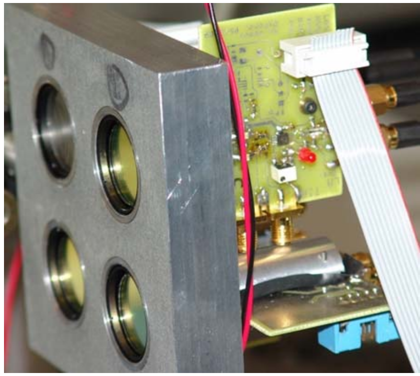
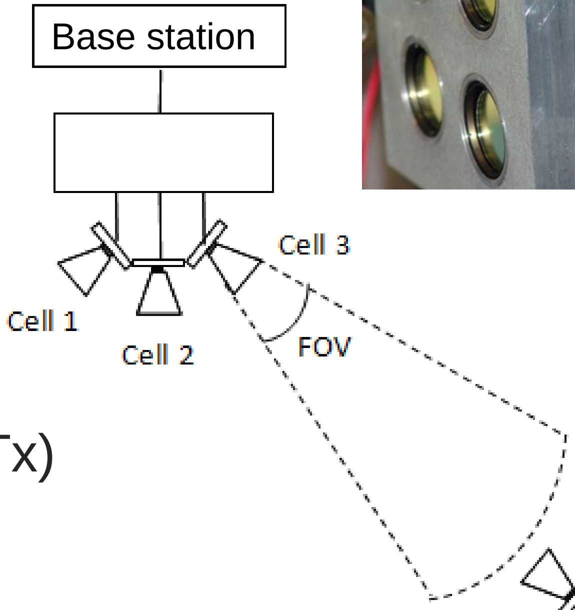
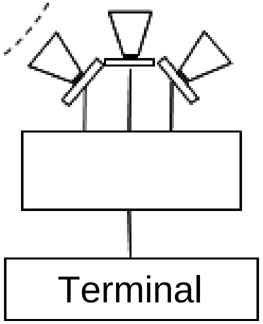
Main Framework for IR Links

- Tradition: PtP links, e.g. IrDA: 16 Mbit/s up to Giga-IR
  → short-range, low coverage
- Eye and skin safety
- Available Rx components (850 or 1550 nm range) mainly developed for fibre optics → small-area PDs, OW needs large-area ones
- Background light noise, multipath dispersion
- High-speed indoor use → coverage and mobility wanted
  - Multibeam-forming Tx and angle diversity Rx (complex)
  - Simple optics with advanced signal processing

Gbit/s Cellular LOS Communication

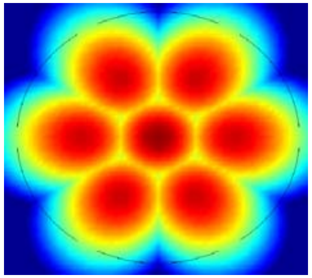




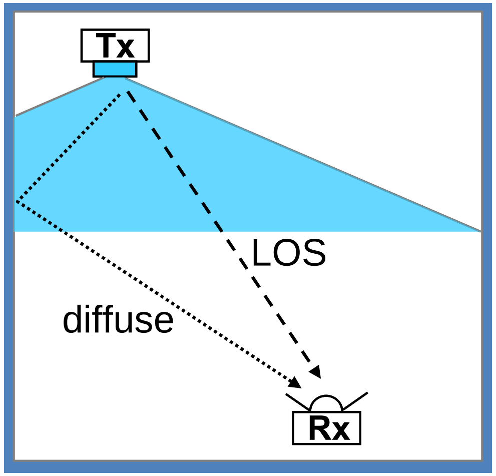


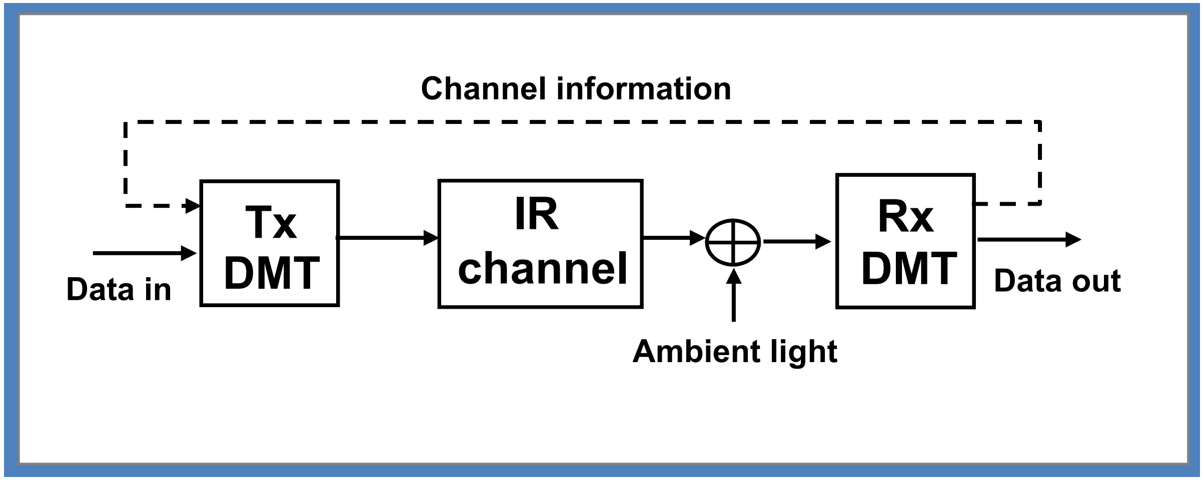
Universities of Oxford & Ilmenau, 2010

- 7-cell design
- Tx laser 14 dBm @ 825 nm, APD-Rx
- 1.25 Gbit/s (gross)
- 4 m reach, ~1.5 m diameter (3 m below Tx)
- HD video transmission demonstrated
- Bidirectional



Rate-Adaptive Signal Processing





- Single-element optical front-ends
- Channel varies from low-pass to flat (LOS / diffuse signal ratio)
- Low-speed feed-back link provides channel information to Tx
- System dynamically adapts data rate to channel state using DMT: Bit- and power-loading, handling of multipath distortion, efficient signal processing by FFT
- Theoretical predictions: up to ~400 Mbit/s (depending on the Rx position), with BER≤$2 \cdot 10^{-3}$, in a 5x5x3 m^3 room with complete coverage

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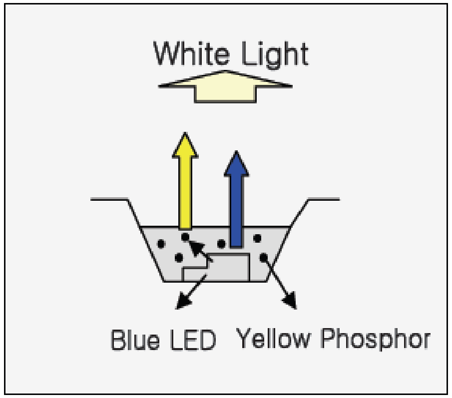
Additional Motivation for VLC

- Omnipresence of LEDs;
  signalling and illumination
- LEDs offer significant potential for modulation
- Combination of illumination or signalling
  with data transmission
  → data transfer as "piggyback"
  → broadcasting hot-spots
- Attractive where light is always "on"
  office, industrial settings, medical area, public transport,…

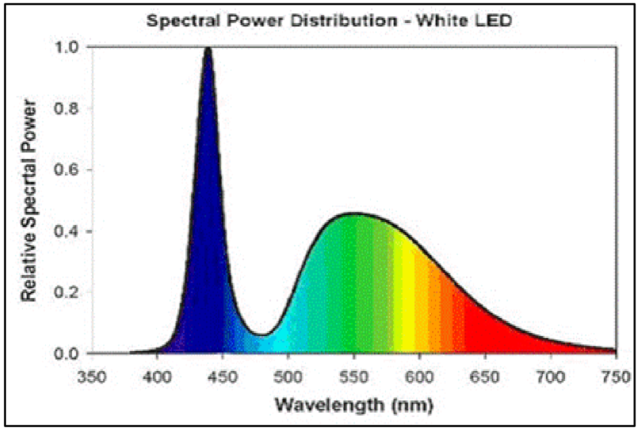
VLC Key Component: White LED

- Phosphorous white LED:
  Blue LED + yellow Ph-layer → white light

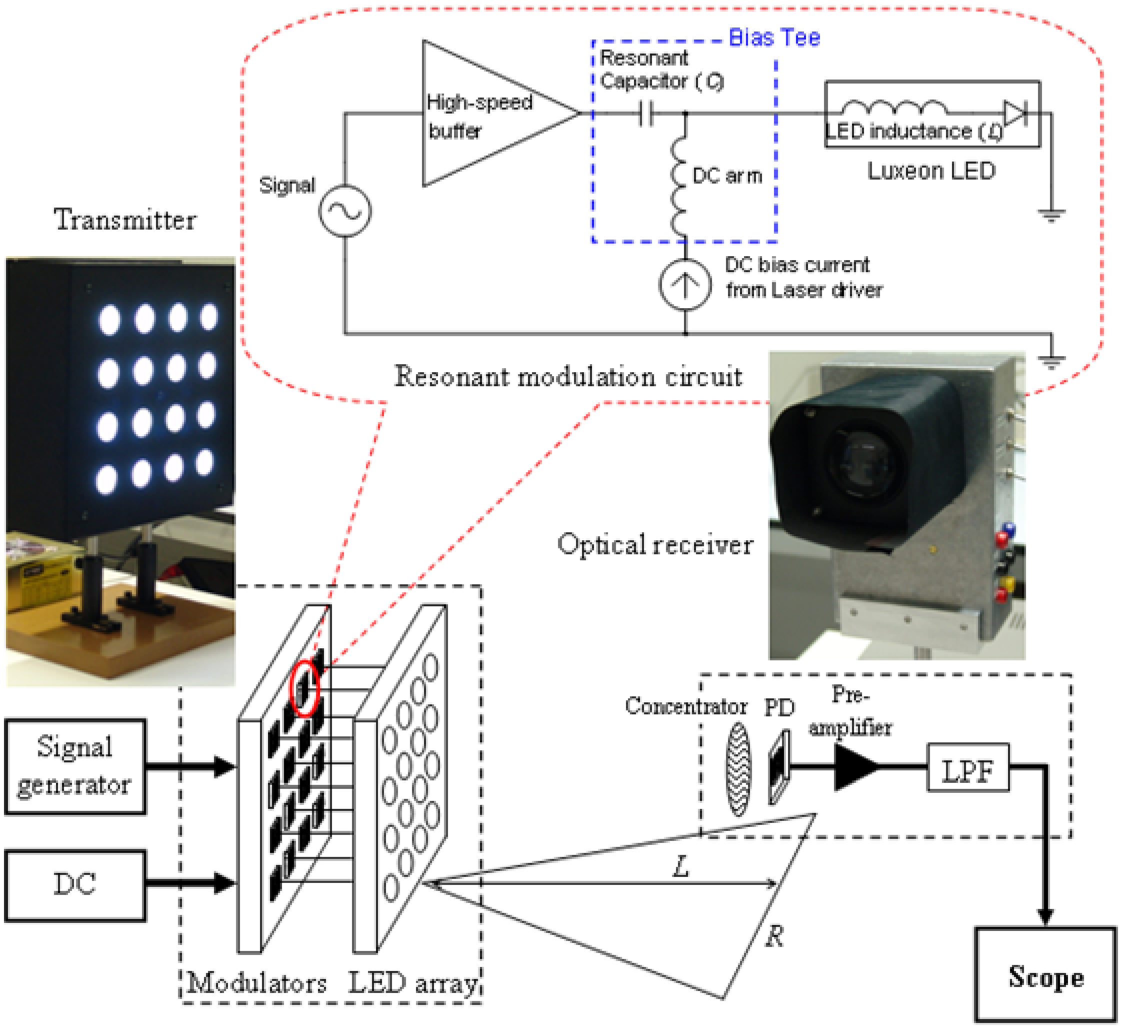


- Modulation bandwidth limited to 1-2 MHz by slow response time of the Ph layer

- Manipulation of LED resonant frequency
- „Blue" bandpass filter in front of the Rx
  → suppress the slow Ph-component
  → ~20+ MHz white LED BW (~10x)



Enhancing the Bandwidth - Pre-Equalization

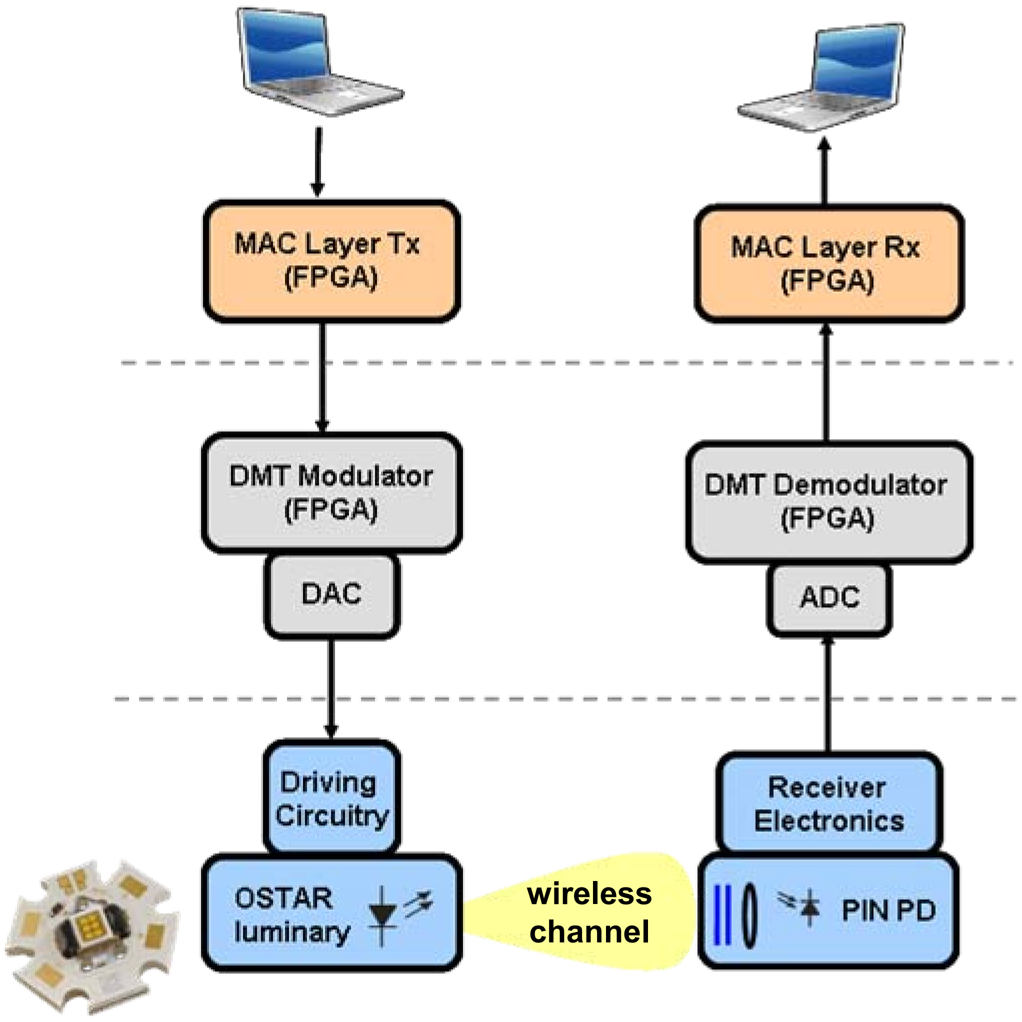


University of Oxford, 2008-9

- 4 x 4 LED array
- Pre-equalization @Tx: 3 → 25 MHz
- 40 Mbit/s, 2 m reach using NRZ-OOK
- Customized equalizing needed

VLC Transmission System in OMEGA

Goal for VLC in OMEGA:
~100 Mbit/s broadcast via ceiling lighting

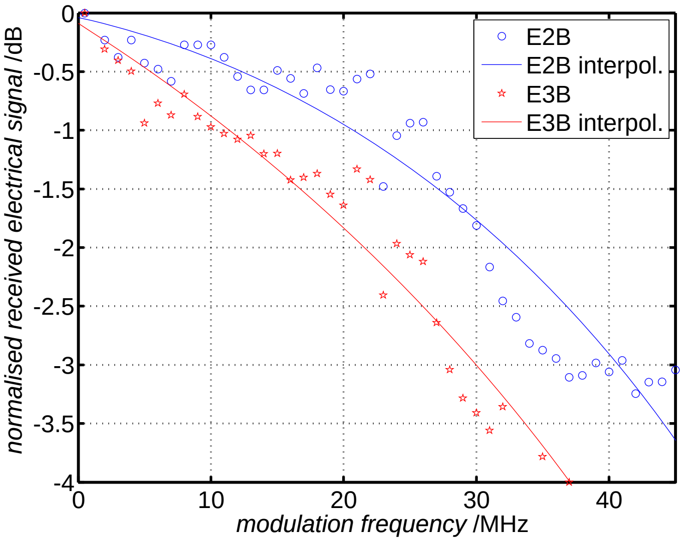


Analogue Tx Front-End (Ω demo)

- Commercial LED luminary (OSTAR E3B)
  – 6 thin-film Ph white LEDs
  – Luminous flux ~ 400 lm (@ dc = 700 mA)
  – Integrated optic:
  76° semi-angle @ half power circular light spot

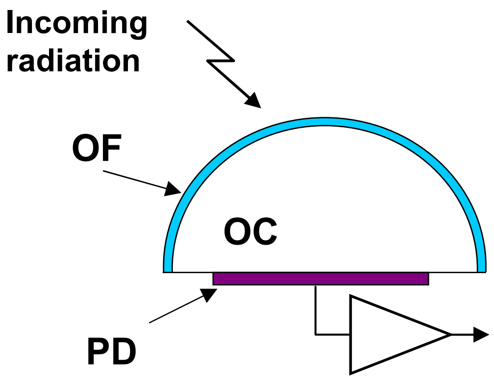
OSTAR E3B

- Custom-designed driving circuit
  electrical 3-dB BW: 90 kHz – 12 MHz



Analog Rx Front-End (Ω demo)

- Optimized Optical filter (OF)
  – Rejects background illumination
  – 500 nm cut-off wavelength
  → Suppresses Ph component;



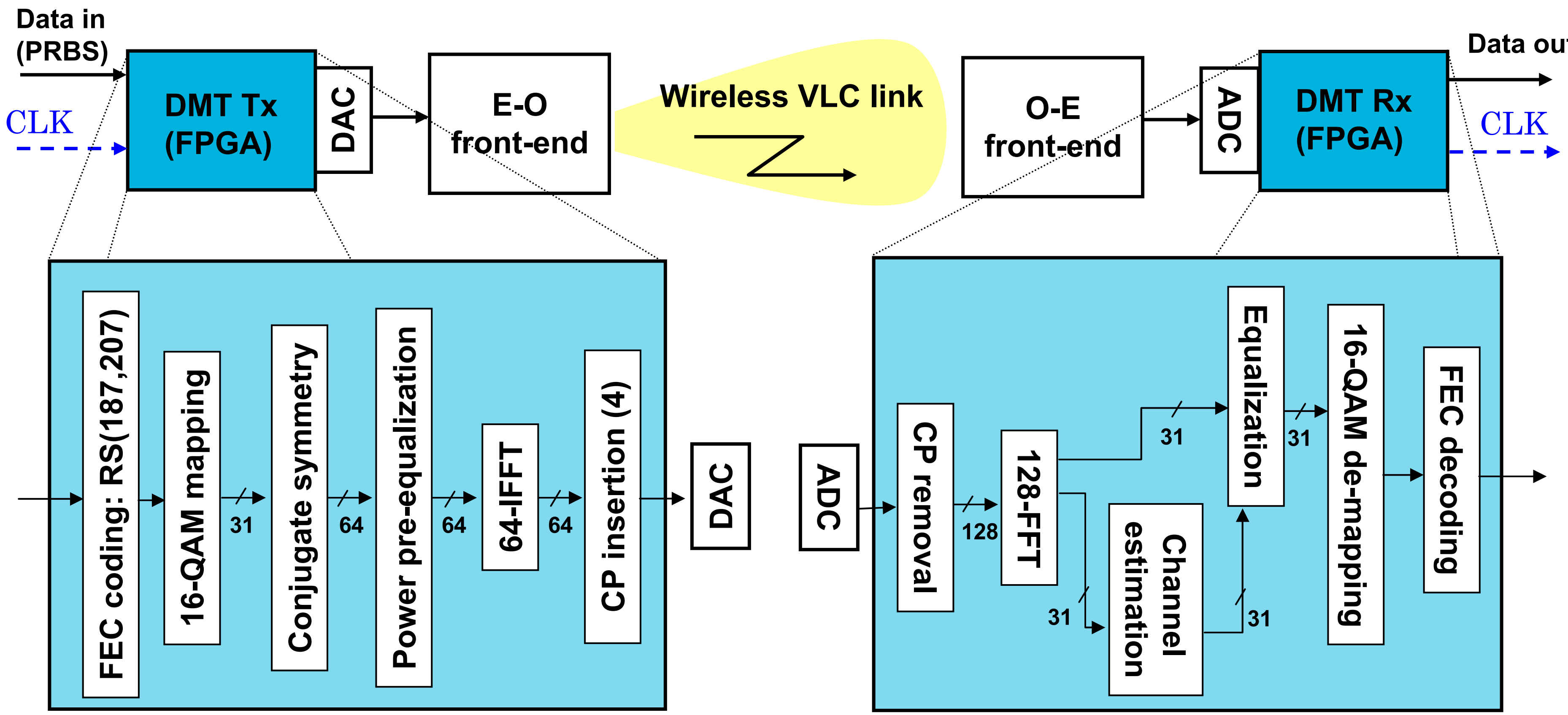
- Optical concentrator (OC)
  – Collects and concentrates incoming radiation
  – Integrated with PD; field of view 70°

- Photodetector (PD)
  – Commercially available Si-PIN PD
  – Effective detector area of ~110 mm²

- Custom-designed two-stage amplifier (TIA)
- Rx 3-dB bandwidth ~35 MHz

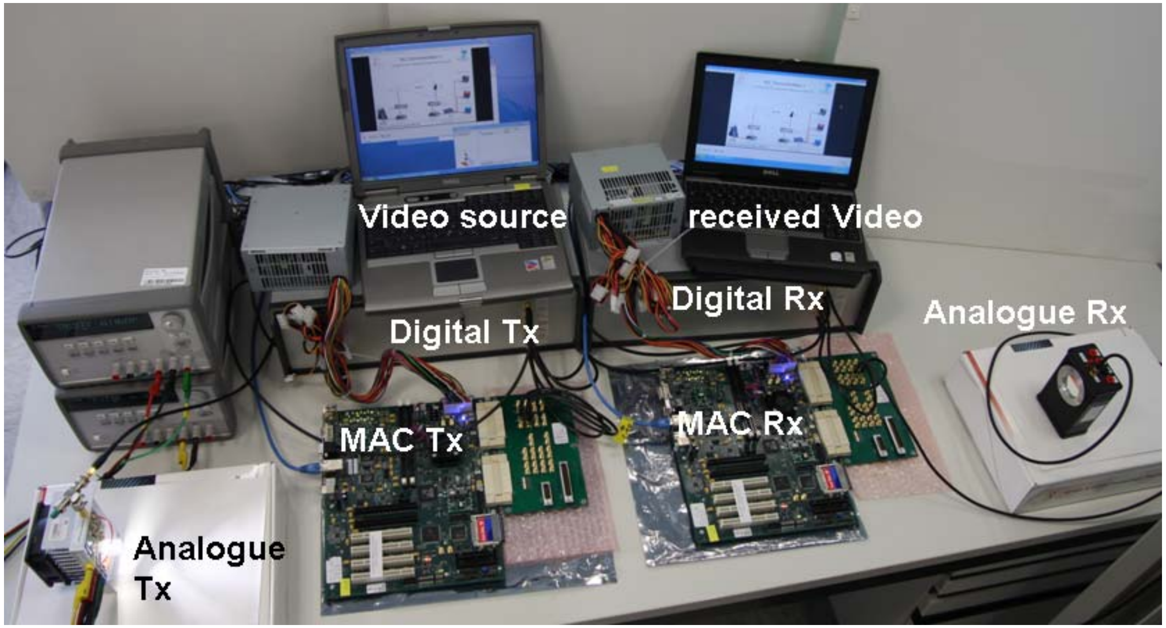
PHY Digital Signal Processing (Ω demo)

Photonic
Networks + Systems



- For ~1.4 m (500 lx) FEC renders error-free performance
- Longer Rx-Tx distances → multiple luminaries

Video Transmission Demo



- Video transmission @ 100 Mbit/s (PHY)
- ~1.4 m wireless link length (500 lx @ Rx)
- Scenario with 16 luminaries in preparation (~10 m^2 coverage)
- Transmission over ~2-3 m distance

Conclusions

- OW technology interesting for many indoor applications
- Standardization efforts (PHY + MAC)
  – IrDA, VLCC, IEEE, others
- Potential for high-speed transmission via both IR and VLC links
- Towards further performance improvements
  – Optimization of optical frontends (Rx bandwidth, power efficiency of LED driver, handling of imperfect LED linearity…)
  – Spectrally-efficient modulation, advanced signal processing techniques (e.g., MIMO)

Acknowledgement

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SEVENTH FRAMEWORK PROGRAMME

Thank you.

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