

Opportunities and Challenges for High-Speed Optical-Wireless Links

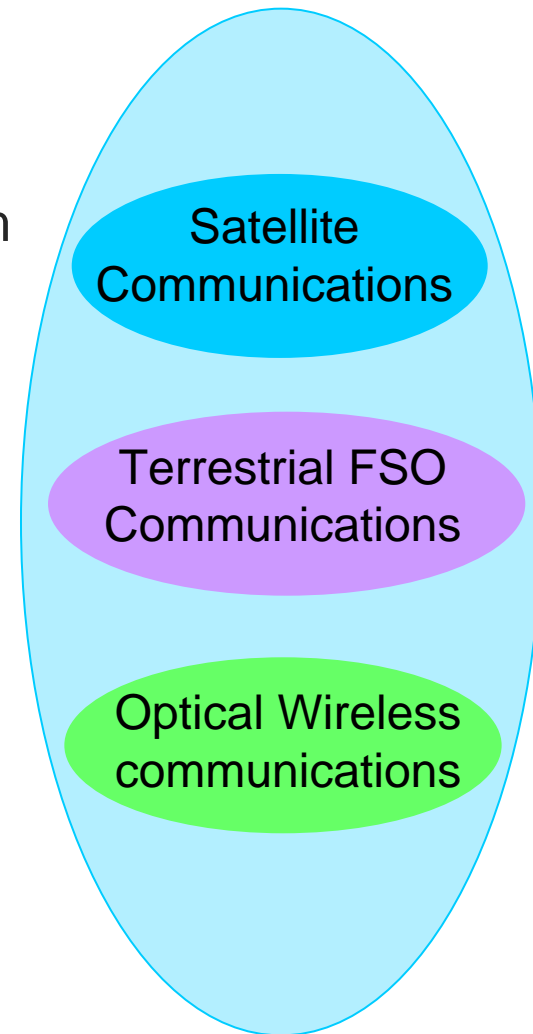
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Fraunhofer Heinrich-Hertz-Institut

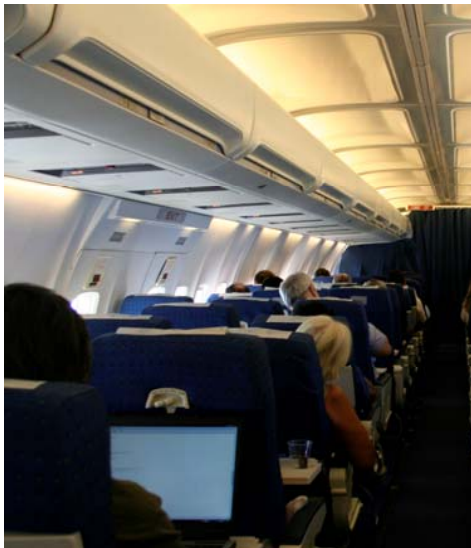


- Introduction to Optical Wireless Communications
 - Motivation and Domains of Application
- Infrared Links
 - Main Features and Recent Efforts
- Visible Light Links
 - Main Features and Recent Efforts
- Summary and Conclusions

- **Satellite communications**
 - Inter-satellite, satellite-to-earth links, $\sim 10\,000$ 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, \sim km range, \sim Gbit/s range
- **Optical wireless (OW) communications**
 - Indoor applications in \sim m range
 - P-t-P, P-t-MP links (LOS and/ or reflections)
 - 10 ... 1000 Mbit/s

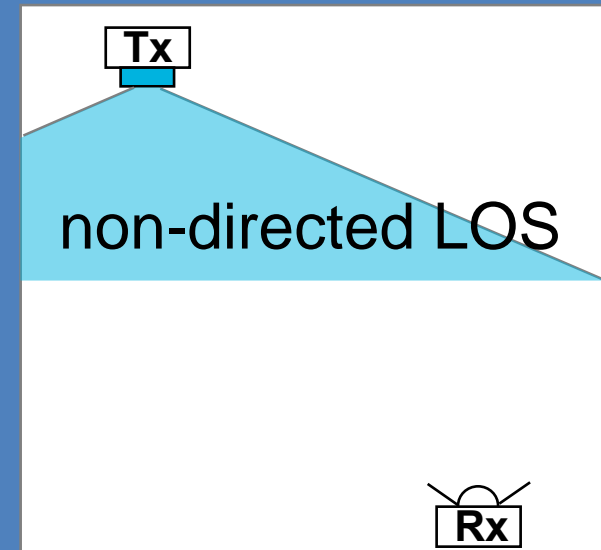
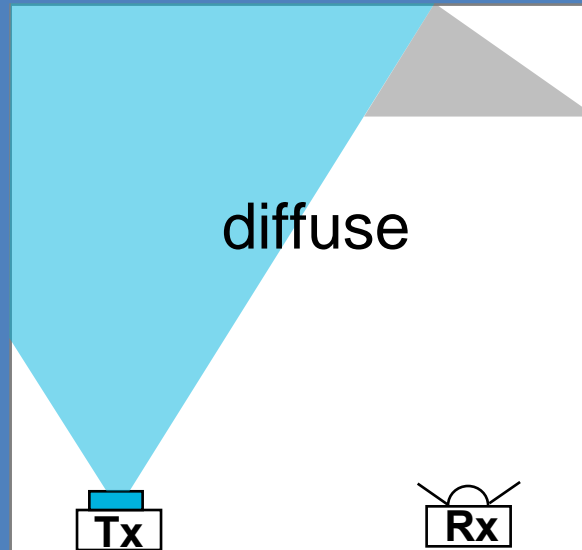
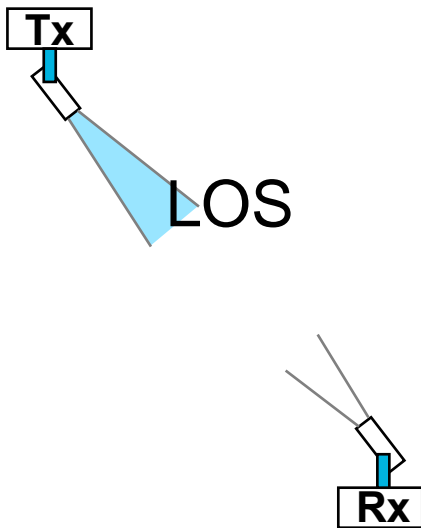


- No EMI with radio systems, no “e-smog”
- Available and unregulated spectrum
- Simple shielding by opaque surfaces → easily obtainable privacy
- Complementary to radio for wireless access



directed

non-directed



- LOS
- High data rates
- Sensitive to blocking

- Reflections
- High coverage
- High path loss

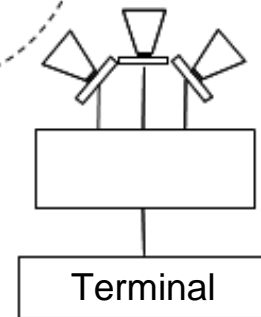
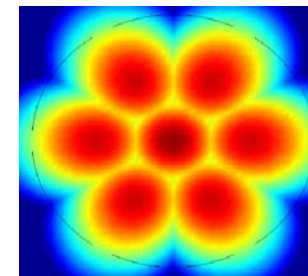
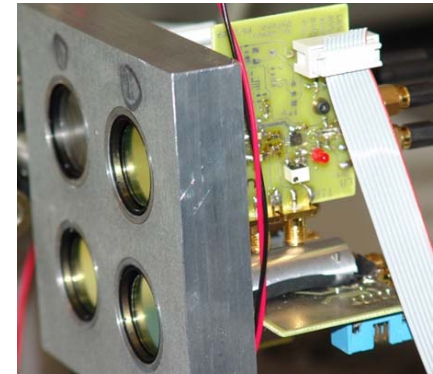
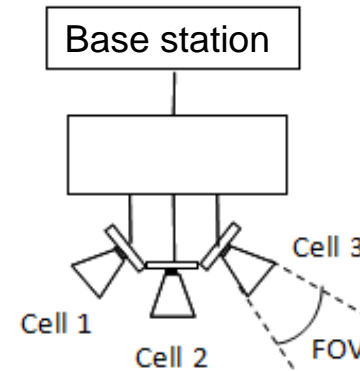
- LOS + diffuse
- High coverage + potentially high data rates

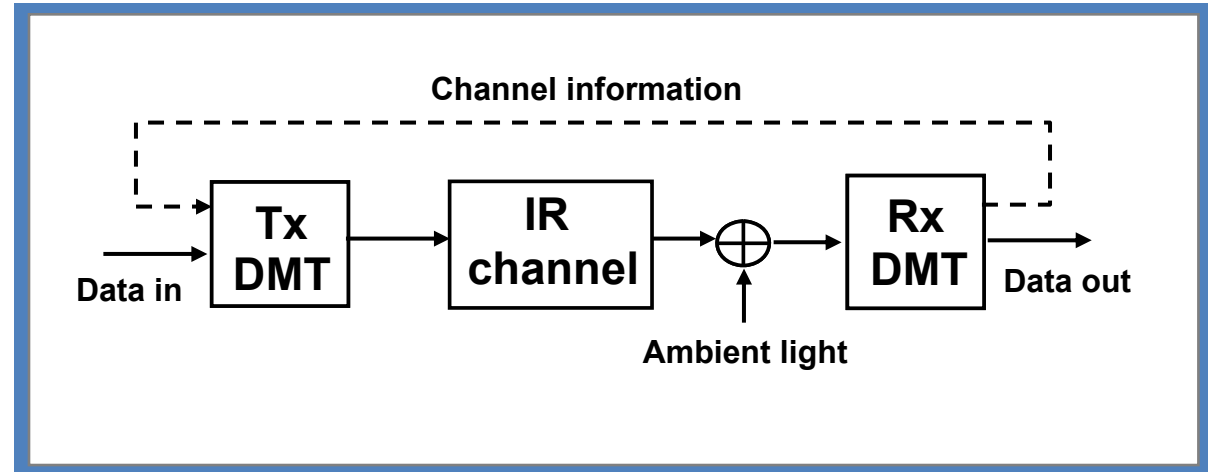
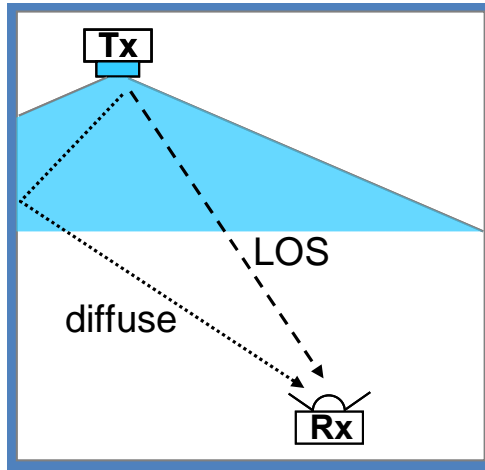
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- Tradition: PtP links, e.g. IrDA: 16 Mbit/s up to Giga-IR
→ short-range, low coverage
- Eye and skin safety
- Available Rx components (850 or 1550 nm range) mainly developed for fibre optics → small-area PDs, OW needs large-area ones
- Background 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

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





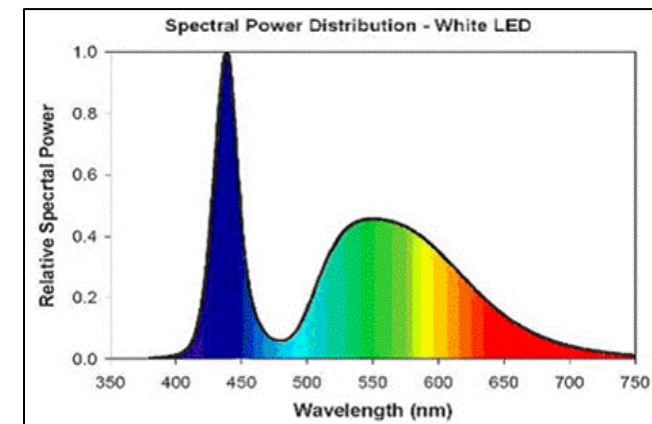
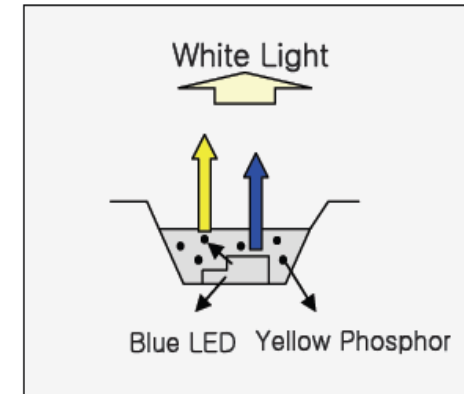
- Single-element optical front-ends
- Channel varies from low-pass to flat (LOS / diffuse signal ratio)
- Low-speed feed-back link provides channel information to Tx
- System dynamically adapts data rate to channel state using DMT: Bit- and power-loading, handling of multipath distortion, efficient signal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

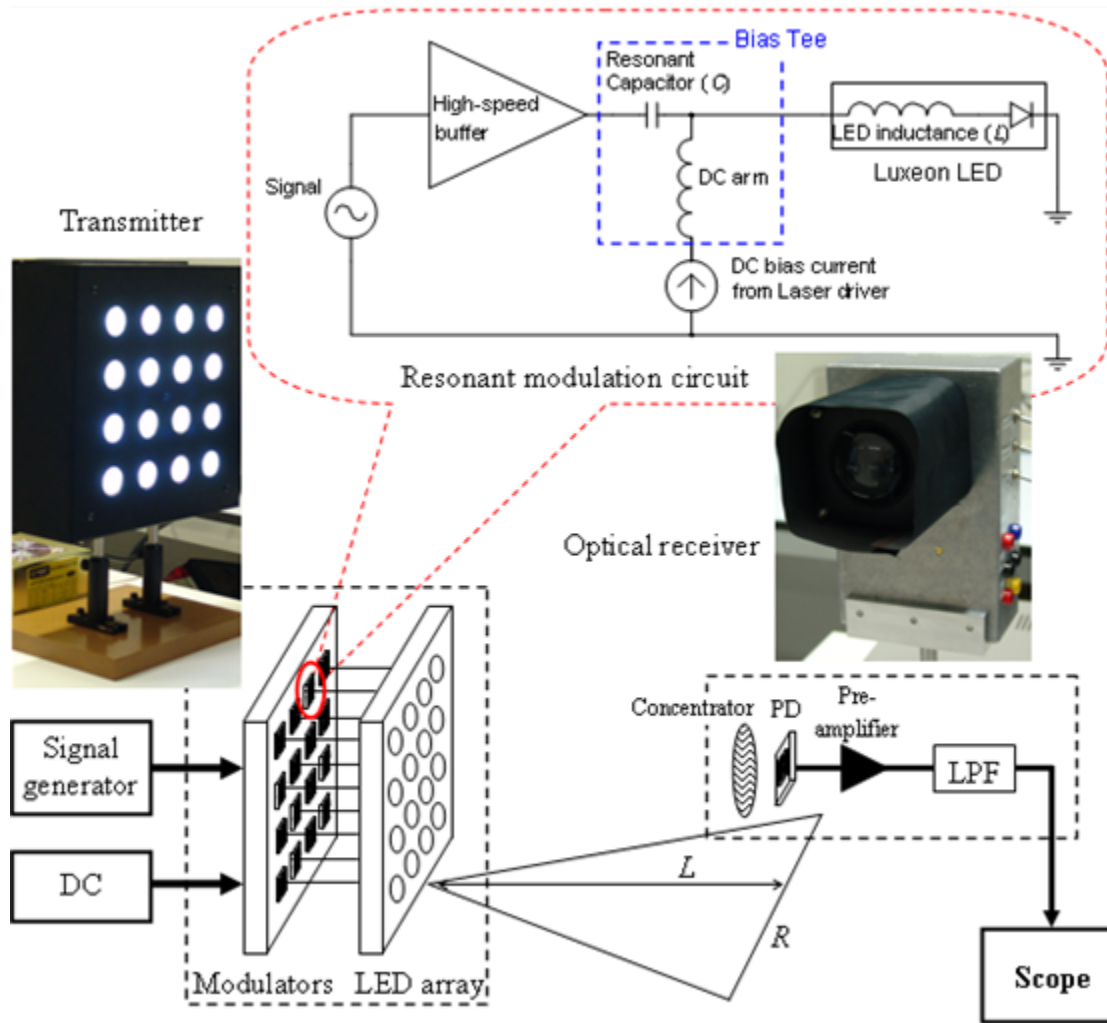
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- Omnipresence of LEDs; signalling and illumination
- LEDs offer significant potential for modulation
- Combination of illumination or signalling with data transmission
 - data transfer as “piggyback”
 - broadcasting hot-spots
- Attractive where light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



- 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)





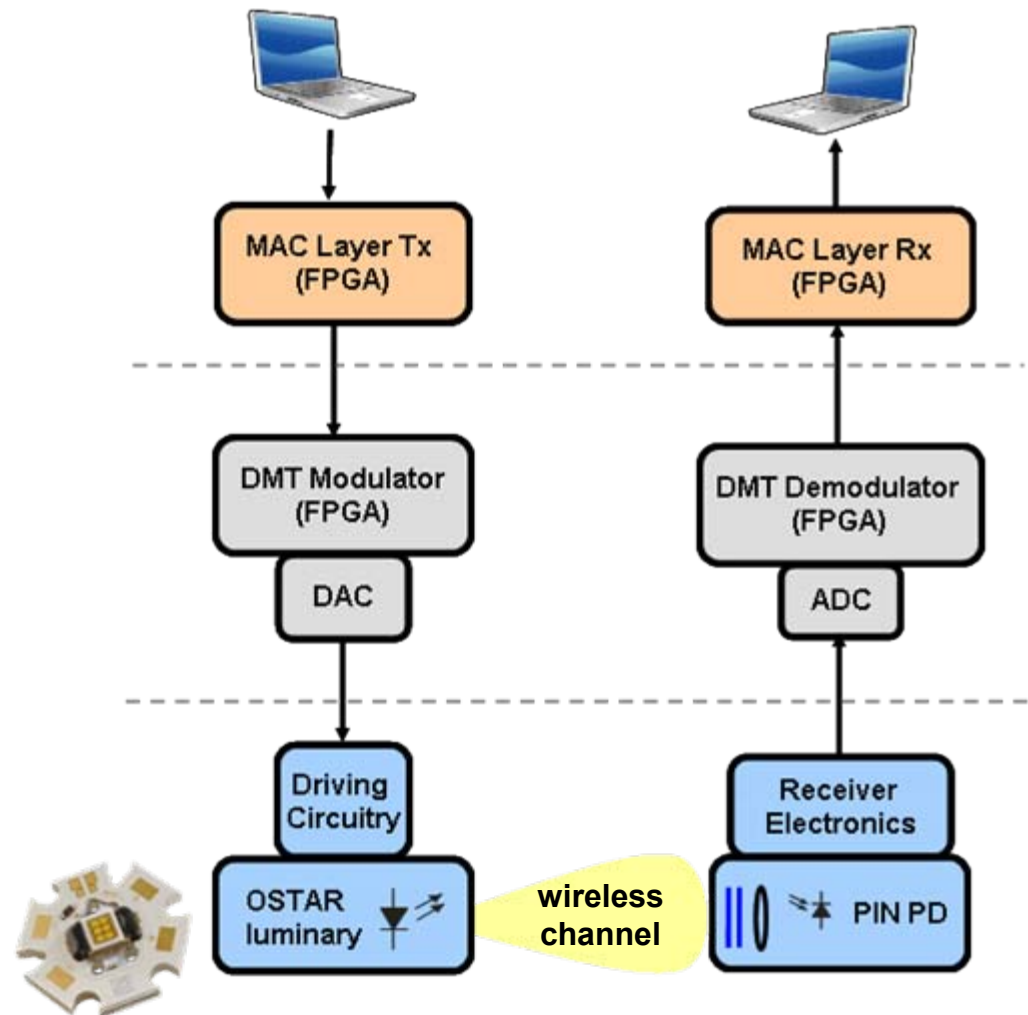
University of Oxford,
2008-9

- 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**

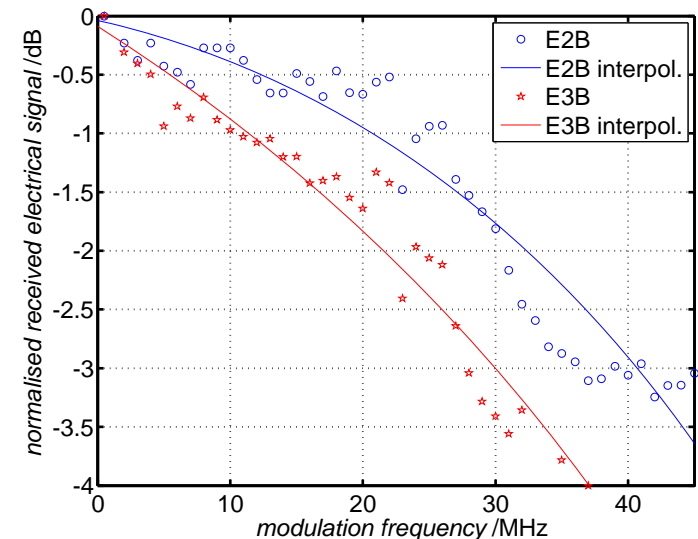


- Commercial LED luminary (OSTAR E3B)
 - 6 thin-film Ph white LEDs
 - Luminous flux ~ 400 lm (@ dc = 700 mA)
 - Integrated optic:
76° semi-angle @ half power circular light spot



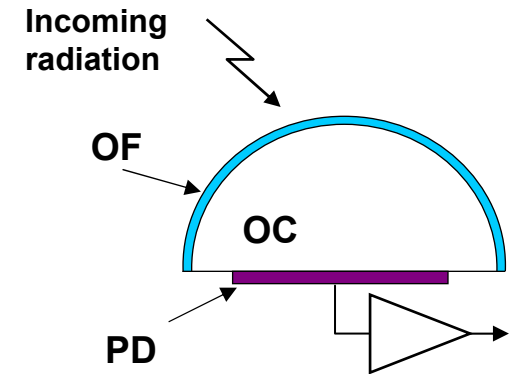
OSTAR E3B

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

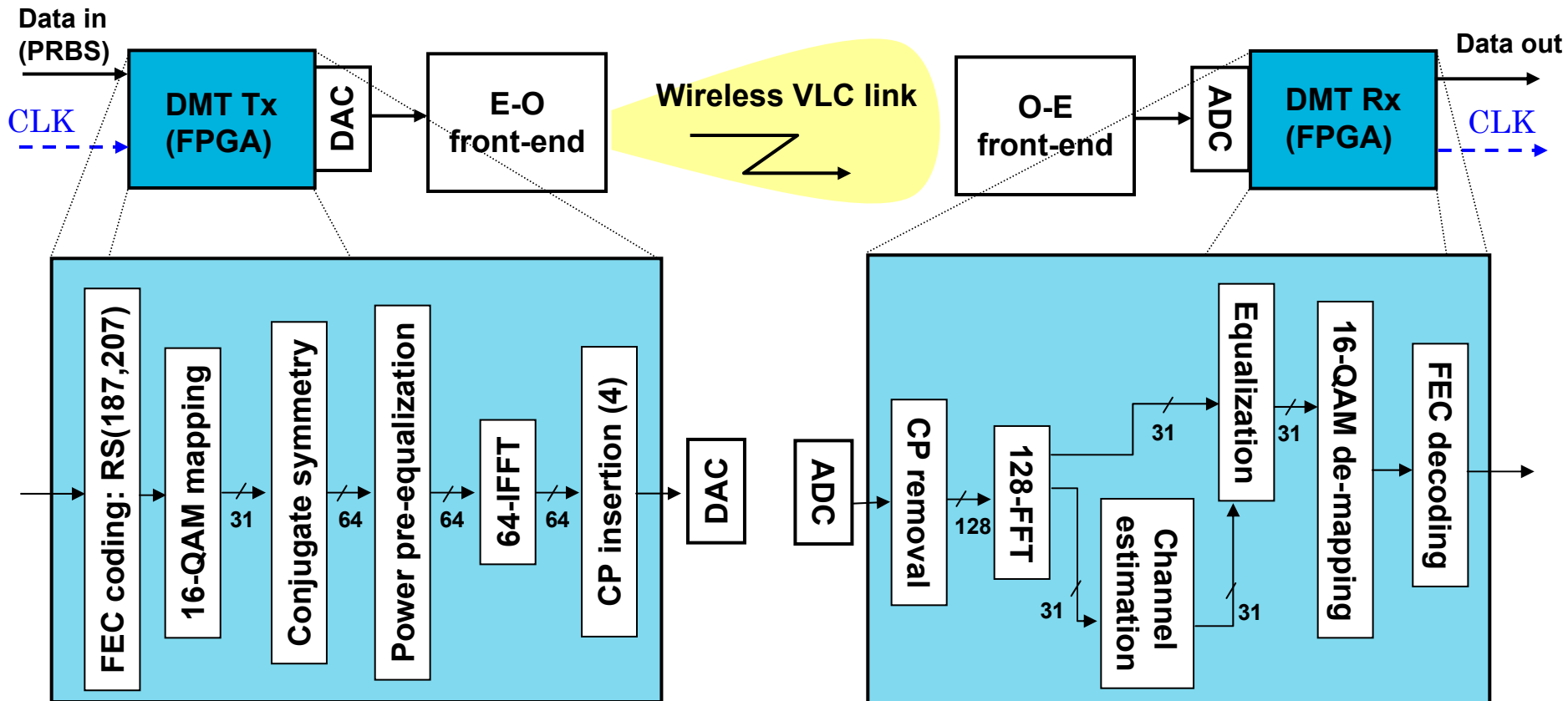


Analog Rx Front-End (Ω demo)

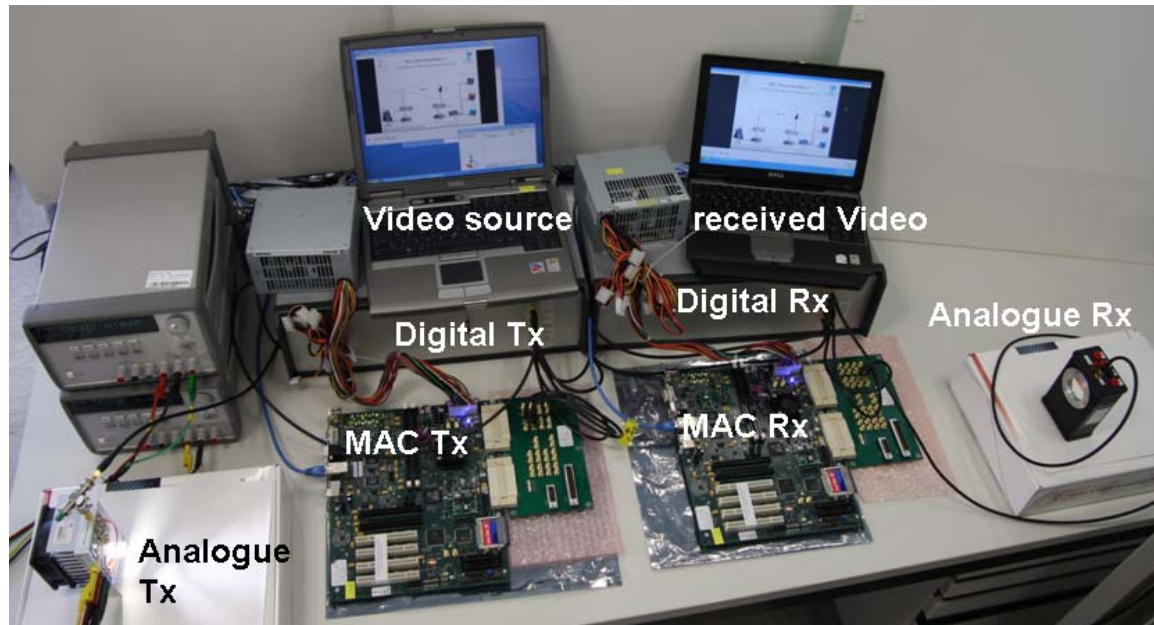
- Optimized Optical filter (OF)
 - Rejects background illumination
 - 500 nm cut-off wavelength
 - Suppresses Ph component;
- Optical concentrator (OC)
 - Collects and concentrates incoming radiation
 - Integrated with PD; field of view 70°
- Photodetector (PD)
 - Commercially available Si-PIN PD
 - Effective detector area of $\sim 110 \text{ mm}^2$
- Custom-designed two-stage amplifier (TIA)
- Rx 3-dB bandwidth $\sim 35 \text{ MHz}$



PHY Digital Signal Processing (Ω demo)



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



- Video transmission @ 100 Mbit/s (PHY)
- ~1.4 m wireless link length (500 lx @ Rx)
- Scenario with 16 luminaries in preparation (~10 m² coverage)
- Transmission over ~2-3 m distance

- 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)

- The research leading to these results received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement N^o 213311 also referred to as OMEGA.



Thank you.

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