

ECOC 2011
16th Opto-Electronics and Communications Conference
Sep 4-8, 2011, Geneva

Workshop
"Towards high capacity fibers for space and mode division multiplexed transmission"

MIMO COUPLERS AND SIGNAL PROCESSING

Sun, 18th Sep, 2011 10:00 to 13:30 PM, Room "Le Saleve"

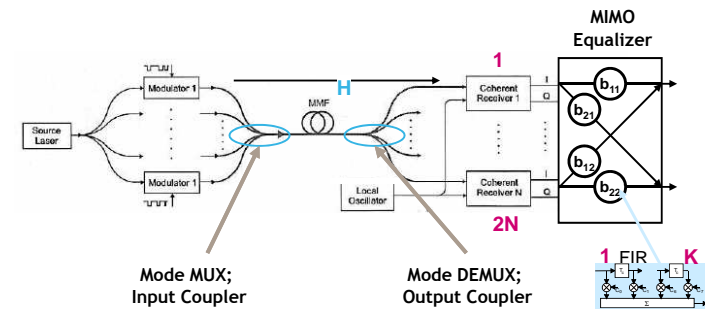
Henning Bülow, B. Franz - Alcatel-Lucent, Bell Labs, Germany
H. Al-Hashimi, B. Schmauss, - LHFT, Univ. Erlangen-Nuernberg, SAOT
B. Tamene



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OUTLINE

- Characteristics of optimized MMF
- Equalizer requirements, complexity ($K \cdot N$)
- Mode MUX options

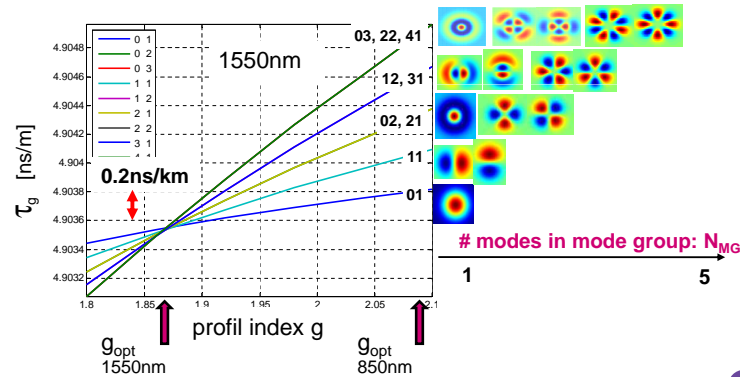
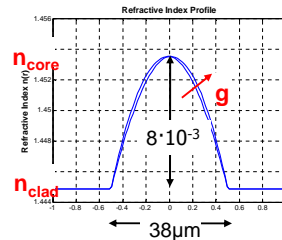


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GI MMF

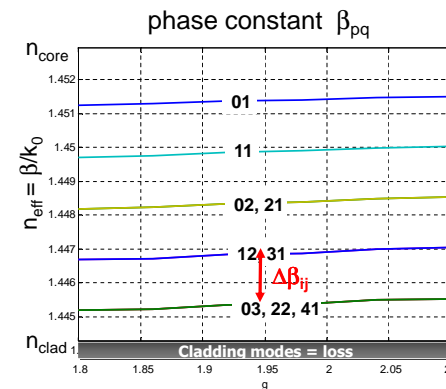
- Power law index profile of graded index MMF
- Group delay of LP mode (DMD)



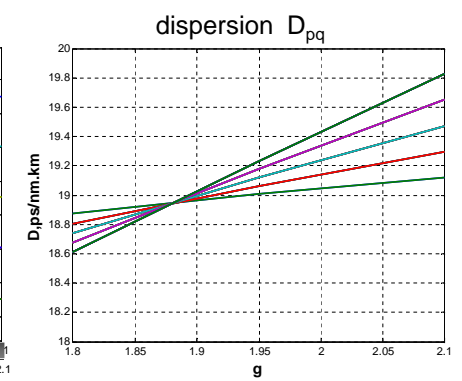
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GI MMF Phase constant

- Xtalk $\sim (c/\Delta\beta)^2$



GVD (CD)



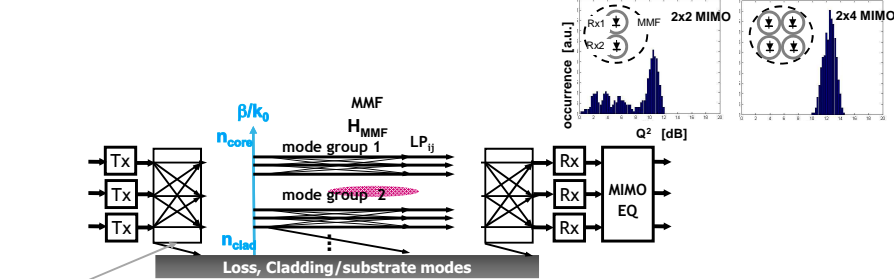
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MODE GROUP DIVISION MULTIPLEXING (MGDM) DIRECT DETECTION (DD)

- DD: Limited MUX Xtalk equalization performance



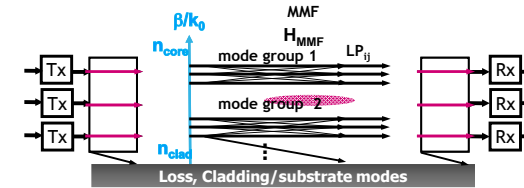
MMF multi offset MG MUX

- C.P. Tsekrekos, et al., PTL, 2008, pp.1112 (optical MG selective DEMUX)
- W. Rosenkranz, et al., 3x3 DD MIMO 10G: OECC 2010, 6B2-3
- Thomsen et al., 2x10G: OFC 2010, OThM6
- B. Franz et al., 2x 4G: ECOC 2010
- H. S. Chen, et al., 3x3 30G: PTL, 2011, pp. 1283

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MODE GROUP DIVISION MULTIPLEXING (MGDM) DIRECT DETECTION (DD)

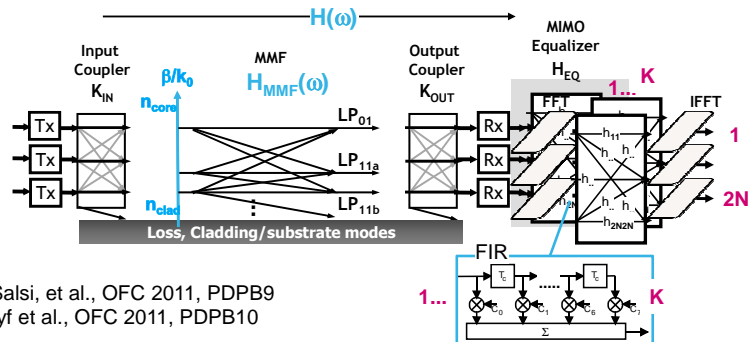
- Equalizer obsolete if optical Mode Group Mux solutions available



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MODE DIVISION MULTIPLEXING (MDM) COHERENT DETECTION (CO)

- Complexity $K \cdot (4N)^2$: # adaptation parameters
 - N: # spatial modes ; K: # FIR taps (channel memory)



- M. Salsi, et al., OFC 2011, PDPB9
- R.Ryf et al., OFC 2011, PDPB10

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OPTICAL PATH / POTENTIAL COMPLEXITY REDUCTION

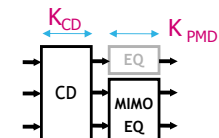
- Negligible MDL, PDL $\rightarrow H_{MMF}(\omega)$ unitary
 - \rightarrow Complexity/2 : i.e. $K \cdot 78$ vs. $K \cdot 144$ for 3 modes

different to
• Juarez, Petermann, et al., OFC 2011
• K.-P. Ho, Kahn, OptExp, 2011

- Tailored MMF: moderate N, $K_{DMD} \approx 1$ + good mode MUX (splitter)
 - $\rightarrow H(\omega)$ unitary
 - \rightarrow Intra mode group MIMO sufficient (?): $K \cdot (4N_{MG})^2$



- Common CD compensation

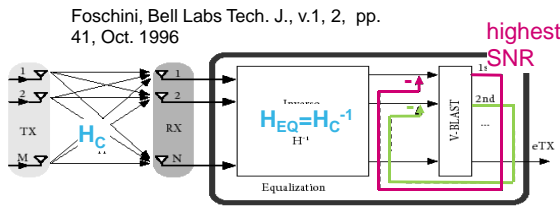


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EQUALIZATION W. MODAL LOSS: MDL, PDL

$K = 1$

- Successive Interference Canceller (SIC)
- V-BLAST algorithm sorted vertical DFE (space-time domain)



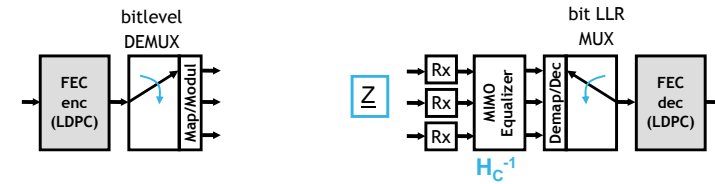
$K > 1$

- Spectral factorization



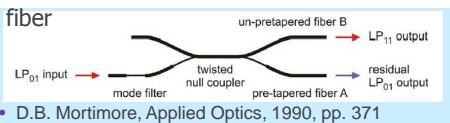
CODING SCHEME

- Distribution of code word among all spatial modes
 - see also Tu.6.A.1
- analogously to
 - D. Penninckx et al., "WDM redundancy to counteract PMD effects in optical systems", ECOC 2001



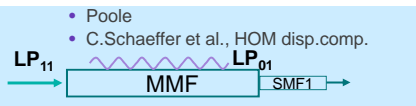
KEY BUILDING BLOCK: MODE DE/MUX

- MMF fused fiber coupler



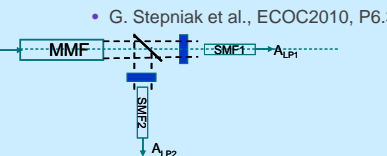
- N. Hanzawa et al., Proc. OFC2011, OWA4

- LP fiber Bragg grating



- An Li, et al., OFC2011, PDPB8, Shieh et al. OECC2011

- Phase holograms + power divider



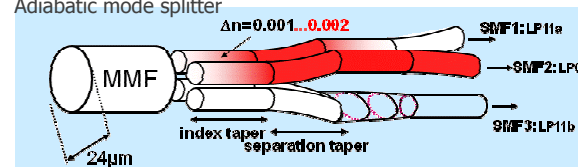
- M. Salsi et al., OFC2011, PDPB9

- R. Ryf et al., OFC2011, PDPB10



KEY BUILDING BLOCK: MODE DE/MUX

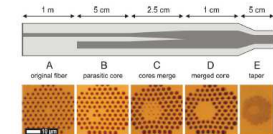
- 3-D waveguide structure/ photonic crystal fiber
- Adiabatic mode splitter



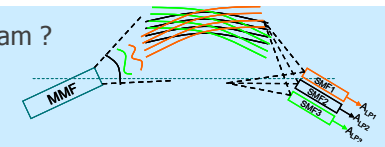
- concept, ECOC 2010, OECC 2011
- scalability ?

- motivated by photonic crystal fiber mode transformer

- A. Witkowska, et al., Opt. Lett. 33, 306-308 (2008)



- Volume hologram ?

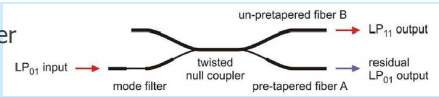


- concept, bandwidth?



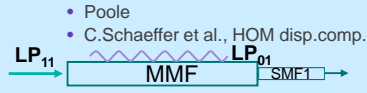
MODE DE/MUX

- MMF fused fiber coupler



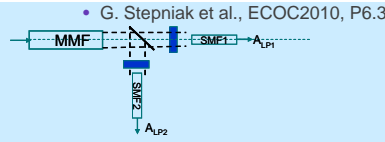
• D.B. Mortimore, Applied Optics, 1990, pp. 371

- LP fiber Bragg grating



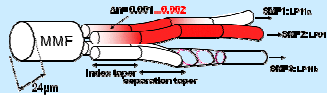
• Poole
• C.Schaeffer et al., HOM disp.comp.

- Phase /amp holograms + power divider



• G. Stepniak et al., ECOC2010, P6.3

- 3-D waveguide structure/ photonic crystal fiber



| loss | extinction | scalability |
|----------|------------|-------------|
| 1 | ? | ? |
| N | ? | ? |
| N | ✓ (?) | ✓ |
| 1 (?) | ✓ (?) | ? |

CONCLUSION

- Mode De/MUX, mode group De/MUX
- To date scalabel / low loss / high extinction solution lacking
- joint w. tailored MMF
 - high inter mode group isolation
 - low modal delay spreading
- potential of MIMO processing reduction
 - common CD pre-compensation
 - intra mode group MIMO
- Successive interference cancellation
- Joint FEC