„Lossless“ Broadband Signal Transfer

Carat 1st Workshop

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To loose or no loss – Is it a question ?

Diamond Detectors – fast risetime, short pulses, random signals
Radiation level – Damage to electronics
High energy physics – Wide experimental areas

Acquisition electronics far away from detector frontends
-> Broadband Detector Signal Transfer

Use lossy wires, coax etc.
or
“Not so lossy” optical fibers

Now a brief look at it...

Motivation

Demands

- Signal transfer from very fast Detectors to Analysis Crates in the Distance
- Time-of-Flight (TOF) Measurements
- Amplitude Spectra Measurements

„Linear Time Invariant" (LTI) – System recommended!

Requirements for Broadband Detector Signal Transfer

- Transfer of RF-Frequencies: > 1 GHz
- Distances: > 100 m … 10 km
- Dynamic Range: > 1:100, 40dB
- Transfer Link Budget 1:1, Link Gain = 0 dB
- Timing rms: < 30 ps maintained

Transfer of Broadband Signals over long Paths

A „lossy" Nightmare: Coaxial Cable

Attenuation loss, frequency dispersion, propagation delay drift@temperature:

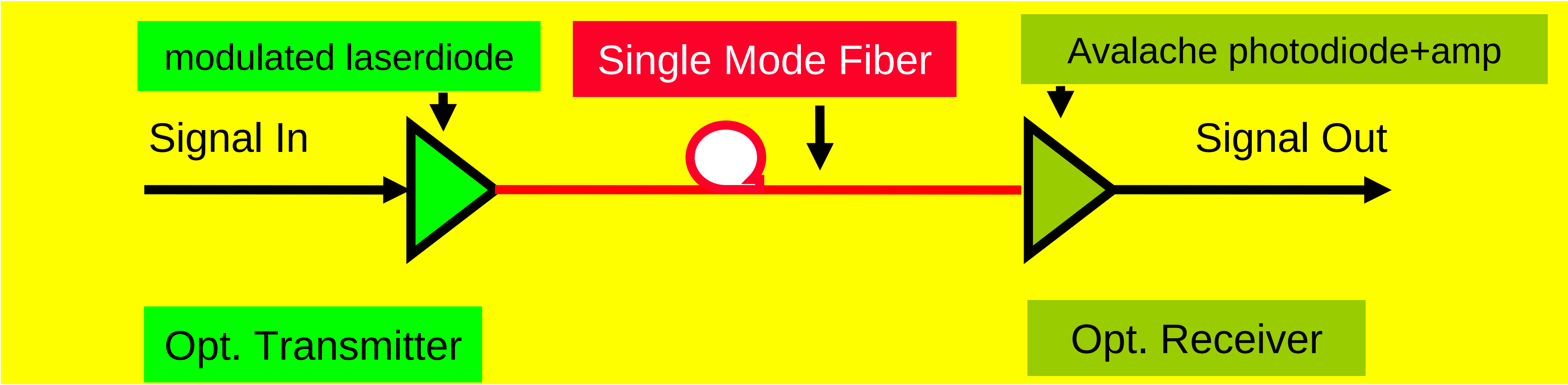
much to high if path length exceeds some 10s of meters

almost everybody has had problems using long coax runs

A „lossless" Dream: Analog RF Optical Fiber Links !

- **~ 0.3 dB/km attenuation for single-mode 9 μm fibers,**
- **very low frequency dispersion (group delay) at GHz bandwidth,**
- **propagation delay drift of standard fibers (30 ppm/K) -> 200 ps/(km*K)**
- **Optical RF transfer systems on market, known as „Optical RF Links"**
- **Signal Transfer Link Budget 1:1 flat into GHz**

„Optical RF – Link" or „RF over fiber", how it works



Optical Fibers, the Signal Transfer Medium

Optical Standard Fibers (SMF28)

- Most common fiber in use, several producers, low-cost
- Available in mechanical rugged versions
- Temperature drift: 30 ppm/K = 150 ps/km*K
- Propagation dispersion (group delay) very flat
- Propagation constant: ß=0.66c (like PE coax)
- Common wavelength bands: 1550 nm and 1310 nm
- Frequencies: 197 THz and 247 THz
- Available bandwidth: several THz
- Electrical isolation: exceptional
- Radiation hardness: average
- Costs: ~ 1€ / m + 50€ connector assembly (FC/APC type)

Optical Signal Transfer - Analog or Digital ?

Digital Transmission Systems

Digital optical communication systems on market:

- **time quantization with the bitrate (eg. 100ps for 10G System)**
- **fast amplitude quantization (ADC) required at detector frontend**
- **synchronous clocks used -> preventing time invariance**
- **Cost advantage for time-sequential multichannel transfer**

Analog Transmission Systems

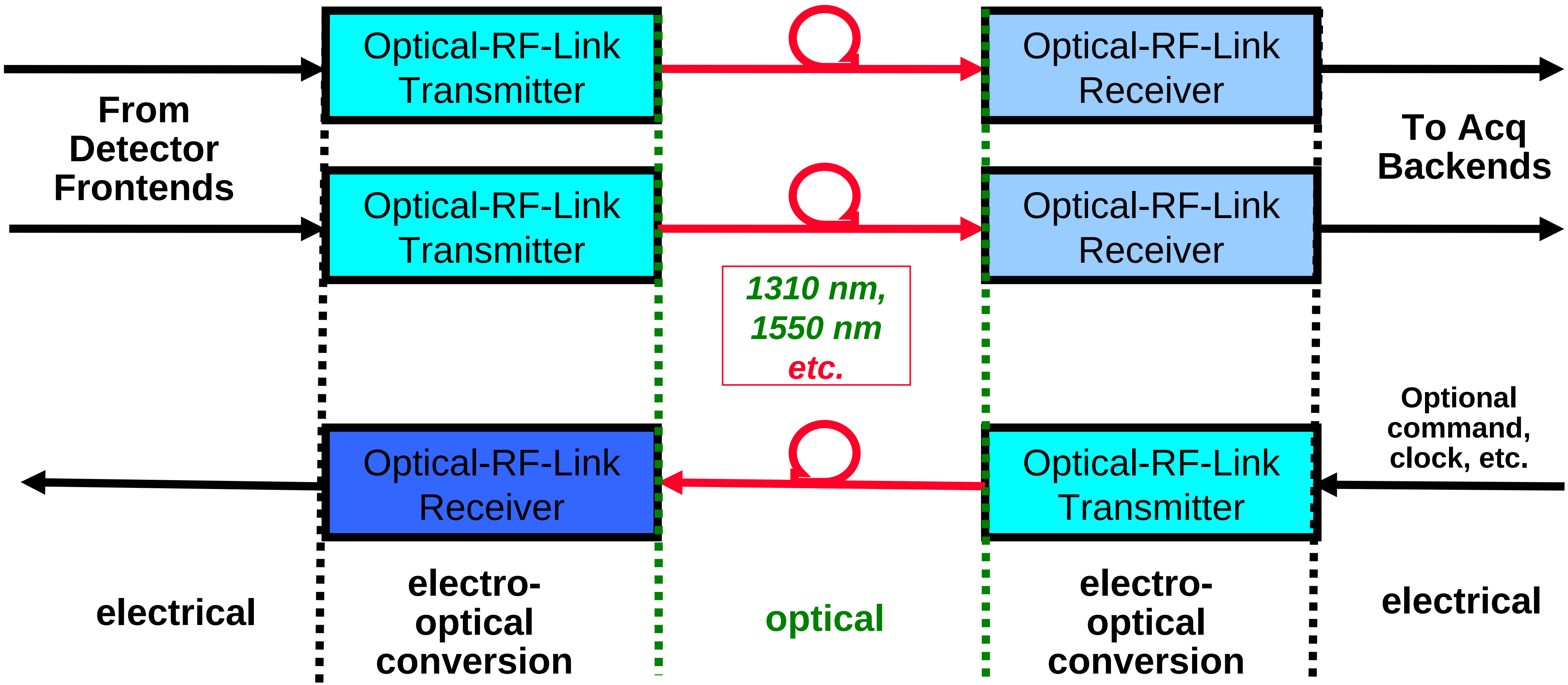
- ✓ **One optical link and fiber per channel or**
- ✓ **Multiplexing channels to a single fiber**
- ✓ **Preserve detector signal properties in time and amplitude**
- ✓ **Time invariance, mandatory for TOF**

Optical Fiber RF-Links

- **Broadband analog „optical rf-links“ on market**
- **Available from stock**
- **No need to develop new electronics for signal transfer**
- **Bandwidth 100kHz…2GHz or more, linear and time invariant**
- **Available at any level:**
  devices, modules, boards, link stations, distribution systems
- **Bidirectional analog links available using a single fiber**
- **Can work on different wavelengths**
- **Transfer of multiple channels:**

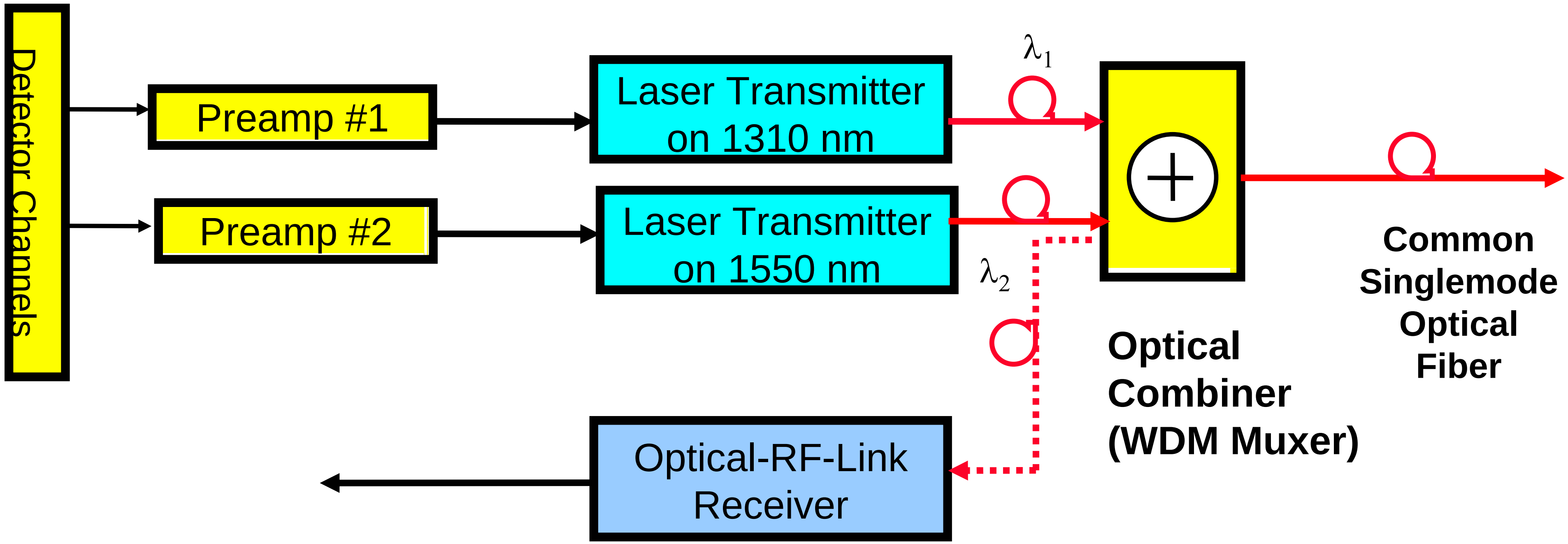
  Parallel - ***one optical fiber per channel***
  Multiplexed - **WDM** / **CWDM** / **DWDM** – bundles

Parallel Signal Transfer



WDM - Wavelength Division Multiplexing

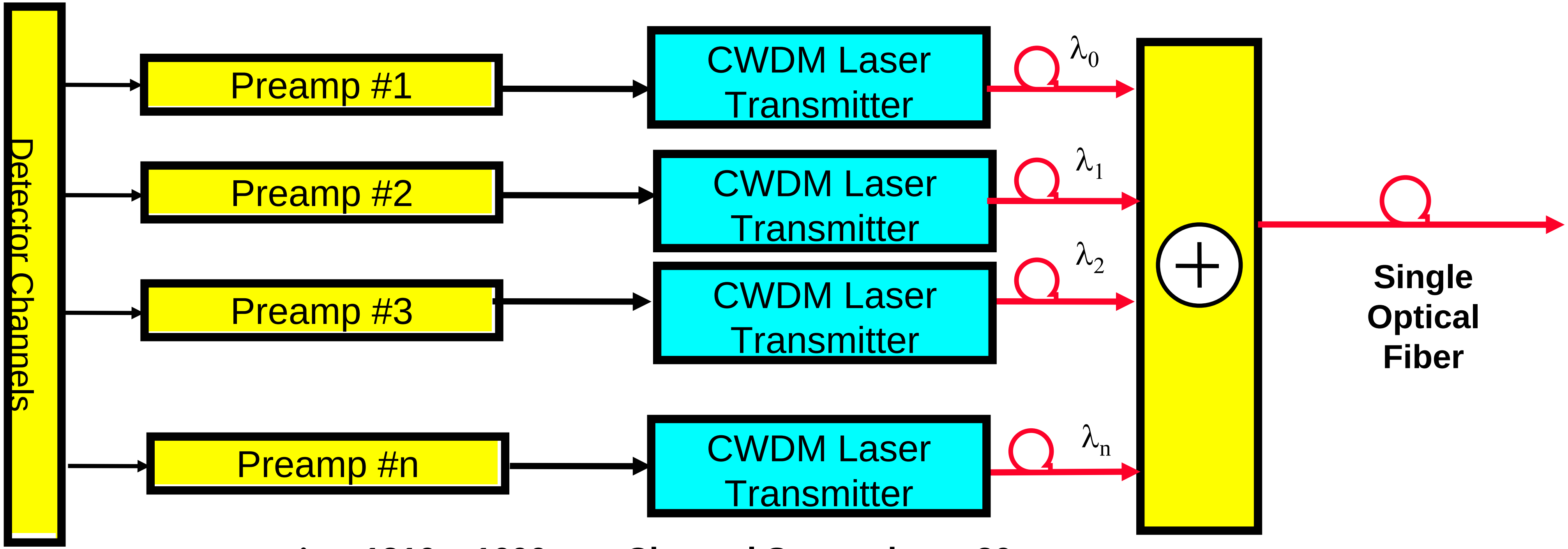
λ_0 = 1310 nm, λ_1 = 1550 nm - Channel Separation by Laser Bands



2 channels, uni- or bidirectional

λ_1 = 1310 nm, λ_2 = 1550 nm

CWDM - Coarse Wavelength Division Multiplexing



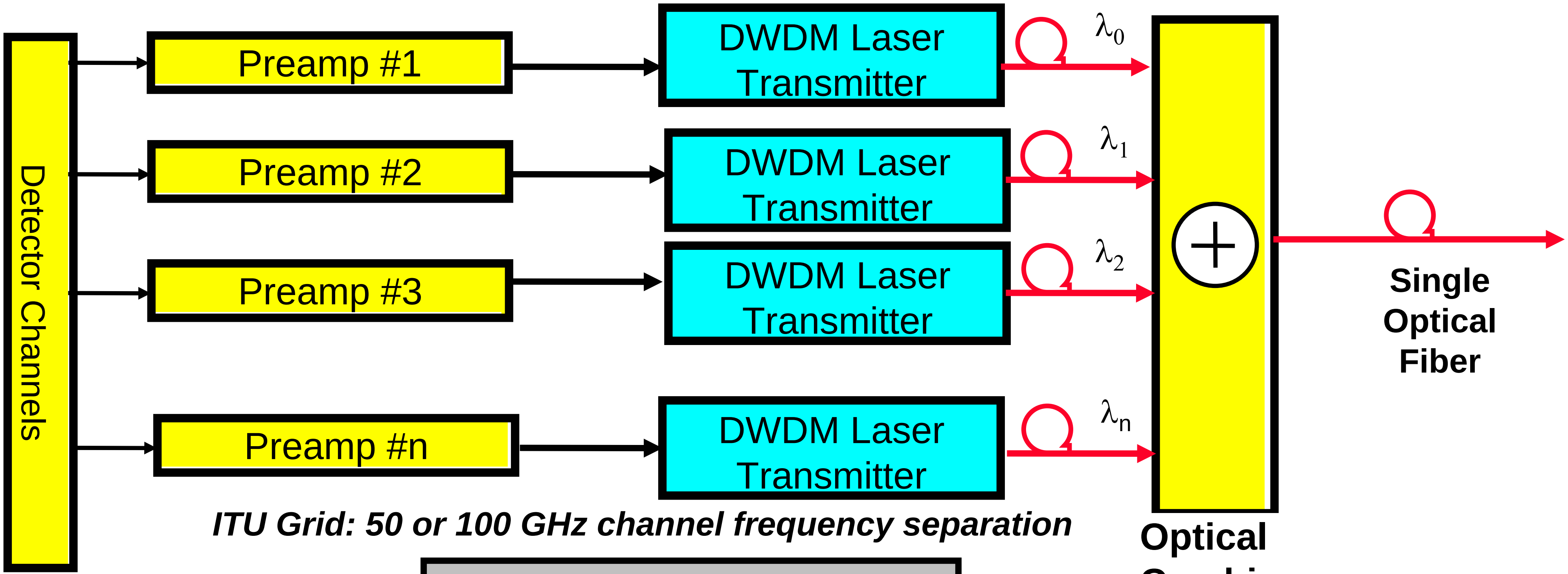
λ_0 = 1310 – 1600 nm, Channel Separation = 20nm

> 8 channels / CWDM Band

Optical Combiner (CWDM Muxer)

DWDM - Dense Wavelength Division Multiplexing

λ_0=1310 or 1550nm

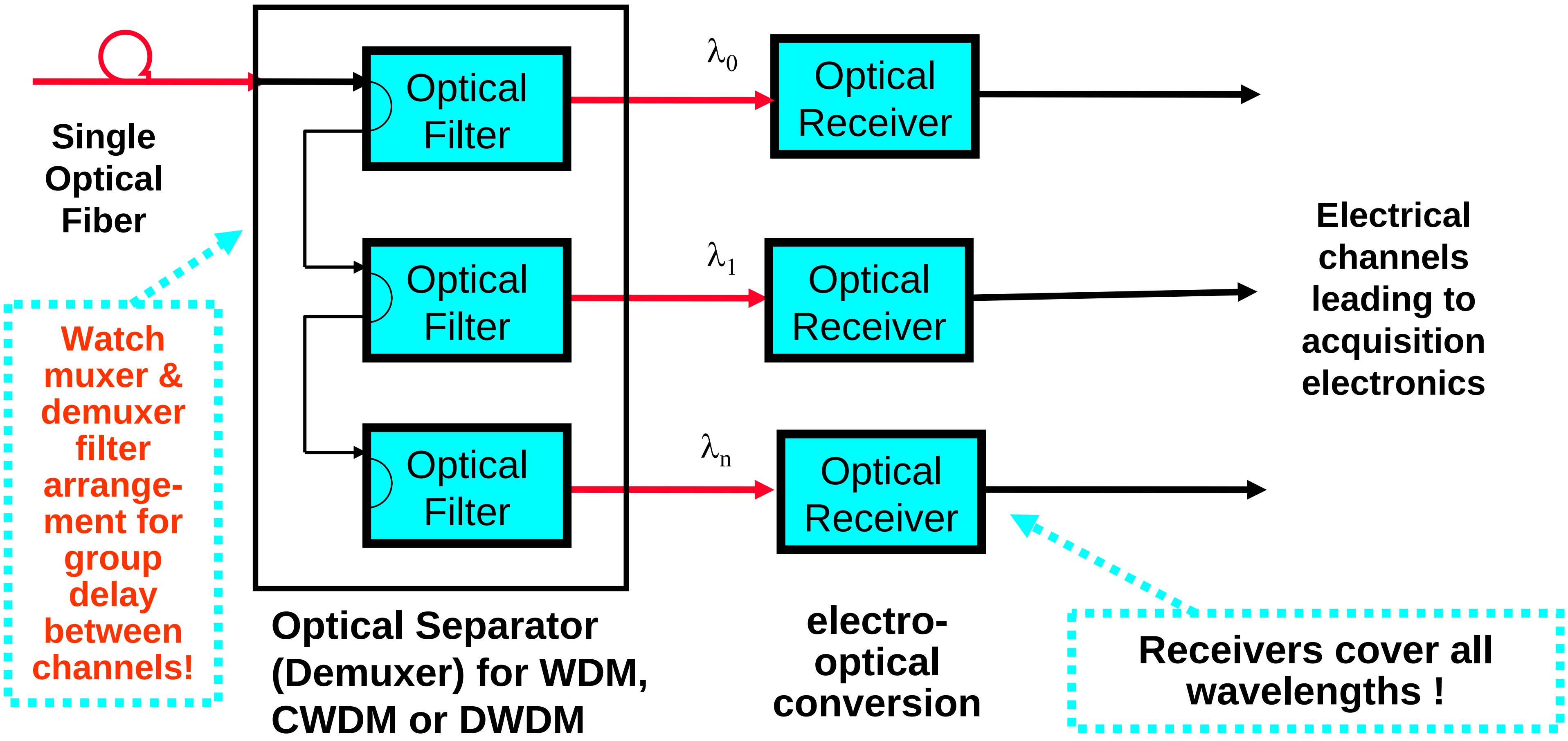


ITU Grid: 50 or 100 GHz channel frequency separation

> 192 channels / DWDM Band

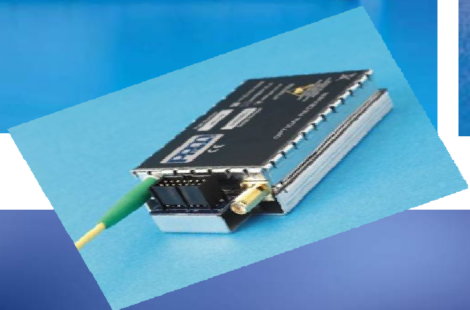
Optical Combiner (DWDM Muxer)

WDM, CWDM or DWDM Channel Demultiplexing



"Lossless" Broadband Signal Transfer

RF-Optical Links - Market Variety



ViaLite®

Wideband Fibre Optic Link

- *2kHz to 4.2GHz bandwidth operation*
- *Suitable for SatCom / WiMax / WiFi / Cellular / TETRA and other applications*
- *Superior Linear Performance and Low Noise*
- *High Spurious Free Dynamic Range – negligible signal loss*
- *Transmits all signal formats*
- *Transmission distances of >50km*
- *Interfaces with M&C systems for remote monitoring*
- *Multiple signal carrier transmission*
- *SNMP Network Control Module Compatible*

supporting up to ten individual receiver modules at all of the covered frequency bands. The card cage features hot ...pable connection and summary alarm contacts for each ...e. The card cage can be ordered with up to ten receiver modules at any available frequency or any combination of L-Band tranmitters or receivers.

Für weitere Informationen - fragen Sie uns an!

Multiple Receiver Card Cage

Description	Model Number	Frequency
Card Cage	OCC-1	-
Power Supply	PS-OCC-1	-
L-Band Receiver	OCCR-103000-1	10–3000 MHz
L-Band Transmitter	OCCT-103000-1	10–3000 MHz
C-Band Receiver	OCCR-3442-1	3.4–4.2 GHz
Broadband Receiver	OCCR-95012750-1	0.95–12.75 GHz

One Third Rack Unit
Fiber Optic Transmitter and Receiver

Fiber Optic Link Models

Model Number	Frequency
OL-103000-1	10–3000 MHz
OL-3442-1	3.4–4.2 GHz
OL-95012750-1	0.95–12.75 GHz

Fiber Optic Transmitter Models

Model Number	Frequency
ORT-103000-1	10–3000 MHz
ORT-3442-1	3.4–4.2 GHz
ORT-95012750-1	0.95–12.75 GHz

Fiber Optic Receiver Models

Model Number	Frequency
ORM-103000-1	10–3000 MHz
ORM-3442-1	3.4–4.2 GHz

MITEQ

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FPA

"Lossless" Broadband Signal Transfer

A specs example

(from RFPA, 19" plug-in)

The link gain budget

Equates to 45dB dynamic range in 1Ghz Bandwidth

FC/APC is recommended standard !

Specifications

Characteristics	Data	Units
Frequency range	25 KHz - 1000 MHz	MHz
Wavelength Typ. Min	1360 1310 1290	nm
Optical output power	2 < Po < 4	mW
link gain (for 0 dBo)	+/- 2	dB
Flatness	+/- 2,5	dB
Input power for rated output power	0	dBm
Max. RF input power	20	dBm
In impedance nom.	50 ***	Ohms
Input VSWR	1,5 : 1	
Relative intensity noise	-135	dB/Hz
Intercept point 3 rd Order typ.(link)	30	dBm
Alarm (over current)	dry loop	
Optical connectors	FC/APC *	
Fiber loss	0,4	dB/km
optical connectors loss	0,5	dB/paire
Typical RF link NF	40 **	dB
RF connectors	SMA female	
Storage temperature range	-40 °C … + 85	° C
Operating temperature Range	-20 °C … + 60	° C
Power Supply	12 V DC +/- 5 %	
size (W x L x H)	7 F x 175 mm x 3 U	mm

All data at room temperature + 22 °C, into 50 Ohms, subject to change without notice

A second example (from ppm, 4 GHz wideband devices)

RF Performance Characteristics

	Rack Module Wideband Link	OEM Module Wideband Link
Frequency Range	2 kHz – 4.2 GHz	2 kHz – 4.2 GHz
Link Gain (nominal)	0 dB [a b]	0 dB [a b]
Flatness (max) [a]	±1 dB (10MHz – 3GHz), ±1.5 dB (3 - 4.2GHz), +2.5/-1.5 dB (2kHz - 10MHz)	±1 dB (10MHz - 3GHz), ±1.5 dB (3 - 4.2GHz), +2.5/-1.5 dB (2kHz - 10MHz)
Gain Stability (max)	±3 dB over operating temperature range	±3 dB over operating temperature range
VSWR (50 Ohm)	<2 : 1 [t]	<2 : 1 [t]
CNR	>107 dB [a c d t]	>107 dB [a c d t]
Noise Figure	23 dB [a c t]	23 dB [a c t]
Input P1dB	+3 dBm [c t]	+3 dBm [c t]
Maximum Input Power (without damage)	+15 dBm	+15 dBm
Output IP3	+13 dBm [b c t]	+13 dBm [b c t]
Input IP3	+13 dBm [c t]	+13 dBm [c t]
SFDR	109 dB Hz 2/3 [b t]	109 dB Hz 2/3 [b t]
External LNA Voltage	Option for the module to come with +5V or +12V feed from RF input of Tx	External LNA feed can be supplied into pin on Tx module which is directed out of centre pin on RF input connector
[a] nominal input power (-10 dBm) [b] 0 dB optical loss [c] @ 1.2GHz [d] 2.4kHz bandwidth [t] typical		

Confused after all this Specs and Electronics Gaga?

Now:
An Attempt for a „Step-Receipe"

Optical RF Links – *ORFL Step-Receipe Version 1.0*

1: Link Bandwidth – Use preamp frequency response or calculate:
$F_{min} \sim 1 / (10^{*}\ \text{pulsewidth})$, $F_{max} = 0.35 / t_{rise}$

2: Output Peak Voltage – Take the peak voltage data from frontend output
0 dBm = 223mVrms or 320mVpeak
Do not use pp value data, you have single unidirectional pulses!

3: Dynamic Range – Your minimal signal from frontend must be above link noise floor output

4: Check Discriminator Input Voltage – The backend acquisition system may need additional amplification after the optical link receiver!

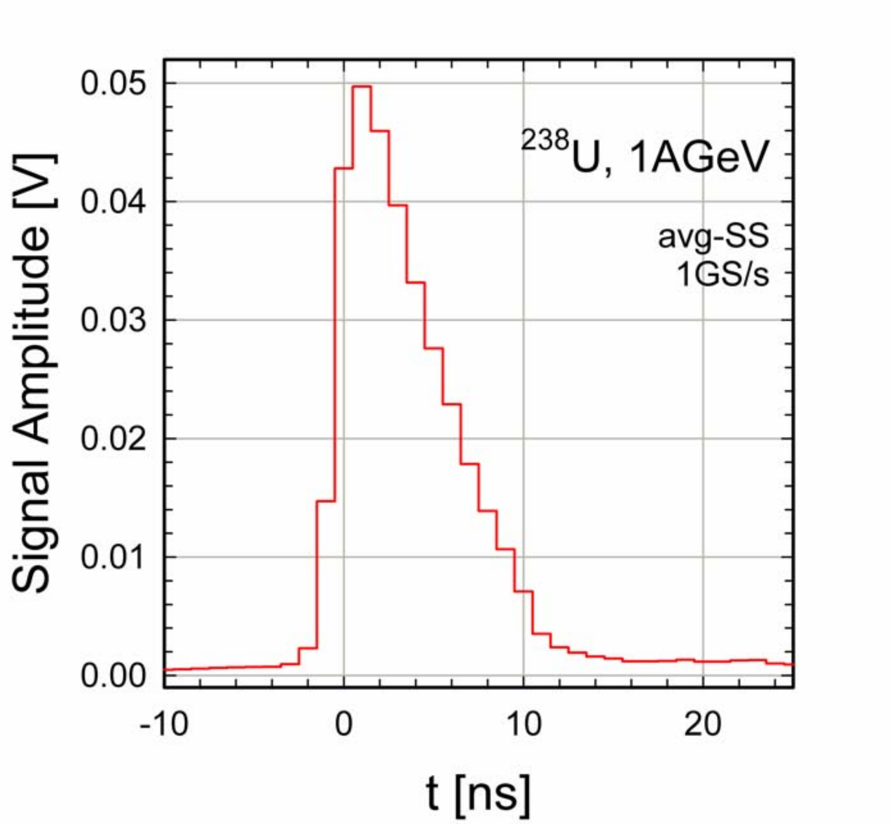
5: Optical Connectors – Use FC/APC unless other specs must be met

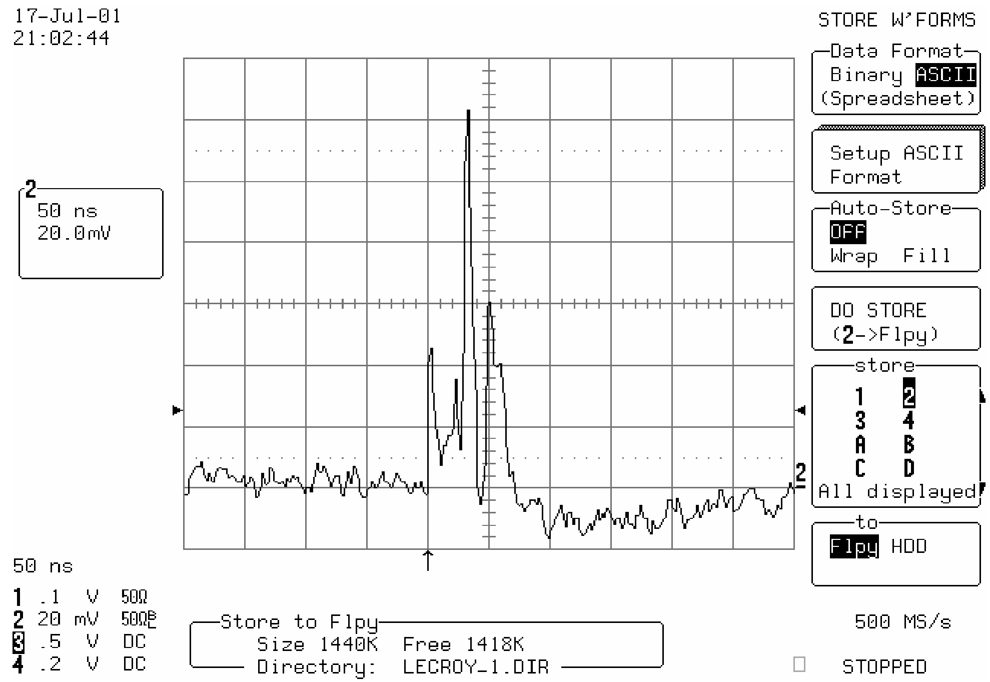
6: Contact appropriate Vendor

7: Check Costs – Parallel links and fibers or multiplexing (C/DWDM)

An Example

Beamloss data acquired with diamond detectors using rf optical links





Fast 2GeV/u Ni beamloss
detected from SIS 18

Conclusion and Outlook

- Use of broadband optical rf-links (ORFL) and single mode fibers for detector signal transfer makes separation of the frontends possible
- Kilometer-long path runs are easily achieved with „ORFL“
- ORFL components readily available from vendors
- Market competition provides second sources
- Headroom to use bandwidths beyond 10 GHz per channel
- Transfered signals carry correct timing information -> TOF
- Optical transfer system can be upgraded anytime
- CWDM and DWDM share the same receivers and single mode fibers, different muxers/demuxers/lasers needed
- *Start-up at* moderate costs for one or a few channels possible
- DWDM can be merged into CWDM systems
- Digital systems can be embedded in analog systems in C/D/WDM