Multi-band OFDM Transmission with Sub-band Optical Switching

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Context & Motivations

Context & Motivations

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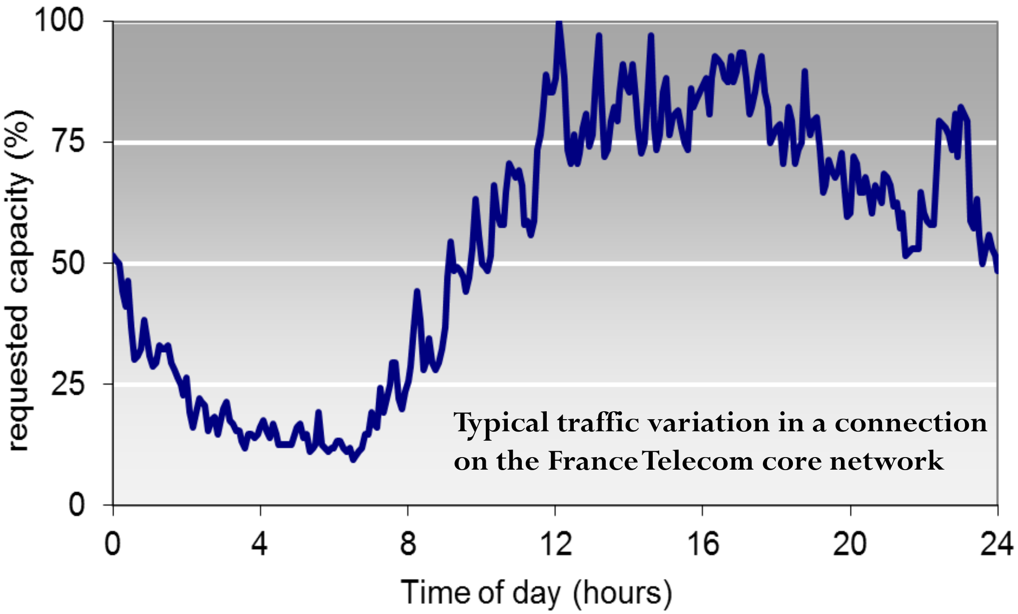
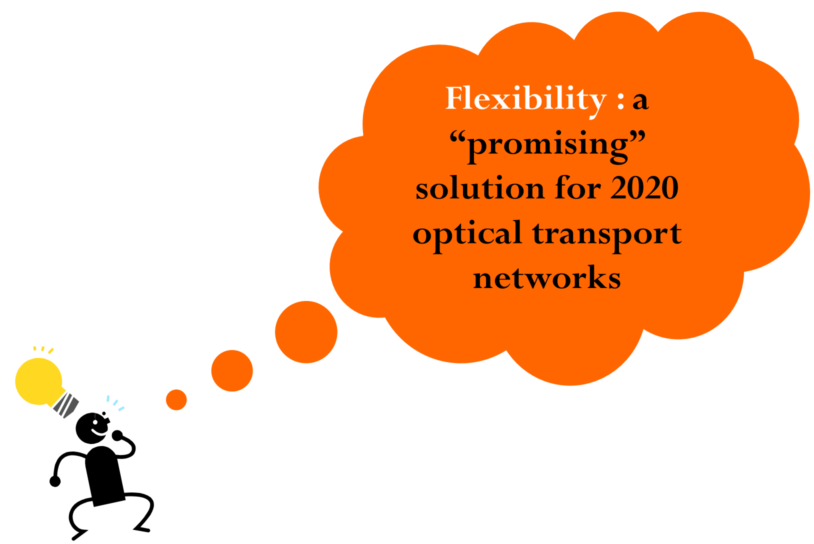
- In a non-flexible transport network, a large over-provisioning of network capacity is carried out to absorb the peaks of traffic.
- ~ 55% of the channel capacity is filled in average over the Orange transport network.
- Flexibility should maximize both the filling of fibre bandwidth and WDM channels.





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Context & Motivations

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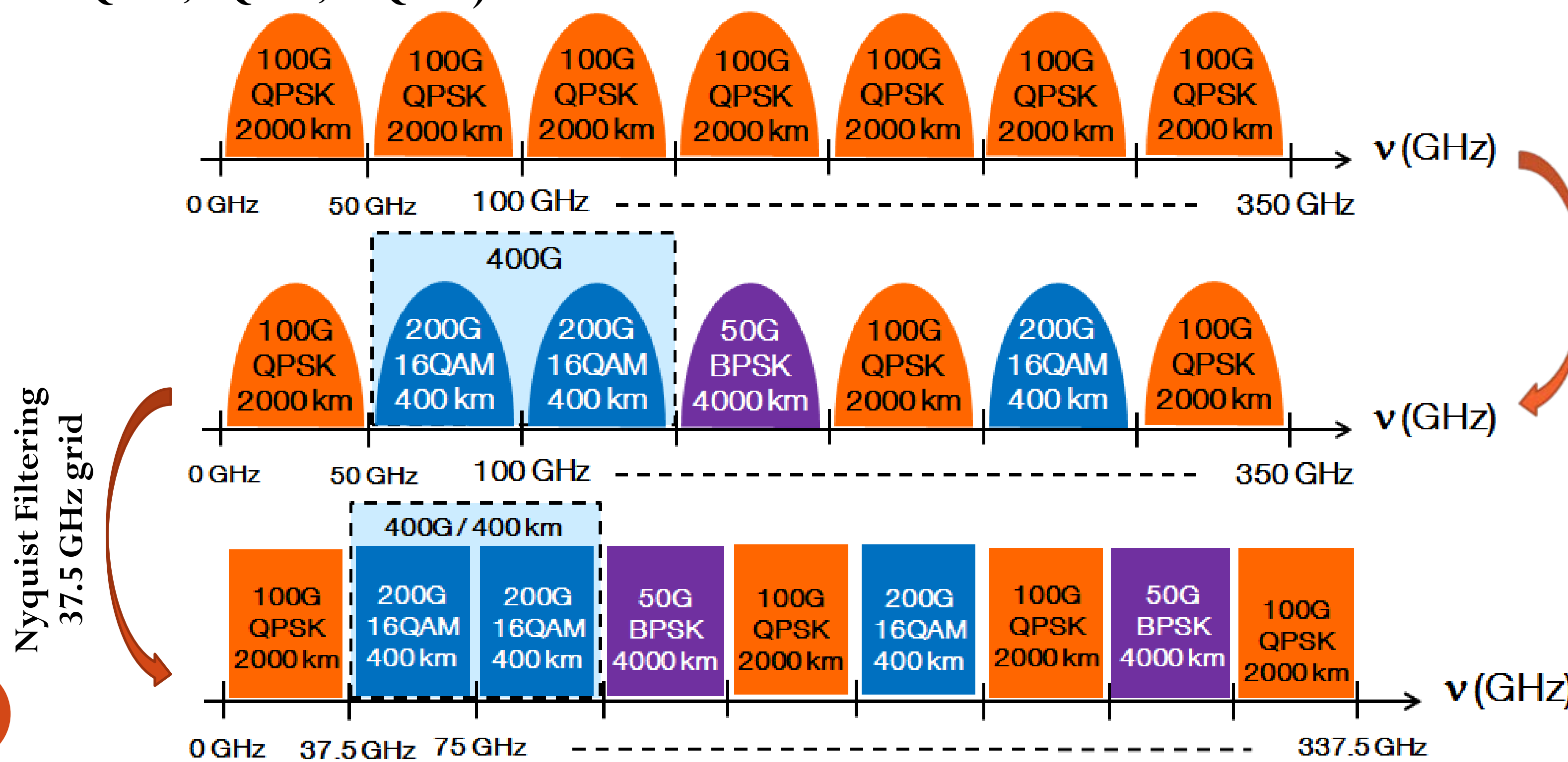
- Today, meshed optical transport networks based on ROADM are deployed.
- By the transparency provided, ROADM results in cost savings: the need for OEO regeneration is strongly reduced and the channel provisioning is remotely controlled.
- A first step towards flexibility is provided by both:
  - flex-grid ROADM compliant with the ITU-T G.694.1 standard.
  - up-coming flex-rate WDM interfaces able to generate over the 50 GHz or 37.5 GHz grid various data-rates (50G, 100G, 150G, 200G, 300G, 400G) with various modulation formats (BPSK, QPSK, 8QAM, 16QAM).



Context & Motivations

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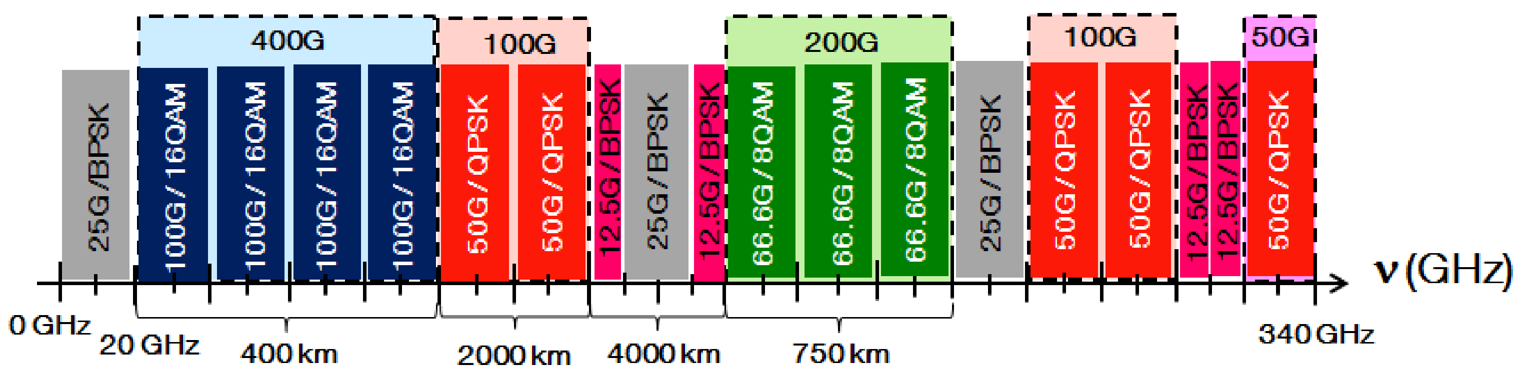
- In the 100GFLEX project, a more disruptive approach is privileged based on the use of Multi-Band OFDM (MB-OFDM) format and sub-band optical switching.
- In order to fill optimally the fibre bandwidth / WDM channel and to trade-off the capacity transported, the spectral occupancy and the transmission reach, a multi-band transmission technique with the following elastic features has to exist:
  - each sub-band can carry a specific data-rate.
  - each sub-band can adapt it spectral occupancy to the data-rate transported.
  - each sub-band can adjust its modulation format to the transmission reach targeted.
- In order to have a network able to adapt its resources according to the connectivity demands in an automated fashion, a Flexible Optical Add/Drop Multiplexer (FOADM) has to be built to manage, route, aggregate and split the previously defined sub-bands.



100GFLEX project

100GFLEX project

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- The general context of the 100GFLEX project is the continuous increase of data-rate transported by the optical transport networks with two main constraints:
  - the 25% IP traffic growth per year results in a high increase of the size of the WDM pipes from 10G to 100G and soon 400G.
  - offering enough flexibility for efficient traffic aggregation and connection filling involves to handle the traffic with a fine data-rate granularity.
- Main objectives of the 100GFLEX project were thus to propose:
  - an elastic transmission technique able to adapt its capacity, spectral occupancy and transmission reach to the constraints of a modern and ultra-high data-rate optical transport network.
  - a Flexible Optical Add/Drop Multiplexer (FOADM) able to handle the previously introduced transmission techniques.
- The French National collaborative 100GFLEX project has been launched in 2010 for three years (funded by DGCIS) with the following consortium covering a wide range of players in the optical networking domain:
  - 1 operator: Orange.
  - 3 equipment suppliers (components, sub-systems & systems): Ekinops, Yenista Optics, Mitsubishi-Electric.
  - 2 academic research centers: Institut Mines-Telecom (Telecom-ParisTech, Telecom Bretagne), ENSSAT-IRISA/Rennes University.

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Optical Filters for the Flexible Optical Add/Drop Multiplexer

Technology overview

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- Free-space optics technology.
- Combination of bulk-based diffraction gratings (for wavelength separation) and monochromator (for OFDM sub-band selection).
- Technology suitable for both Pass-Band and Stop-Band/Notch optical filters.
- Technology able to provide both tunability in wavelength and bandwidth.
- Flat-top profile and very steep edges:
  - roll-off > 800 dB/nm between the 3-dB and 40-dB bandwidths for a FWHM= 60 pm.
- Minimum bandwidth:
  - 32 pm (4 GHz) for the Pass-Band filter.
  - 65 pm (8 GHz) for the Stop-Band filter.
- High isolation: up to 60 dB.
- Insertion loss of the Pass-Band filter:
  - 5 dB typical for the common bandwidth tunings.
  - 10 dB typical @ FWHM=32 pm.
- Rejection of the Stop-Band filter:
  - 60 dB typical for the common bandwidth tunings.
  - > 30 dB for FWHM=65 pm.

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Pass-Band Optical Filter

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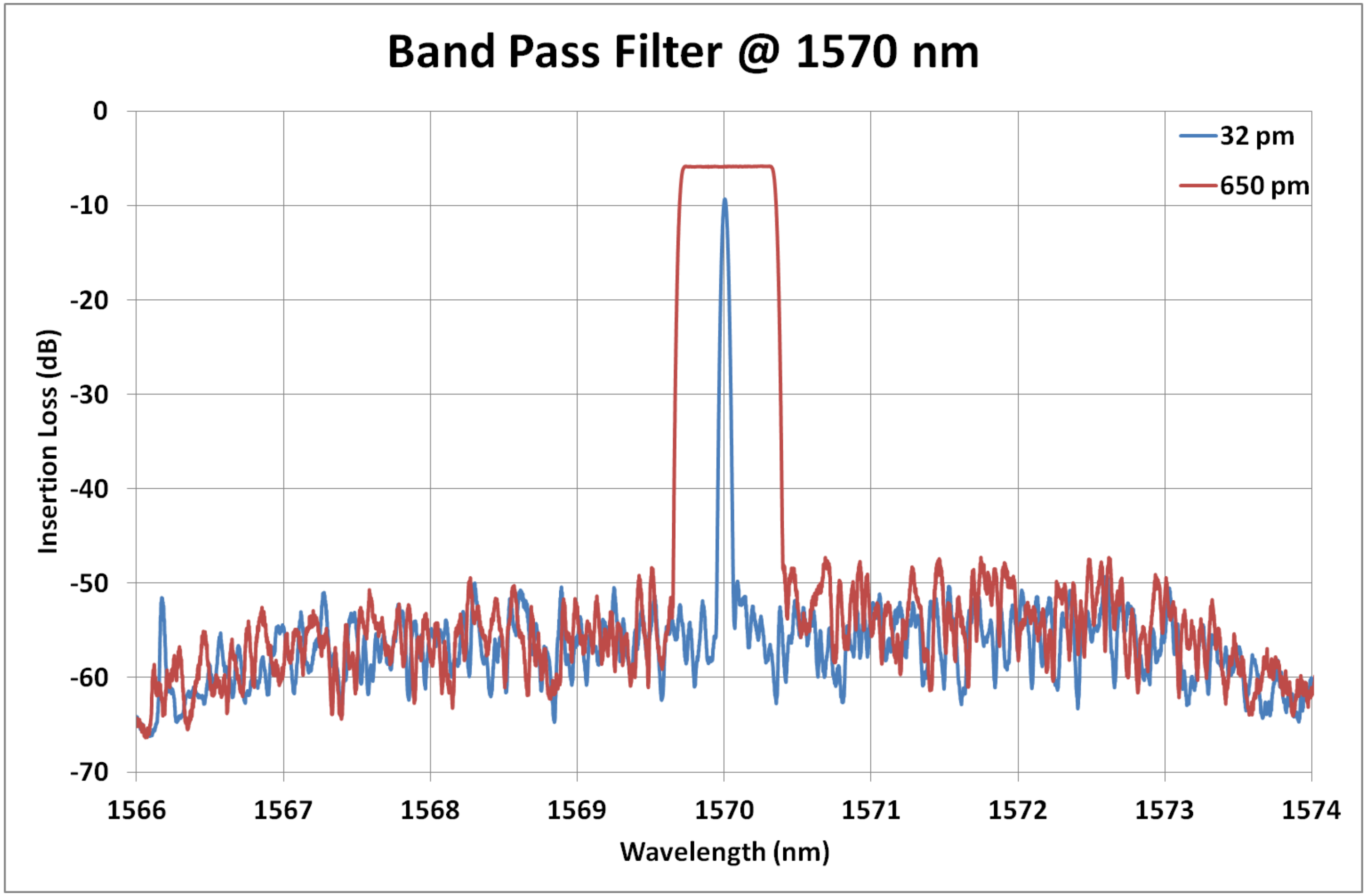

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Stop-Band/Notch Optical Filter

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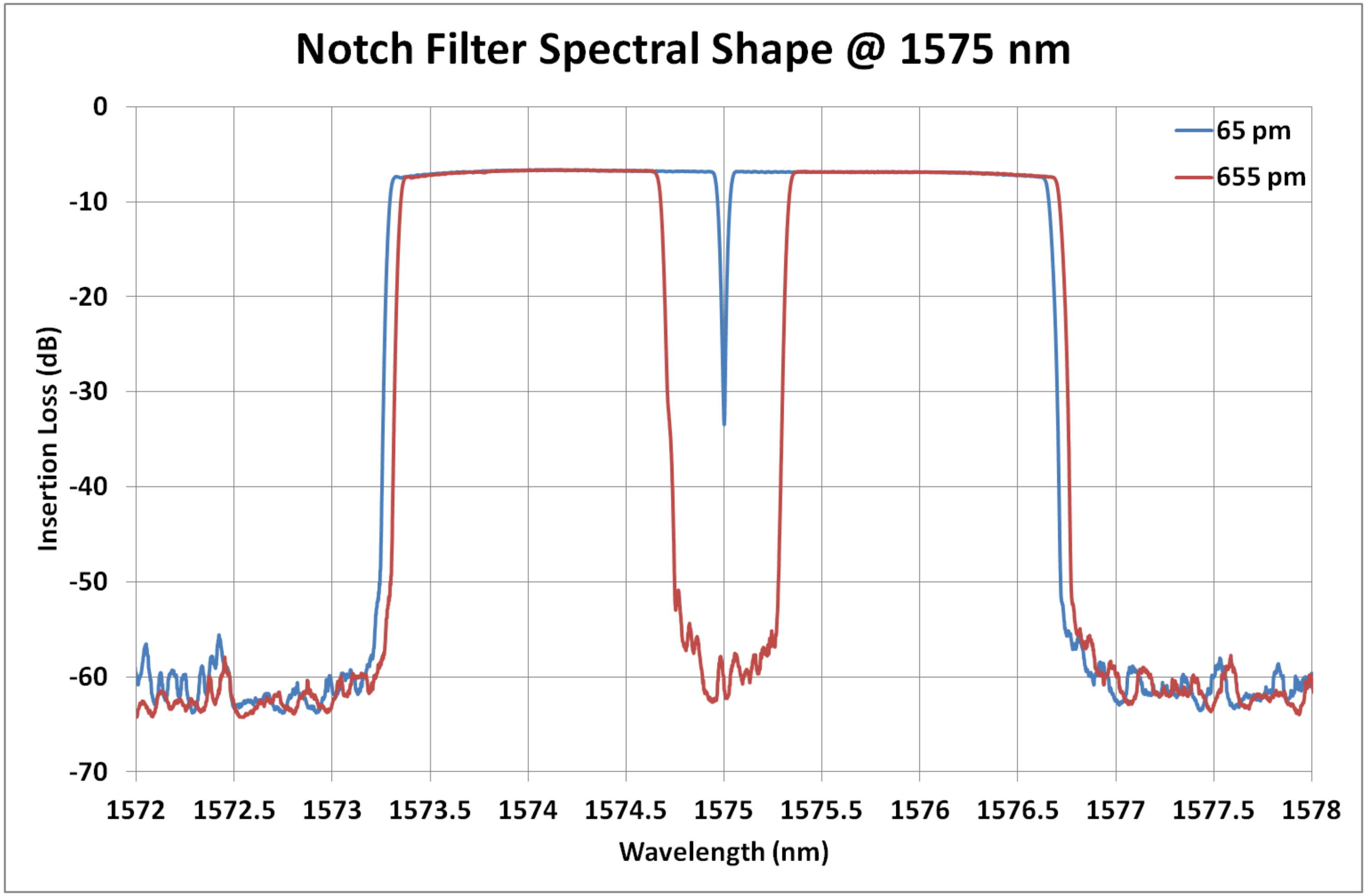

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Back-to-Back Experiments

Multi-band OFDM Transmission with Sub-Band Optical Switching

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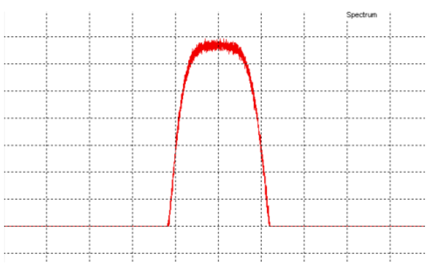
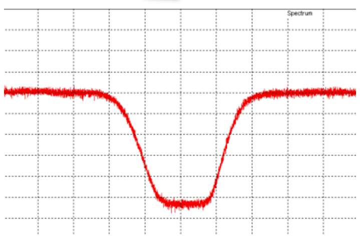
- **Objective:**
  - to demonstrate that optical add-drop of OFDM sub-bands as narrow as 8 GHz inside a 100 Gbps Dual-Polarization MB-OFDM signal constituted of four sub-bands spaced by 12 GHz is feasible in the middle of a 10x100-km DCF-free G.652 fibre line.
- **Equipments used:**
  - MB-OFDM transmitter & receiver
  - 10x100-km DCF-free G.652 fibre line
  - Pass-Band or "Drop" filter
  - Stop-Band or "Notch" filter





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OFDM transmitter & receiver set-up

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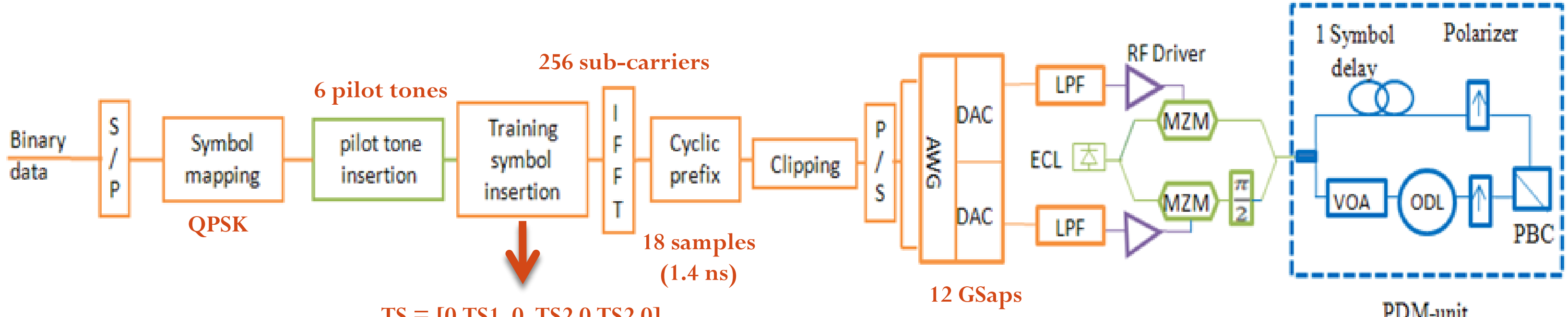
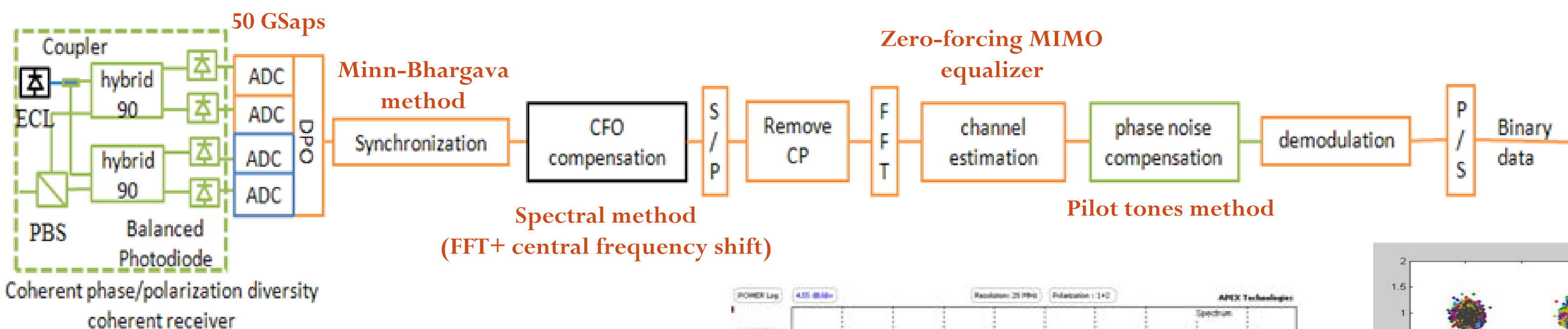
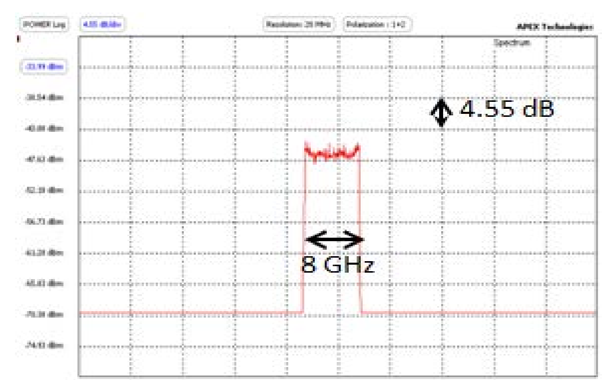
- Transmitter

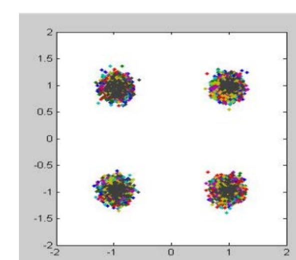


TS = [0 TS1 0 TS2 0 TS2 0]
TS1 = [+B +B +B -B]

- Receiver







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Multi-band OFDM transmitter

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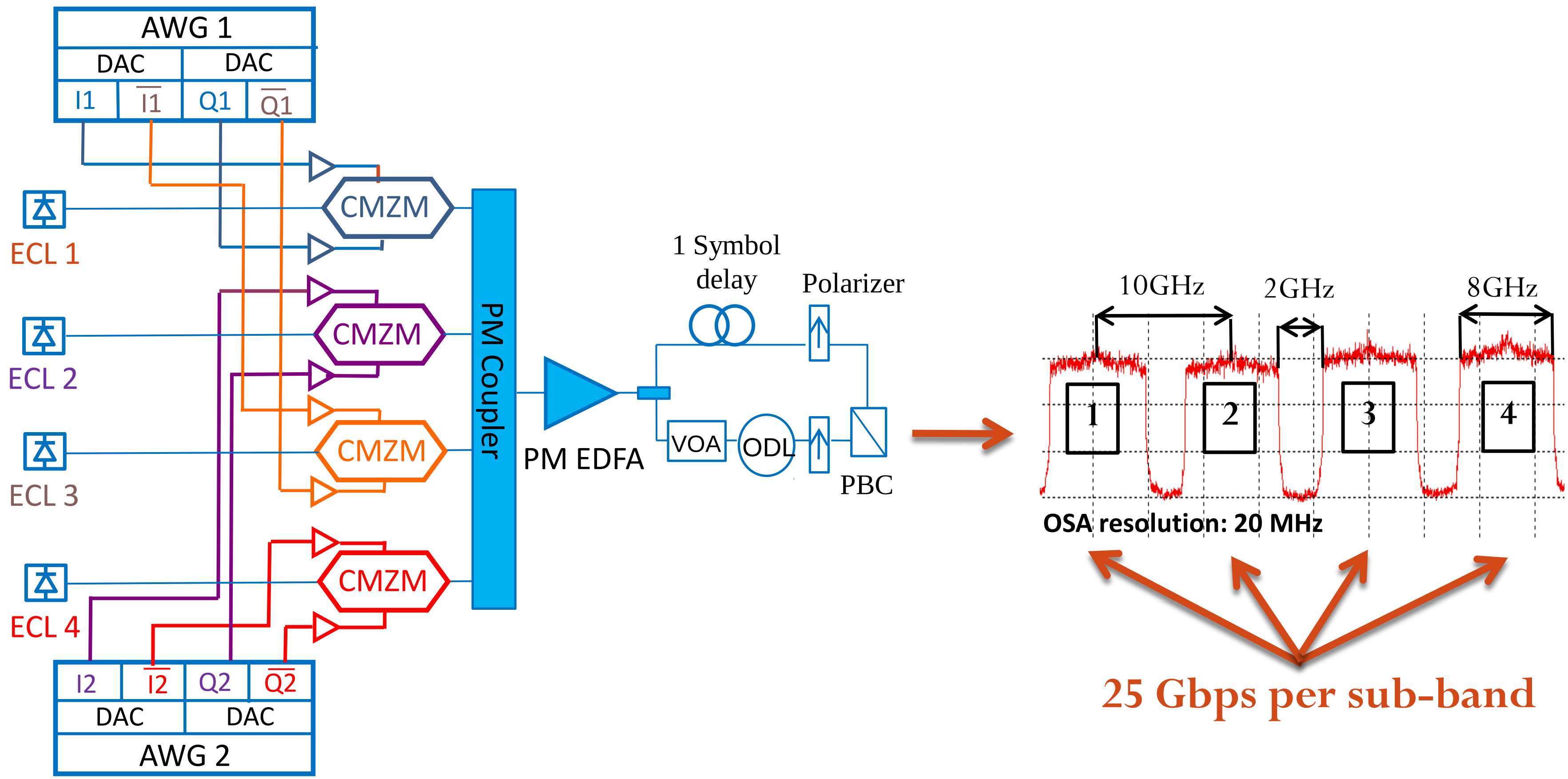
- Four dual-polarization OFDM sub-bands transmitter at 100 Gbps



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Principle of optical OFDM sub-band switching

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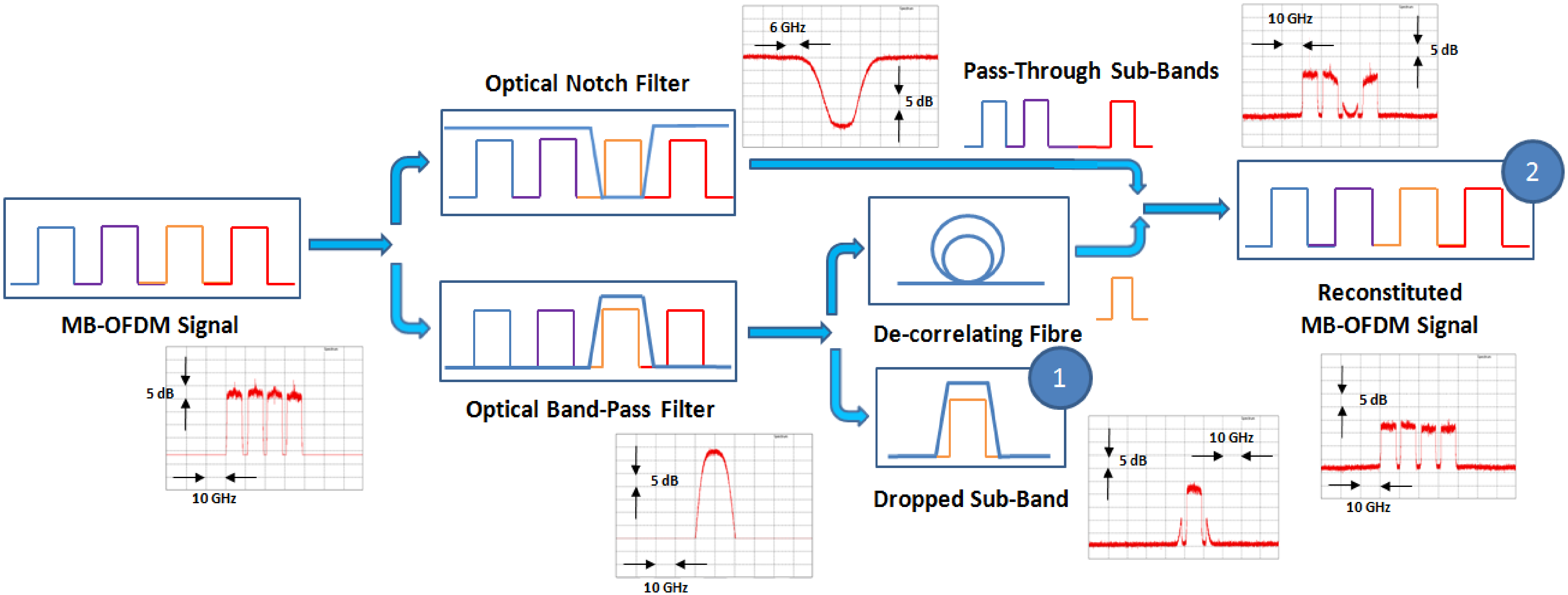
- Flexible Optical Add/Drop Multiplexer (FOADM) set-up



- 1: "Drop" function thanks to the Pass-Band optical filter.
- 2: "Stop & Add" function thanks to the Stop-Band optical filter.

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Experimental process for evaluation

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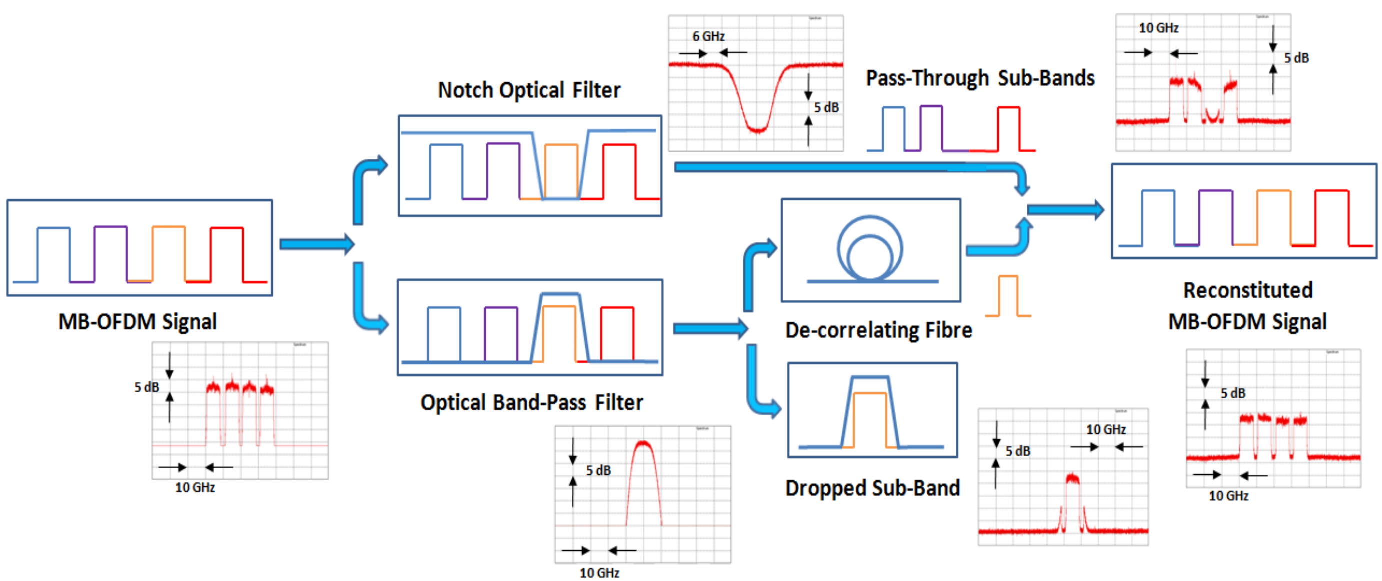
- Step 1: Implementation of the Pass-Band or "drop" optical filter.
- Step 2: Implementation of the Stop-Band or "notch" optical filter.
- Step 3: Performance evaluation in back-to-back:
  - *Measurement of BER vs. OSNR curves for the concerned sub-bands.*
- Step 4: Performance evaluation with the 10x100-km G.652 fibre-based transmission line:
  - *Measurement BER vs. OSNR curves for the concerned sub-bands.*



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Implementation of the Pass-band or “drop” optical filter

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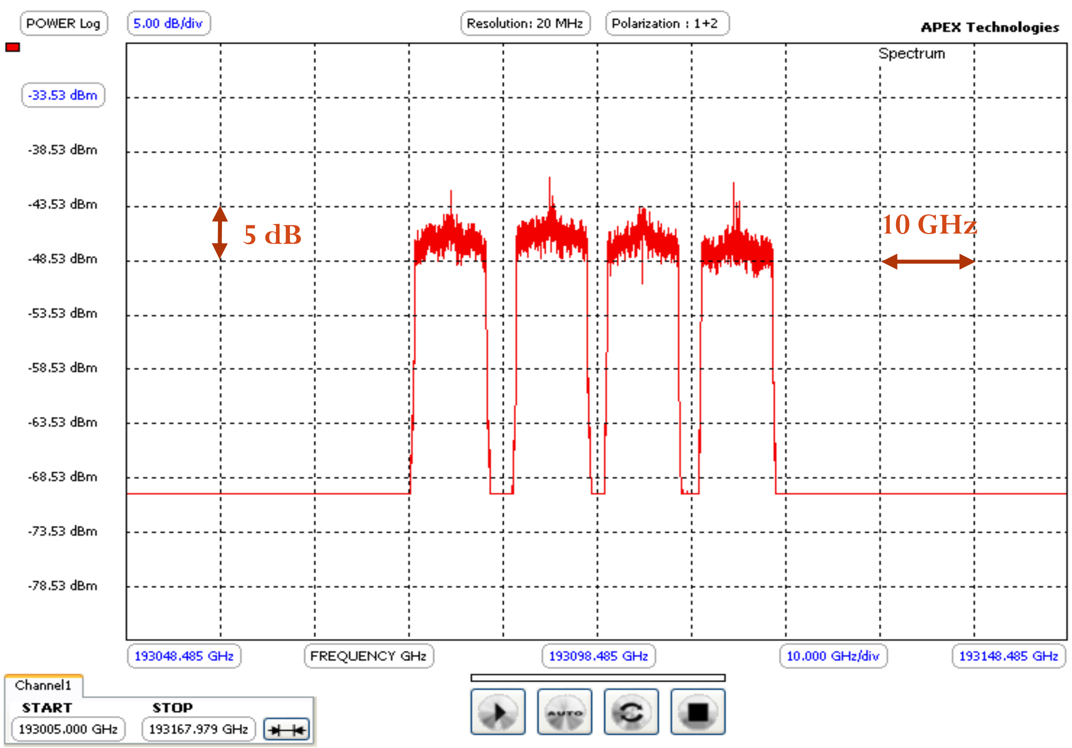
- Below, the spectrum of our 4 sub-bands MB-OFDM system measured with a high resolution(20 MHz) OSA (APEX Technologies)



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Implementation of the Pass-Band or “drop optical filter

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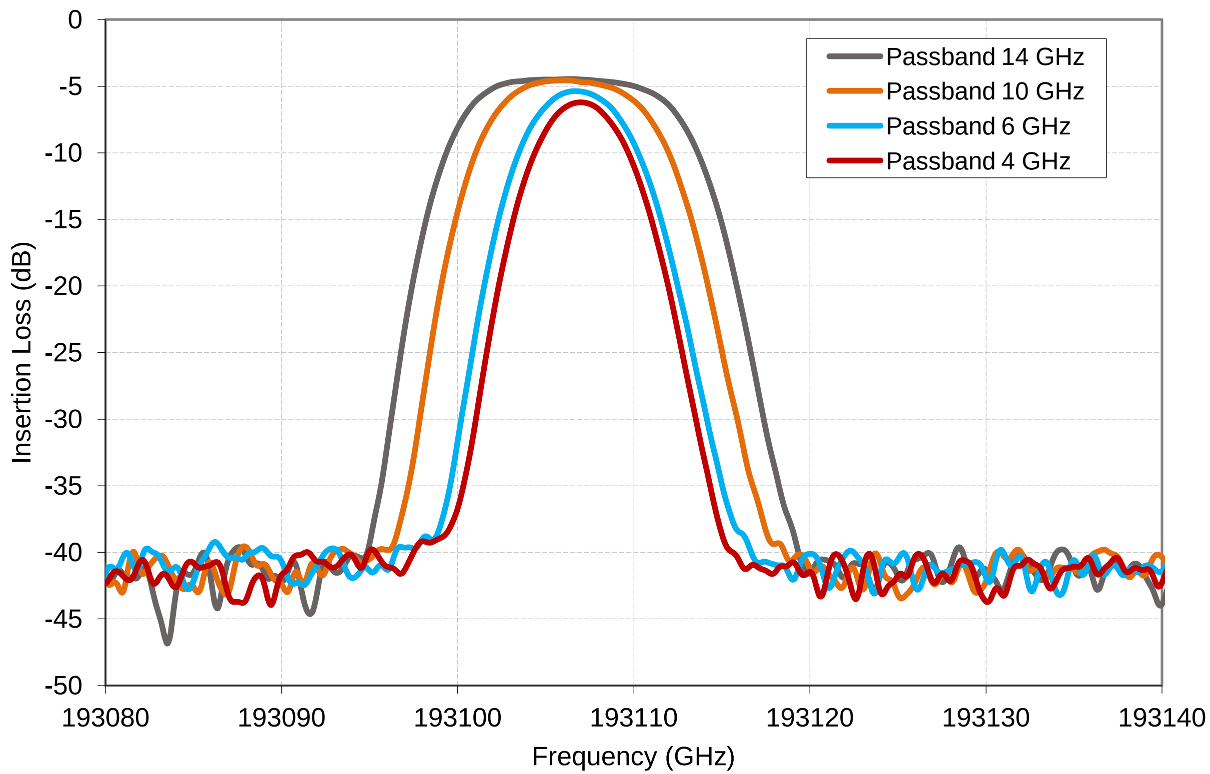
- Measurement of the transfer function of the Pass-Band or “drop” filter with various bandwidth tunings (LUNA Technologies OVA)



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Implementation of the Pass-band or “drop optical filter

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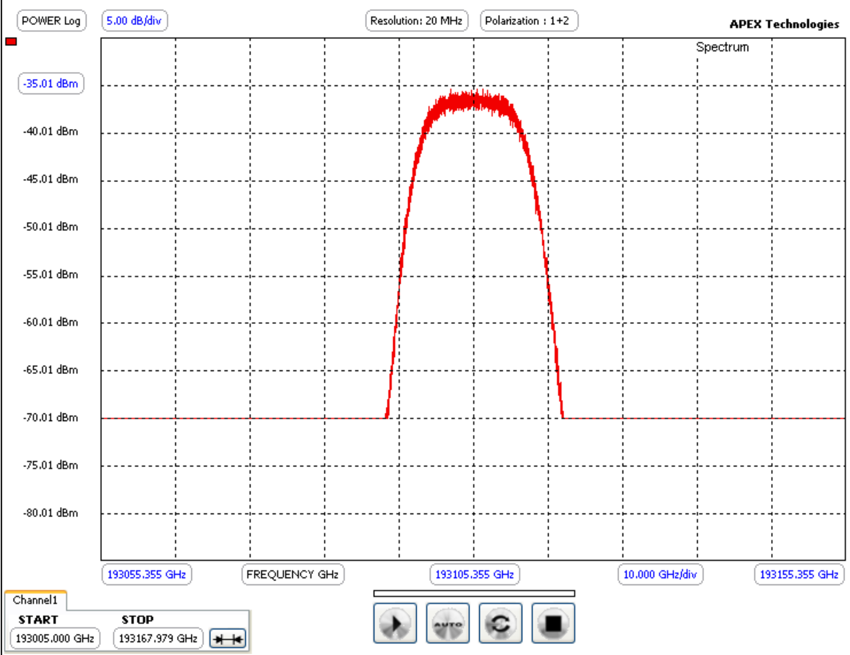
- 3-dB bandwidth ~ 14 GHz



“Drop” Transfer Function

Corresponding selected signal

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Implementation of the Pass-band or “drop optical filter

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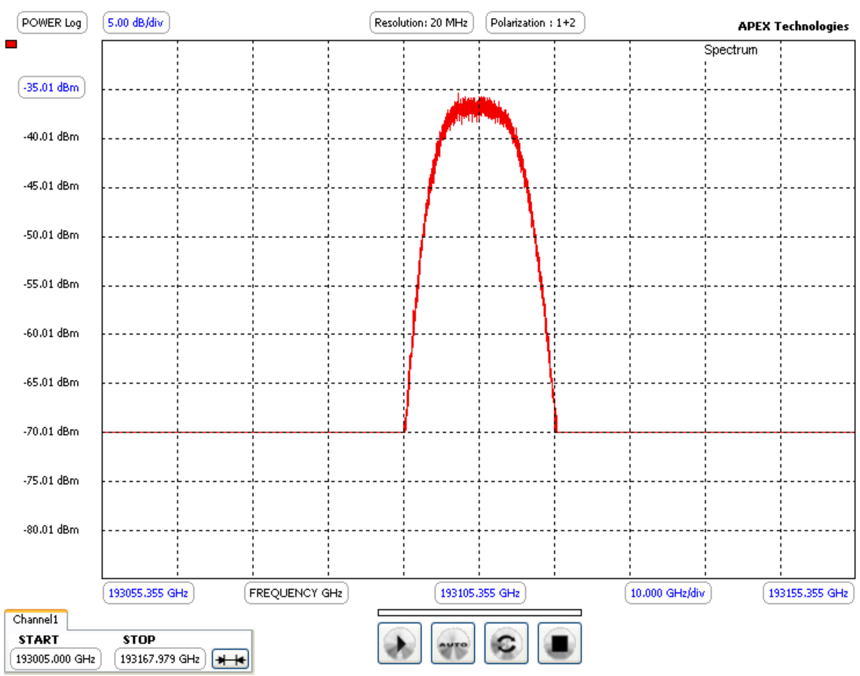
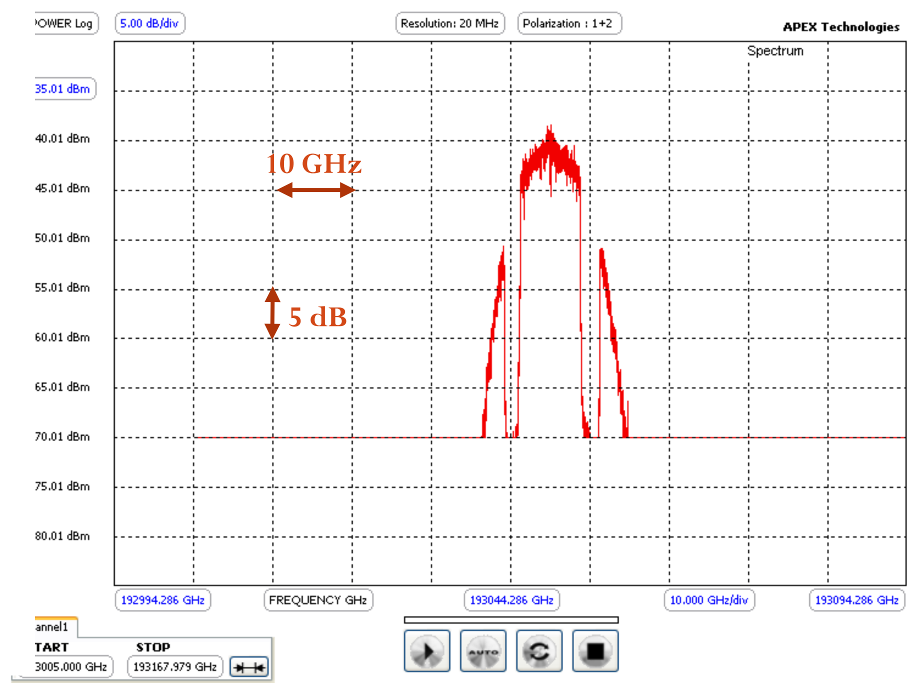
- 3-dB bandwidth ~ 10 GHz



“Drop” Transfer Function



Corresponding selected signal

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Implementation of the Pass-band or “drop optical filter

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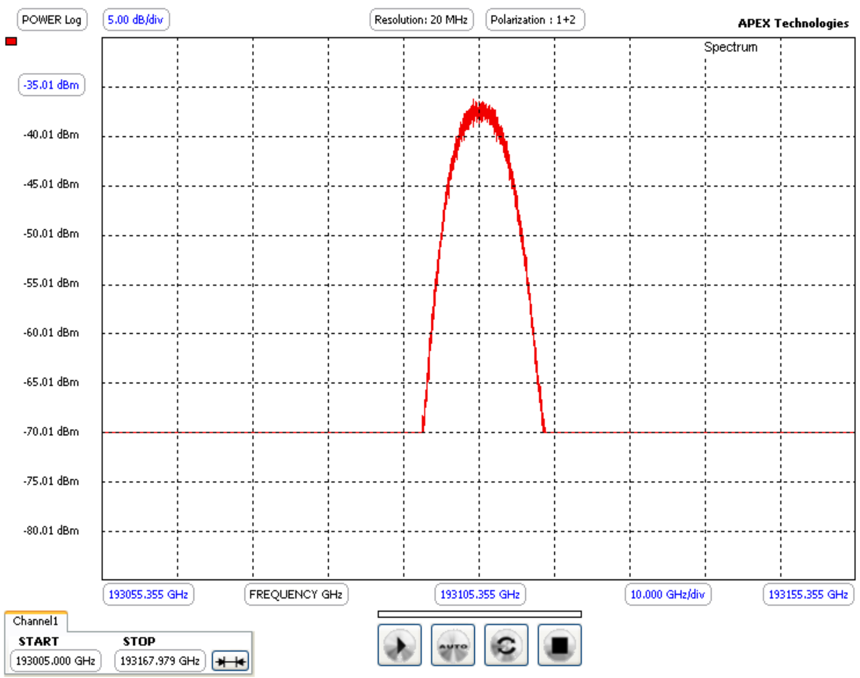
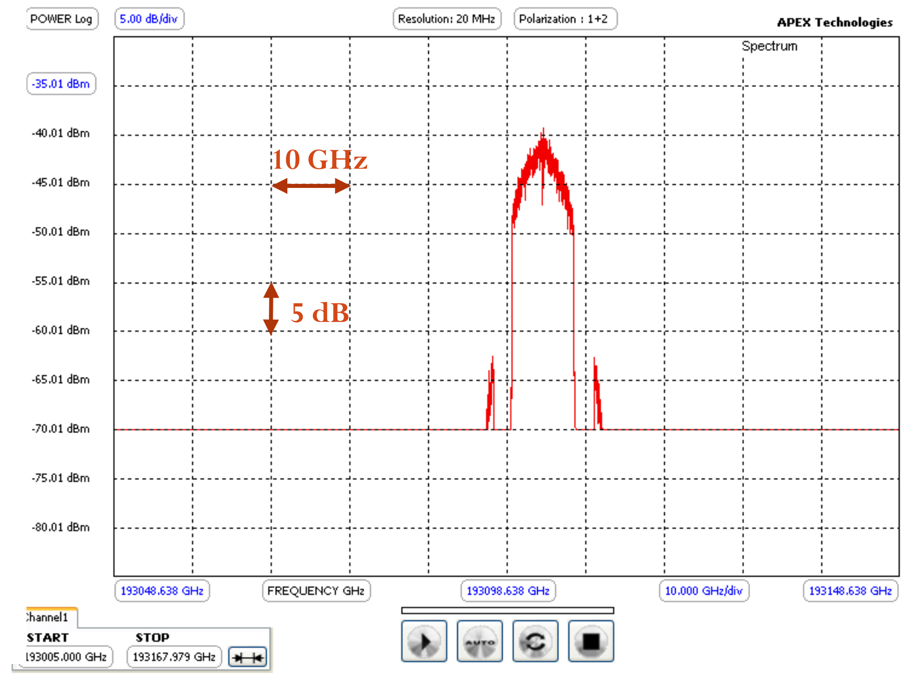
- 3-dB bandwidth ~ 6 GHz



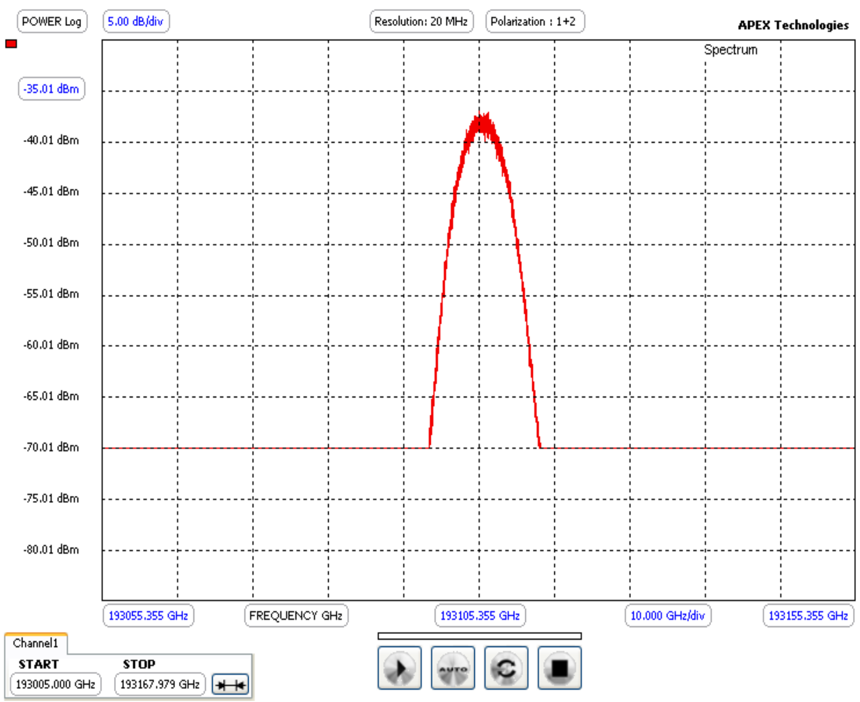
“Drop” Transfer Function



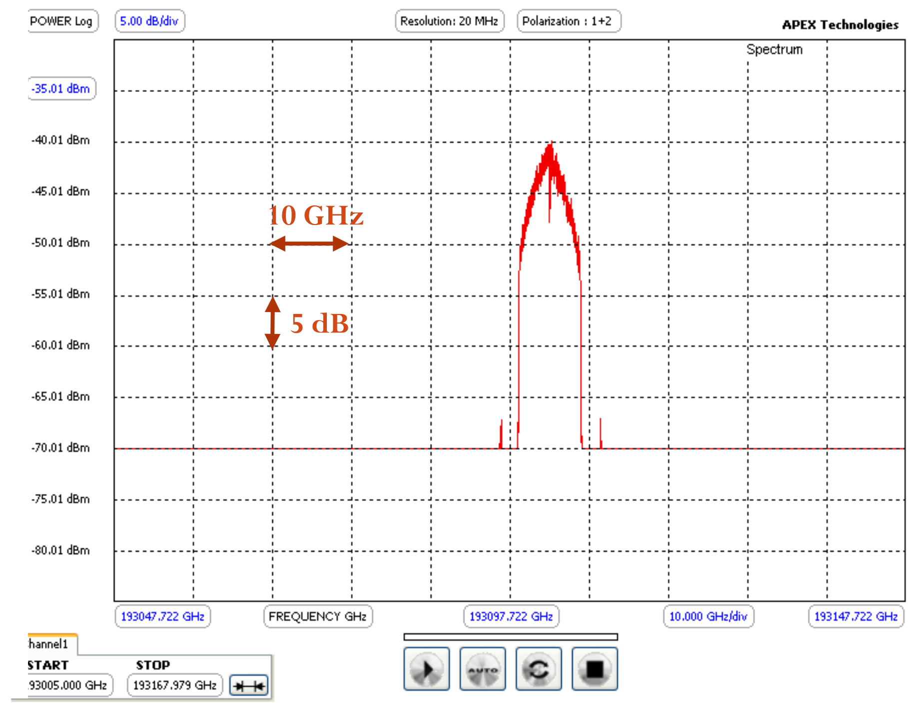
Corresponding selected signal

Implementation of the Pass-band or "drop optical filter

- 3-dB bandwidth ~ 4 GHz



"Drop" Transfer Function



Corresponding selected signal

Impact of the Pass-Band or "drop" optical filter

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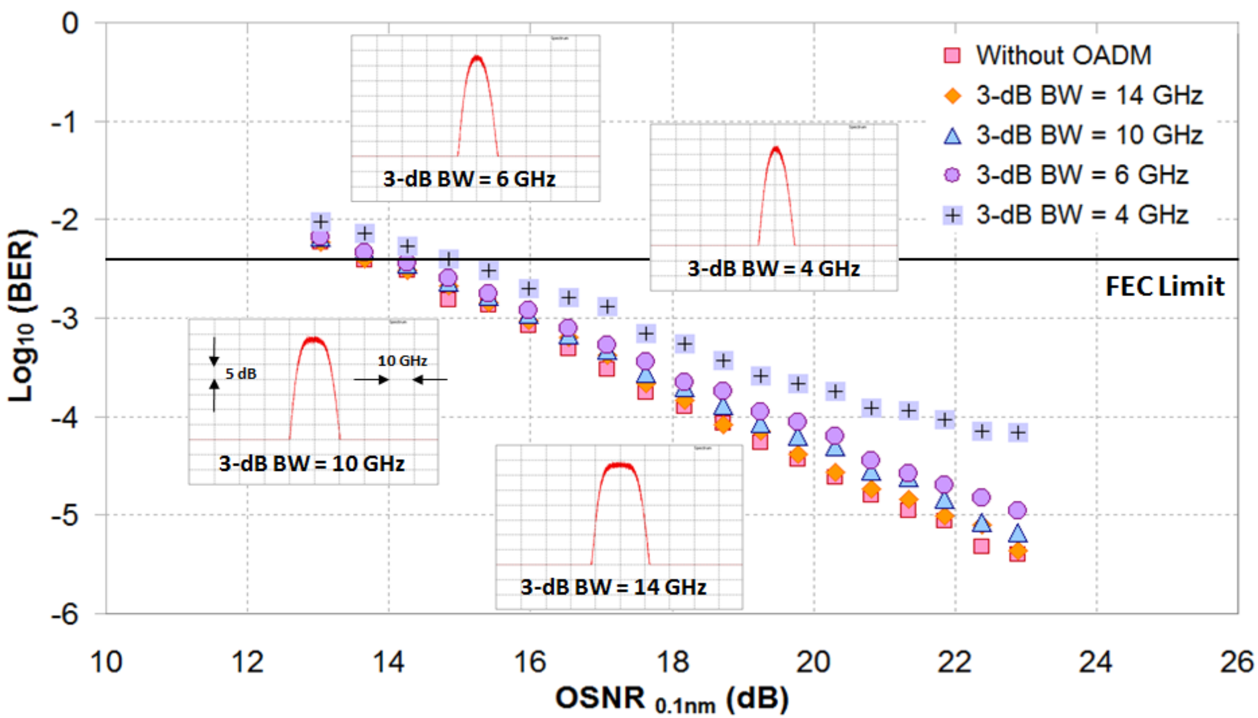
- BER vs. OSNR $_{0.1\ nm}$ curves for the various bandwidth tunings of the "drop" filter function



OSNR penalties are acceptable for 14 GHz, 10 GHz and 6 GHz bandwidths.

Implementation of the Stop-Band or “notch” optical filter

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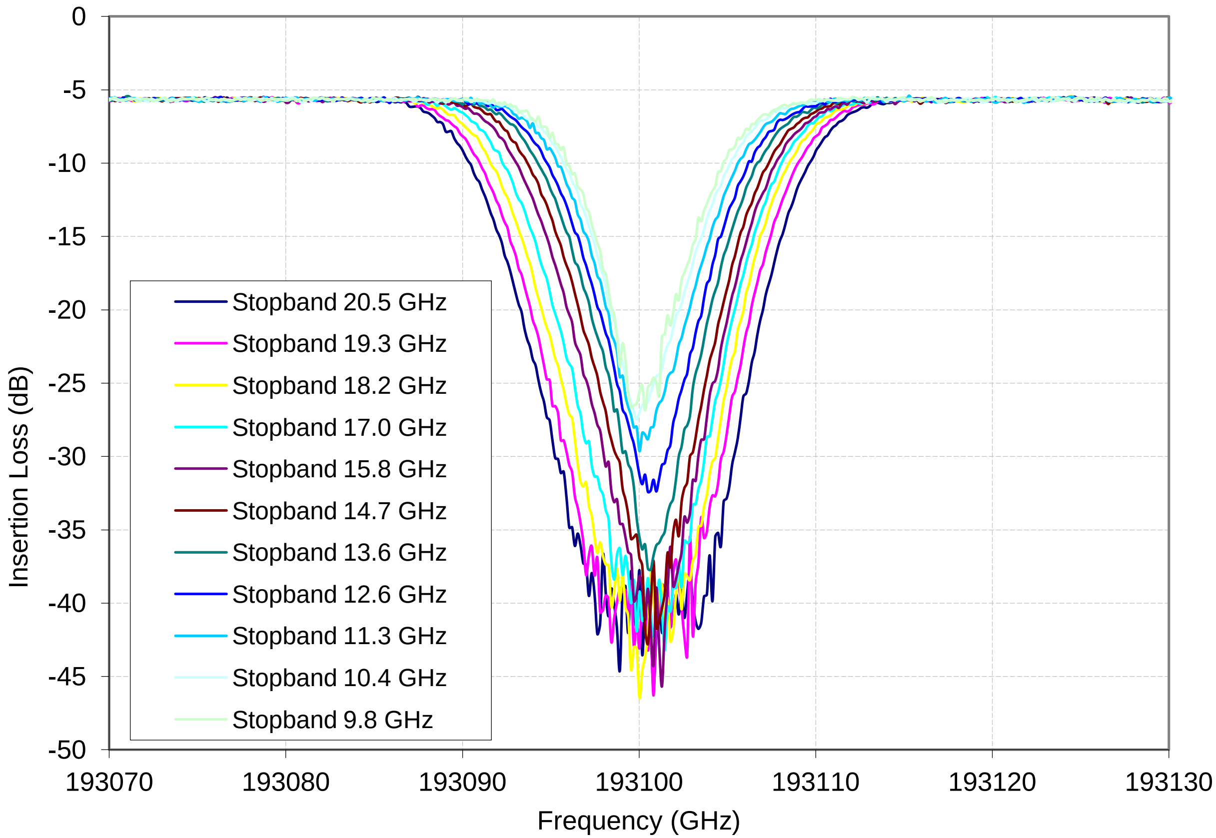
- Measurement of the transfer function of the Stop-Band or “notch” filter with various bandwidth tunings (LUNA Technologies OVA)



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Implementation of the Stop-band or “notch” optical filter

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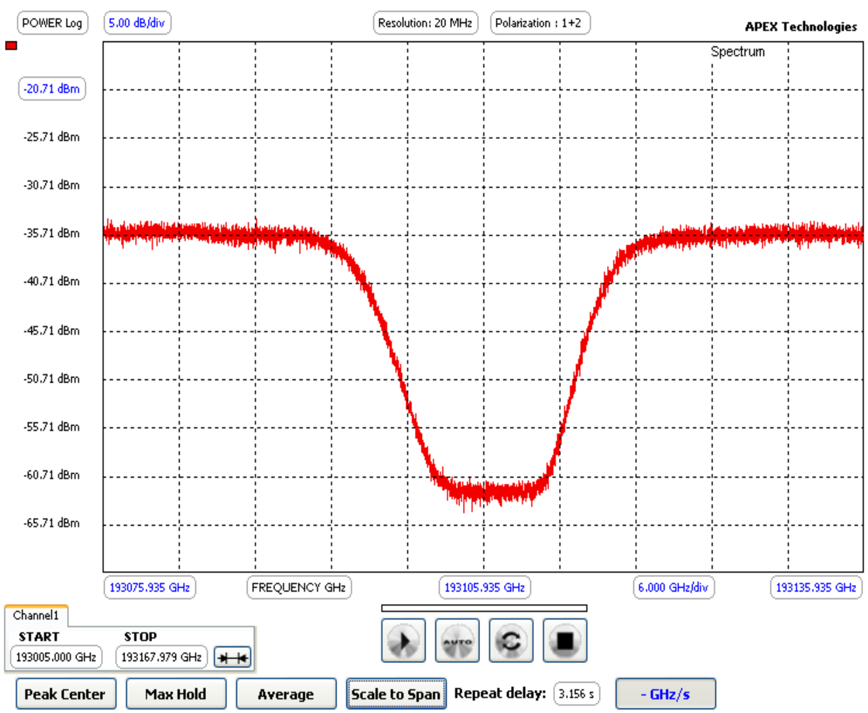
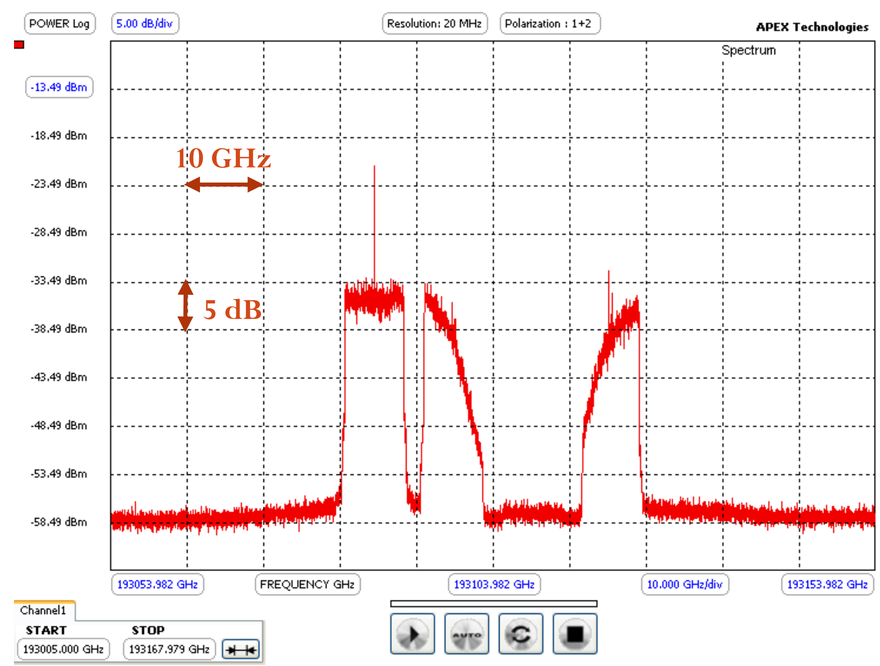
- 3-dB bandwidth ~ 20.5 GHz





<u>“Notch” Transfer Function</u>

<u>Corresponding selected signal</u>

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Implementation of the Stop-band or “notch” optical filter

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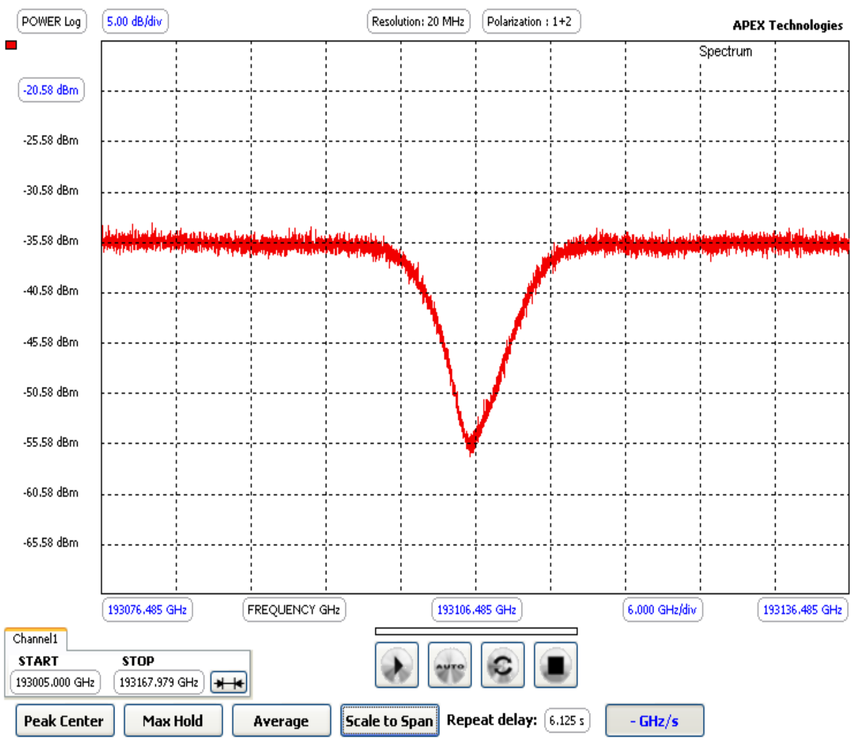
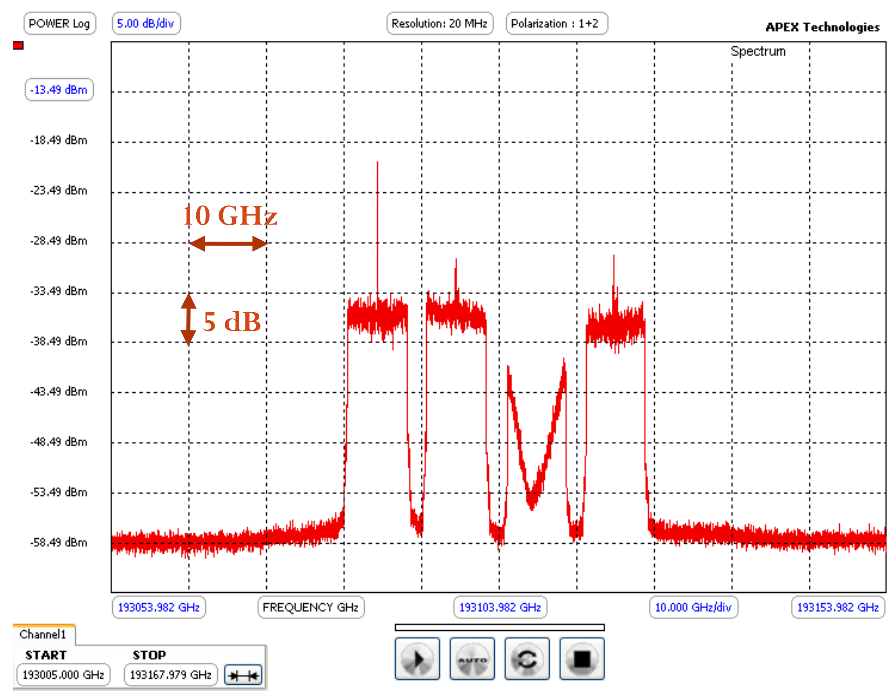
- 3-dB bandwidth ~ 9.8 GHz



“Notch” Transfer Function



Corresponding selected signal

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Impact of the Stop-Band or "notch" optical filter with a Guard-Band=2 GHz

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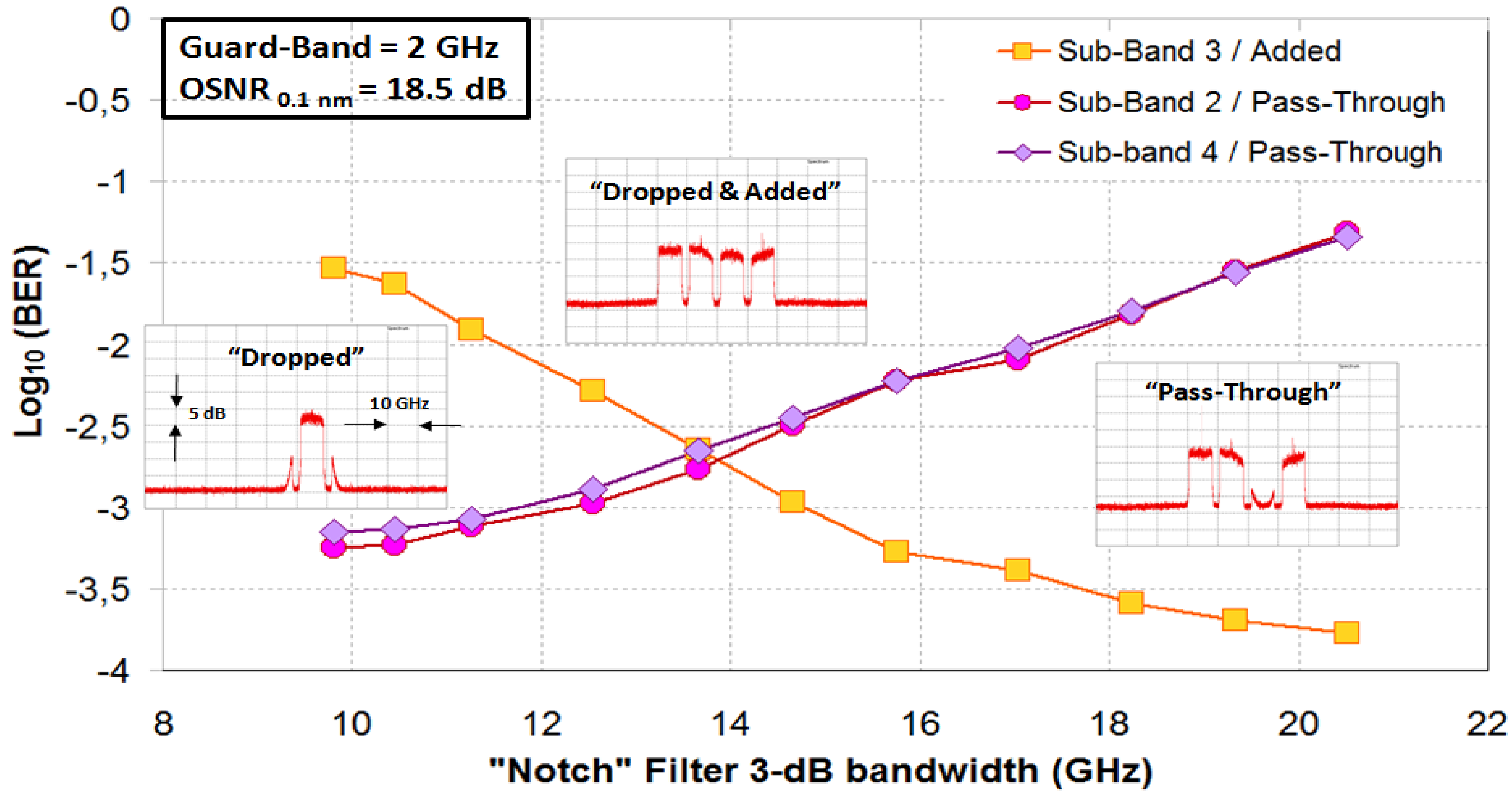

The optimum "notch" filter 3-dB bandwidth is ~14 GHz, while the BER of sub-bands 2, 3 & 4 is ~$3x10^{-3}$.

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Impact of the Stop-Band or "notch" optical filter with a Guard-Band=4 GHz

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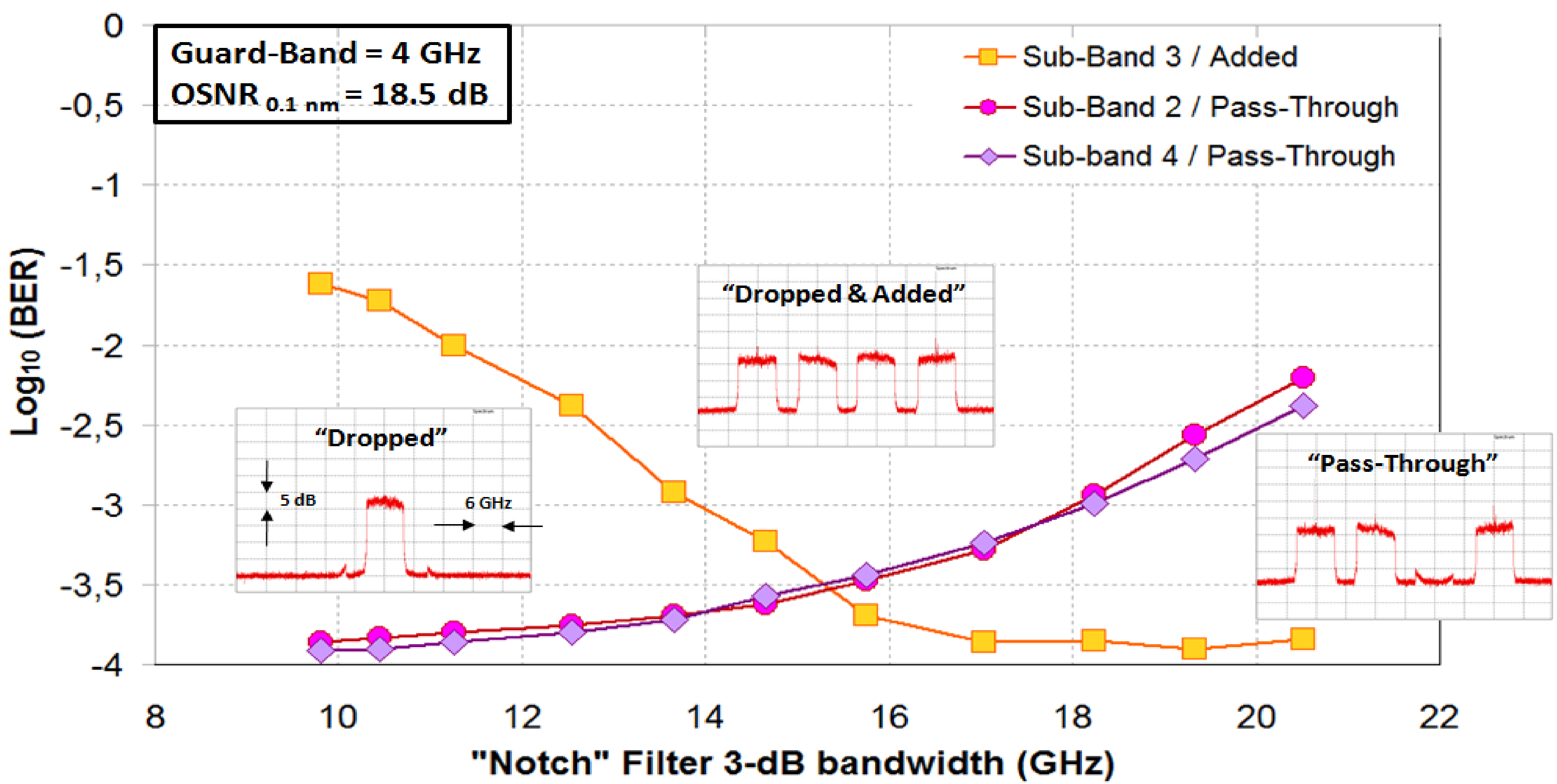

The optimum "notch" filter 3-dB bandwidth is ~15.7 GHz, while the BER of sub-bands 2, 3 & 4 is ~3x10^{-4} .

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BER vs. OSNR for the "add/drop" function with the optimum filter tunings

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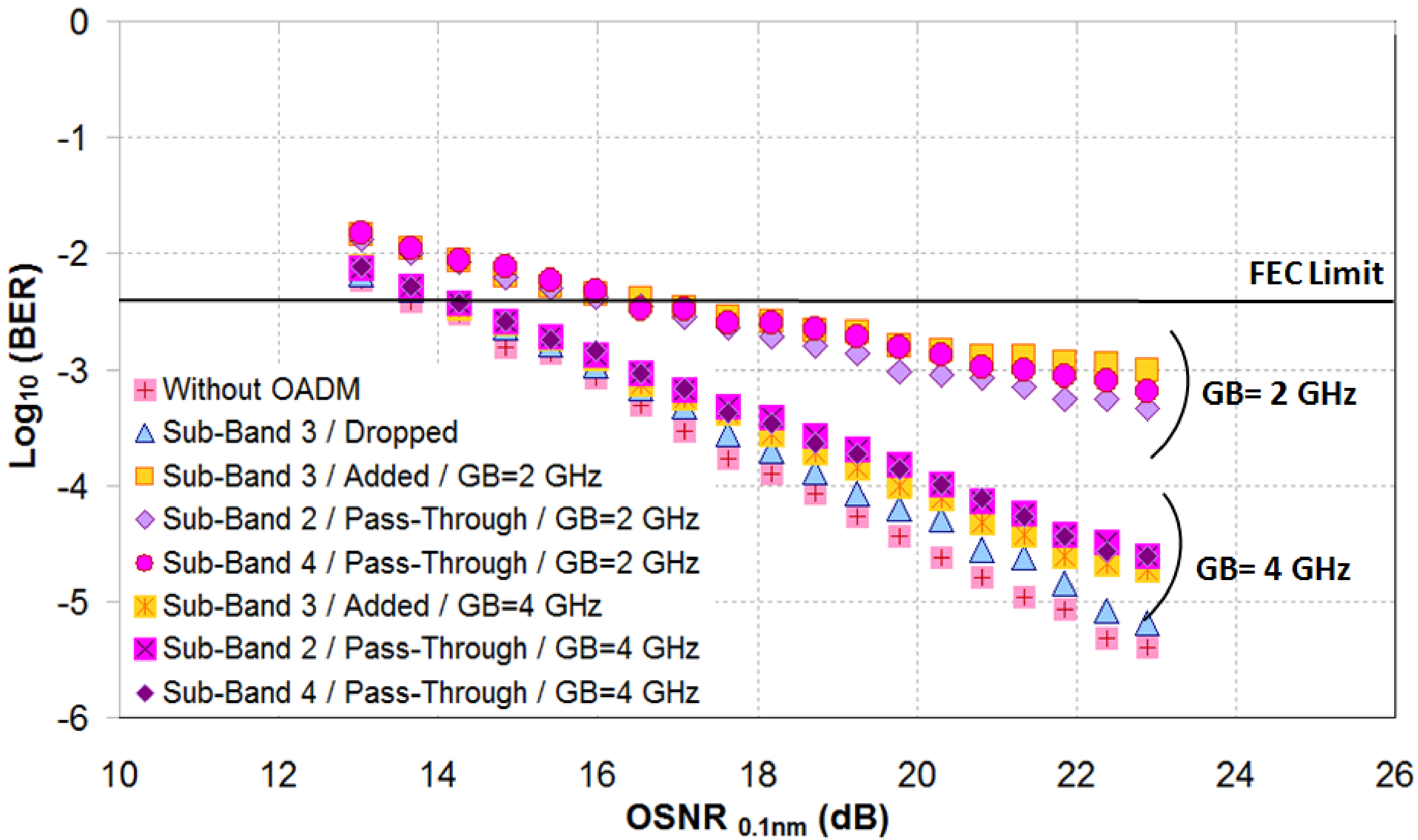
- 3-dB bandwidth of Pass-Band or "drop" optical filter: 10 GHz
- 3-dB bandwidth of Stop-Band or "notch" optical filter: 14 GHz (Guard-Band = 2 GHz)
- 3-dB bandwidth of Stop-Band or "notch" optical filter: 15.7 GHz (Guard-Band = 4 GHz)



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Transmission Experiments

Performance evaluation in 10x100-km DCF-free G.652 fibre line

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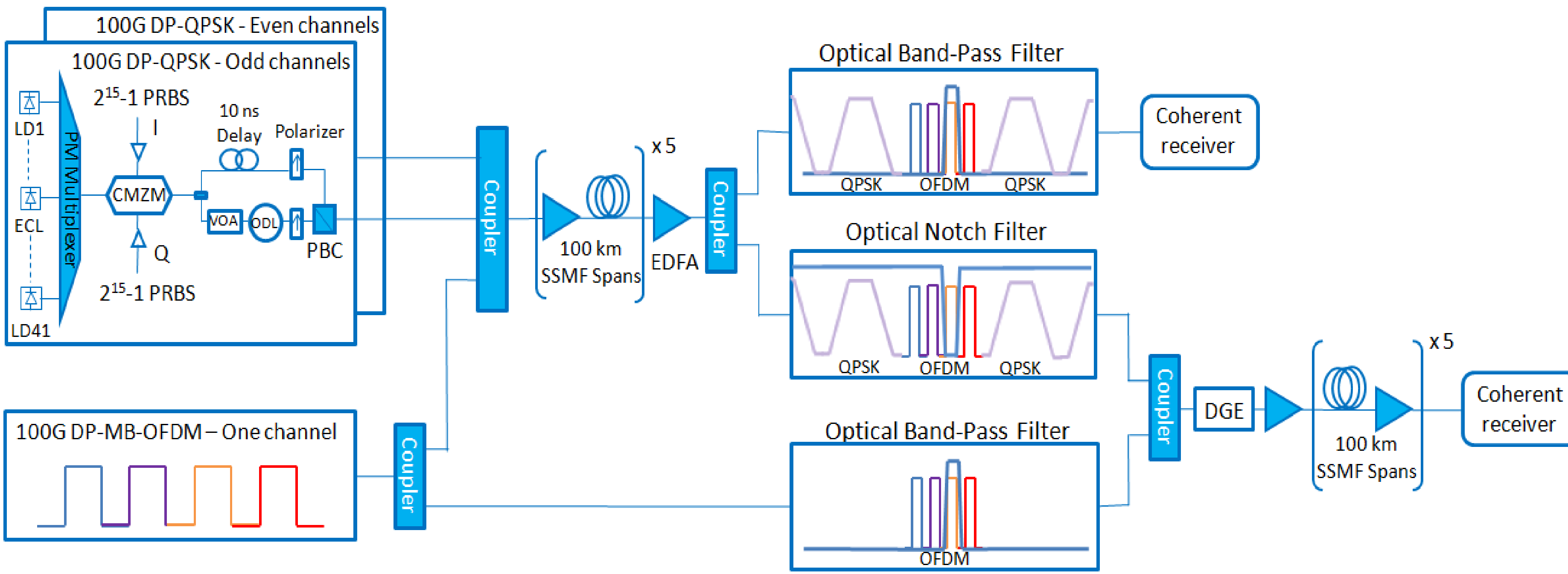
- Experimental setup:
  - 60 DP-QPSK channels @ 100 Gbps
  - 100Gbps Dual-Polarization MB-OFDM signal @ 1552.52 nm
  - Channel spacing = 50 GHz
  - EDFA : Gain = 20 dB, NF = 5.5 dB
  - Lasers: external cavity lasers with 100 kHz linewidth



"Add/Drop" is carried out over sub-band 3.

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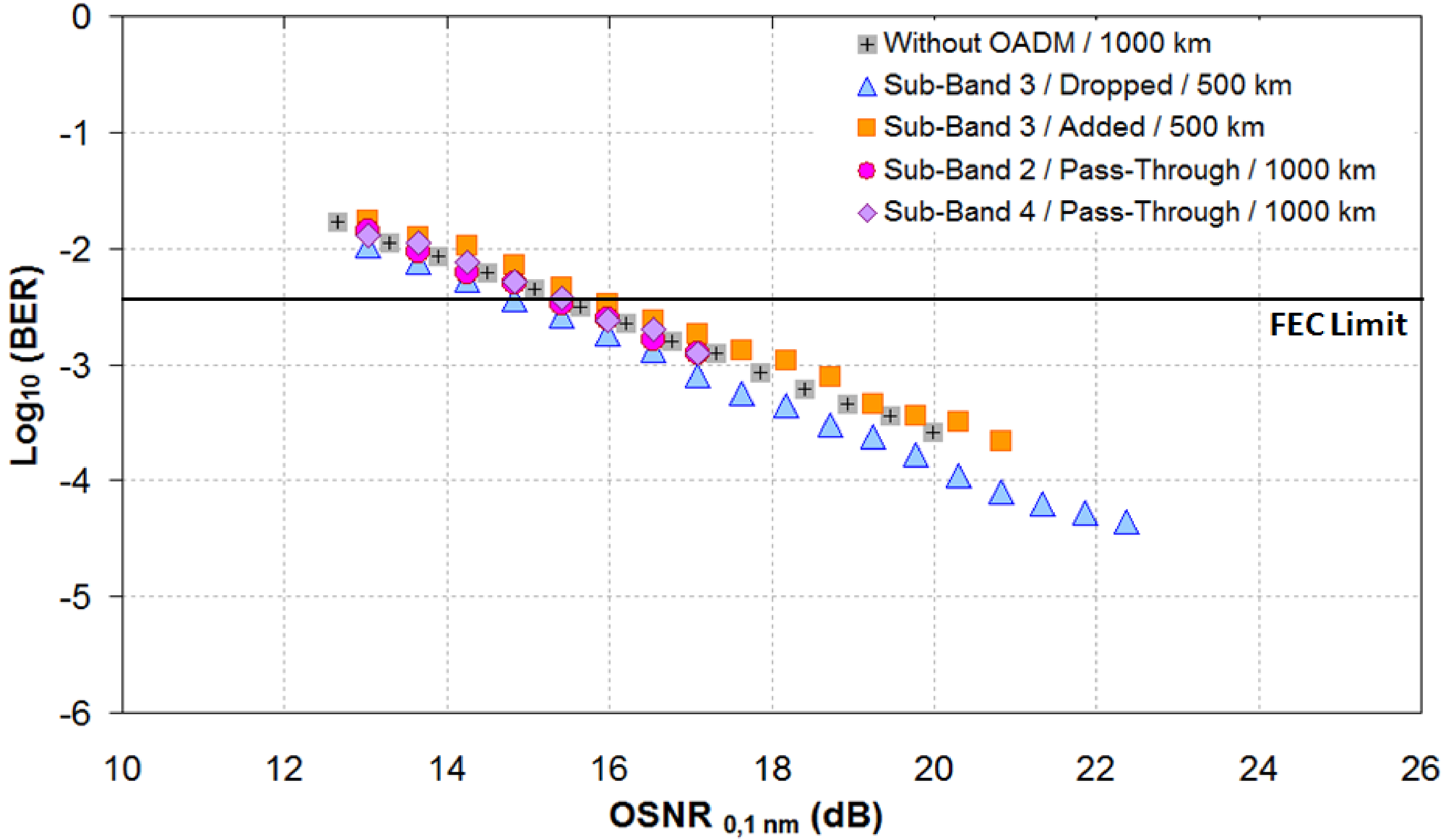
Performance evaluation in 10x100-km DCF-free G.652 fibre line

- BER vs. $OSNR_{0.1\ nm}$ for the sub-bands 2, 3 & 4 after transmission & "Add/drop"



No OSNR penalty is measured here for the "add/drop" & "Pass-Through" OFDM sub-bands.

Conclusion

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- Optical "Add/Drop" of OFDM sub-bands as narrow as 8 GHz inside a 100 Gbps DP-MB-OFDM signal constituted of a multiplex of four sub-bands spaced by 12 GHz has been demonstrated.
- The BER of the dropped, added and "pass-through" sub-bands are below the FEC limit after the 10x100-km DCF-free G.652 transmission line.
- Further experiments have to be done in a 2x100-km recirculating loop to study the cascadability of FOADM.
- These experiments constitute a first step toward the road of flexible optical networking based on use of MB-OFDM.
- A more industrial FOADM is under study and building in the FOX-C project.

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Questions