CEF 2023
Difference between 10G and coherent transmission in CEF networks – any?

Jan Radil, Jaromír Šíma, Tomáš Horváth
CESNET

SPM for Nyquist shaped coherent subcarriers.

- Customer Empowered Fibre Networks.
- empowered = authorized, commisioned,…
- We as Customers should tell/do what is useful for our networks.
- The first CEF Workshop in 2004!
  - https://archiv.ces.net/events/20040525/
- So our contribution is trying to tell what could be useful to our networks.

SPM for Nyquist shaped coherent subcarriers.

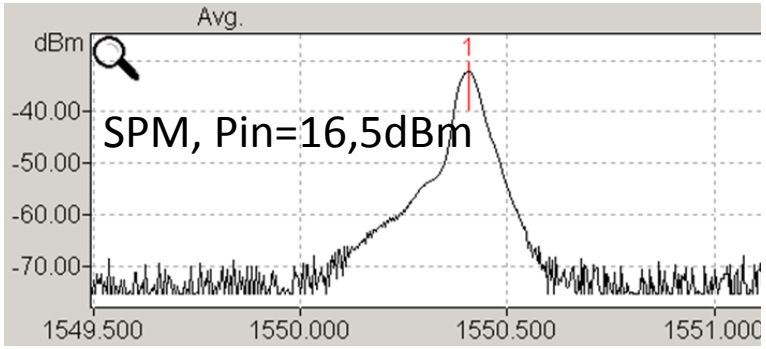
- Self Phase Modulation (SPM) is rather limiting nonlinear effect.
  - Other effects like FWM and XPM are also unwanted but SPM can be investigated easily (to some extent).
- Maximum optical power injected into fibre is (rather) limited for higher speeds.
- 20 years ago we had PoS 622 Mb/s and 2.5 Gb/s and 1GE and 10GE.
- Now we have coherent systems and speeds from 200 Gb/s to 800 Gb/s (and 1.6 Tb/s on one wavelength just round the corner).
- Also Time and Frequency i.e non-digital signals.
- When building Customer Empowered Fibre networks, we should know what is really best solution for NRENs.

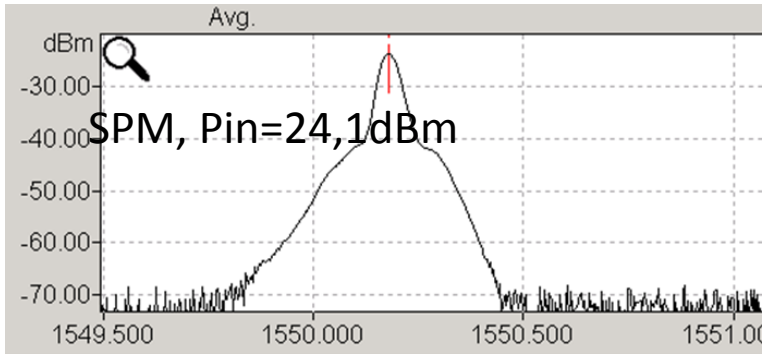
One short trip to the past: SPM and 10G.

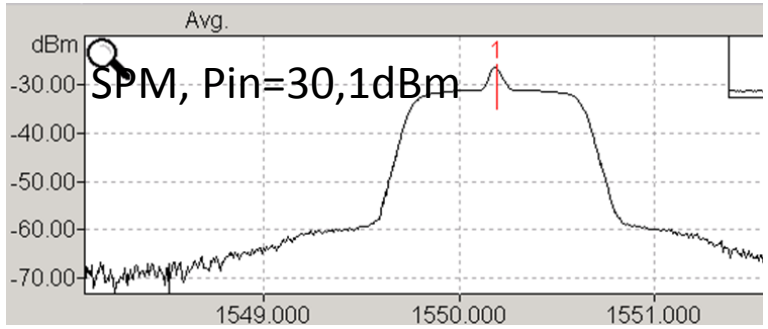
- Parts of measurements done for CESNET more than 15 years ago.
- When designing so called NIL (Nothing In line) fibre links.
  - All equipment located at end stations, no inline amplifiers.
- 20 years ago such designs were NOT so straightforward and this was one of our reasons to help with the CEF networks.
- CEF/NREN networks were evolving with Time, Frequency, perhaps QKD and sensing…
- Can all these signals be transmitted in one fibre?
- Short answer – yes.
- SPM limit for 10G NRZ signal over 100 km of G.655+ fibre is approx. 16 dBm (for G.652/657, SPM limits are slightly higher).

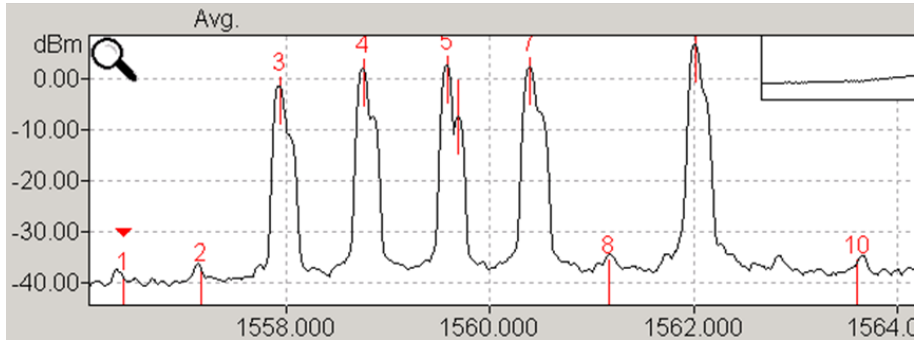
One short trip to the past: SPM and 10G.

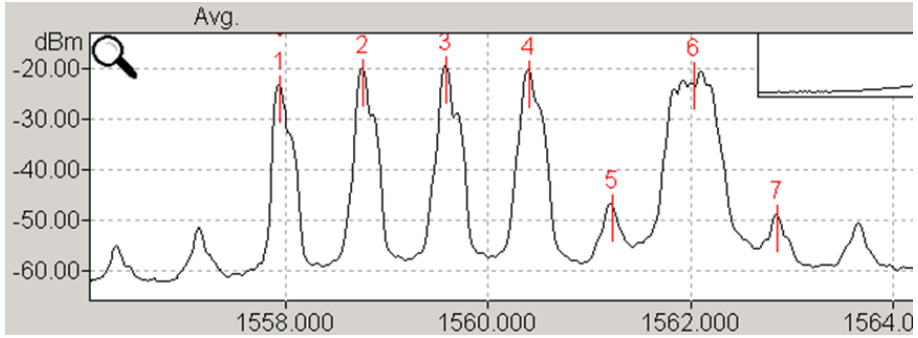
- Measurements from 2004-2006, figures taken from my presentation prepared for Masaryk University in Brno.





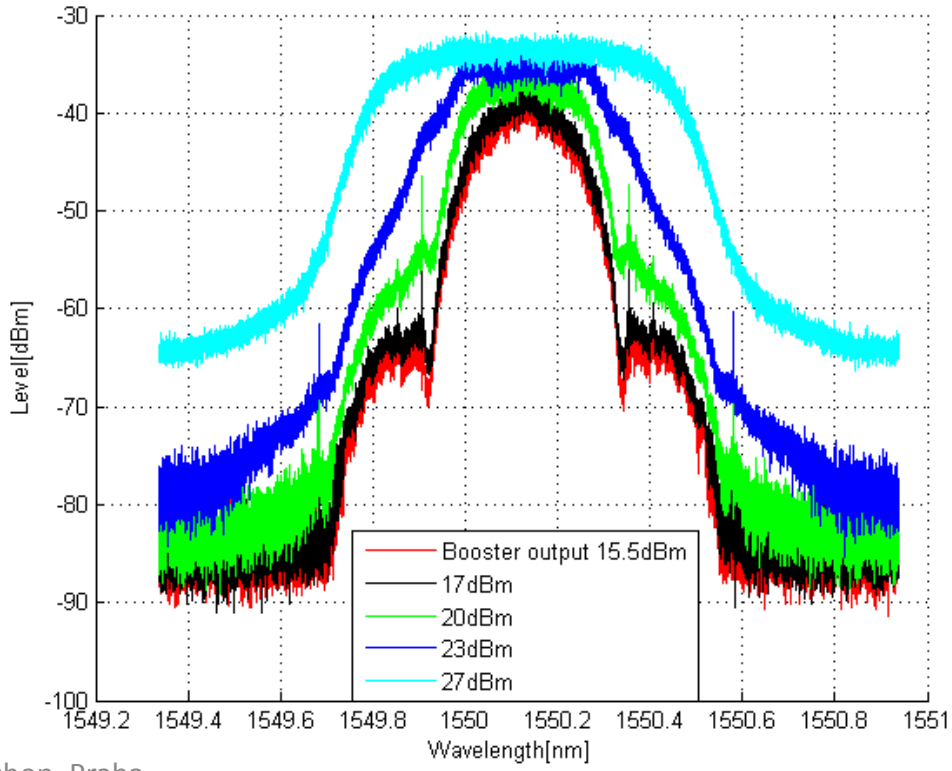






One short trip to the past: SPM and 100G.

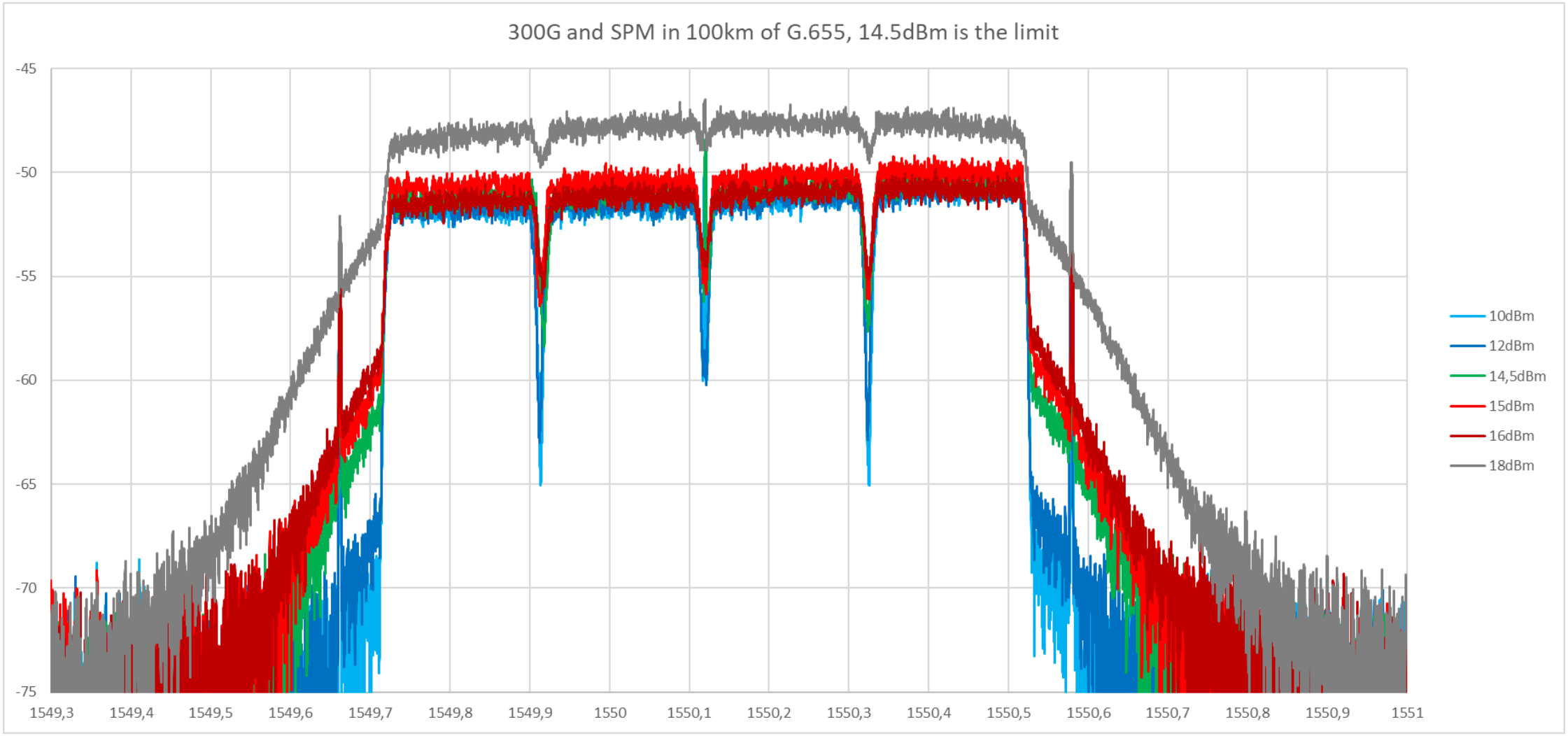
- Measurements from 2012, figures taken from my upgraded presentation prepared for Masaryk University in Brno. Thanks to Pavel Škoda for this figure!
- The first coherent systems, Opnext.
- 100G DP-QPSK.



Today: SPM and 200/800G.

- Now CEFs have evolved with Time, Frequency, QKD, sensing and who knows what else…AND coherent, phase modulated and multilevel signals.
- Can all of these signals be transmitted in one fibre?
- Short answer again – yes.
- Few pitfalls – some coherent signals (with Nyquist subcarriers) are so broad that cannot be transported over legacy 100 GHz multiplexers.
- Chances are that in some part of some network 100 GHz muxes are deployed.
- SPM limit for coherent signals (with Nyquist subcarriers) is 14.5 dB for 100 km of G.655 fibre.

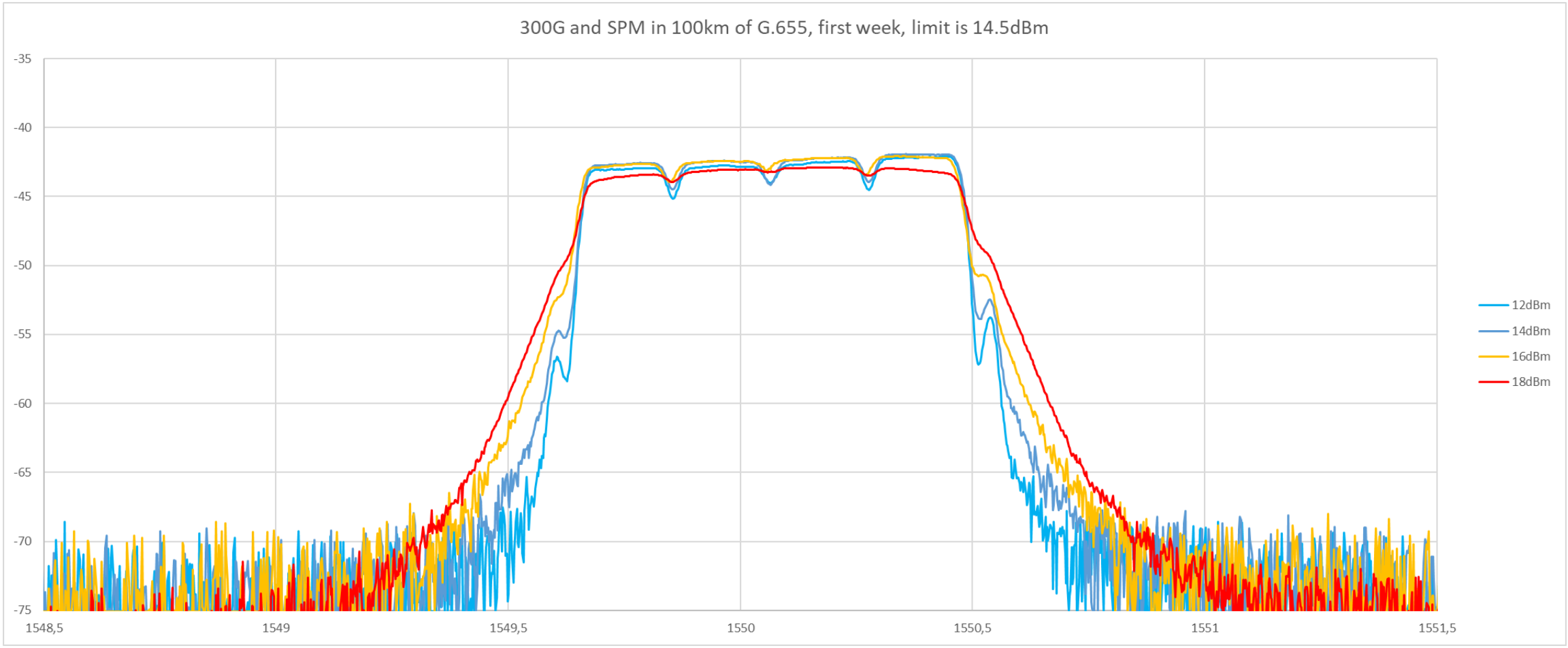
SPM and 300G: 14.5 dBm is the limit for error free transmission.



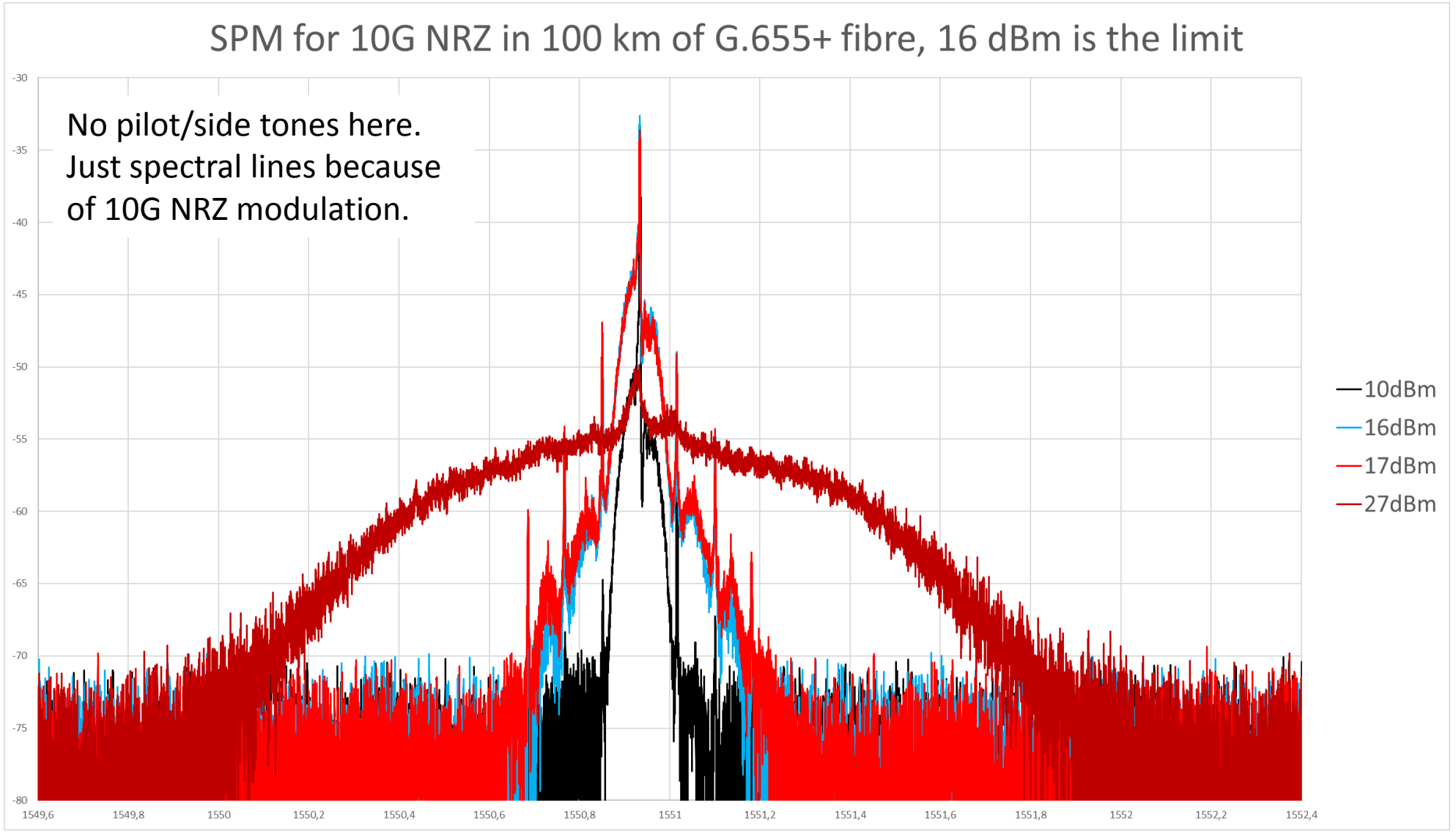
SPM and 300G: 14.5 dBm is the limit for error free transmission.

2 side tones?
1 pilot tone?
Other vendor use subcarriers but without(?) these tones…

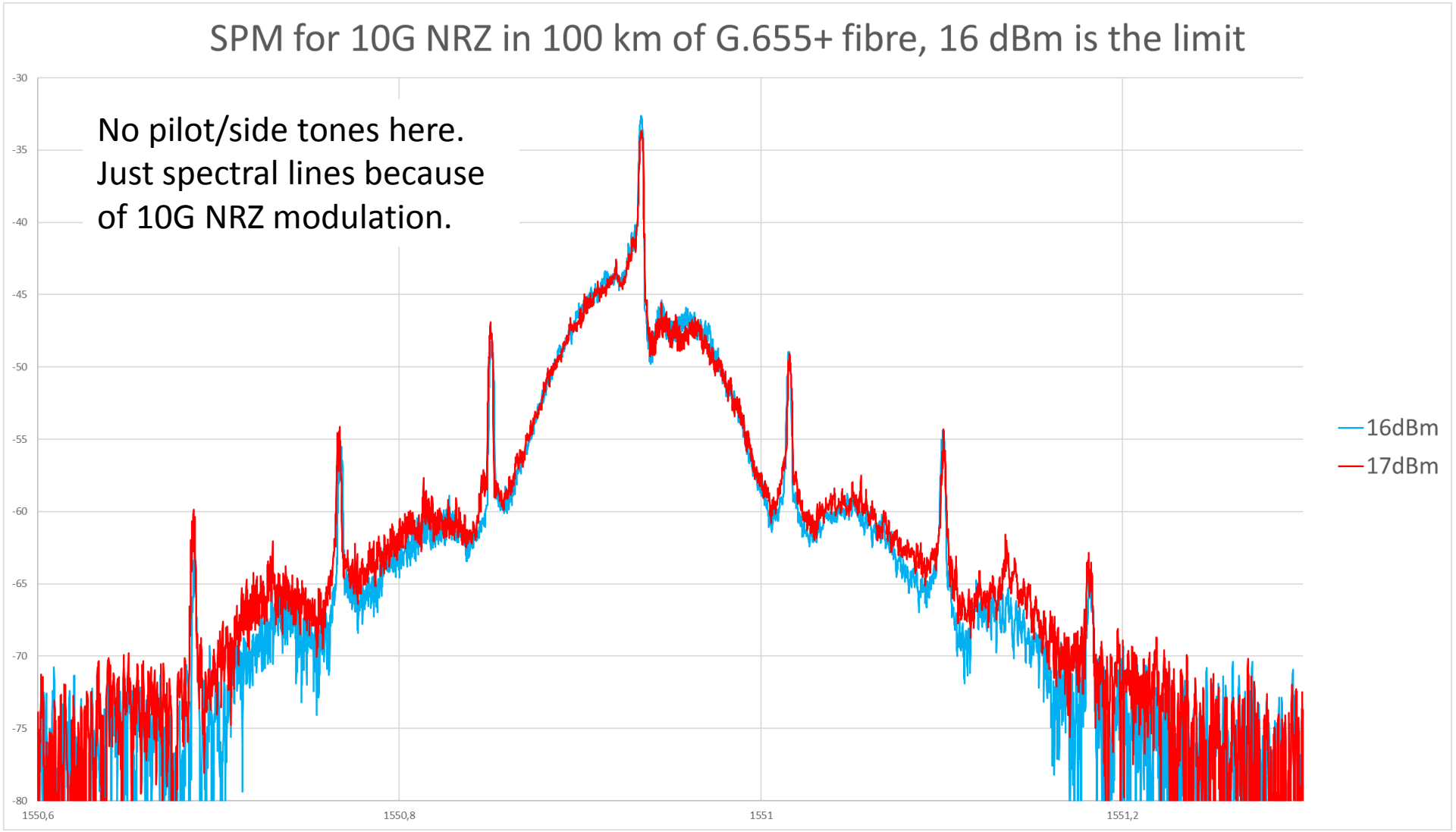
SPM and 300G: 14.5 dBm is the limit for error free transmission. Spectra recorded gratings-based (aka ‚standard/usual') OSA.



SPM and 10G: 16 dBm is the limit for error free transmission.

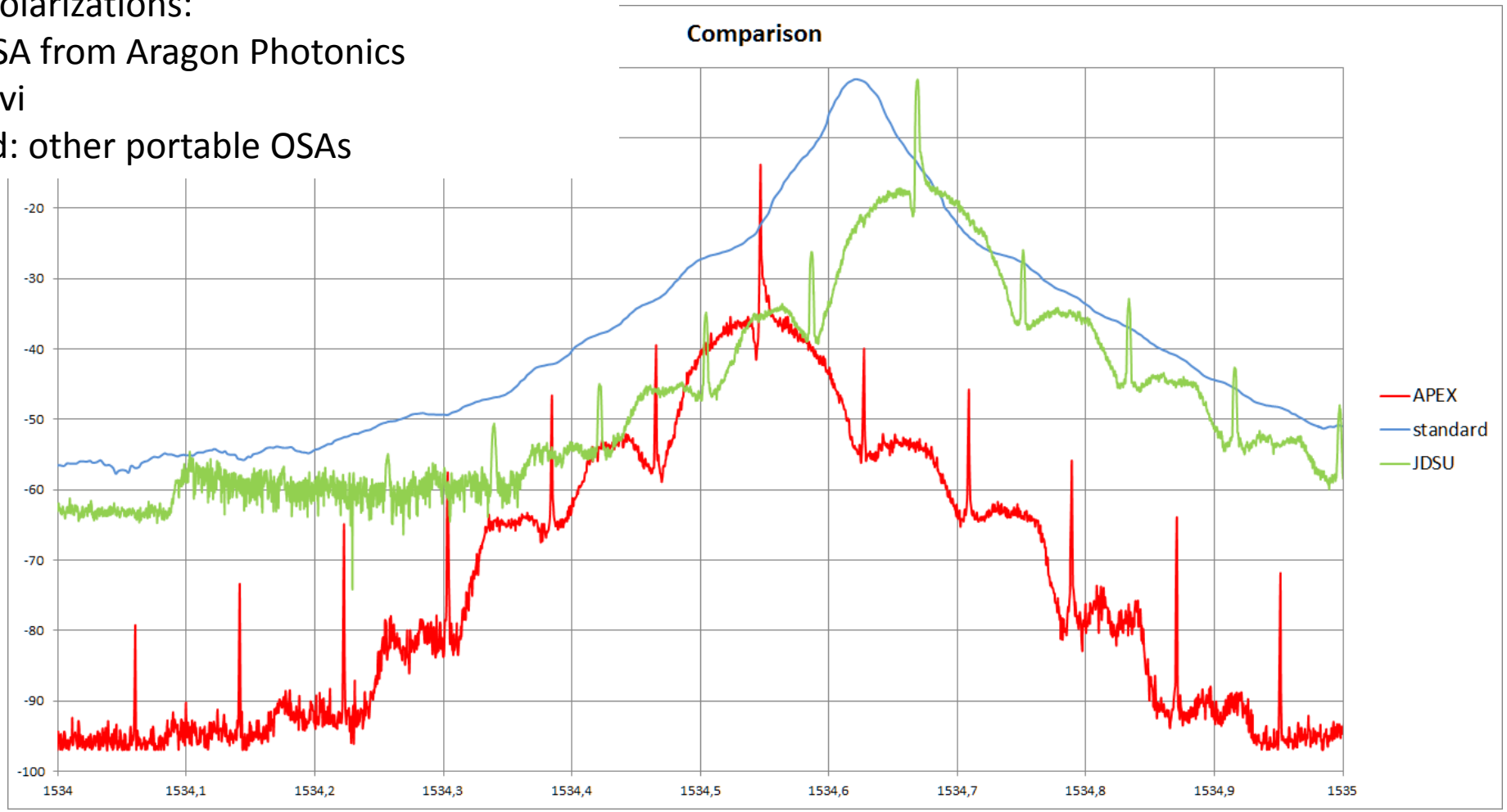


SPM and 10G: 16 dBm is the limit for error free transmission.



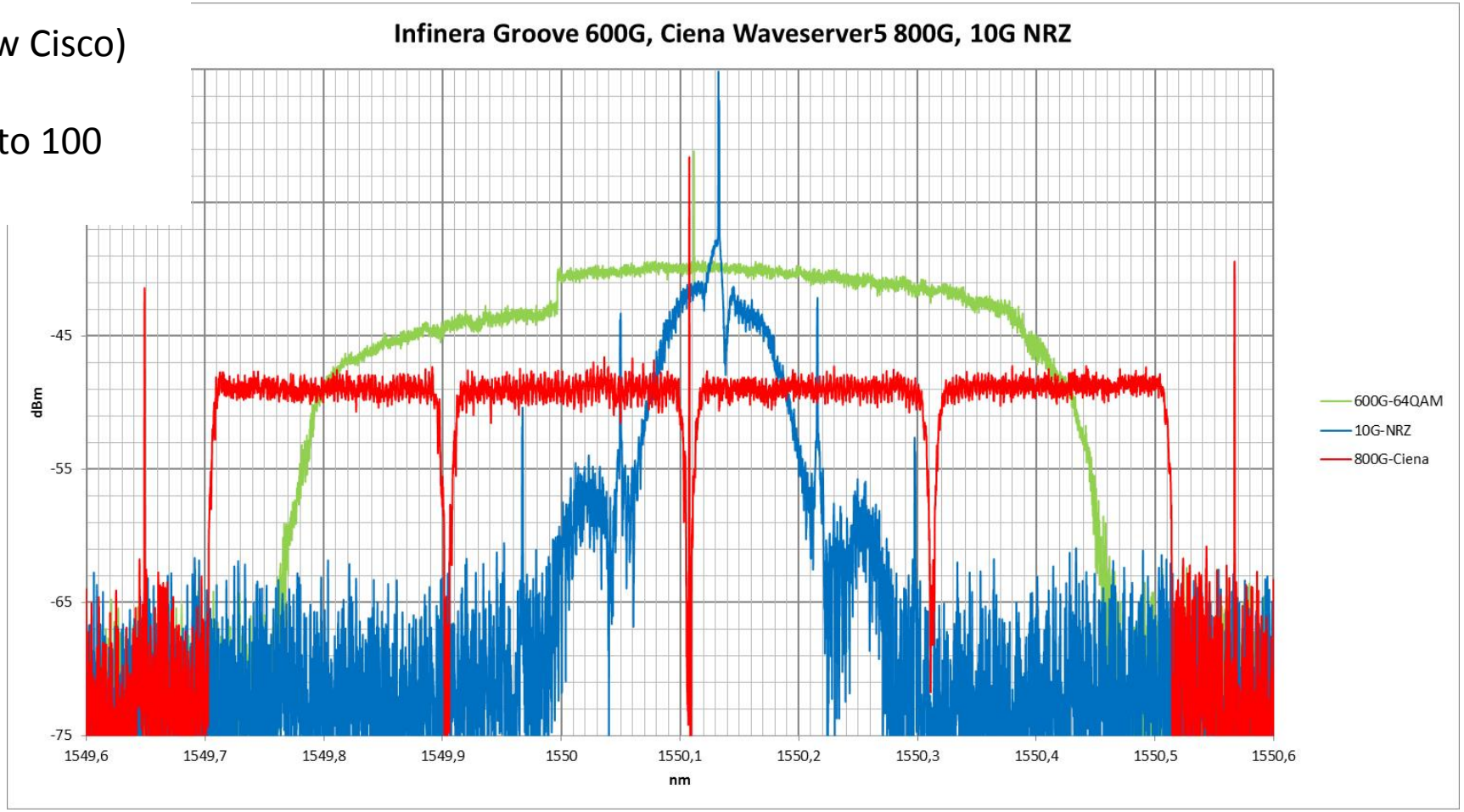
Comparison of high-res and standard OSAs.

Super high-res with 2 polarizations:
Apex Technologies, BOSA from Aragon Photonics
High-res: JDSU now Viavi
Standard=grating based: other portable OSAs



Comparison of 10G, 600G and 800G spectra.

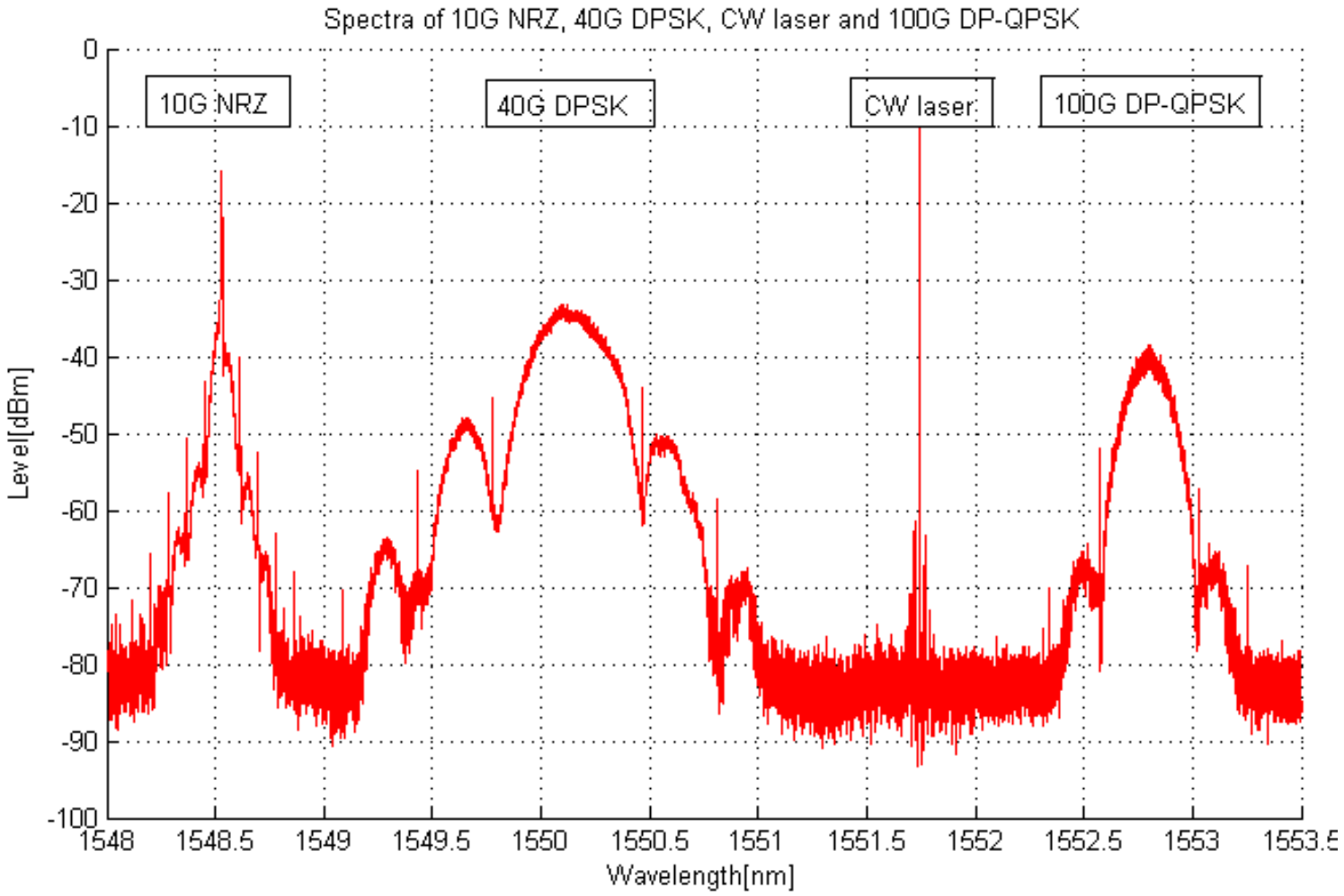
10G NRZ: any transceiver.
600G: 64Gbaud QAM (Acacia, now Cisco)
800G: Nyquist subcarriers Ciena.
Nyquist subcarriers will NOT fit into 100 GHz ITU spacing.



Amplitude and phase modulated signals.

- Stable Frequency transmission/transfer is CW and is not considered to be so big problem.
- But Accurate Time transmission/transfer is amplitude (or intensity) modulated and there are some fears that such amplitude modulated signals can disturb coherent data signals.
- All vendors recommend to use ‘guard bands’ i.e. some space between NRZ and coherent signal.
- How wide this guard bands should be? Opinions differ because such interaction can be very complex.
- But 300 GHz spacing is considered to be safe.
- Our measurements show that 10G and 300G can be even overlapping!

Amplitude and phase modulated signals.



APEX OCSA
Resolution: 0.8 pm (i.e. 100 MHz)
Thanks to Pavel Škoda for this figure!

CW can represent ultrastable frequency.
10G can represent accurate time.
Nyquist subcarriers not in this picture.

Amplitude and phase modulated signals.

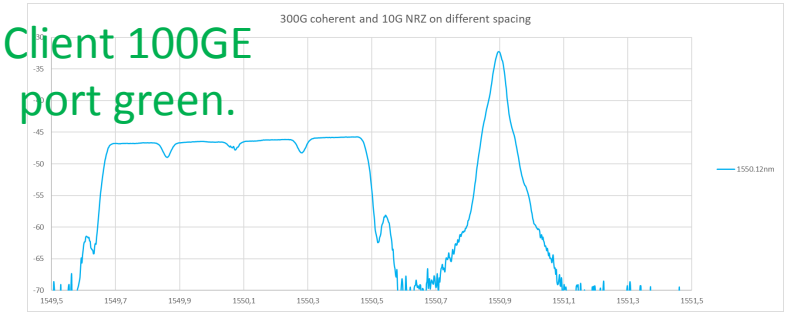
- For the last 10 (or 15?) years all of us heard that legacy NRZ signals (amplitude modulated) can disturb coherent (phase modulated) signals.
- The first advice from vendors was ‘do not use NRZ signals.
- Then it became ‘use guard bands’ i.e. do not put legacy NRZ and coherent signals in the same part of C band.
- The only trouble was – nobody knew how broad these guard bands should be…
- We did some tests for CESNET and I think results were not very clear and bigger problem was power unbalance between channels.
  - NRZ signal stronger for 1 dB was more dangerous than close NRZ signal.
  - Unfortunately I have no details left because it was difficult and time-limited…

Amplitude and phase modulated signals.

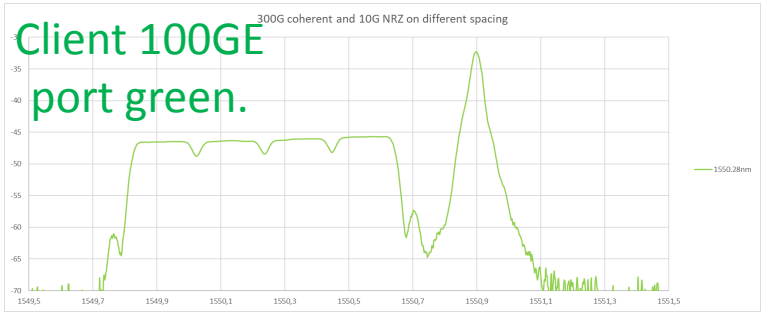
- 10 Gb/s is centered at 1550.92 nm and coherent 300G (because of better receiver sensitivity for our configuration i.e. 100 km of G.655 fibre without chromatic dispersion compensators) is moving from 1550.12 nm to 1550.92 nm.
- 300G@1550.52nm is really limit – sometimes it is OK, sometimes it is not OK.
- 1550.52 nm is on the ITU 50 GHz grid BUT REMEMBER: 50 GHz grid was designed for 10G NRZ signals. Coherent Nyquist subcarriers are much broader and there is overlapping in this case!
- 300G@1550.44nm is always safe for coherent data.
- Our conclusion – 100 GHz guard band is OK for shorter distance.
- For pan-European and submarine distances wider guard band may be required.

10G NRZ and 300G coherent signals.

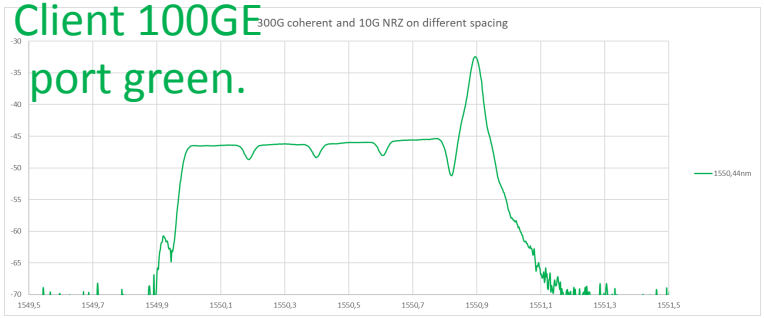
Client 100GE port green.



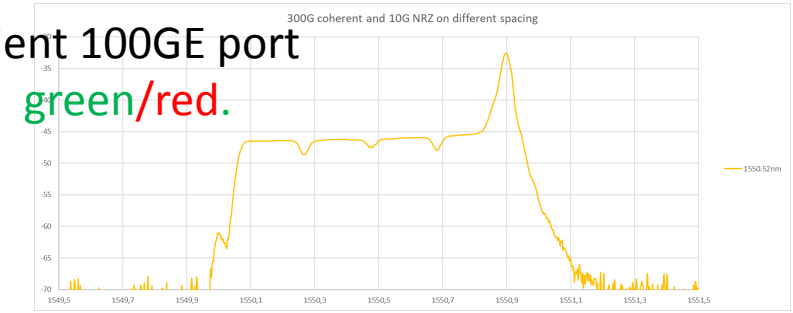
Client 100GE port green.



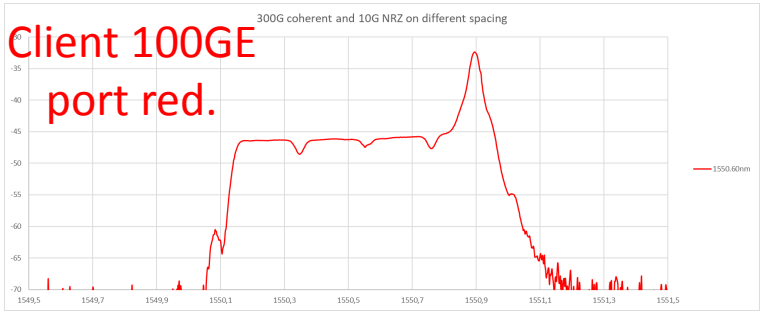
Client 100GE port green.



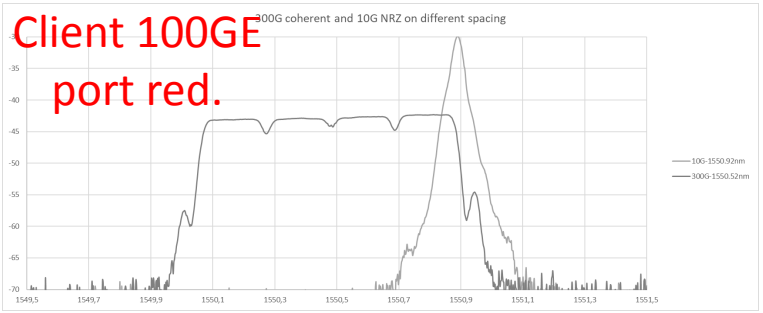
Client 100GE port green/red.



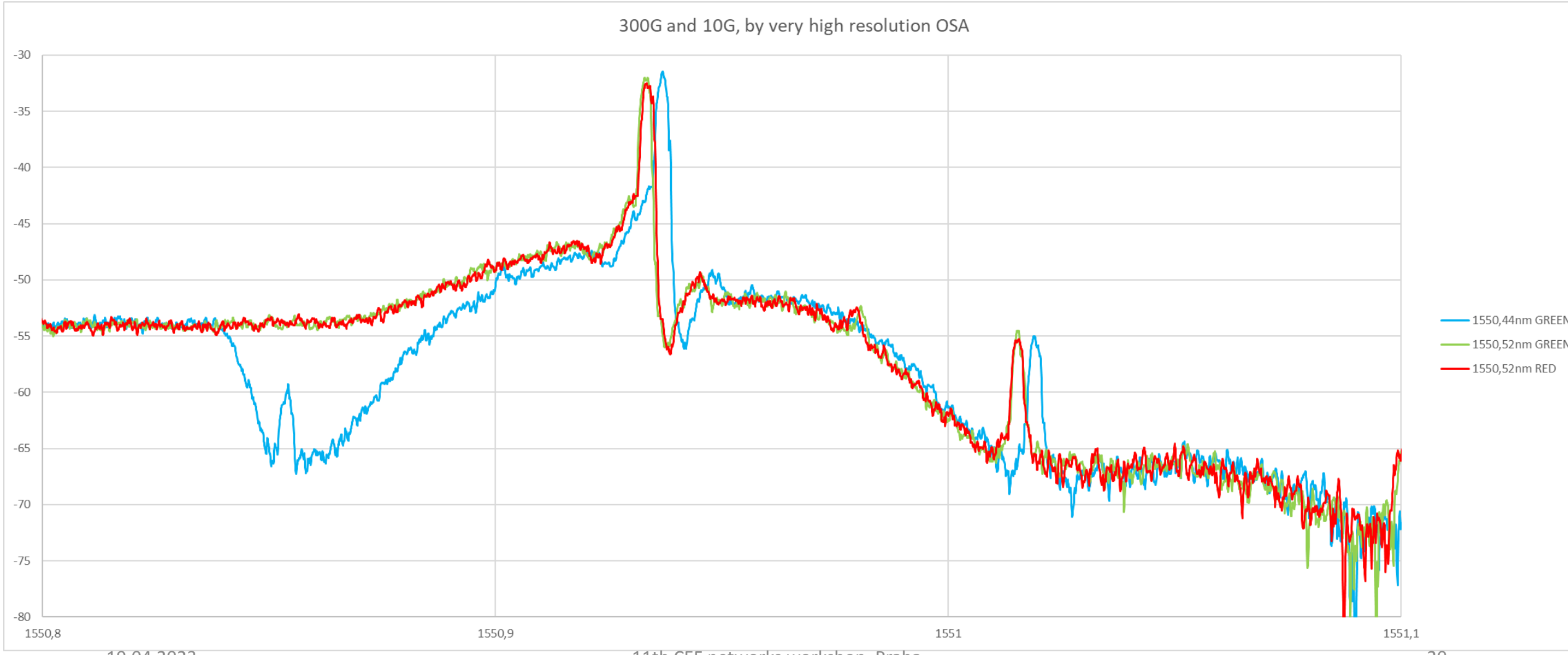
Client 100GE port red.



Client 100GE port red.

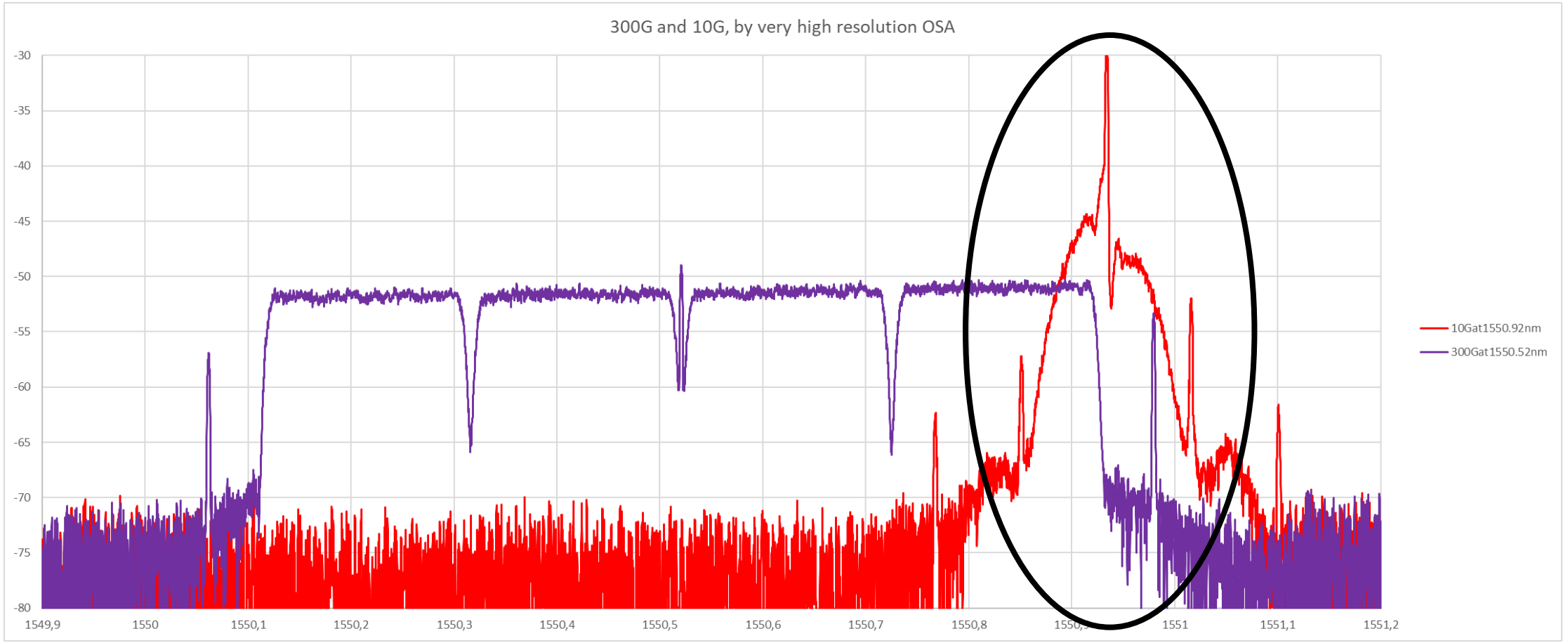


10G NRZ and 300G coherent signals.



10G NRZ and 300G coherent signals.

300G@1550.52nm is really limit – sometimes it is OK, sometimes it is not OK.
Clear overlapping – strange it is working…



10G NRZ and 300G coherent signals.

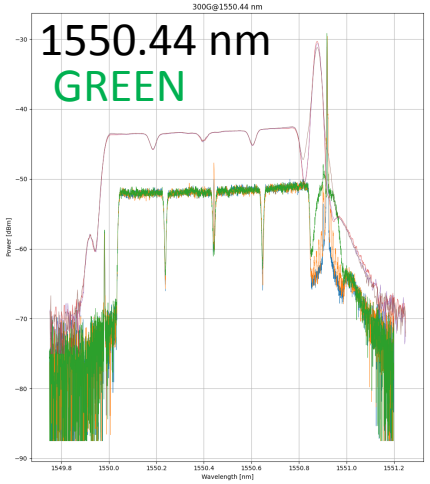
- I ended my measurements at 300G@1550.52nm but coauthors Tomáš and Jaromír told me ‘well, let’s do more measurements’.
- So they moved the coherent 300G signal even closer to 10G@1550.92 nm.
- To my VERY VERY BIG surprise, 100GE client port on Waveserver5 became GREEN again.
- In some spectral positions, 100GE client port stayed GREEN, in some spectral positions it went to RED.
- How is this possible???

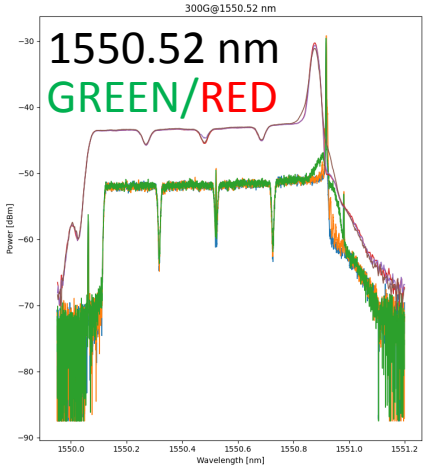
10G NRZ and 300G coherent signals.

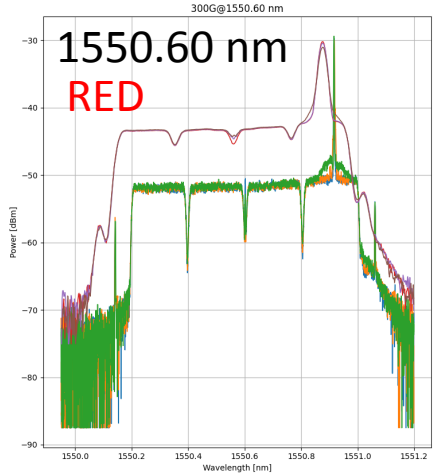
- Summary table, NRZ fixed at 1550.92 nm:

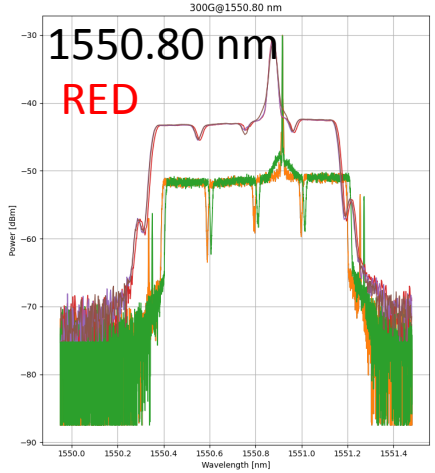
300G lambda, nm	100GE client port	NRZ position to 300G	Remark
1550.12	GREEN	NRZ not overlapping	100 GHz ITU spacing
1550.28	GREEN	NRZ not overlapping	
1550.44	GREEN	NRZ not overlapping	
1550.52	GREEN/RED	NRZ@4th subcarrier, edge	50 GHz ITU spacing
1550.60	RED	NRZ@4th subcarrier, middle	GREEN for 100M.
1550.80	RED	NRZ@3th subcarrier	GREEN for 100M.
1550.92	RED	NRZ@middle pilot tone	At the same wavelength
1551.00	GREEN	NRZ@2th subcarrier	
1551.16	GREEN	NRZ@1th subcarrier, edge	
1551.24	GREEN	NRZ@1th subcarrier, middle	
1551.32	GREEN	NRZ@1th subcarrier, edge	

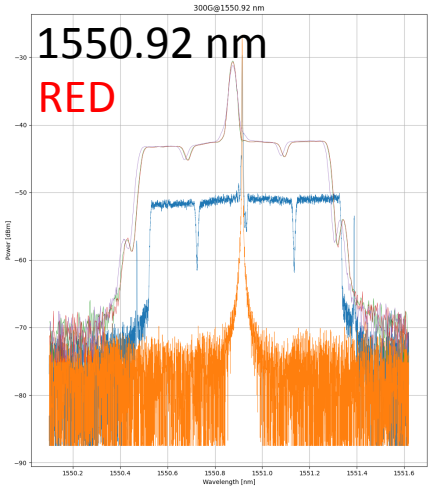
10G NRZ and 300G coherent signals.

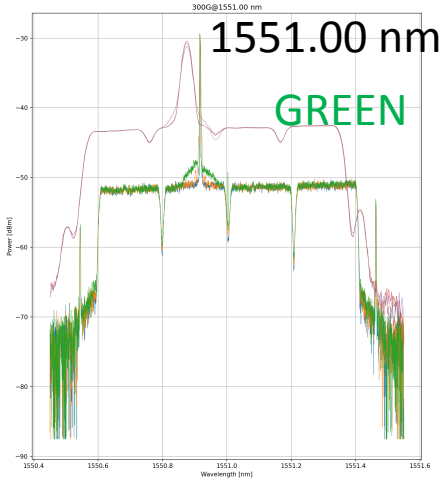


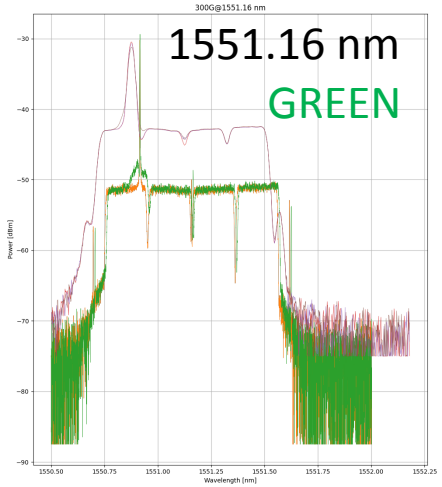


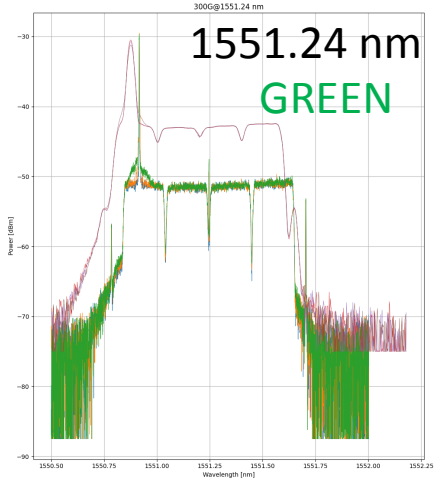


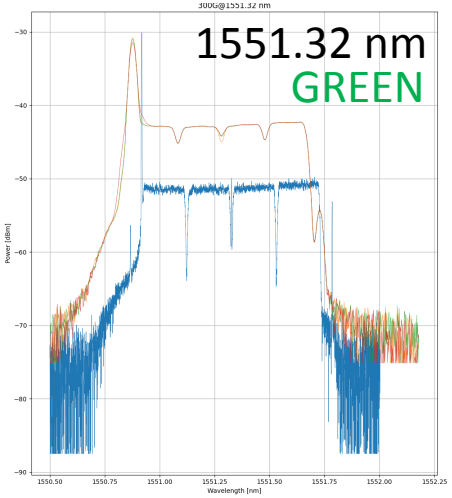










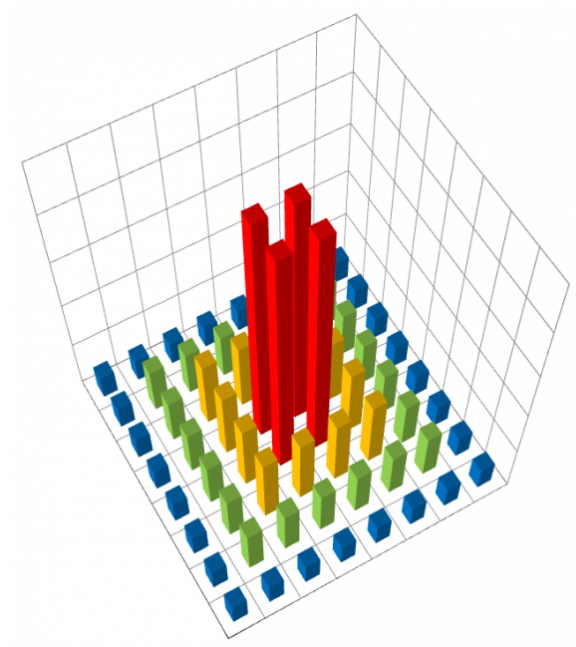


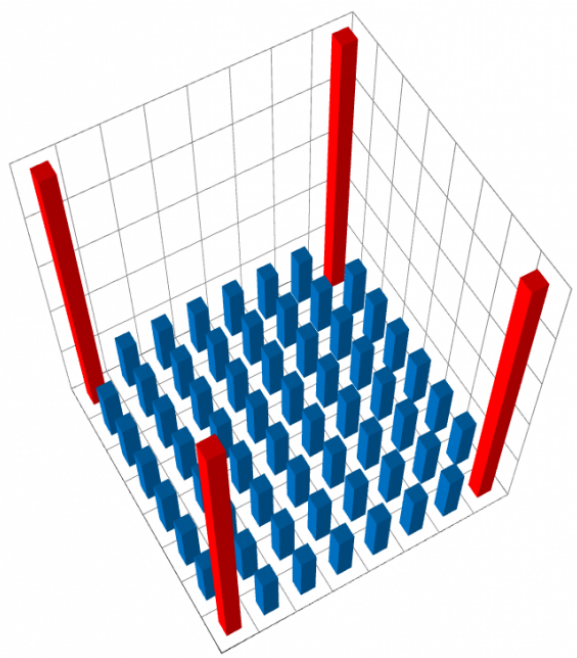
10G NRZ and 300G coherent signals.

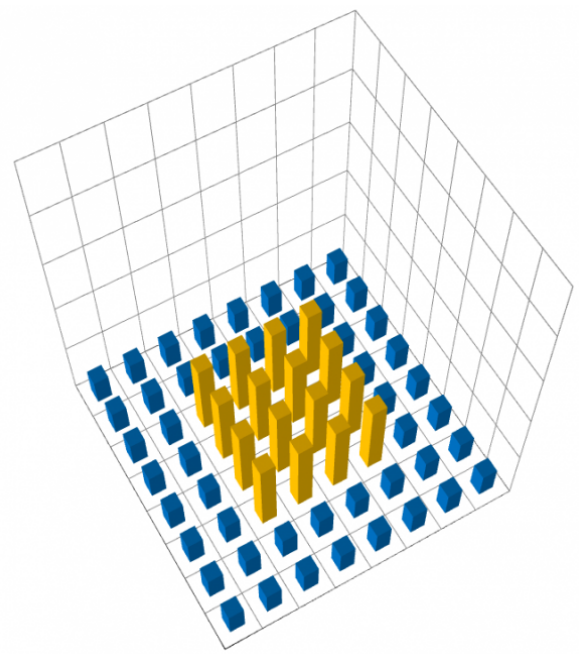
- Someone suggests that 100GE client signals are ‘distributed among’ all subcarriers – e.g. 3x100GE port do not use the 4th subcarrier.
- I’m not 100% sure – what about 350G, 450G etc.
- We do not know what these 3 pilot/side/auxiliary Ciena signals do…
- Also, none of us is expert on math and DSP.
- Perhaps constellation diagrams can help?
- Our ‘disturbing’ signal can be placed between constellation points, modern DSPs can do probabilistic shaping and in theory, everything is possible.

10G NRZ and 300G coherent signals.

Figures from my texts for edu purposes (in Czech).
https://www.vovcr.cz/odz/tech/512/page09.html

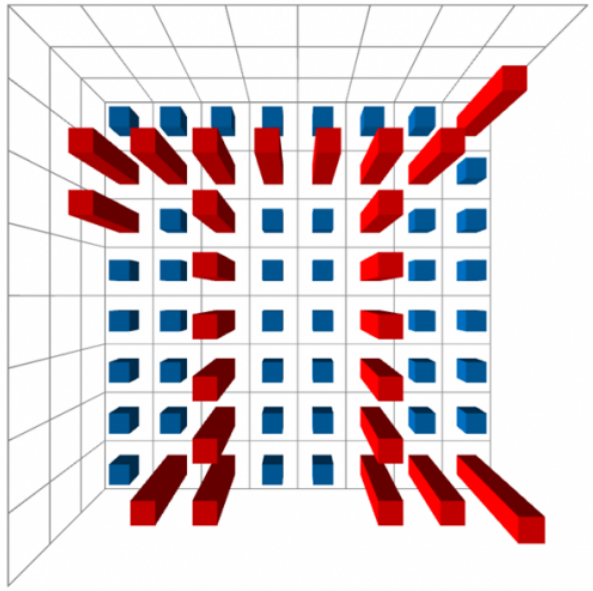


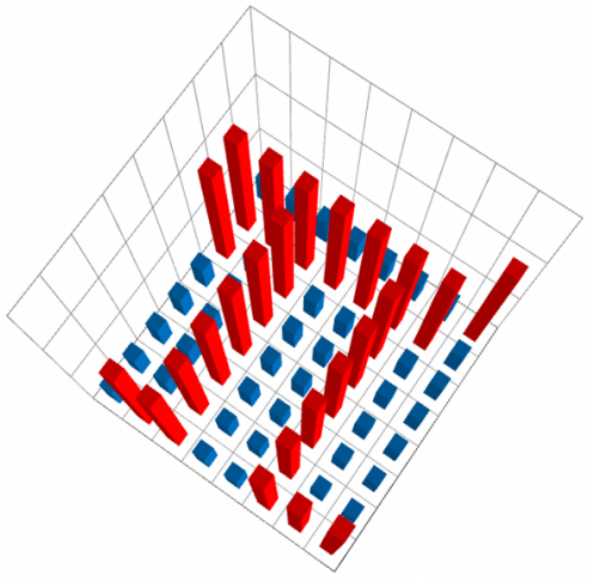




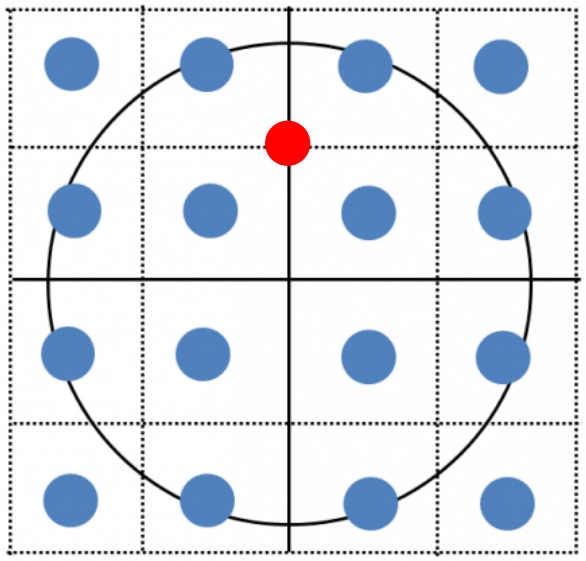
10G NRZ and 300G coherent signals.

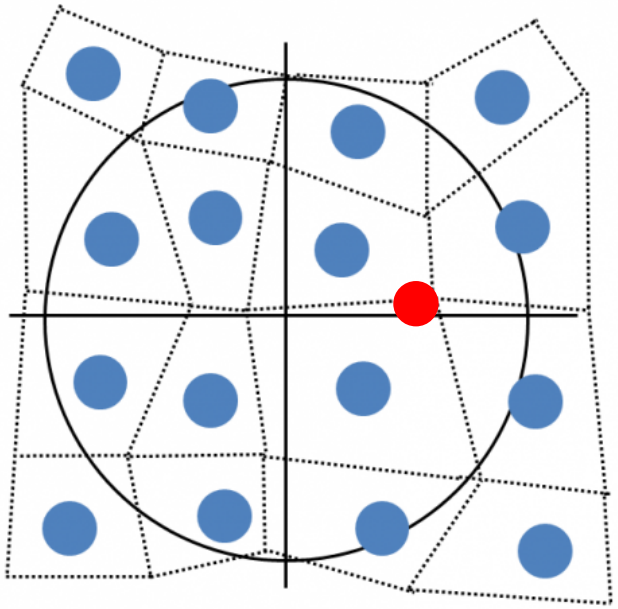
Figures from my texts for edu purposes (in Czech).
https://www.vovcr.cz/odz/tech/512/page09.html





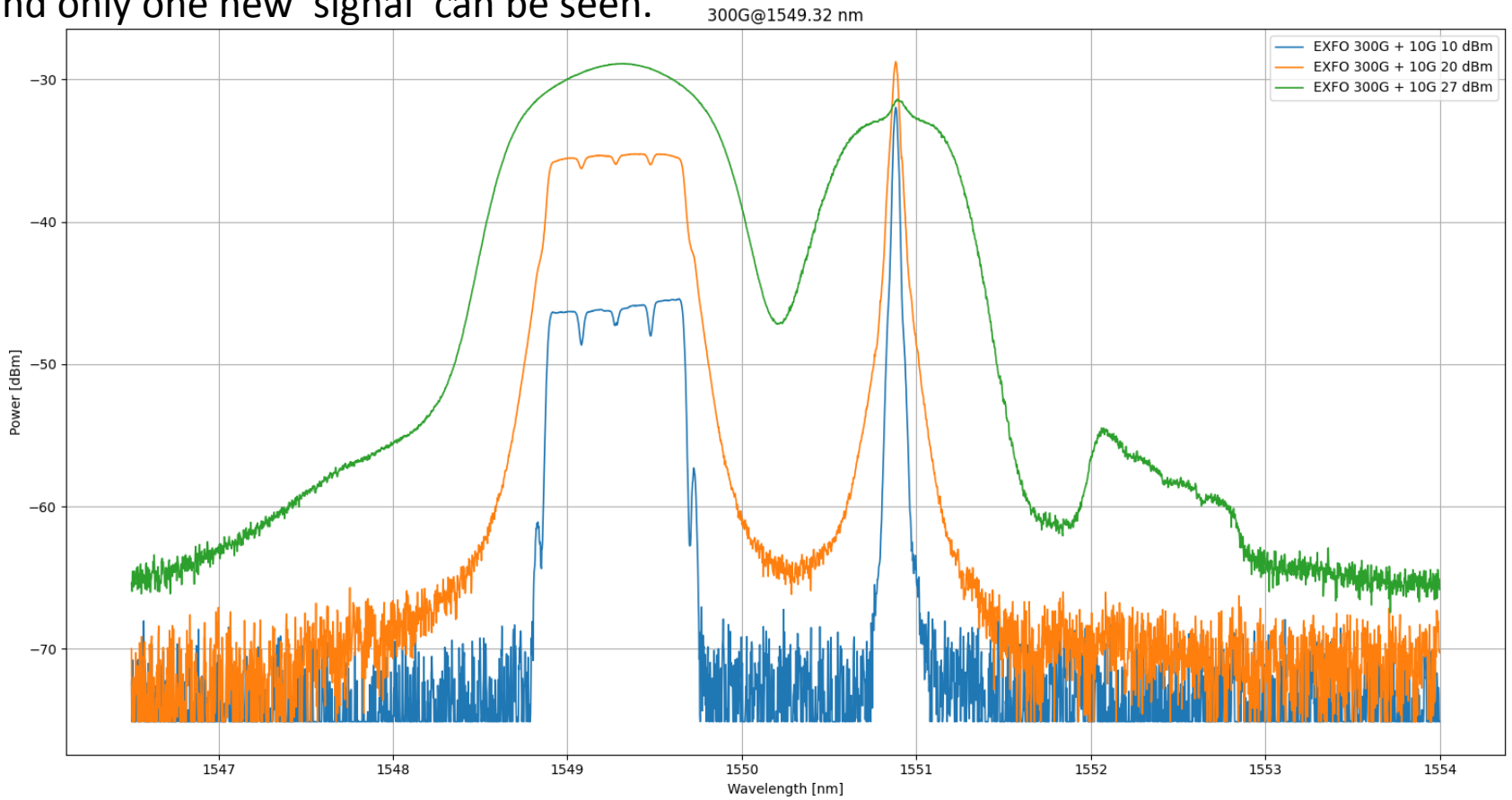
Time, frequency, 1/10G NRZ signals may be ‘in-between’.





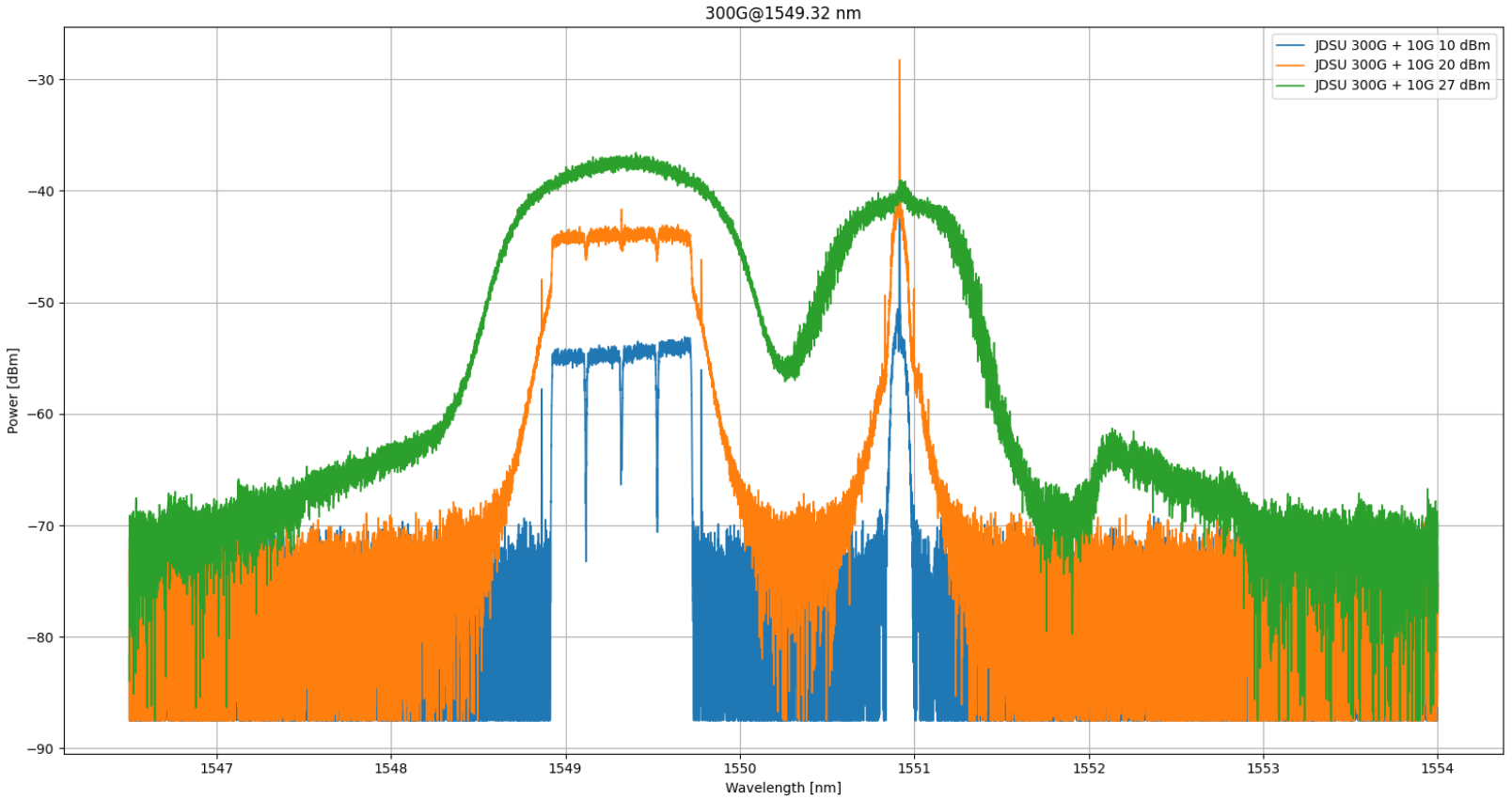
FWM for 10G NRZ and 300G coherent signals.

The FWM limit is very high, SPM is more limiting.
27 dBm (0.5 W!) and only one new ‘signal’ can be seen.



FWM for 10G NRZ and 300G coherent signals.

The FWM limit is very high, SPM is more limiting.
27 dBm (0.5 W!) and only one new ‘signal’ can be seen.



Conclusions (if any?).

- Coherent systems are rather resilient nowadays (lightnings are no problems anymore).
- They can guarantee error-free transmission, even when channels are overlapping (well, sometimes, under peculiar circumstances).
- But NOBODY will transmit overlapping channels, of course not!
- With some very reasonable guard bands (100 GHz?) we can transmit coherent, frequency, time, QKD signals over shorter distances (up to 1000 km?).
- SPM is THE limiting factor, but all vendors keep SPM under limits.
  - So then OSNR is THE limiting factor under standard circumstances.
- But in CEF networks, some of us can try to experiment and push the limits of transmission systems.

Thank you list...

- Too many people to mention…sorry:-)
- But let me say BIG THANKS to these two wonderful human beings:
- **Stanislav Šíma (1944–2015).**
  - Working for CESNET from the very beginning in 1996, and even before. A very big fan and supporter of CEF. The SEER.
- **Miroslav Karásek (1946–2013).**
  - Working for CESNET from 2000 I believe. Working for Czech Academy of Sciences for his whole life. The BRAINIAC.

Resources

- Previous CEF workshops.
- Ciena Waveserver5 manuals.
- Theory described (but not mentioned) for example in:

Govind P. Agrawal. Fiber-Optic Communication Systems, 5th edition. 2021. ISBN: 978-1-119-73736-0.

- Our measurements, mostly unpublished....