High Resolution Optical Spectrum Analyzer (OSA)

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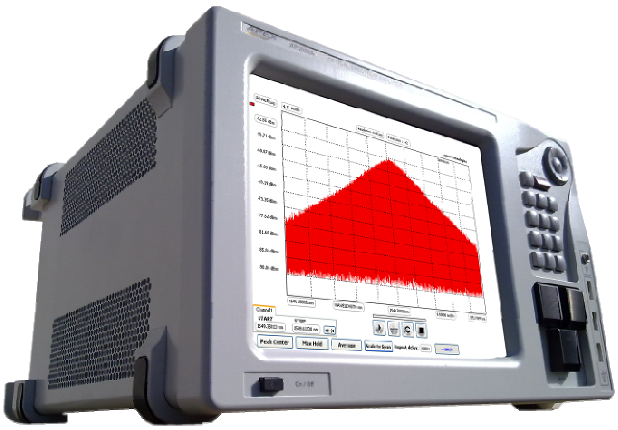
Ultra High Resolution OSA: a perfect tool for optical OFDM measurement and adjustment



The Ultra High Resolution OSA (UHR-OSA) proposed by ***APEX Technologies*** remains a very important tool not only to measure the optical OFDM (Orthogonal Frequency Division Multiplexing) signal spectrums even with few tens of MHz spacing sub-carriers but also to adjust and adapt it to other modulation techniques.

APEX-UHR-OSA incessant need in OFDM research area

APEX UHR-OSAs have found a wide industrial and academic success marked by the incessant demand of researchers and experts in all aspects of the OFDM technique. Indeed, more than 30 APEX-UHR-OSAs are currently used throughout the world by several universities such as Dublin City university (IRELAND) (1), Melbourne university (AUSTRALIA), IT AVEIRO (PORTUGAL), Bangor university(2),... and industries such as Orange Labs (3), KDDI R&D Lab (4),...

What is OFDM?

Optical OFDM (Orthogonal frequency division multiplexing) is a promising format for the next generation of long-haul and access networks because of its high spectral efficiency and the resistance to a variety of dispersions including chromatic dispersion (CD). The basic principle of OFDM technique is to carry information using several hundred sub-carriers which transport a fraction of the data rate each. The main feature of OFDM resides in the orthogonality of its sub-carriers obtained by spacing each of them with a multiple of the inverse of symbol duration (of the low bit-rate streams).

Its main advantage is to avoid the inter-carrier interference and to allow spectral overlapping in order to ensure a high spectral efficiency. The orthogonality is maintained by adding a cyclic prefix to each OFDM symbol in order to eliminate the inter-symbol interference (ISI). In terms of transmission, OFDM has received increased attention thanks to its robustness to ISI, namely chromatic dispersion (CD) and polarization mode dispersion (PMD), provided by the low sub-carrier data rate without any need for complex equalization at the receiver side. For this reason, increasing the sub-carrier number is very crucial so that each sub-carrier transports the lowest possible bit-rate stream (equal to the nominal bit-rate divided by the number of sub-carriers). In frequency domain, it corresponds to a few ten of MHz (typical 20 MHz to 50 MHz) sub-carrier spacing. Fiber-optic OFDM systems can be realized either with direct detection optical (DDO) or with coherent optical detection (COD).

What else makes APEX-UHR-OSA so good?

The key feature of the APEX-UHR-OSA is its capacity to measure the OFDM signal spectrum and to display all the sub-carriers clearly even with a few tens of MHz spacing, this is not possible with a traditional grating based OSA resolution (down to 20 pm/ 2.5 GHz). Based on an interferometric method, APEX Technologies UHR-OSA combines high resolution (up to 5 MHz, 0.04 pm), wavelength accuracy (+/- 3 pm) and high dynamic range. These equipment specifications (in particular the resolution) are good enough to see the details and the separation between adjacent sub-carriers (figure 1).

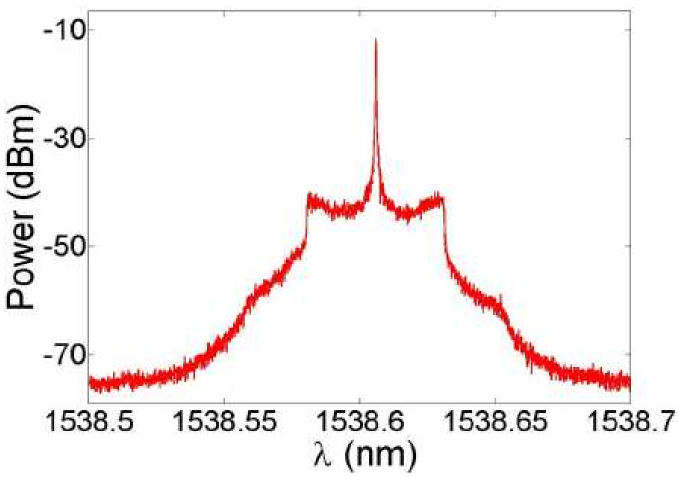


Figure 1: Double Side Band (DSB) OFDM spectrum measured by APEX-UHR-OSA taken from (5)

Single Side-Band DDO-OFDM: a key solution for future access networks

The cost control, energy consumption, high bit rate and extended transmission reach are challenging constraints for the next generation of access networks deployment. Thanks to its great resistance to fiber dispersion and high spectral efficiency, OFDM becomes a key solution which satisfying this requirements. DDO-OFDM is usually preferred for its simplicity, low cost and energy consumption efficiency. However, DDO-OFDM signals are more suitable for cost-effective short-reach applications because of a CD issue. Indeed, the frequency domain equalization in the OFDM receiver corrects partially the CD and can't completely recover the data signal when its power is close to or below the noise floor.

In this context, many research works are focusing on reducing the signal spectrum width by removing one of its two interfering side-bands (DSB: Double Side-Band) in order to overcome CD in DDO systems. Adapting OFDM signals to the Single Side-Band (SSB) modulation mode is usually employed to avoid the serious CD coming from large signal bandwidth and transmission distance. Traditionally, optical SSB signals can be generated using a double sideband filtered by a fibre Bragg grating (FBG) or a Single Side-Band modulator.

Adjusting SSB-OFDM signals with APEX-UHR-OSA?

In order to further increase the OFDM spectral efficiency and to improve the bit rate and the transmission reach, the use of the APEX-UHR-OSA is crucial to verify the OFDM signal compatibility with the SSB modulation technique when adjusting the operating point of the SSB signal generator. Below, an APEX UHR-OSA users' testimony proves the high APEX-UHR-OSA efficiency in adjusting and adapting SSB-OFDM signals.

"***The APEX-UHR-OSA is the perfect tool for checking the Single Side Band (SSB) nature of my 40MHz spaced sub-carriers OFDM signal***", ***Mr. Colm Browning, PhD Student*** at Radio and Optical Communications Group, the Rince Institute, Dublin City University, APEX-UHR-OSA (AP2443B) user (6).

Indeed, OFDM offers very high spectral efficiency due to its overlapping sub-carriers. Spectral efficiency is even further increased by the use of SSB modulation. Current experimental work is focused on using an external modulator to modulate light intensity from a tunable laser with a Single Sideband (SSB) OFDM signal (synthesized using a combination of Digital Signal Processing (DSP) and the external modulator itself). To produce the SSB spectrum in the optical domain, the external modulator needs to be biased precisely at its quadrature point. A problem arises when the bias conditions necessary for this change over time, this is known as modulator drift and can severely affect system performance as the optical signal will no longer be SSB if quadrature bias conditions are not met. The only true way to verify if the signal is SSB is by observing the transmitted optical signal with the APEX-UHR-OSA. The high resolution of this OSA allows observing in detail the optical carrier as well as the OFDM sidebands. System performance can then be optimized by ensuring that SSB operation is maintained (figure 2).

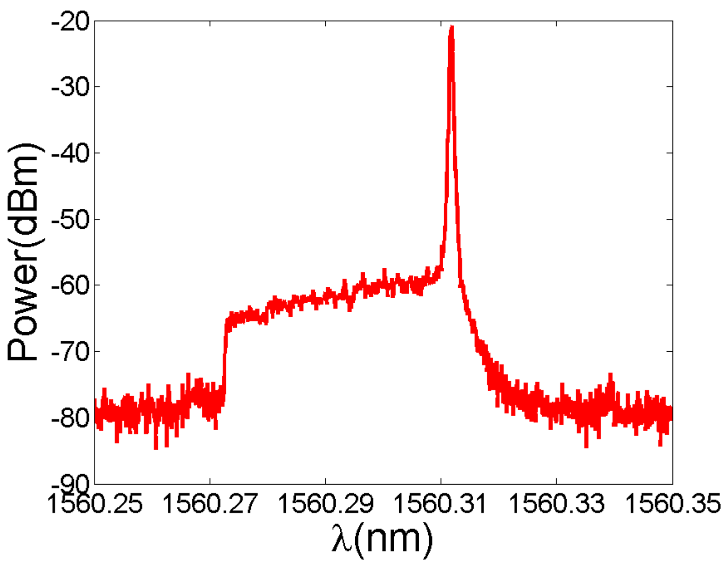


Figure 2: Single Side-Band OFDM spectrum with 40MHz MHz sub-carriers spacing measured by APEX-UHR-OSA.

Multi-Band COH-OFDM: a strong candidate for long-haul transmission beyond 100 Gbps

Another solution to eliminate the CD effect is to use COD at the receiver. At this step, low-linewidth lasers are required for both transmitter and receiver in order to reduce the laser phase noise. COD-OFDM is usually required for its major performance making it a strong candidate for long-haul transmission system. We know that the main challenge in single band OFDM is probably the realization of the digital to analog converters (DAC) and the analog to digital converter (ADC) that are required at the transmitter and receiver side, whose performance is still limited in terms of bandwidth. Instead of using single band OFDM technique several independent OFDM sub-bands are generated by dividing the Wavelength Division Multiplexing (WDM) channel spectrum, each of them has its own optical frequency carrier as depicted in figure 3. In this context, by using multi-band (MB) OFDM, the constraints on both the DAC and ADC are relaxed and the cyclic prefix in-between the OFDM symbols (which makes OFDM robust to ISI) is reduced. Therefore, COD-OFDM technique in its multi-band approach is a key solution to carry WDM long-haul transmission beyond 100 Gbps due to its intrinsic robustness to ISI caused by chromatic dispersion and polarization-mode dispersion (7).

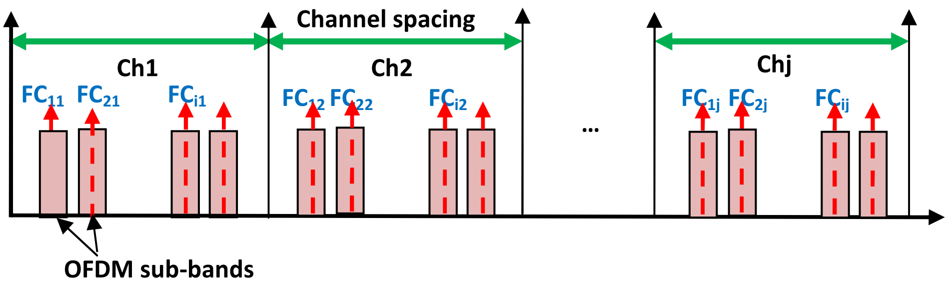


Figure 3: MB-OFDM optical spectrum (7)

Recently, by using a multi-band OFDM approach combined with polarization multiplexing, one could imagine to carry 100 Gbps over long haul networks by four polarization-multiplexed sub-bands as depicted in figure 4 (3). It has been shown that coherent dual polarization multi-band OFDM (DP-MB-OFDM) is a very interesting candidate for WDM transmission at 400 Gbps and even 1 Tbps (3).

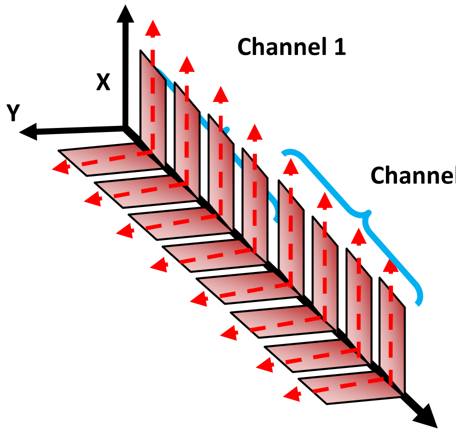


Figure 4: Schematic of DP-MB-OFDM signal

DP-MB-OFDM signals with APEX-UHR-OSA?

Figure 5 shows the experimental setup of 100 Gbps DP-MB-OFDM transmitter as mentioned in reference (3). A comb of optical carriers spaced by 10 GHz is generated by using an external cavity laser (ECL) and driving a dual-arm Mach-Zehnder modulator (MZM) with a 10 GHz RF frequency (5). A combination of 20 GHz and 40 GHz polarization-maintaining delay line interferometers (PM-DLI) splits into four groups of carriers spaced by 40 GHz the initial comb of 10-GHz-spaced optical carriers. Each of the four generated combs is modulated by a complex-MZM (CMZM) and combined by a 4:1 polarization-maintaining (PM) coupler. Thanks to two arbitrary waveform generators (AWG), data carried by neighboring sub-bands are totally decorrelated, provided that AWG 1 generates the first and third sub-bands while AWG 2 generates the second and fourth sub-bands (3).

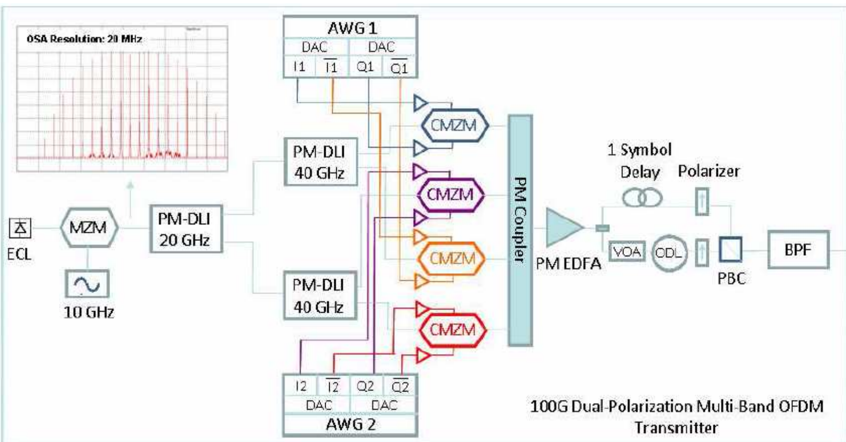


Figure 5: Set-up of 124 Gbps DP-MB- OFDM transmitter (3). The comb spectrum shown in the first inset is measured by the APEX-UHR-OSA

The important role of our APEX-UHR-OSA is to adjust the operating point of the CMZM in order to generate the DP-MB-OFDM signal. Orange Labs France, a second APEX UHR-OSA user proves the high equipment efficiency in adjusting and adapting their 45MHz spaced sub-carriers DP-MB-OFDM signal (3).

As depicted in figure 6, the APEX UHR OSA allows to flexibly access to the zero transmission point of the two MZM related to the in-phase (I) and the quadrature (Q) arms. In addition, the APEX UHR OSA can be used for tuning the integrated phase shifter to Π/2.

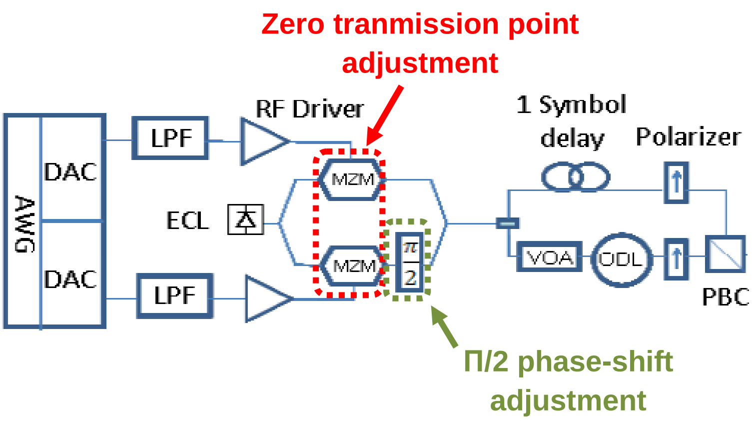


Figure 6: APEX UHR OSA roles in adjusting polarization-multiplexed OFDM sub-band transmitter (8)

Figures 7(a) and 7(b) depict the optical spectrum of the polarization-multiplexed OFDM sub-band before and after the adjustment step of the operating point of the CMZM marked by the carrier suppression.

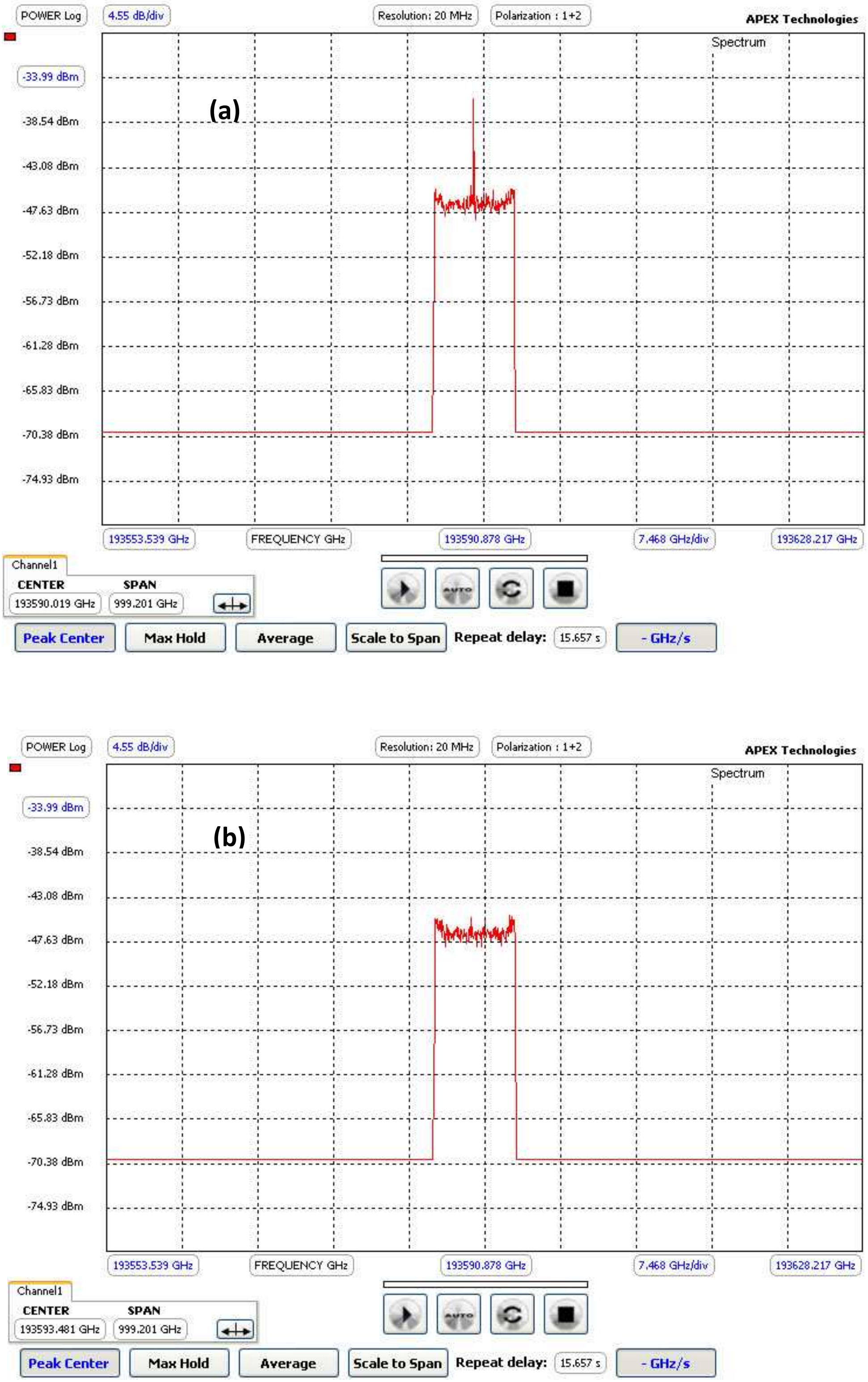


Figure 7: Polarization-multiplexed OFDM sub-band optical spectrum before (a) and after (b) the adjustment step.[1]

[1] 100G-FLEX project of the « Pole de compétitivité Images & Réseaux »

The required four optical carriers are selected at the transmitter output by a square flat-top optical band-pass filter (BPF) of ~ 40 GHz bandwidth (figure 5). The optical spectrum of the 100 Gbps DP-MB-OFDM measured by the APEX UHR OSA is shown in figure 8.

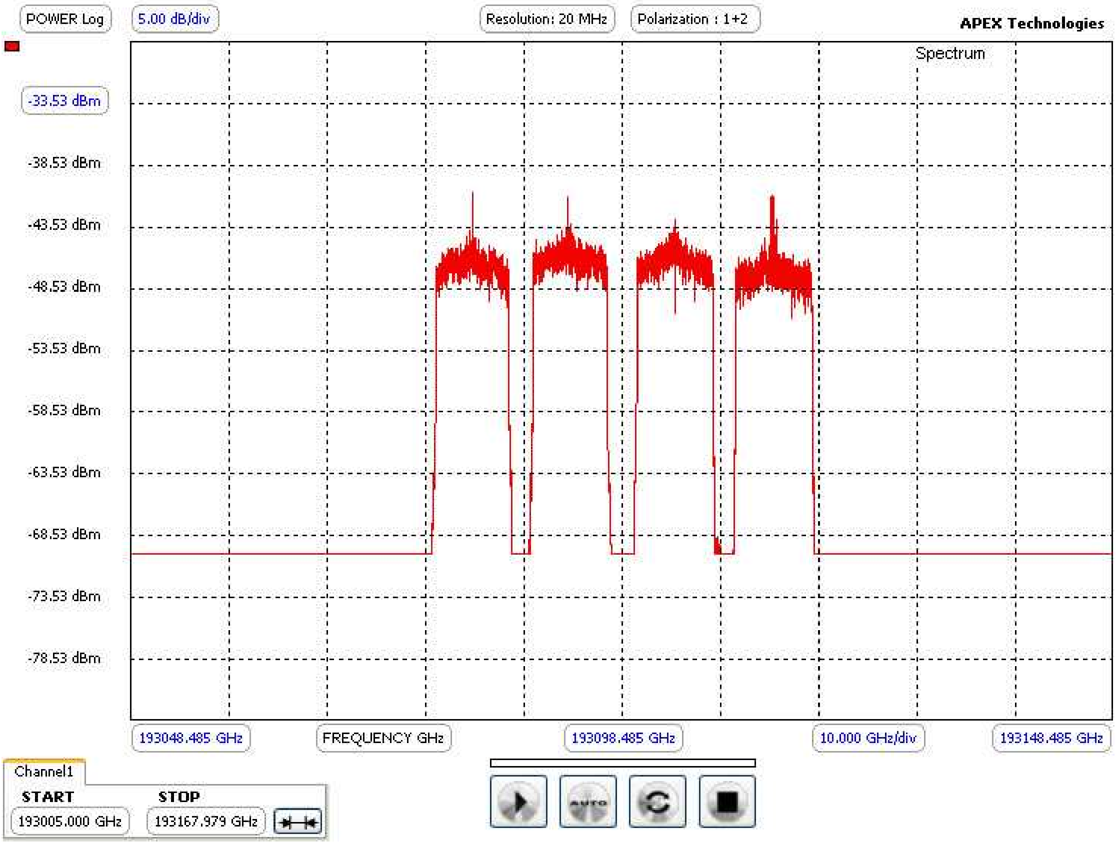


Figure 8: DP-MB-OFDM optical spectrum measured by APEX-UHR-OSA[2]

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