

Optical Complex Spectrum Analyzer (OCSA)

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This paper explains clearly the patented method used by the Apex Technologies Optical Complex Spectrum Analyzer AP2441B/AP2443B developed in collaboration with France Telecom scientists. It is based upon a spectral analysis of the optical field; it extracts the amplitude and the phase of each frequency component (whereas classic optical spectrum analyzers measure only the power spectral density, giving only the amplitude). By knowing the amplitude and the phase of each spectral component, the temporal variations of the amplitude and the phase can be calculated by means of the Fourier transform, providing the intensity, the chirp and the phase as a function of time.



Optical Complex Spectrum measurement steps

Based upon a spectral analysis of the optical modulated signal, the Optical Complex Spectrum Analyzer (OCSA) extracts the amplitude and the phase of each frequency component. For each complex spectral analysis, three steps can be distinguished :

- First step : Power measurement
- Second step : Phase measurement
- Third step : Calculation of the different characteristics

For the OCSA, the optical modulated signal under test have to be periodic with a repeat frequency ($Fr1$) of 2.5GHz or ($fr2$) of 625MHz in order to obtain respectively a 2.5 GHz or 625 MHz spaced spectral components. The clock signal can be set from 9.92GHz to 12.5GHz (front panel clock) or from 2.48GHz to 3.125GHz (back panel clock), so the repeat frequency can be set from 2.48GHz to 3.125GHz($fr1$) or from 620MHz to 781MHz ($fr2$).

1. Power measurement

The power measurement of each spectral component of the modulated signal under test is realized by the Optical Spectrum analyzer by using a peak search function (figure1).

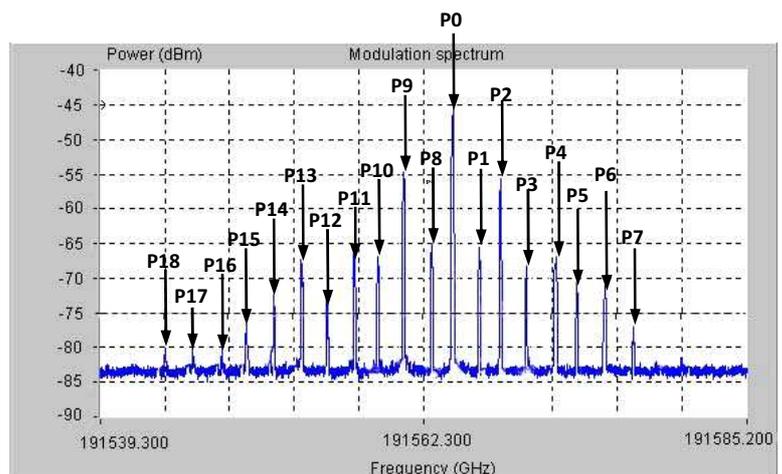


Figure 1: Power Measurement of the modulated signal

2. Phase measurement

For the phase measurement, a frequency shifting of $\pm Fr/2$ of the modulated signal under test is realized for each spectral component using the clock signal.

With this frequency shifting, two consecutive spectral components of the signal under test will interfere together as shown in figure 2.

Then, the clock signal is delayed several times (with different particular delays) and the resulting spectrums are measured (figure 3).

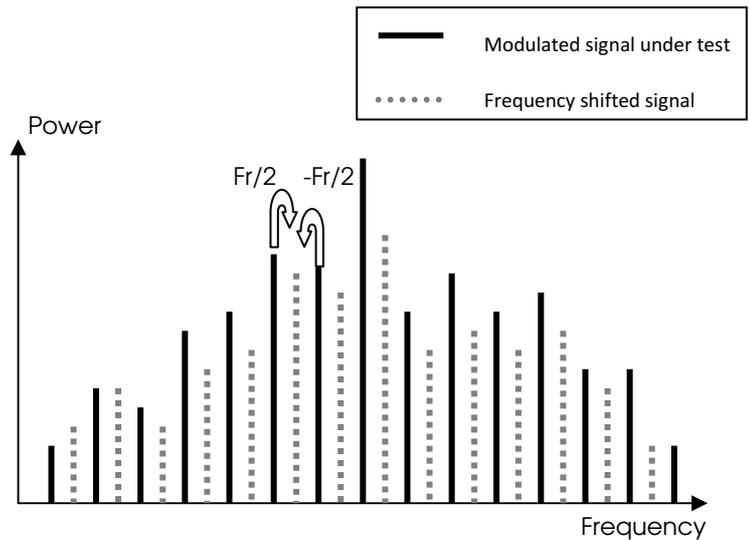


Figure 2: Modulated signal under test and frequency shifted signal for phase measurement

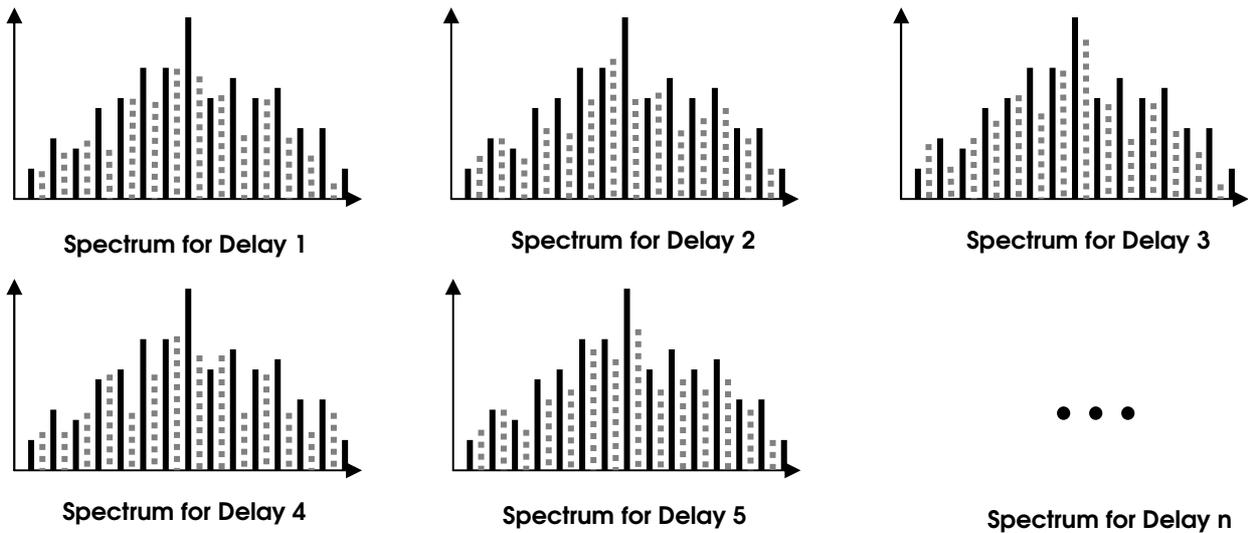


Figure 3: Phase measurement principle

So, by knowing the exact delay applied and by analyzing the resulting power of the frequency shifted signal as a function of the delay, it is possible to deduct the relative optical phase of two consecutive spectral components.

3. Fast Fourier Transformation (FFT) calculation

An electromagnetic field of an optical wave can be expressed in the complex form as:

$$E = |A| \exp[i2\pi f_0 t + \varphi] \quad (1)$$

where A is the complex envelop, f_0 is the frequency and φ is the phase of the optical wave. The « chirp » designates the transient deviation of the instantaneous frequency f from the value f_0 , caused by a temporal variation of the phase φ . The instantaneous frequency is given by:

$$f(t) = f_0 + \frac{1}{2\pi} \frac{d\varphi}{dt} \quad (2)$$

The chirp is defined by:

$$\Delta f(t) = f(t) - f_0 = \frac{1}{2\pi} \frac{d\varphi}{dt} \quad (3)$$

This method is adapted to periodic modulation signals only. Let T be the period, $Fr = 1/T$ the fundamental frequency of the modulation signal $M(t)$. Then the complex envelop of the optical field has the same period and thus the Fourier expansion of the complex field can be written as:

$$E(t) = A(t) \exp[i2\pi f_0 t] = \sum_k A_k \exp\{i[2\pi(f_0 + kFr)t + \Phi_k]\} \quad (4)$$

The corresponding spectrum is composed of discrete and regularly spaced lines. One is located at the carrier frequency f_0 , surrounded by modulation lines located at $f_0 + kFr$. A_k is the amplitude and Φ_k is the phase of the line k .

The amplitude values are given by the power levels of the spectral lines. Knowing A_k and Φ_k , an FFT algorithm calculates:

$$A(t) = \sum_k A_k \exp\{i[2\pi k F t + \Phi_k]\} = |A(t)| \exp[i\varphi(t)] \quad (5)$$

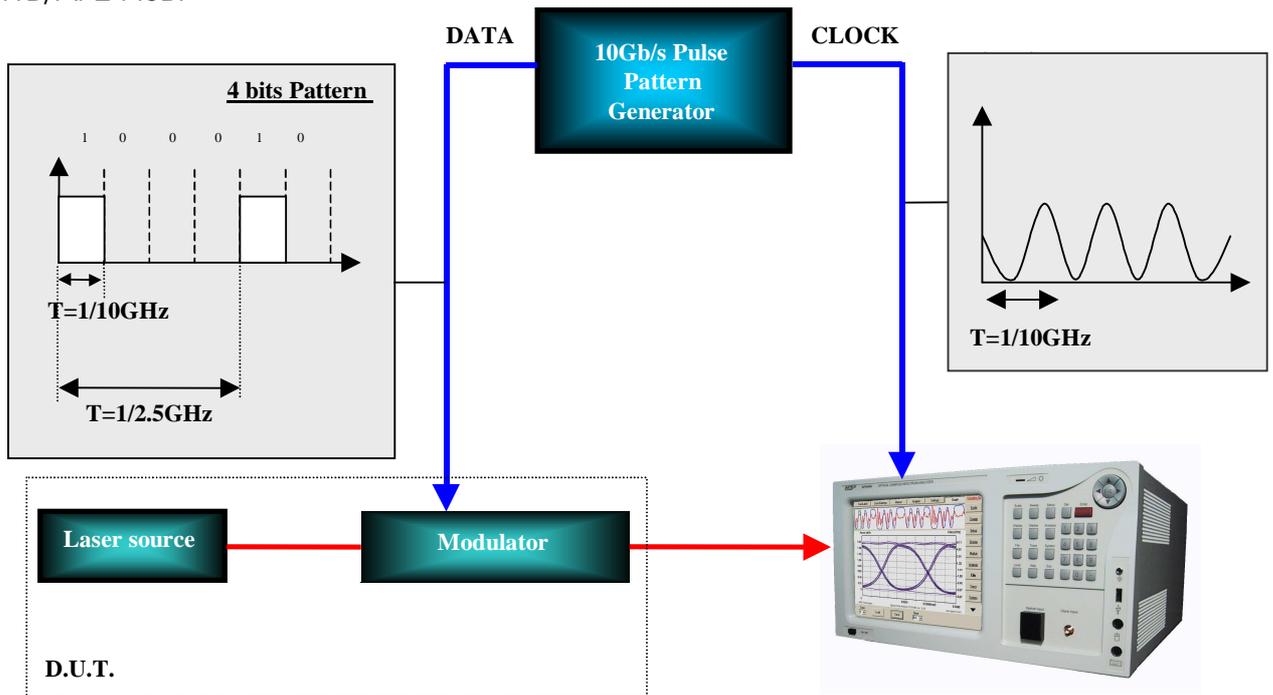
which leads to the measurement of the intensity and chirp temporal profiles as well as the α -parameter defined by:

$$\alpha(t) = 2I \times \frac{d\varphi/dt}{dI/dt} \quad (6)$$

where I is the optical signal intensity.

Measurement configuration example at 10 Gb/s

For 10 Gb/s NRZ (period of 100ps) measurements, it is necessary to generate a 4 bits pattern. For any bit rates, to measure the complex spectrum, we need a 10 GHz clock (front panel clock input) or 2.5 GHz clock (back panel clock input). The clock frequency can be tuned from 9.95 GHz to 10 GHz or from 2.48 GHz to 3.125GHz. The minimum power required for the clock is -10dBm and the maximum is +10dBm. The figure 4 shows a 10 Gb/s measurement configuration using the Optical Complex Spectrum Analyzer AP2441B/AP2443B.



Conclusion

While Optical Spectrum Analyzer can measure only the power of a modulated signal, APEX Technologies Optical Complex Spectrum Analyzer (OCSA) is able to measure the optical phase in frequency and time domain with a maximum bandwidth > 6 THz and a maximum temporal resolution of about 75 fs. The OCSA is using a patented method for Short Pulse Shape, time resolved Chirp, optical phase and α -parameter measurements.

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