

# FM-to-AM conversion measurement for high power nanosecond lasers

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**Abstract.** Through numerical simulations we show that the spectral content of amplitude modulations induced by a transfer function converting frequency modulations required for high-power lasers may be very broad. Hence, measurement of FM-to-AM conversion should be first done in the spectral domain to remove unwanted transfer functions at low frequency scale and then in the time domain to obtain an accurate value.

## 1. Introduction

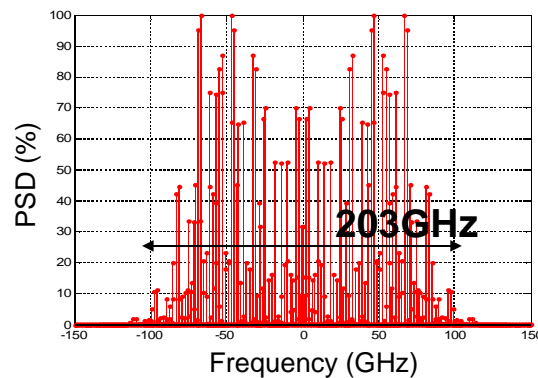
High-power nanosecond lasers like LMJ or NIF require phase modulations both for avoiding stimulated Brillouin scattering in the optics which could cause damage and for beam smoothing of the focal spot. Typical induced spectral broadenings are 200GHz at  $1\omega$ , and 600GHz at  $3\omega$  for LMJ. Because of any small distortion of the spectrum, part of the phase modulation is converted into unwanted amplitude modulation. This is called FM-to-AM conversion [1]. The spectral content of AM may be narrow (a few gigahertz) or wide (up to the spectral content of the optical pulse, i.e.: 200GHz or 600GHz depending on the wavelength) depending of the type of distortions. FM-to-AM conversion should be reduced as much as possible to avoid laser damage of the optics and changes of the optical waveform reaching the target. Hence, a lot of work has been done during the last ten years to reduce FM-to-AM conversion (by reducing spectral distortions), to reduce the sensitivity to distortions (by changing the phase modulation), and to precompensate for distortions [2]. Only smooth and stable filtering functions may be precompensated. However, to assess the improvement brought by these schemes, FM-to-AM conversion has to be measured with accuracy. The aim of this paper is to give rules for an accurate measurement of FM-to-AM conversion.

## 2. Measuring in the spectral domain

Spectral broadening is obtained with sinusoidal phase modulations:  $e^{i m \sin(2\pi f_m t)}$  where  $f_m=2\text{GHz}$  and  $m=7$  for anti-Brillouin and  $f_m=14.25\text{GHz}$  and  $m=5$  for smoothing. Such modulations induce the power spectral density given in Figure 1. The intensity remains constant in time. FM-to-AM conversions are usually characterized by the  $\alpha$  factor equal to  $2 \cdot (I_{\max} - I_{\min}) / (I_{\max} + I_{\min})$ . It is equal to 0 when there is no FM-to-AM conversion.  $\alpha$  should be measured in the time domain. However, it is possible only if the spectral content of AM is narrow, because of the limited bandwidth of single-shot oscilloscopes. Another way of measuring AM is to measure the spectral transfer function and to use a Fourier

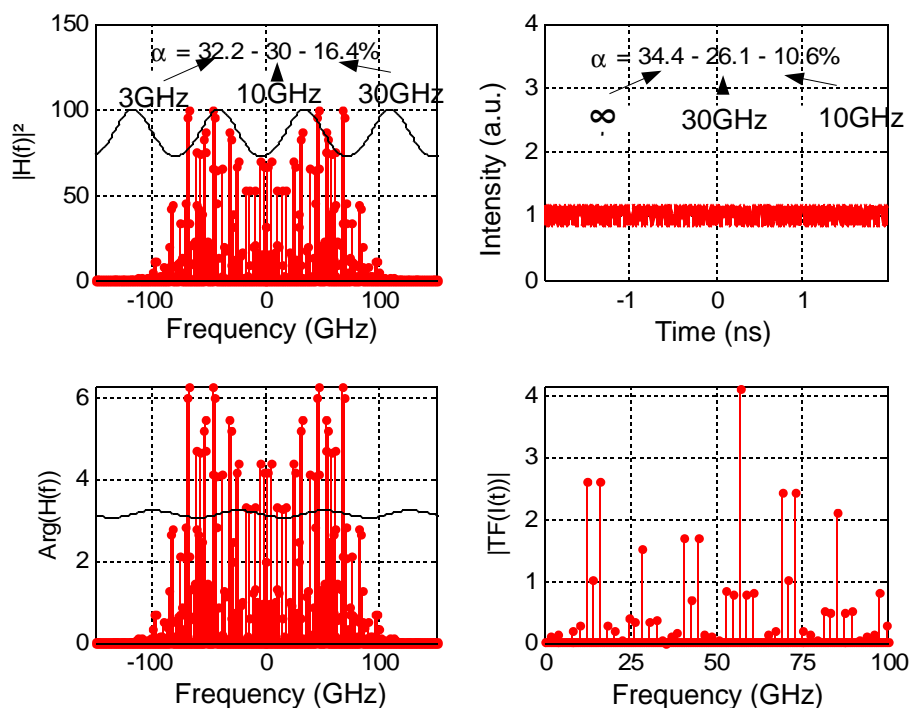


transform. However, not only the spectral intensity distortions but also the spectral phase distortions should be measured which is quite difficult.



**Figure 1:** Power spectral density of an LMJ pulse.

As a matter of fact, let us consider a two-wave interferometer filter like the one shown in Figure 2.  $\alpha$  is equal to 34.4%. We can simulate what could happen to a pulse seeing either only the transfer function in intensity or only the transfer function in phase. It happens that  $\alpha$  is still in the same order of magnitude (31,9% for the transfer function in intensity only and 33% in phase only).

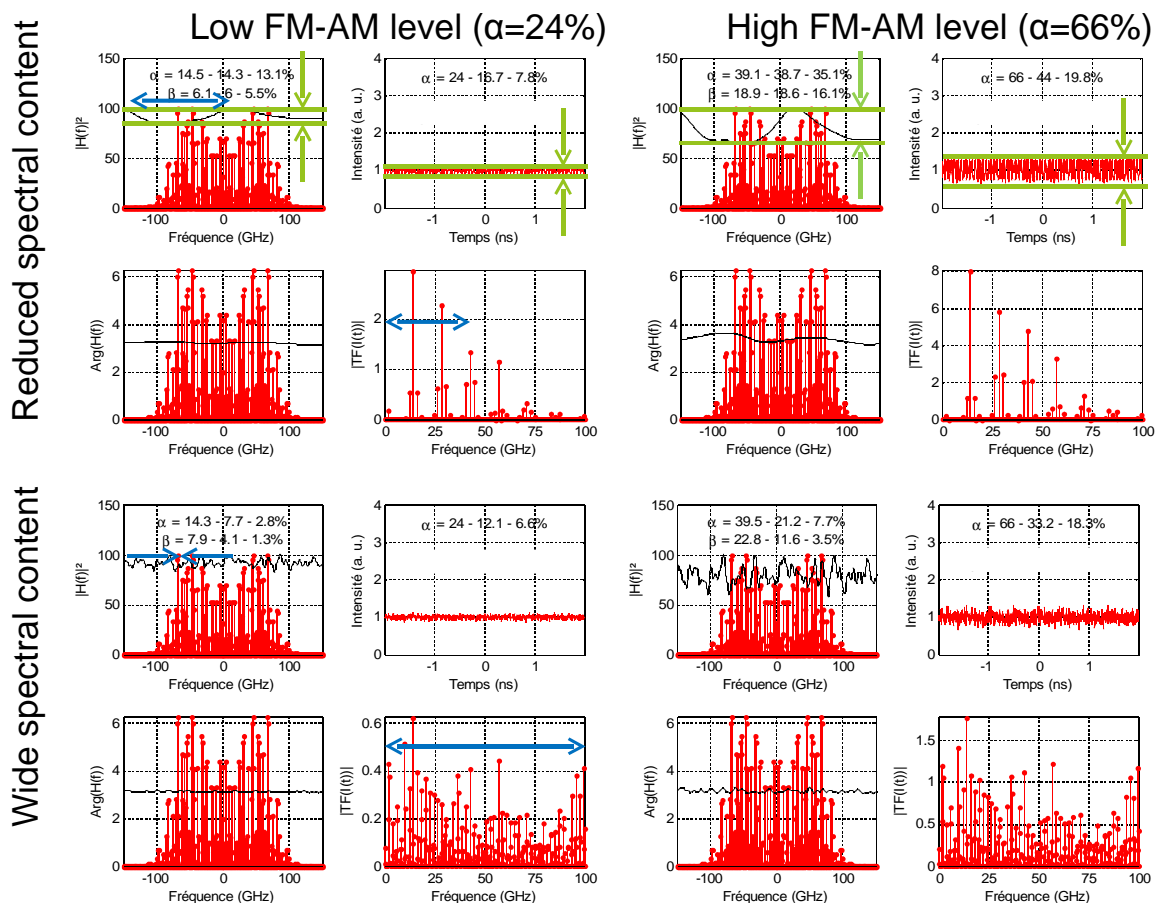


**Figure 2:** FM-to-AM conversion due to a two-wave interferometer transfer function. The left part shows the transfer function in intensity (above) and in phase (below). The power spectral density is given at the same frequency scale. On the right, we show the resulting AM modulation and its Fourier transform. The values of  $\alpha$  given in the figures correspond to simulated measurements in the spectral domain on the left (by measuring the transfer function in intensity) with a spectral resolution of 3GHz, 10GHz and 30GHz and in the time domain on the right with an infinite, 30GHz or 10GHz bandwidth. The value in the time domain with an infinite bandwidth (34.4%) corresponds to the actual value.

Although in this case, measuring the transfer function in intensity to compute  $\alpha$  would give the correct order of magnitude of  $\alpha$ , the transfer function in phase cannot be neglected in general since its impact can be as high as the transfer function in intensity. Therefore, measuring the transfer function in intensity to compute  $\alpha$  is only possible when the transfer function is supposed to be known and is a dangerous process for the one wanting an accurate value.

### 3. Measuring in the time domain

Thus, a measurement in the time domain seems compulsory. But the measurement bandwidth is limited. Hence, the spectral content of AM should be studied. As a matter of fact, as shown in Figure 3, the level of AM is determined by the amplitude variations of the transfer function (the higher the amplitude variations, the higher the AM level, as can be seen with the vertical green arrows) while the spectral extension of AM is determined by the frequency scale of the transfer function (the lower the frequency scale, the broader the spectral content of AM, as can be seen with the horizontal blue arrows).

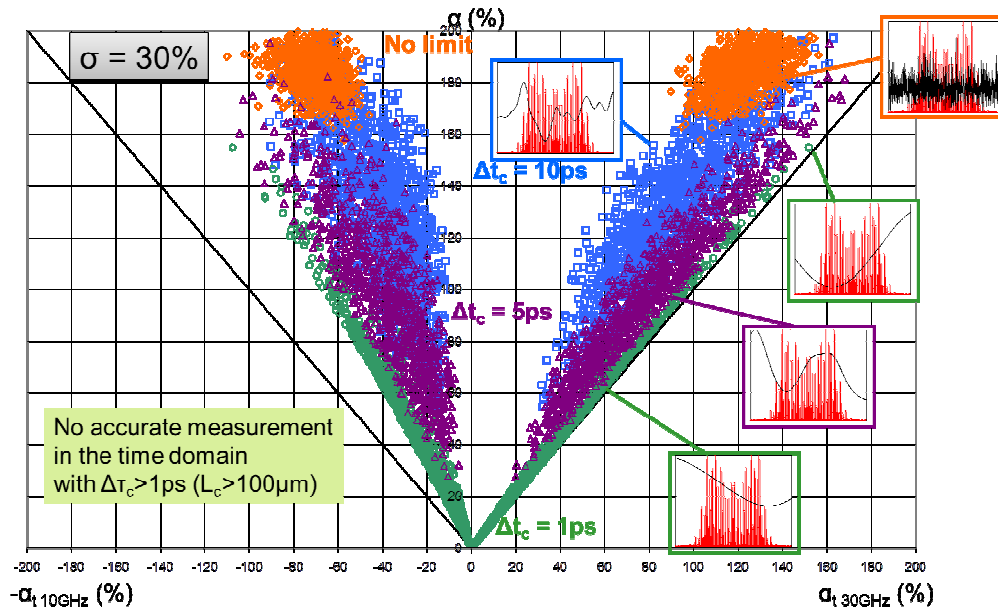


**Figure 3:** FM-to-AM conversion for different transfer functions. Above with a reduced spectral content, below with a wide spectral content. On the left with lower FM-to-AM conversion level. On the right with higher FM-to-AM conversion level.

Spectral distortions may either come from smooth and stable filtering functions (gain narrowing, spectral acceptance for frequency conversion...) or from interferometric filtering due to parasitic

effects. Interferometric filtering may have almost any length scale ranging from  $\mu\text{m}$  inside coatings to meters between components. These length scales correspond to different times of flight or to different frequency scales as the ones shown in Figure 3. The longer the time of flight, the more rapidly the spectral function changes.

We thus performed numerical simulations of  $\alpha$  measurements in the time domain with a given oscilloscope bandwidth and we compared the measured values to the actual ones (Figure 4). The transfer functions were randomly drawn with different frequency scale (i.e.: different typical times of flight  $\Delta t_c$ ) but for a given standard deviation  $\sigma$  of the amplitude variation of the transfer function. We can conclude from this figure that for a good correlation between the measured and the actual values, the typical time of flight should be below 1ps.



**Figure 4:** Actual FM-to-AM conversion level (vertical axis) versus the measured value when the measurement is performed in the time domain with 30GHz bandwidth (right of the horizontal axis) or 10GHz bandwidth (left of the horizontal axis). An accurate measurement corresponds to a point on the diagonal line and the wider the point cloud the lower the correlation. The different colors correspond to different times of flight. Typical example of transfer functions are given in the insets.

#### 4. Conclusion

We have shown that FM-to-AM measurement should be done in two steps:

1) first measuring the spectrum with a high resolution, for instance with a Fabry-Perot interferometer with a reduced phase modulation. This measurement should allow removing your set-up parasitic effects with long times of flight by anti-reflection coating, tilting optics...

2) once the times of flight are sufficiently low, typically below 1ps (corresponding to lengths below a few hundreds micrometers), FM-to-AM conversion can be accurately measured in the time domain with an oscillator having at least 10GHz bandwidth, ideally 30GHz. This measurement can be safely used for the compensation of FM-to-AM conversion.

#### References

- [1] J.E. Rothenberg et al., Proc. SPIE, 1999, 3492, pt. 1-2, pp. 51-61.
- [2] S. Vidal et al., Applied Optics, Vol. 51, No. 24, pp. 5818-5825, 08/2012.