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Automated Optical Amplifier Gain Flattening

1. Scope and Overview

Commonly used amplifiers such as Erbium Doped Fiber Amplifiers (EDFA) and Raman amplifiers provide optical amplification that varies with wavelength. One solution is to flatten out the powers across the transmission window by attenuating higher power channels comparatively to the lower power channels. This is more generally referred to as gain flattening.

This note describes how a WaveShaper combined with an optical spectrum analyzer (OSA) can be used to create a robust automated gain flattening system that adapts on-the-fly to changes in the optical power spectrum. This system algorithm can successively improve the level of flatness down to as little as ±0.1 dB deviation from the mean. The system is versatile and applicable for use both in the field and as part of an optical test bed.

Four key pieces of hardware are needed for the automated gain flattening system: the computer, the WaveShaper, the fiber tap, and the OSA. The equipment configuration is shown in Figure 1.

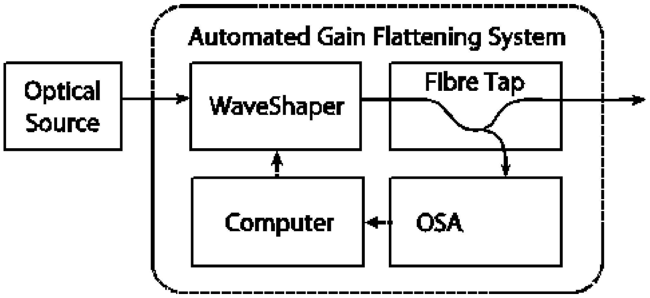

Figure 1: Experimental Setup Schematic for an AGF system.

The optical source to be flattened is connected to the WaveShaper common port. The WaveShaper output is then connected to a fiber tap, sending a small amount of optical signal to an OSA such as Finisar's WaveAnalyzer. The data from the OSA is sent to the computer and is used to perform the gain flattening algorithm.

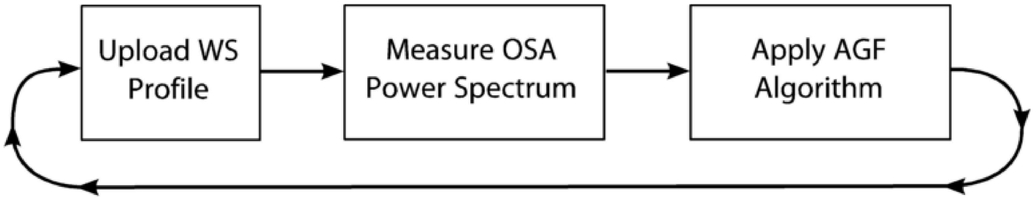

Figure 2: Illustrates the algorithm feedback loop used in the AGF system.

The automated gain flattening (AGF) system uses a feedback loop shown in Figure 2 to maintain a flat spectral profile even after spectral changes occur.

Conceptually, this feedback loop allows the WaveShaper profile to be systematically modified based on the OSA measurement. The key idea behind the AGF algorithm is to attenuate the power level at each frequency down to common power level. In other words, additional attenuation is introduced into spectral regions of increased power. The deviation in measured power from the common level is added to the WaveShaper attenuation profile at each iteration of the algorithm. This algorithm can be expressed mathematically by the equation:

$$\begin{aligned} B_n &= A_n - \mathrm{Meas}(A_n), \\ A_{n+1} &= B_n - \min(B_n). \end{aligned}$$

Where An is the WaveShaper attenuation profile i.e. the 2nd column of the *.wsp file. Meas(An) denotes the OSA measurement of the attenuation after applying profile . It is the negative of the measured power spectrum. The initial WaveShaper profile, Ao can be set to zero attenuation for all frequencies. A schematic of this process showing the first two iterations is illustrated in Figure 3.

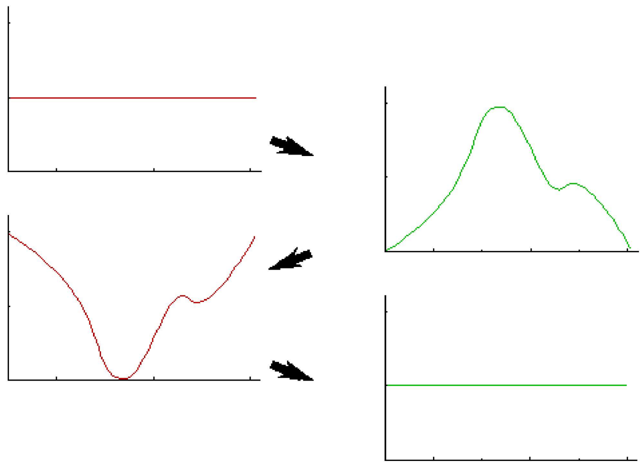

Figure 3: Schematic showing the automated gain flattening algorithm. The left figures show the WSP attenuation profiles uploaded to the WaveShaper, while the right figures show the corresponding experimental measurements.

In practice, the following steps are taken for the nth iteration:

1. A wsp profile with an attenuation profile of An is uploaded to the WaveShaper.
2. The resulting power spectrum is measured using the OSA.
3. The power spectrum data is transferred to the computer, converted to attenuation and then filtered.
4. This data is subtracted off An to give Bn.
5. To remove the possibility of negative attenuation, the profile for the next iteration is equal to Bn minus a constant given by the minimum value of Bn.

The WaveShaper is capable of producing filters containing spectral features as small as 10 GHz. Features smaller than 10 GHz are beyond the resolving capabilities of the WaveShaper and are filtered out by the internal optics. As a result, spectral features smaller than 10 GHz in the measured OSA data can lead to instabilities and diverging profiles. This is prevented by using an appropriate filtering algorithm.

2. Measuring and Filtering

There are two main regimes that an AGF system may run under: the first encompasses the flattening of a broadband light source with a continuous power spectrum e.g. an ASE light source. The second involves flattening a light source consisting of a series of optical comb lines of varying peak power. The implementation of the flattening algorithm varies slightly for each regime. Specifically the measurement in the equation above, Meas(An), is interpreted differently for each regime.

2.1 Flattening a Continuous Power Spectrum

Many optical light sources e.g. ASE broadband sources have a non-flat power spectrum, and flattening this light source is often essential for many applications. For flattening this type of source, the entire spectrum is measured with the OSA and then filtered with a smoothing filter. In this regime, Meas(An) from Eq. 1 includes the filtering process. An illustration of this smoothing filter is shown in Figure 4.

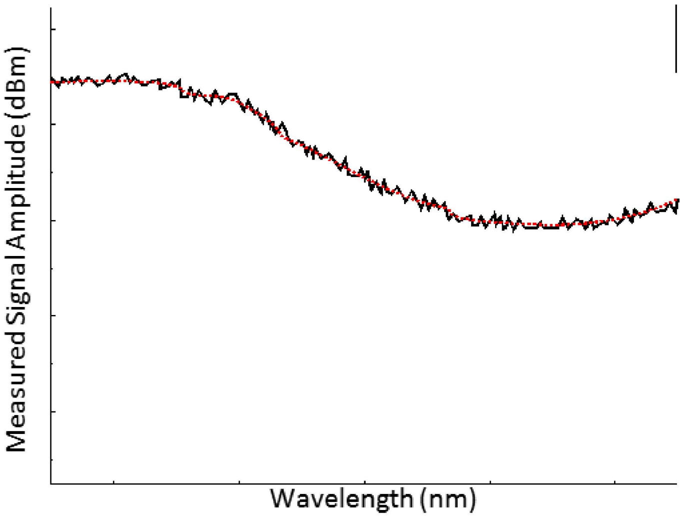

Figure 4: Illustrating measuring and filtering the power spectrum of a continuous light source. The black line represents the data taken from an OSA trace, while the red line represents , the smoothed data used to calculate the next iteration.

The OSA trace must be filtered to remove sharp features which would otherwise cause instabilities in the iterative system. It is sufficient to suppress features smaller than around 20 GHz. The data reported here used a zero-phase Butterworth filter, however other filters such as a Savitzky-Golay, or Gaussian filter are suitable. Note that the filter chosen must be a zero-phase filter to prevent data misalignment.

2.2 Flattening an Existing Channel Plan

When the optical signal already contains a set of modulated optical channels, the measured power spectrum will consist of a series of comb lines, each corresponding to an optical channel. If the same approach taken when using a continuous light source is applied here, the algorithm would aim to flatten the comb lines themselves, rather than the comb line peak power. For this reason, the approach taken in Section 2.1 is not suitable under this regime.

To perform spectral flattening on a set of optical comb lines, the OSA measurement, denoted by Meas(An) , is calculated by measuring the peak power level at each comb line peak and linearly interpolating for power levels between peaks. Unlike in the previous regime, no filtering is required.

3. Algorithm Implementation

3.1 Formatting Data

As the format of the trace data supplied by the OSA may vary, the data must be interpolated to the same resolution used by the WSP profile string, e.g. a 1 GHz grid. Furthermore, before being used in the equation above, care should be taken to make sure that the trace data is converted to attenuation, i.e. the negative of power in dB.

3.2 Limiting the Attenuation Range

It can be useful to place a limit on the total amount of flattening that can occur. For example, if a light source varies in intensity by more than 10 dB, it might be useful to prevent the algorithm from defining an attenuation greater than 10 dB. To do this, simply coerce each evaluation of Bn to values between 0 and 10 dB.

3.3 Algorithm Loop

The following function is called as part of the main iterative gain flattening loop. The necessary WSP profile(s) are generated by the algorithm and then uploaded to the WaveShaper.

For A-Series WaveShapers, this is done by using the **loadprofile** command.

For earlier models, it is necessary to use the **ws_load_profile** function call in the WaveShaper API to load the WSP profile to the WaveShaper.

4. Results

A gain automated system was implemented to flatten the power spectrum of a broadband ASE light source using a C+L Band WaveShaper, with experimental results shown in Figure 5.

In this example here, the gain flattening algorithm was operated in a frequency range of 187.5 to 196.275. The maximum attenuation limit was set to 10 dB. The regions between 186 THz to 188 THz and 195 THz to 196 THz are not flattened because doing so requires attenuating the whole profile beyond the 10 dB limit. The results show that only 3 – 4 iterations were needed before the profile converged to within 0.1 dB.

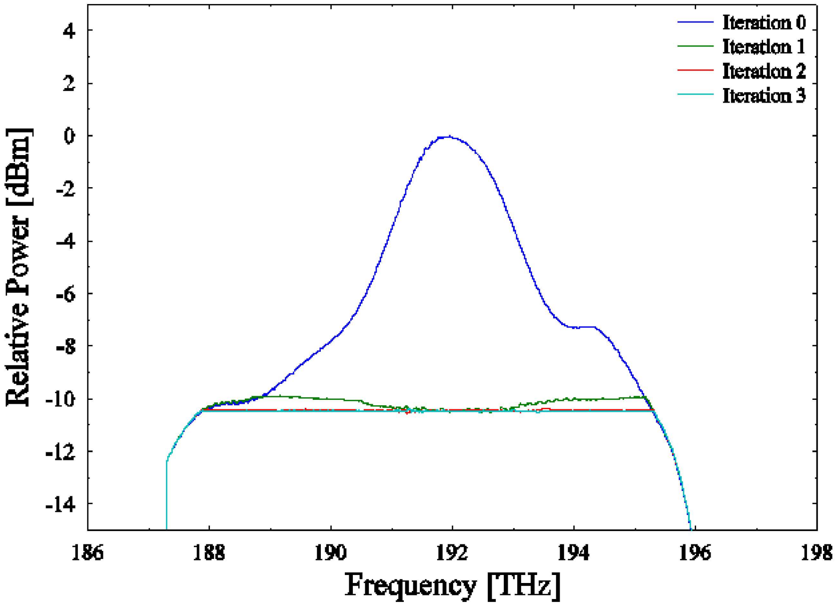

Figure 5: Experimental results showing the automated gain flattening of a broadband ASE light source using a C+L band WaveShaper. It shows the first 4 iterations.

5. Further Application – Carving Comb Lines

The gain flattening algorithm produces a WSP profile that is specifically tailored to flatten the power spectrum of a particular optical light source. It is possible to apply additional WSP filters to 'carve' out new filter shapes while simultaneously counteracting the non-flat power spectrum of the light source.

For example, optical test beds often require optical sources that emulate the power spectrum of real-life optical communication systems. A WaveShaper can be used to accurately reproduce the power spectrum of a modulated data signal by carving out comb lines. The shape of the comb line filter could correspond to a particular modulation format of a WDM system. Furthermore, the automated gain flattening system allows the power of each channel to be equalized.

To do this, the automated gain flattening system is first used to flatten a broadband light source. The final attenuation profile generated by the algorithm acts as a base flattening profile that will then have the attenuation of another WSP profile added onto it. In this case, a series of comb lines designed to emulate a DPSK channel plan with 50 channels equally spaced at 50 GHz spacing are filtered out.

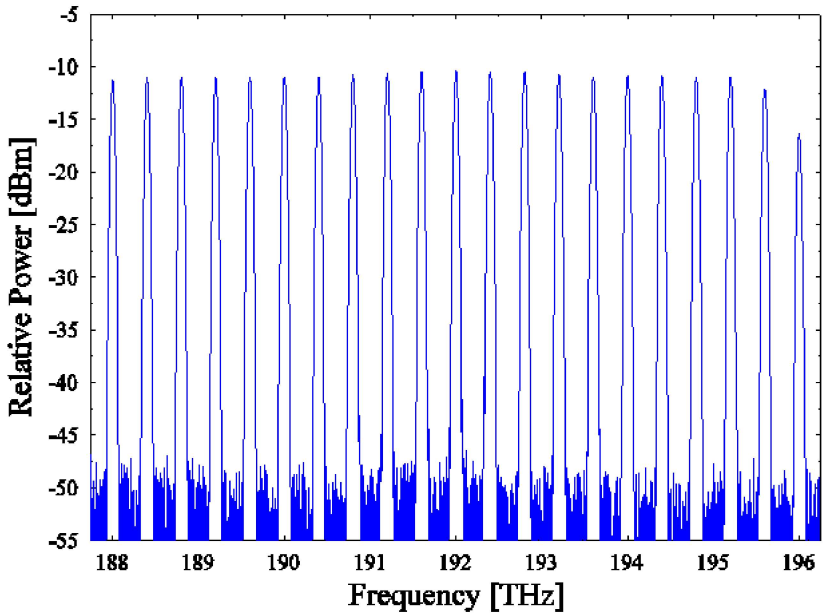

Figure 6: Experimental measurement of Gaussian channels spaced every 200 GHz. Each channel has a 3-dB bandwidth of 40GHz. This was obtained by adding the attenuation profile of the filter to the attenuation profile of a flattened light source.

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