Designing the dispersion for optimum supercontinuum bandwidth using picosecond pulses

Nikolov, Nikola Ivanov; Bang, Ole; Bjarklev, Anders Overgaard

Published in:

Link to article, DOI:
10.1109/OFC.2003.1247457

Publication date:
2003

Document Version
Publisher’s PDF, also known as Version of record

Citation (APA):
change of the POF (principal state of polarization), while simulation test may not consider these restrictions. The requirement on real time response means that the selected algorithm needs to be efficient (real time) response.

The requirement on reliable response means that the selected algorithm needs to be globally convergent, so that response is always in the correct direction. The starting point of the fiber is chosen to be the center of the fiber. In this paper, we will consider the problem described in [1] and propose an algorithm to meet the challenging requirements.

2. PULSE-WIDTH

A very good introduction on POF in optical fibers can be found in [1] [5] [9]. It is a highly nonlinear phenomenon. The derivatives because of this nonlinearity are real valued. Direct calculation will give the partial derivatives with respect to the real valued functions.

The Lagrange multiplier method is used for constrained optimization problems. In [1], the optimization algorithm of the pulse-width compression problem was presented. Since a and b are complex, we denote by $a_{00}$, $a_{01}$, $b_{00}$, and $b_{01}$ the real and imaginary parts of $a$ and $b$ respectively. Direct calculation will give the partial derivatives of $a_{00}$, $a_{01}$, $b_{00}$, and $b_{01}$ with respect to the real valued functions.

The constraint can be rewritten as a product manifold of two spheres $M=BS_{1} \times S_{2} \times S_{3} \times S_{4}$, where $S_{1}$ is the real sphere, $S_{2}$ is the complex sphere, $S_{3}$ is the real sphere, and $S_{4}$ is the complex sphere. The search for the minimizer will be carried out along the geodesic on the surface of $M$ corresponding to the partial derivatives. For this purpose, we first find

based on the partial derivatives, the gradient of $s(q)$, which is a product manifold of the derivative vector on to the tangent plane of $M$ at the current position. Let $w_{1}$, $w_{2}$, $w_{3}$, and $w_{4}$ be the derivatives of the diagonal matrix with its argument as the diagonal elements, and let $V=diag(w_{1}, w_{2}, w_{3}, w_{4})$. Then the derivative vector on to the tangent plane is given by $\nabla l(V-t(V) + det(g)(V-t(V))$, where $g$ is the metric of $g$.

Using the geodesic formula for sphere, it is easy to obtain the following result:

Claim: The geodesic of $M$ emanating from $w$ along the direction $d$ is given by $\exp_{w}(d)$ (see also [1]).

From this result, it is clear that the iteration in step 1, which involves the calculation of the derivatives and projection, is much more straightforward and simpler than the iteration described in [1], which involves to solve a set of complex nonlinear equations.

Several properties were proved in [11] about this algorithm. First, inequality in step 1 is well defined in the sense that one can always find an $\alpha$ such that the inequality holds. This means the search will never fail. Second, the objective function is improved in every iteration, and all intermediate points obtained in Step 2 are feasible, i.e., they meet the constraint. This feature is important for real-time applications. Third, the algorithm is globally convergent to a set of optimizer candidates. Finally, the convergence rate is linear.

This proposed algorithm is implemented in MATLAB for a simple problem proposed in [1]. Starting from any point, after a few iterations, the algorithm finds a local optimizer.

4. CONCLUSIONS

A new algorithm is proposed to optimize a pulse-width compression problem. This algorithm is better for real-time implementation. Since many POF compensation problems are constrained optimization problems with variables as Jones vectors, this technology can easily be extended to all the cases.

REFERENCES


We use the standard split-step Fourier method with 210 points in a time window of T=236ps. In our longest simulation out to L=7.7m the photon number is conserved to within 5% of its initial value. Due to our large spectral window (405nm-1613nm) we see in Fig.1(left) the emergence of FWM stokes and anti-stokes waves at the wavelengths $\lambda_{s}=1100nm$ and $\lambda_{as}=1450nm$ for which the phase matching condition $\Delta \theta=\beta_{s}\beta_{as}\Delta \lambda=0$ is satisfied. The spectral window presented in [6] was narrower and thus $\lambda_{s}$ and $\lambda_{as}$ were not observed. We find the maximum FWM parametric gain to be twice the maximum SRS gain, which explains why the FWM stokes and anti-stokes components appear before the SRS components.

The loss and walk-off of the PCF gives the maximum distance $L_{m}$ over which nonlinear processes, and thus the SC process, are efficient. From Fig.1 we see that after the FWM stokes and anti-stokes components are generated they broaden much in the same way as the central part of the spectrum around the pump. The merging of the spectral parts around $\lambda_{s}$ and $\lambda_{as}$ would create an ultra broadband spectrum as observed in tapered fibers with femtosecond pulses [2,4]. However, in this particular case the FWM stokes and anti-stokes lines are too far away for a merging to take place within the maximum length $L_{m}$, i.e., before nonlinear effects become negligible.

In Fig. 3, we show the spectrum for the dispersion profiles D2-D4, which have two Stokes and two anti-Stokes lines. The corresponding dispersion coefficients $\beta_{s}$, $\beta_{as}$ and $\beta_{4}$ are $\beta_{s}=-0.285ps^{-2}km$, $\beta_{as}=0.051x10^{-6}ps^{-4}km$, and $\beta_{4}=0.251x10^{-6}ps^{-4}km$ for D2, $\beta_{4}=-1.31ps^{-2}km$, $\beta_{as}=2.51x10^{-6}ps^{-4}km$, and $\beta_{as}=5.85x10^{-6}ps^{-4}km$ for D3 and $\beta_{4}=-3.92x10^{-6}ps^{-4}km$ for D4. For the dispersion profile D4, cascaded direct degenerate FWM peaks appear. This leads to an even broader SC of approximately 600nm within 20dB.

For the dispersion profile D2 we have $\beta_{s}=1.1ps^{-1}km$, $\beta_{as}=2.74x10^{-6}ps^{-2}km$, and $\beta_{as}=3.92x10^{-6}ps^{-2}km$. In Fig.4 the spectrum for the dispersion profile D5 is shown and for this case the direct degenerate FWM process generates three Stokes and anti-Stokes lines. As seen this improves a lot the spectrum for shorter fiber lengths. For longer lengths, as $\Delta \theta=\beta_{s}(4)$, the wavelengths of the Stokes and anti-Stokes lines shift due to the input power depilition and dips in the final SC spectrum are formed. To overcome this feature we increase slightly the input power to $P_{in}=500W$, and as is seen from Fig.4 the resulted spectrum is 800nm wide within 20dB.

The absence of Stokes and anti-Stokes lines from the direct degenerate FWM process in the experiments in [6], is explained with the violation of the phase matching condition $\Delta \theta$ due to irregularities along the fiber. We estimate the robustness of the proposed method for SCG, towards random dispersion fluctuations along the fiber. We consider the highly nonlinear PCF fiber reported in [7], and estimate the variation of the dispersion coefficients $\beta_{2}$ and $\beta_{as}$ to be: $\Delta \beta_{2}=-9.5\%$. We assume that the variation $\Delta \beta_{as}$ for all dispersion coefficients $\beta_{as}$ is 10%. The random process is Gaussian white noise. From Fig.5 it is seen that for dispersion profile D2, the random dispersion variations significantly reduce the effectiveness of the direct degenerate FWM and it finally does not contribute to the generated SC. This is explained by the narrow gain-band for direct degenerate FWM for the dispersion profile D1, strongly reducing the average gain. However for dispersion profile D5, the generation of the Stokes and anti-Stokes lines is more robust, due to the broader gain band-width. By a more thorough theoretical study it can be shown that for dispersion profiles D3-D5 the band-width of the direct degenerate FWM gain profile is even broader. This allows us to conclude that for modified dispersion profiles D3-D5, the improvement of SCG due to generation and merging of Stokes and anti-Stokes lines is robust to fiber imperfections.

We have shown that the direct degenerate FWM can significantly improve the SCG due to broadening and final merging of stokes and anti-stokes lines. The bandwidth of the achieved SC can be optimized by a proper design of the fiber. The robustness of the process towards variations in the dispersion coefficients along the PCF was also investigated. It is shown that for a fiber with a modified dispersion profile the generation and final merging of the Stokes and anti-Stokes lines with the main SC part is robust. This work was supported by the Danish Technical Research Council (Grant no. 26-00-0355) and the Graduate School in Nonlinear Science (The Danish Research Agency).

References:

Authorized licensed use limited to: Danmarks Tekniske Informationscenter. Downloaded on March 03, 2010 at 10:15:01 EST from IEEE Xplore. Restrictions apply.