Designing the dispersion for optimum supercontinuum bandwidth using picosecond pulses

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the minimizer will be found. For this purpose, we first find, expressing mathematical formulae by plain words, the gradient of the derivative vector to the tangent plane of $\mathcal{M}$ at the current position (e.g., $\mathbf{w}$). Let $\mathbf{w} = [\mathbf{w}_1, \mathbf{w}_2]^T$ be the output of the optical fiber can be represented as $\mathbf{E}(t)$, where $\mathbf{E}$ is the wave function. The purpose of this paper is to propose a new algorithm to select the polarization state vectors of the input and the output to minimize the output pulse-width for the fiber transmission system described by transfer matrix. Let $\mathbf{E}(t)$ be the Fourier transform of the pulse $\mathbf{E}(t)$. The time varying electric field at the input of an optical fiber is given by $[\mathbf{E}(t)] = \mathbf{E}(t)$, where $\mathbf{E}(t)$ is the field vector at the input to the fiber. This result of receiving $\mathbf{E}(t)$ on a state of polarization $\mathbf{O}$ will be $\mathbf{E}_p = \mathbf{T}(\mathbf{w})\mathbf{E}(t)$, where $\mathbf{T}$ denotes transfer matrix to the fiber. First, inequality in step 1 is well defined in the sense that one can always find an $\mathbf{O}$ 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.

3. THE NEW OPTIMIZATION ALGORITHM

The problem described above is a typical nonlinear constrained optimization problem. In [1], Lagrange multiplier method was used for computer simulation to find the solution. Since Lagrange multiplier method is used for general nonlinear equality constrained optimization problem, it is not efficient for this very special problem. In addition, the set of complex nonlinear eigenvalue equations used in [1] are very difficult to be solved from the viewpoint of numerical analysis. Also, the convergence property of Lagrange multiplier method for this problem was not addressed in [1]. We will use optimization techniques on Riemannian manifold (cf. [1]) to solve this problem. The problem described above is solved using optimization techniques along geodesics of the smooth surface presented by the constraint set, and therefore all intermediate directions are feasible. Since $\mathbf{O}$ and $\mathbf{E}$ are complex, we denote by $\mathbf{x}_1, \mathbf{y}_1, \mathbf{z}_1$ and $\mathbf{t}_1$ the real and imaginary parts of $\mathbf{O}$ and $\mathbf{E}$ respectively. Direct calculation will give the partial derivates of $\mathbf{O}(\mathbf{w}), \mathbf{y}(\mathbf{w}), \mathbf{z}(\mathbf{w}), d\mathbf{O}(\mathbf{w})d\mathbf{w}$, and $d\mathbf{E}(\mathbf{w})d\mathbf{w}$ (we omit here the proofs to save the space, and omit the formulation of the algorithms). The purpose of this paper is to propose a new algorithm to select the polarization state vectors of the input and the output to minimize the output pulse-width for the fiber transmission system described by transfer matrix. Let $\mathbf{E}(t)$ be the Fourier transform of the pulse $\mathbf{E}(t)$. The time varying electric field at the input of an optical fiber is given by $[\mathbf{E}(t)] = \mathbf{E}(t)$, where $\mathbf{E}(t)$ is the field vector at the input to the fiber. This result of receiving $\mathbf{E}(t)$ on a state of polarization $\mathbf{O}$ will be $\mathbf{E}_p = \mathbf{T}(\mathbf{w})\mathbf{E}(t)$, where $\mathbf{T}$ denotes transfer matrix to the fiber. First, inequality in step 1 is well defined in the sense that one can always find an $\mathbf{O}$ 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 an $\mathbf{O}$, 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 PMD compensation problems are constrained optimization problem with variables as Jones vectors, this technology can easily be extended to all those cases.

REFERENCES

We use the standard split-step Fourier method with 311 points in a time window of T=230ps. In our longest simulation out to L=3.7m the photon number is conserved to within 5% of its initial value. Due to our large spectral window (460nm-1613nm) we see in Fig.1 (left) the emergence of FWM stokes and anti-stokes waves at the wavelength $\lambda_s=1000nm$ and $\lambda_a=450nm$ for which the phase matching condition $\delta\Delta=\beta_s+2\beta_a=0$ is satisfied. The spectral window presented in [6] was narrower and thus $\lambda_s$ and $\lambda_a$ were not observed. We find the maximum FWM parametric gain to be twice the maximum SRS parametric gain, where $\beta_s$ and $\beta_a$ are 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 can be observed, and the SSG process, are efficient. From Fig.1 we see that after the FWM stokes and anti-stokes components are generated they broaden much more slowly than the central part of the spectrum around the pump. The merging of the spectral parts around $\lambda_m$ and $\lambda_m$ would create an ultra broad 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 merging to take place within the maximum length $L_m$, i.e. before nonlinear effects become negligible.

The wavelengths $\lambda_s$ and $\lambda_a$ can be adjusted to be closer to the pump wavelength $\lambda_p$ by a proper design of the dispersion. This will enable the FWM stokes and anti-stokes lines to broaden enough to allow a final merging. To show the effect we modify $\beta_s$, $\beta_a$, and $\beta_l$ to $\beta_s=0.02\times10^{-3}/\text{ps}\cdot\text{km}$, $\beta_l=2.5\times10^{-3}/\text{ps}\cdot\text{km}$, and $\beta_a=2.25\times10^{-3}/\text{ps}\cdot\text{km}$. The phase matching condition $\delta\Delta=\beta_s+2\beta_a$ for this dispersion profile D2 then gives $\lambda_a=850nm$ and $\lambda_s=530nm$.

The numerical results shown in Fig.1 confirm our hypothesis. The FWM stokes and anti-stokes lines are still widely separated, but now generated close enough to the pump to broaden and merge. The resulting ultra broadband SC is flat within 20dB and spans 500nm in contrast to the original 230nm observed in [5].

Fig.1 Upper row: phase-mismatch $\delta\Delta$ and spectrum of the slow axis polarization component at L=10cm. Bottom row: same spectrum at L=20cm, 30cm, and 2m. Left figures are for dispersion profile D1 and right figures for D2, respectively. For case D1 additional spectral line is shown for $L=1.7m$.

Fig.2 Original dispersion [5] D1 (thick solid line) and our modified dispersion D2 (thick solid line), D3 (dotted line), D4 (dash-dotted line), and D5 (dashed line).

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Fig.3 Upper row: phase-mismatch $\delta\Delta$ and spectrum of the slow axis polarization component at L=10cm. Bottom row: same spectrum at L=20cm, 30cm, 1m, and 2m. Left: dispersion profile D3. Right: dispersion profile D4.

In Fig.3, we show the spectrum for the dispersion profiles D3-D4, which have two Stokes and two anti-Stokes lines. The corresponding dispersion coefficients $\beta_s$, $\beta_a$, and $\beta_l$ are $\beta_s=0.02\times10^{-3}/\text{ps}\cdot\text{km}$, $\beta_l=2.5\times10^{-3}/\text{ps}\cdot\text{km}$, and $\beta_a=2.25\times10^{-3}/\text{ps}\cdot\text{km}$. The phase-matching condition $\delta\Delta=\beta_s+2\beta_a$ for this dispersion profile D2 then gives $\lambda_a=850nm$ and $\lambda_s=530nm$.

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Fig.4 Upper row: phase-mismatch $\delta\Delta$ and spectrum of the slow axis polarization component at L=10cm. Bottom row: same spectrum at L=20cm, 30cm, 1m, and 2m. Left: dispersion profile D3. Right: dispersion profile D4.

The second-order SPM dispersion $\Delta_2$ gives rise to a SPM gain profile that is 10% broader than the standard gain profile. It is shown in Fig.4 that the direct degenerate FWM gain profile is even broader. This allows us to conclude that for the modified dispersion profiles D3-D5, the improvement of the direct degenerate FWM gain profile is even broader. This work is supported by the Danish Technical Research Council (Grant no. 26-00-0355) and the European Commission (GRD4-CT-1999-00033).

References