

Optimizing low loss negative index metamaterial for visible spectrum using differential evolution: reply

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Abstract: We reply to the comment written by Aslam and Güney on our previous paper, Zhao et al. [Opt. Express **19**(12), 11605-11614 (2011)]. We maintain that the proposed implementation of the DE algorithm for NIMs optimization in our work is correct, and the mentioned ambiguities in the comment due to the existence of multiple branches for n' in the retrieval procedure have been considered and eliminated by using the proposed robust retrieval method. Furthermore, the FOM of 15.2 for the DE-designed optimal fishnet structure reported in our work is reasonable for ideal fabrication conditions.

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References and links

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In the comment to our paper by Zhao et al. [1], Aslam and Güney claim that the presented retrieval method of effective parameters does not consider the effect of multiple retrieved branches for n' given by [2],

$$n' = \left\{ \operatorname{Re} \left(\cos^{-1} \left[\frac{(1 - s_{11}^2 + s_{21}^2)}{(2s_{21})} \right] \right) + 2\pi m \right\} / (kd); \quad m = 0, \pm 1, \pm 2, \dots \quad (1)$$

Effective parameters of a metamaterial may easily be misinterpreted by using the wrong branch for n' especially when there are discontinuities in the retrieved index.

However, we disagree with the above-mentioned viewpoint and believe that the comment actually misunderstood the proposed S-parameter retrieval methods [3] in our paper. In fact, after the transmission and reflection coefficients of each individual in DE algorithm are calculated by a FDTD solver, the robust retrieval method [3] proposed by X. D. Chen et al. is applied in our paper to determine the wave impedance Z , refractive index n , permittivity ϵ and permeability μ of the metamaterial which can be described as following:

$$n = \frac{1}{k_0 d} \left\{ \left[\left[\ln(e^{ink_0 d}) \right]'' + 2m\pi \right] - i \left[\ln(e^{ink_0 d}) \right]' \right\} \quad (2)$$

The proposed retrieval method [3] by X. D. Chen et al. is fundamentally different from the argued retrieval method [2] in the comment by Aslam and Güney. In the robust retrieval method [3], a Taylor mathematical method is proposed to choose the correct branch of the real part of the refractive index in order to guarantee the continuities of retrieval n' . The branch of n' can be obtained by a Taylor expansion approach considering the fact that the refractive index n is a continuous function of frequency. Since the refractive index n at the initial frequency determines the values of n' at the subsequent frequencies, we can determine the branch of the real part of n at the initial frequency by requiring that μ'' and ε'' are non-negative across all the frequency bands. The Taylor iterative procedure to determine the correct branch of n' has been elaborated in detail in the literature [3].

Moreover, the proposed robust retrieval method has been applied to various metamaterials and the successful retrieval results prove its effectiveness and robustness. For instance, P. Y. Chen et al. [4] present a genetic algorithm (GA) as one branch of artificial intelligence for the optimization-design of the artificial magnetic metamaterial whose structure is automatically generated by computer. After the S parameters of each chromosome are obtained by a FDTD solver, the robust retrieval method [3] is also applied to compute the effective impedance Z , refractive index n , permittivity ε_{eff} , and permeability μ_{eff} of the metamaterial.

Therefore, in our optimization procedure of DE algorithm, we can also determine the correct retrieved branch of n' and eliminate the discontinuities in n' branches by using the proposed robust retrieval method [3]. Moreover, in order to further guarantee the validity and accuracy of retrieval n' , all the optimal solutions of fishnet structure design at different generations have been tested and verified by a wedge-shaped model for negative refraction simulation which is proposed by X. Zhang et al. [5]. Thus, the proposed implementation of the DE algorithm for NIMs optimization in our paper is correct, and the mentioned ambiguities in the comment due to the existence of multiple branches for n' in the retrieval procedure have been considered and eliminated by using the proposed robust retrieval method [3].

Finally, we agree with Aslam and Güney's comment that if the CST simulation with collision frequency $\omega_{col} = 13.5\text{THz}$ for the Drude model of silver is considered, the highest FOM obtained in our work would be 6.4 as opposed to 15.2. However, we don't think that the FOM of 15.2 reported in our work is unrealistically large. Firstly, in our CST simulation, the optical parameters of silver are exactly the same as G. Dolling's work in literature [6]. In brief, we use the free-electron Drude model with plasma frequency $\omega_{pl} = 1.37 \times 10^{16} \text{s}^{-1}$ and collision frequency $\omega_{col} = 8.5 \times 10^{13} \text{s}^{-1}$ for silver. Moreover, according to the theoretical calculation results proposed by X. Zhang et al. [5, Fig. 5], the FOM could rise as high as about 20. The lower experimental FOM is due to reduced transmission resulting from fabrication imperfections. Therefore, the FOM of 15.2 for the DE-designed optimal fishnet structure reported in our work is reasonable for ideal fabrication conditions.

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