3-Bit Optical Coding for Improving the Power of Optical Computing

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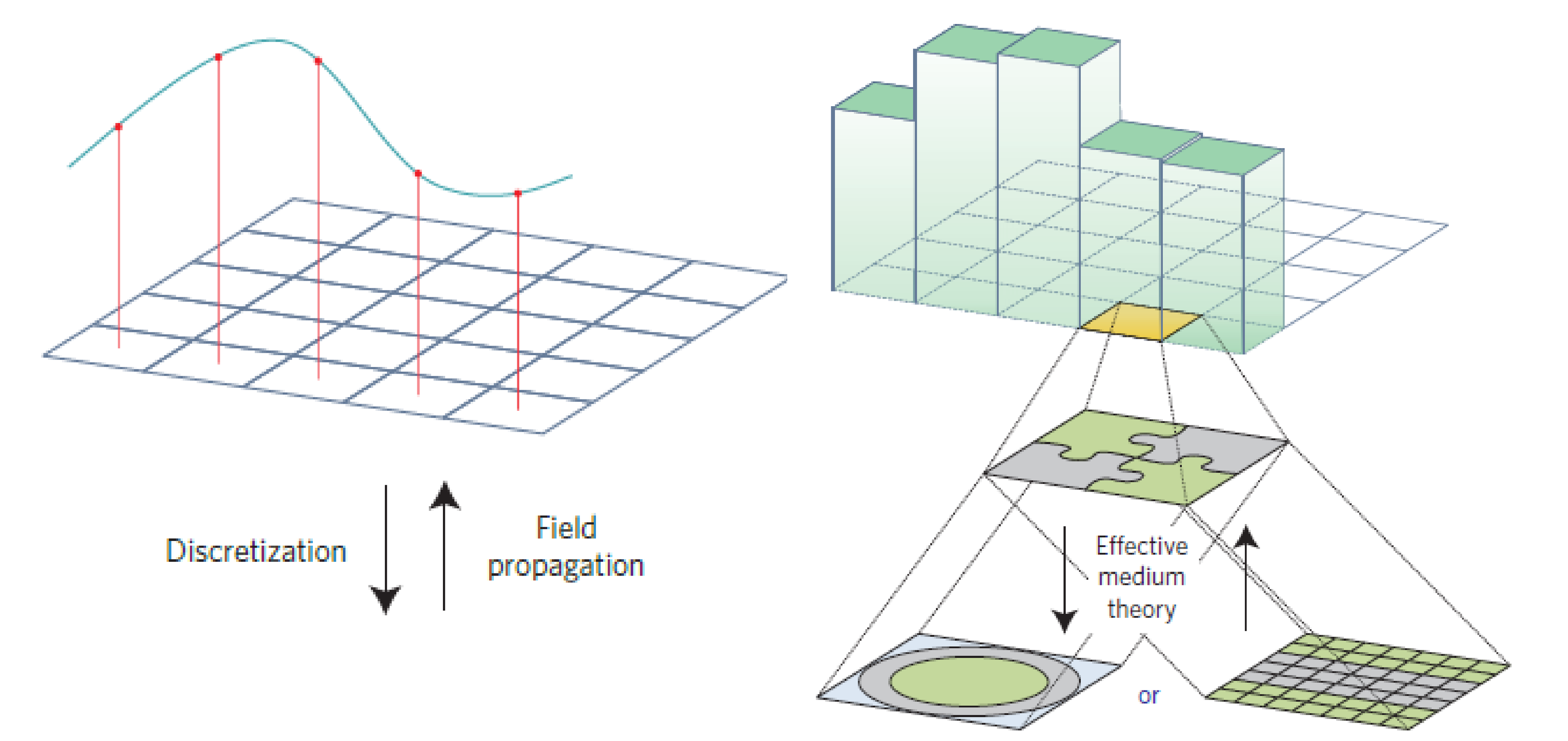
Motivations

(1) Study Optical computing Theory and fundamentals of Digital Metamaterials, and how to perform simulations using COMSOL.

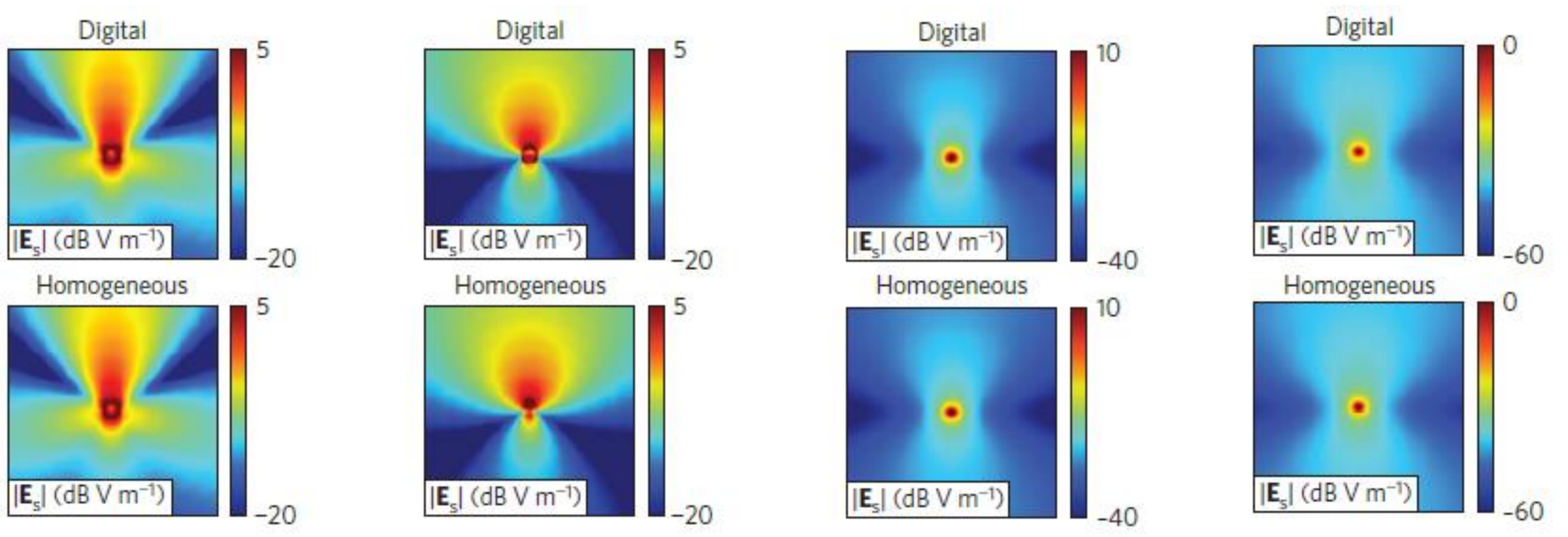
(2) Verify the sub-wavelength condition with periodic micro-particle cells by tuning the order of input wavelength using COMSOL.

(3) Overcome the limitation of '2 Bit Optical Coding' by applying '3 Bit Optical Coding' which is able to fill the whole upper complex plane of permittivity.

Digital Metamaterials



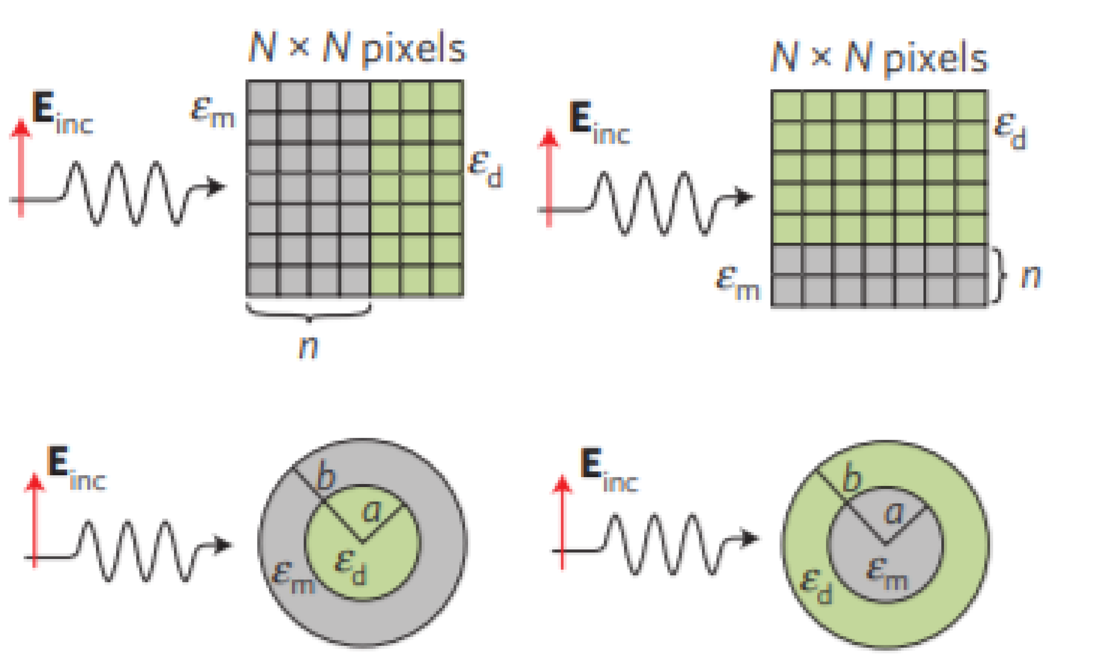
Digital Metamaterials can take advantage of the effective medium theory, which can give us optical properties that cannot exist naturally but only be implemented by engineering.



There is no difference between the digital composite of two optical byte and the material which is assumed to have same homogeneous optical parameter depending on effective medium theory.

Basic types of Digital Metamaterials

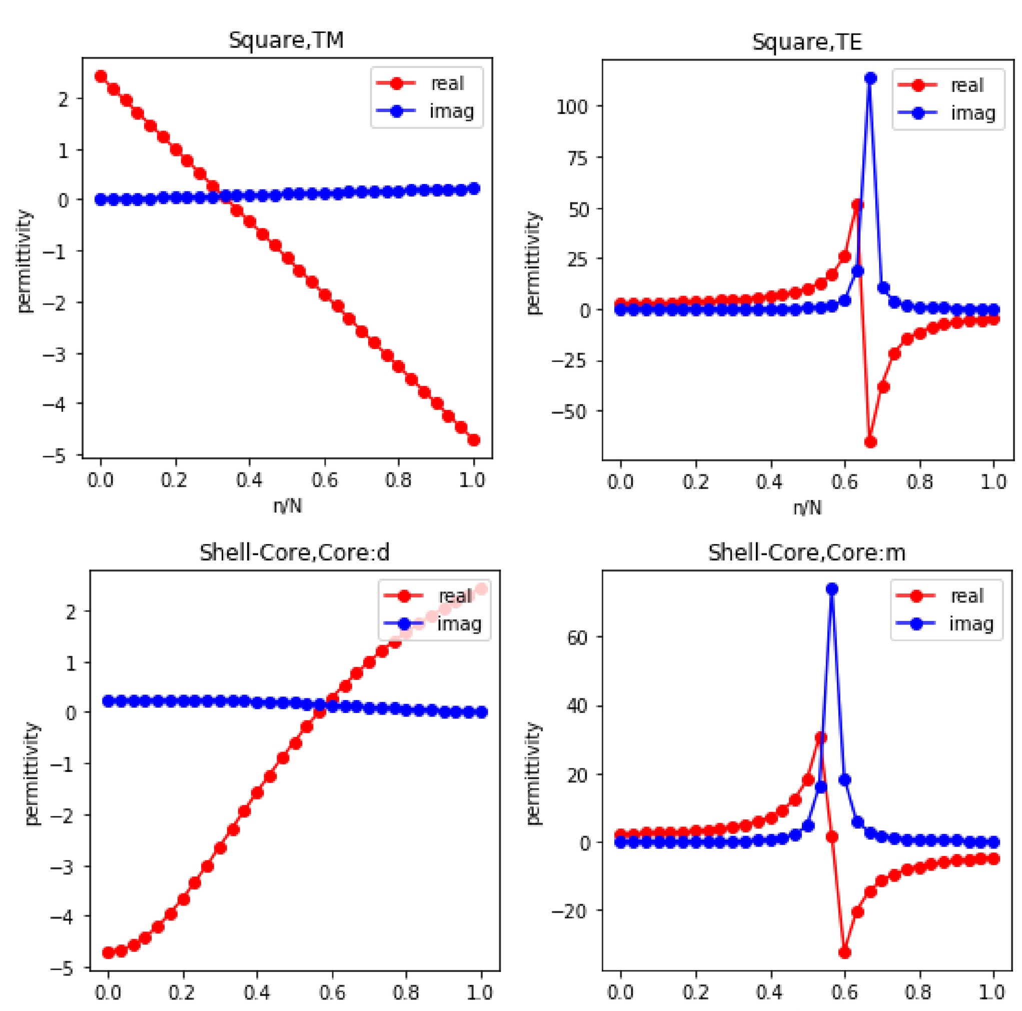
Planar Type / Concentric Type / Ordinary Characteristics / Extraordinary Characteristics



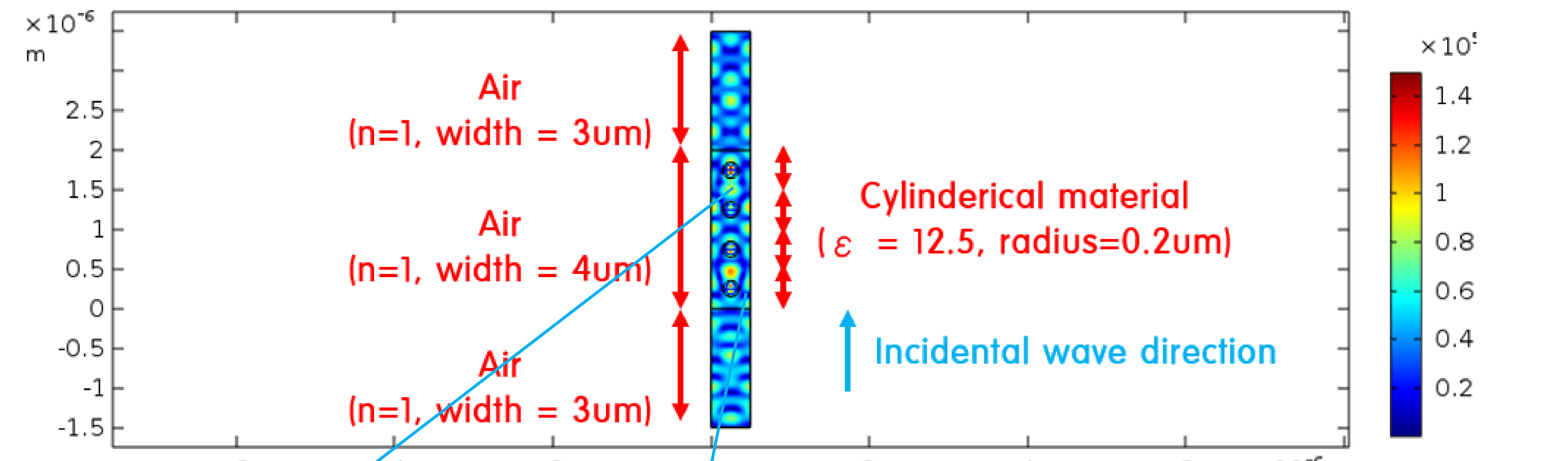
We can take 2 types of shape for 2 bit optical computing. One is planar type which is cubical structure made of 2 different metamaterial bits, the other is concentric type which has the core metamaterial bit covered by another shell metamaterial bit.

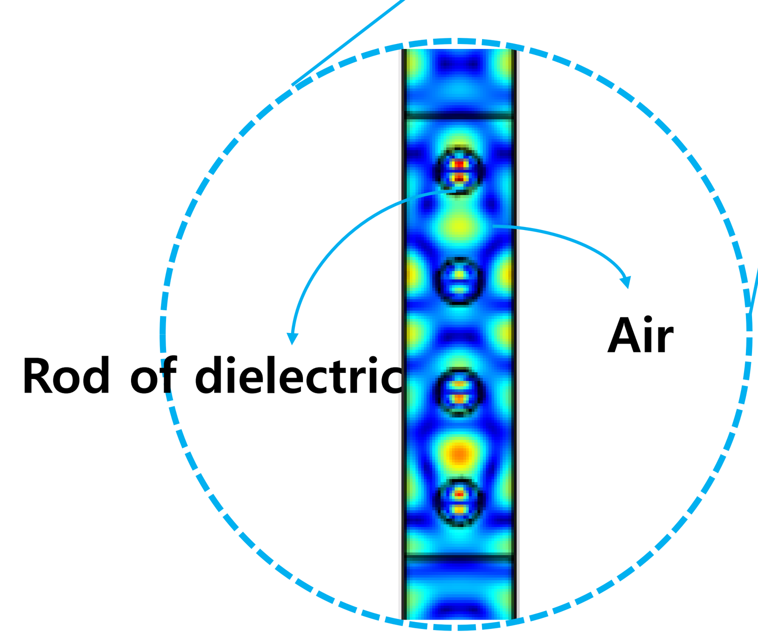
$\varepsilon_m = -4.7 + j0.22$ (Metalic Bit)
$\varepsilon_d = 2.42$ (Dielectric Bit)

After the simulation with COMSOL, we derive the permittivity of digital metamaterial bytes, for planar type and concentric type. The difference between 'Square TM' and 'Square TE' is the polarization of input wave, TM or TE. And the difference between 'Shell-Core,Core:d' and 'Shell-Core,Core:m' is used material for core, 'd' means dielectric, 'm' means metal. Shell material's composition is vice versa. Among these 4 types of metamaterial bytes, 2 types of left graphs are translated the arithmetic mean value of two different bit parameter, the others, 2 types of right graphs are translated harmonic mean value of two different bit parameter.

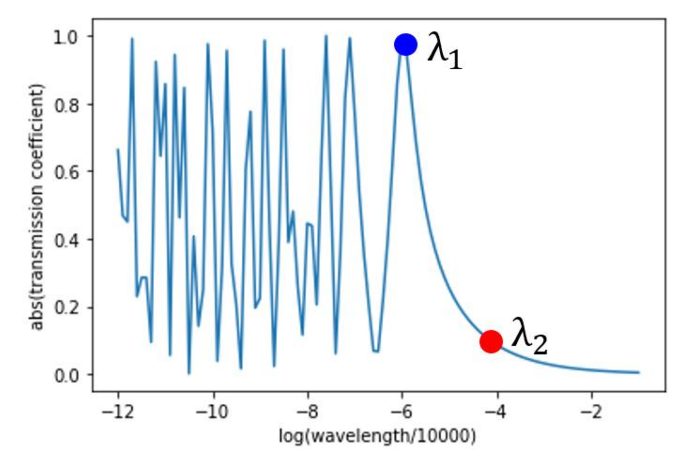


Subwavelength Condition





Target cell Length : $0.5\mu m$
Rod of Dielectric Material, $\varepsilon_d = 12.5$, $r_0 = 0.2\mu m$
Input Source : $y = 0$, Output Source $y = 2 * 10^{-6}$
Simulation Program : Comsol

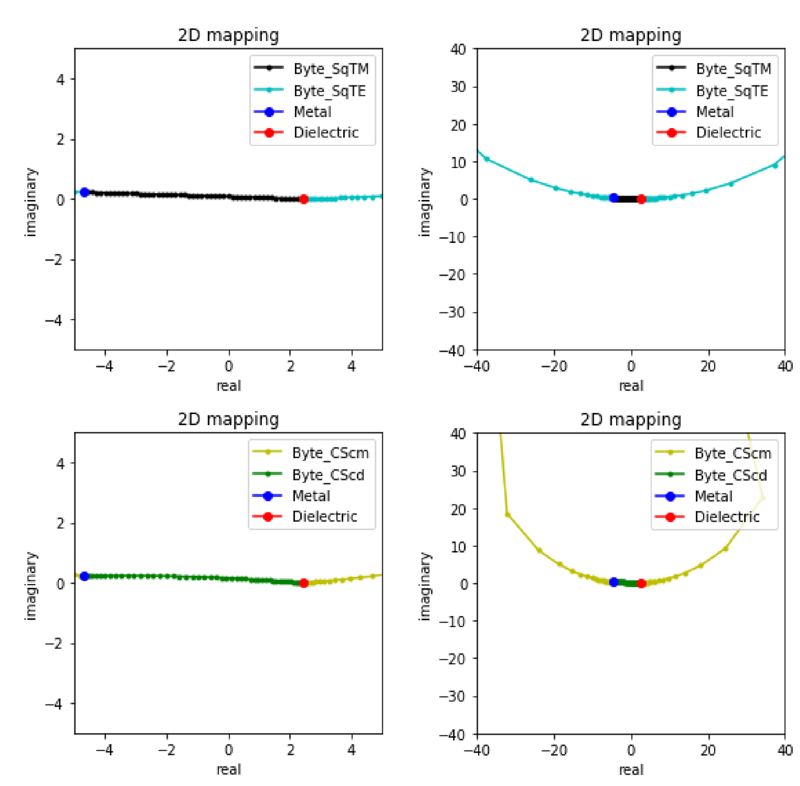


So, as there is no difference between the order of cell length and the order of wavelength, in sub-wavelength condition, target parameter gets dispersive even if the order of wavelength per cell length > 10^4. We can use the functionality of metamaterial system only for very small bandwidth of wavelength, even we should consider only the sinlge wavelength

3 Bit Optical Computing

Mapping the permittivity value in Complex Plane

1D bounded relationship for 2 bit optical computing bits' permittivity

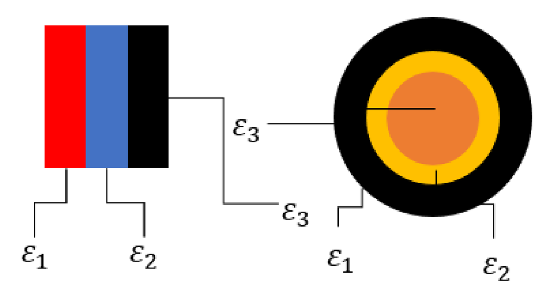


As we say that there is 'mean realationship between the metamaterial Byte and used metamaterial Bits', we can find there is 1D bounded limitation, in other words, the real value of permittivity and the imaginary value of permittivity is dependent each other. The entanglement of these values can be seen graphically in the complex plain mapping.

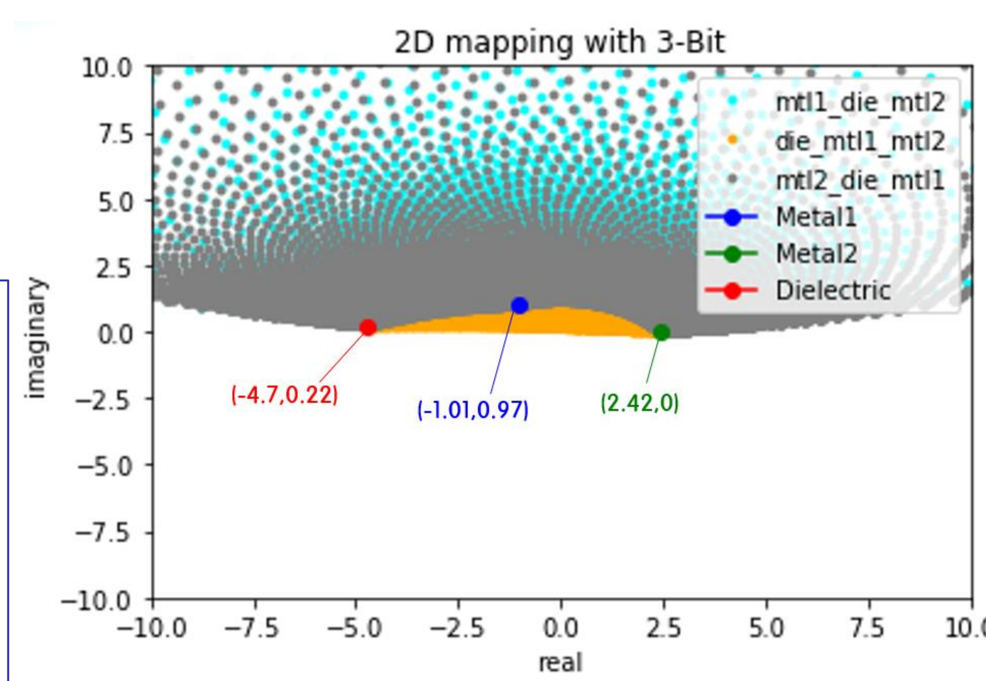
Solution : The 1D relationship, which regared as limitation, can expanded to 2D realationship in complex plane The idea of that is originated from the analogy of space expansion with linearly independent vectors.

3Bit Optical Computing

To eliminate the limitation of 2Bit Optical Computing



Using COMSOL, with the byte materials which consist of 3 different bit materials, we finally filled the whole upper half plane in complex region. It means we jumped over the barrier of 1D bounded engineering, so that we can choose freely the real permittivity and imaginary permittivity independently.



Limiation / Future Works

(1) How to overcome the bandwidth problem of wavelength, in other words, how can we implement the metamaterial system which is not affected by subwavelength condition.

(2) We can implement the permittivity which is far from the value of original used material. But the accuracy is not sufficient we make the 'far value'. The density of dot in 3 Bit optical computing in upper graph says the further from original, the harder for engineering.

References

(1) Della Giovampaola, C., Engheta, N. Digital metamaterials. *Nature Mater 13*, 1115–1121 (2014)
(2) Cui, T., Qi, M., Wan, X. *et al.* Coding metamaterials, digital metamaterials and programmable metamaterials. *Light Sci Appl* 3, e218 (2014).