CHAPTER: 5

CHARACTERISTICS OF METAMATERIAL

[1]JAIMINI SHAH
[1]School of engineering and technology
Apeejay stya university Sohna-Palwal road, Gurugram

[2]Dr. PARIKSHIT VASISHT
[2]School of engineering and technology
Apeejay stya university Sohna-Palwal road, Gurugram

[3]Dr. SUDHAKAR RANJAN
[3]School of engineering and technology
Apeejay stya university Sohna-Palwal road, Gurugram

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BASIC CHARACTERISTICS OF METAMATERIAL

The electromagnetic properties of the materials, permittivity (ε) and permeability (μ) determine how the electromagnetic waves propagate through a material. To understand the propagation of electromagnetic waves through the metamaterial, let us start with the Maxwell's first order differential equations.

$$\nabla \times E = -j\omega\mu H \tag{5.1}$$

$$\nabla \times H = -j\omega\mu E \tag{5.2}$$

Where ω represents the angular frequency of wave. For plane-wave magnetic and electric fields are

$$E = E_0 \, (-jk \cdot r + j\omega t) \tag{5.3}$$

$$H = H0 \, (-jk \cdot r + j\omega t) \tag{5.4}$$

Where k represents the wave vector, on combining the above equations results

$$k \times E = \omega\mu H \tag{5.5}$$

$$k \times H = -\omega\varepsilon E \tag{5.6}$$

When permittivity and permeability are both positive then a right handed orthogonal system is made by vectors E, H and k and wave propagates in forward wave direction in the medium. When permittivity and permeability are both negative, relationship between vectors E, H and k can be given as

$$k \times \; = -\omega \, | \, \mu \, | \, H \tag{5.7}$$

$$k \times H = \; \omega \, | \, \varepsilon \, | \, E \tag{5.8}$$

In this case a left handed orthogonal system is made by vectors E, H and k. Poynting vector S represents the flow of energy and is given as

$$S = 1/2 \, \mathrm{E} \times H* \tag{5.9}$$

From above equation it can be seen that direction of energy flow is not effected with simultaneous change in sign of permeability and permittivity. Thus group velocity is positive for both right handed and left handed system. Refractive index(n) can be given as

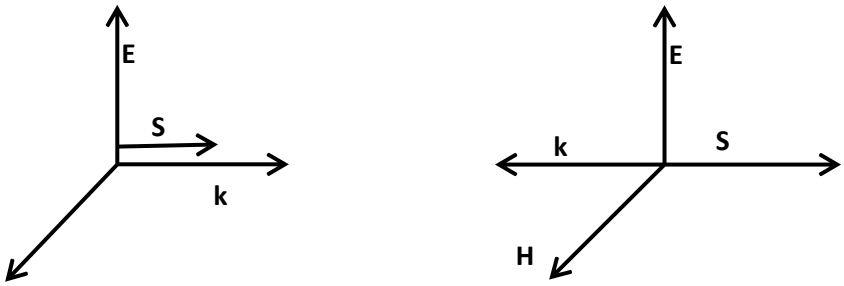
$$n = \pm\sqrt{\varepsilon\mu} \tag{5.10}$$

And phase velocity (v_p) is given as

$$v_p = \frac{c}{n} \tag{5.11}$$

where c represents the velocity of light in vacuum.

which results in forward wave propagation as shown in Fig 1.3 (a).



(a) (b)

Fig. 5.1 (a) Right handed system (b) Left handed system

Refractive index is negative in left handed system and thus the phase velocity will be negative. Therefore the propagation of electromagnetic wave and direction of energy flow will be in opposite direction, which results in backward wave propagation as shown in Fig 5.1(b). In non-uniform waveguide, backward waves commonly propagate

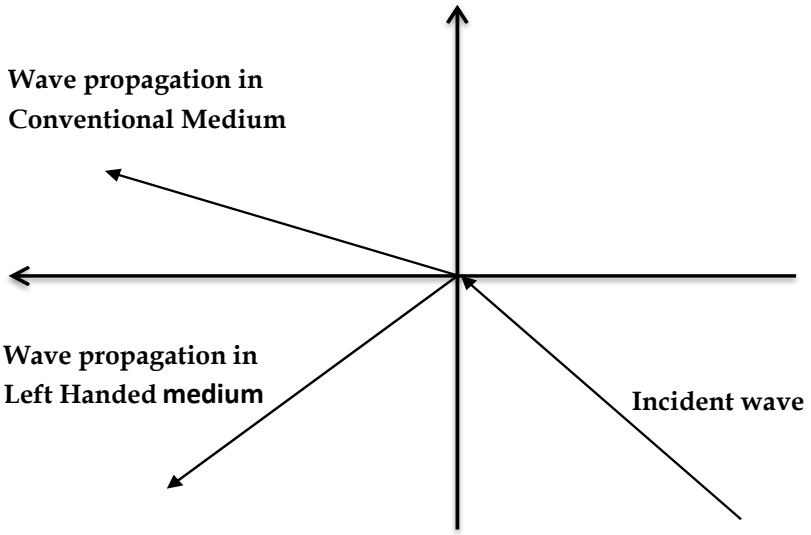


Figure 5.2: wave propagation in metamaterial

CONCLUSION

In metamaterial, wave propagation and design equation used for result observations. For metamaterial Refractive index is positive then the phase velocity is positive and refractive index negative then phase velocity is negative . Hence propagation of electromagnetic wave and direction of energy flow be in same direction when positive and opposite when negative.