BENGAL ENGINEERING & SCIENCE UNIVERSITY, SHIBPUR

**M.E. (ETCE) 2nd Semester Examination, 2013**

# Electromagnetic Metamaterials
## (ETC-1038)

Time: 3 Hours

Full Marks: 70

**Answer any FOUR Questions**

All questions carry equal marks. Two marks are reserved for precise answers.

1. (a) A uniform plane wave is traveling in the $z$-direction with the $x$-component of electric field leading the $y$-component by an angle of $90^0$. Both the components have unequal amplitudes. Draw the continuous waveforms of these two components starting from time $t = 0$. Graphically plot the individual components along with their resultant field at the instants $t$ = 0, T/8, T/4, 3T/8, T/2, 5T/8 and sketch the locus of the tip of the resultant vector with time in the same plot. From this plot tell your observation on the kind and handedness of the polarization generated. State the rule of finding this handedness of polarization.

   (b) Prove that a linearly polarized plane wave can be resolved into a right-hand circularly polarized wave (RHCP) and a left-hand circularly polarized wave (LHCP) of equal amplitude. 11+6

2. What is Doppler effect? Directly from the phase factor of a radiated wave, derive an expression for Doppler frequency in terms of source velocity and phase velocity and Doppler frequency shift. Explain with mathematics and diagrammatic representation of what happens to the frequency emitted by an EM source if a stationary observer looks at the source moving away. (Consider both right-handed medium and left-handed medium separately).

3. Neatly draw an equivalent circuit for a composite right/left-handed (CRLH) loss-less transmission line (TL). Write the per-unit-length immittances for this circuit. From these immitances show that the CRLH TL becomes equivalent to a purely left-handed TL at low frequencies and a purely right-handed TL at high frequencies. Find the expressions for complex propagation constant and characteristic impedance for such a CRLH line. Sketch the dispersion curves on the same plot under both unbalanced and balanced conditions. Label different points on this plot. What is the transition frequency and why is so called?

4. (a) Define phase velocity and group velocity. How do you find the phase and group velocities from the $\omega$-$\beta$ plot ?

   (b) Considering a wave packet consisting of two traveling waves having equal amplitude and slightly different angular frequencies, explain mathematically the phenomena of phase and group velocities. Derive the formula for both the velocities. Sketch a simple diagram showing the velocities. 6+11

5. (a) Classify three types of metamaterials with examples of naturally available (wherever applicable) and artificial structures. Enumerate seven unusual properties of metamaterials.

(b) Derive the transmission line equations for CRLH TL. Map these equations with Maxwell's equations for a TEM wave. From it find the expressions for $\mu$ and $\varepsilon$ in terms of frequency and parameters of CRLH TL. Show that $\mu$ and $\varepsilon$ become negative for frequencies below transition frequency in a balanced configuration. 8+9

6. (a) Distinguish the terms plane wave and spherical wave with neat diagrams. Why is a plane wave important in electromagnetic wave propagation?
   (b) Describe an arrangement for producing a circularly polarized wave by using two dipole antennas. How is the arrangement required for maximum reception of signal from this wave by using dipole antennas? Explain. 5+12

7. Write short notes on (any Two):
   (a) Positive-$\varepsilon$ / negative-$\mu$ metal split-ring resonator (SRR) structure
   (b) History of metamaterials
   (c) Change in roles of lens made of LH materials
   (d) Refractive index in LH, RH and CRLH media