End-Sem: EC2.205-Radio Frequency based Sensors design: Principles and Applications

Time: 2 Hrs. **Max. Marks: 45**

Question 1 Attempt all 4 questions **(5×4=20)**

a) Define S-parameters and explain the physical significance of S_{11}, S_{12}, S_{21}, and S_{22}. A two-port network has $S_{11} = 0.95$, S_{22}=0.1. Explain how Port 1 behaves significantly differently from Port 2 regarding impedance matching and power handling.?

b) What is the physical significance of the Standing Wave Ratio (SWR) in transmission lines? How is it related to the reflection coefficient? An RF transmission line has a reflection coefficient $|\Gamma|$=0.3. Calculate the Standing Wave Ratio (SWR).?

c) Explain the factors that influence the choice of a transmission line in high-frequency applications.?

d) Derive the differential form of Faraday's Law from its integral form using Stokes' theorem. Then, explain its physical meaning regarding a changing magnetic field producing an induced electric field in different media (free space vs dielectric).?

Stokes' Theorem (Statement)

Stokes' Theorem states that the line integral of a vector field around a closed curve is equal to the surface integral of the curl of the vector field over the surface bounded by the curve.

Mathematically:

$$\oint_C \vec{F} \cdot d\vec{r} = \iint_S (\nabla \times \vec{F}) \cdot d\vec{A}$$

Where:

- C = Closed curve or boundary of the surface S
- $\vec{F}$ = Vector field
- $d\vec{r}$ = Infinitesimal element along the curve C
- $\nabla \times \vec{F}$ = Curl of the vector field
- $d\vec{A}$ = Infinitesimal area vector of the surface S

Question 2: Attempt any two of the following questions **(10×2=20)**

(a) **The characteristic impedance Z_o of a microstrip line is:**

$$Z_o = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{eff}}} \ln\left(\dfrac{8h}{w} + \dfrac{w}{4h}\right) & w/h \leq 1 \\ \dfrac{1}{\sqrt{\varepsilon_{eff}}} \dfrac{120\pi}{[w/h + 1.393 + 0.667\ln(w/h + 1.444)]} & w/h \geq 1 \end{cases}$$

A VNA with 50 Ω source impedance is connected to a 250 Ω load through a lossless quarter-wave microstrip line. Given specifications: frequency f = 10 GHz, substrate height h = 1 mm, $\varepsilon_r = 4.4$, $\varepsilon_{eff} = 3.2$ and $w/h \leq 1$.

Answer the following: (i) Find the required Zo of the quarter-wave microstrip line to match the source and load impedances. (ii) Calculate the width w of the quarter wave microstrip line (iii) the physical length l, and (iv) the electrical length for $w/h \leq 1$.

(b) A short-circuited coaxial transmission line is shown in Figure 1, given:

$Z_o = 65 + j38\ \Omega$, $\gamma = 0.7 + j2.5\ \text{m}^{-1}$, $l = 0.8\ \text{m}$.

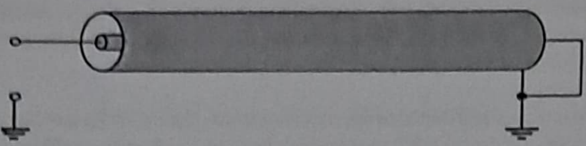

Figure 1: Short-circuited coaxial transmission line.

i. Calculate the input impedance of the short-circuited coaxial transmission line.

ii. Now, assume that the coaxial transmission line is lossless, while all other transmission line parameters remain unchanged. Determine the new values of γ *and* Z_o. Also, compute the minimum length of this lossless line required to transform the short-circuit termination into an open circuit at the input.

iii. Again, assume a lossless line, but now let the length of the coaxial line be $l = x$ while all other transmission line parameters remain unchanged. Plot the imaginary part of the input impedance versus the electrical length. Determine whether the input impedance behaves as an inductor or a capacitor over electrical length and specify the electrical length where each behavior occurs.

[Useful formula]

$$\tanh(x + jy) = \frac{\tanh(x) + j\tan(y)}{1 + j\tanh(x)\tan(y)}$$

(c) (i) Define and explain the following terms in the context of RF sensors: For each term, provide: The formula (if applicable), the physical significance, and the factors that affect the term.

a) Sensitivity
b) Selectivity
c) Response Time
d) Insertion Loss
e) Quality Factor (Q).
f) Bandwidth.
g) Resonance frequency.

(ii) An RF sensor operates at a frequency of 3 GHz with a sensor bandwidth of 150 MHz. The sensor is connected to a transmission line with the following parameters:

- Operating Frequency (f_o) = 3 GHz
- Sensor Bandwidth (BW) = 150 MHz
- Load Impedance (Z_l) = 75 Ω
- Characteristic Impedance (Z_o) = 50 Ω
- Input Power = -10 dBm
- Output Power = -12 dBm.

Find the following:

h) Quality Factor (Q) of the sensor.
i) Return Loss (RL) of the sensor.
j) Insertion loss

Question 3: Multiple Choice Questions (MCQs)

(Note: Each question has only one correct answer)

(i) Which of the following materials will have the smallest skin depth for the same RF frequency?

a) Copper (high conductivity)
b) Carbon (low conductivity)
c) Air
d) Glass

(ii) Which of the following primary constants determines the characteristic impedance of a transmission line?

a) Resistance (R) and Inductance (L)
b) Capacitance (C) and Conductance (G)
c) Resistance (R) and Capacitance (C)
d) Resistance (R), Inductance (L), Capacitance (C), and Conductance (G).

(iii) What does the recovery time of an RF sensor represent?

a) The time it takes for the sensor to detect an incoming RF signal
b) The time required for the sensor to return to its baseline state after the signal is removed
c) The delay between input and output power measurement
d) The duration the sensor remains active after power is turned off

(iv) Which of the following is a direct result of signal reflection caused by impedance mismatch in a transmission line?
a) Increase in modulation index
b) Formation of standing waves on the transmission line
c) Reduction in signal frequency
d) Improvement in signal quality

(v) An RF sensor detects electromagnetic (EM) waves primarily by:
a) Measuring the amplitude of the incident electric field only
b) Detecting the frequency and phase of the EM wave
c) Measuring the temperature fluctuations caused by the wave
d) Generating an opposite EM wave to cancel out the incoming wave

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