IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2003

MICROWAVE TECHNOLOGY

Monday, 28 April 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

Corrected Copy

Any special instructions for invigilators and information for candidates are on page 1.

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1. For a low loss dielectric, which is non-magnetic and isotropic, the propagation constant γ and intrinsic impedance η are given by the following expressions:

$$\gamma \cong 2\pi k(0.5\tan\delta + j) \quad and \quad \eta = \frac{j\omega\mu}{\gamma}$$

where k, $\tan\delta$, ω, and μ have their usual meanings

If the dielectric is Perspex, having a relative permittivity ε_r = 2.6 – j 0.018 at 10 GHz, calculate the following parameters for a frequency of 10 GHz:-

(i) Q-factor. [2]

(ii) Propagation constant. [4]

(iii) Skin depth. [3]

(iv) Thickness of a quarter-wave sheet. [2]

(v) Power attenuation in dB per unit wavelength. [3]

(vi) Intrinsic impedance. [3]

(vii) Power flux density when the RMS electric field intensity is 1V/m. [3]

2. (a) Explain, with the appropriate use of equivalent circuits models and their associated frequency response, the behaviour of low frequency RF inductors, capacitors and resistors at microwave frequencies. [6]

(b) Illustrate how the coaxial cable can be transformed through other guided-wave structures into an optical fibre and a low-loss ribbon cable. Label all the guided-wave structures drawn and comment on the Q-factor and dispersion properties as the transformation occurs. [7]

(c) With the use of Maxwell's equations, illustrate how an electromagnetic wave can propagate from a theoretical loop of lossless wire, in a sequence of quarter-period time steps. [7]

3. (a) Draw the equivalent circuit model for the *p-n* junction diode. Also, give the standard equations for the junction capacitance, Cj(V), and current flow through the diode, I(V). Define all variables used. Sketch the bias dependency of both Cj(V) and I(V).

[5]

(b) Using the equivalent circuit model in 3(a), explain why the *p-n* junction diode is only used at RF in the reverse bias mode and what are its main applications. Also, using the expression for Cj(V) in 3(a), explain why the maximum tuning ratio is larger for hyperabrupt junction diode, when compared to abrupt junction diodes. What is the significance of $\gamma = 2$ in a *p-n* junction diode?

[5]

(c) Draw the physical structure of a PIN diode, indicating the various doped regions and depletion regions. Also, explain how the diode operates in both forward and reverse bias and state its main applications.

[5]

(d) A large power PIN diode is placed between a 50 Ω signal generator and a 50 Ω load impedance. From first principles, derive an expression for the power attenuation of the switch. Clearly state any assumptions made. If the diode in the 'off'-state is represented by an intrinsic region resistance Ri = 10,000 Ω in parallel with an intrinsic region capacitance Ci = 50 fF, calculate the power attenuation at 10 GHz.

[5]

4. (a) What are the 3 frequency domains in electromagnetic simulation? What is the frequency criterion for each one?

[3]

(b) Describe the finite difference method and write expressions for approximating the first and second derivative in this method. Clearly define the variables used.

[4]

(c) Describe the transmission line model (TLM) method, and discuss its range of applicability. Draw the schematic diagram underlying this method.

[3]

(d) Calculate the input impedance of an infinite, lossless, discrete transmission line by using the TLM method. (Hint: Adding 1 segment cannot change the line impedance). Show that the discrete line input impedance has a reactive component, and that there exists a frequency above which waves cannot propagate, i.e. the input impedance is purely reactive.

[5]

(e) Draw a qualitative graph of the error in a numerical simulation as a function of the number of points on which an electromagnetic simulation is discretised. Discuss the combined implications of this diagram and the observations on the TLM method discussed in 4(d) above.

[5]

5. Consider a parallel plate waveguide of spacing *d*.

(a) Draw a diagram showing the wave fronts and direction of partial wave propagation in a parallel plate waveguide. What is the condition for guided wave propagation? What is a mode?

[3]

(b) Define the guide wavelength for the n^{th} mode and express it in terms of the waveguide plate spacing and the free space wavelength. What is the value of the cut-off wavelength?

[3]

(c) What is the group velocity and phase velocity in a waveguide? What is their product?

[2]

(d) Write expressions for the guide wavelength and the cut-off wavelength in a rectangular metal waveguide of width *a* and height *b* for a mode with indices *m* and *n*.

[6]

(e) The standard rectangular waveguide WR75 has internal dimensions a = 19.1 mm and b = 9.55 mm. Calculate its frequency range, defined as the range between the cut-off frequencies of its two lowest modes. Explain why the lower part of this frequency range is not very useful.

[6]

6. (a) Draw a labelled and dimensioned layout diagram for the hybrid ring coupler.

[2]

(b) Use arguments based on geometrical symmetry, wave interference and power conservation to explain the operation of the hybrid ring coupler. In how many distinct ways can a ring coupler be connected? For each distinct connection configuration calculate the signal amplitude and phase (relative to the driving port) at each of the output ports. Calculate also the relative (to each other) amplitude and phase at the output ports. You may assume perfect matching at all ports.

[12]

(c) With reference to your diagram in 6(a), show how (under the assumption that 2 of its ports are simultaneously driven either in phase, or out of phase) the hybrid ring coupler can be partitioned into two identical half circuits. Draw a diagram for the equivalent half circuit in each of these two ways of simultaneously driving 2 ports. Show that driving one port is equivalent to a superposition of the two 2-port drive modes.

[6]