UNIVERSITY OF SURREY

Department of Electronic and Electrical Engineering

MSc EXAMINATION

Module eeMwe

MICROWAVE ENGINEERING PRINCIPLES

Duration: 2 Hours   Autumn 2000/01

READ THESE INSTRUCTIONS

Answer **THREE** questions

SECTION A

1 (a) Define the terms *characteristic impedance* and *complex reflection coefficient* for waves on a transmission line. **[10%]**

(b) In terms of the distributed inductance L (Henrys per metre) and the distributed capacitance C (Farads per metre), the formulas for the characteristic impedance Z_o and the wave velocity u are

$$Z_o = \sqrt{\frac{L}{C}} \qquad\qquad u = \frac{1}{\sqrt{LC}}$$

The velocity factor $F = u/c$ where $c = 3\times10^8$metres per second is the velocity of light in a vacuum. Derive expressions for L and C in terms of Z_o, F, and c. **[5%]**

(c) Given that the units of L and of C are as stated above, show that the units of $\sqrt{\frac{L}{C}}$ are ohms and the units of $\frac{1}{\sqrt{LC}}$ are metres per second. **[10%]**

(d) Determine numbers for L and C for a ribbon cable of velocity factor 0.9 and characteristic impedance 300 ohms. **[10%]**

(e) Write down the formula for the complex reflection coefficient Γ in terms of the line impedance Z_o and the load impedance Z_L **[10%]**

(f) Explain how the SMITH chart may be used to find the input impedance of a transmission line of length d wavelengths in terms of the characteristic impedance and the load impedance. **[15%]**

(g) Describe mathematically how Γ transforms along a transmission line as one moves a distance d wavelengths towards the generator from the load. **[10%]**

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Question 1 Continued

(h) A 50 ohm coaxial cable has a load admittance formed by the parallel combination of a 100 ohm resistor and a 3 pF capacitor. The frequency is 800MHz and the line length is 7.18 wavelengths.

(i) determine the magnitude and phase angle of the complex reflection coefficient at the load

(ii) determine the magnitude and phase angle of the complex reflection coefficient at the generator

(iii) Hence, calculate the input impedance to the cable and check using a SMITH chart plot. **[30%]**

2 (a) State the boundary conditions for electric and magnetic fields at the interface between air and a perfect conductor. **[15%]**

(b) Explain why a rectangular waveguide of cross section dimensions *a* metres by *b* metres has a lowest frequency below which electromagnetic waves will not propagate. Derive an expression for the lowest mode cutoff frequency assuming $a > b$. **[20%]**

(c) For a rectangular waveguide of cross section dimensions 2.3 cm by 1 cm, determine the cutoff frequencies of the following modes.

TE_{10} TE_{01} TE_{11} TM_{11} TE_{20}. **[15%]**

(d) List which of these modes are degenerate (share the same cutoff frequency), and discuss mode conversion between degenerate modes. **[10%]**

(e) Define the terms *group velocity* and *phase velocity* and derive formulas for them in terms of the guide mode cut-off frequency and the signal frequency. **[20%]**

(f) Identify the centre of the band of frequencies in this waveguide where only one mode will propagate and calculate the group velocity and phase velocity of the propagating mode at this band centre. Show that the product of your group and phase velocities is 9×10^{16} in SI units. **[20%]**

3 (a) Describe, and write brief notes on, the general S-matrix and its component scattering parameters. Explain why the *s*-parameters are complex numbers, and state what the modulus and phase angle of a *s*-parameter represents in terms of the incident and scattered wave complex amplitudes. **[30%]**

(b) Give possible S-matrices for the following....

(i) Lossless transmission line of electrical length 1.8 wavelengths

(ii) An imperfect ferrite circulator

(iii) An amplifier with a gain of 9.1 dB

(iv) A perfect -10dB dual directional coupler **[25%]**

(c) A certain 2-port microwave component has s-parameter values

$$s_{11} = 0.1 \angle -30°$$

$$s_{22} = 0.1 \angle -30°$$

$$s_{21} = 5.6 \angle -90°$$

$$s_{12} = 0.03 \angle -120°$$

(d) The component is connected between the ports of a network analyser using two lossless transmission lines. The input port line (port 1) has electrical length 2.1 wavelengths and the output port line (port 2) has electrical length 2.3 wavelengths. Derive the *s*-parameters of the combination of connecting transmission lines and device at the reference planes of the ports of the network analyser. **[25%]**

(d) To what values would the *s*-parameters at the network analyser reference planes change, if the connecting cables each have a loss 0.1 dB? **[20%]**

4 (a) Define the terms *polar radiation pattern, boresight, efficiency, gain,* and *directivity* for a reflector dish antenna. **[15%]**

(b) State the formula which relates the gain of an antenna to its effective aperture and the wavelength of radiation it is designed to receive. **[5%]**

(c) Estimate the gain a) in numerical terms, and b) in dBi, of a domestic broadcast satellite receive dish antenna at 12 GHz. Assume the dish physical diameter is 0.5 metres and the aperture efficiency is 75%. **[15%]**

(d) Derive a formula for the beam half-angle of a circular dish antenna in terms of its numerical directivity, and estimate the pointing accuracy needed for a domestic broadcast receiver dish antenna. **[30%]**

(e) Sketch the arrangement of feeds for a circular dish antenna for the following three cases.

(i) Front fed

(ii) Cassegrain geometry

(iii) Offset fed.

Write notes on the relative advantages and disadvantages of each of these three feed methods. In your notes, discuss the aperture efficiency, blockage, polarisation performance, sidelobe performance, and ease of construction.

[35%]

SECTION B

5 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:

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

where k, tan δ, ω, and μ have their usual meanings.

The dielectric is polyimide, having a relative permittivity $\varepsilon_r = 2.8 - j\ 0.039$, calculate the following parameters for a frequency of 30 GHz:-

(a) Q-factor. **[10%]**

(b) Propagation constant. **[20%]**

(c) Thickness of a quarter-wave sheet. **[5%]**

(d) Skin depth. **[10%]**

(e) Power attenuation in dB per wavelength. **[20%]**

(f) Intrinsic wave impedance. **[25%]**

(g) Power flux density when the RMS electric field intensity is 0.5 v/m. **[10%]**

6 (a) Briefly describe the following, in general terms:- machined waveguide circuit, HMIC and MMIC technologies. Also, state the main advantages and disadvantages each technology may have when trying to implement a transistor amplifier at 30 GHz. **[20%]**

(b) In any order, compare and contrast the three circuit technologies in (a), in terms of:

Reproducibility
Cost
Reliability
Performance
Size and Mass
Investment Required **[30%]**

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Question 6 Continued

(c) With a suitable definition, describe, what is meant by the following microwave technologies: multilayer, micromachining and MEMS. Sketch an example of each technology, clearly identifying each feature. **[25%]**

(d) Describe how MCMs can be assembled at microwave frequencies, millimetre-wave frequencies and upper-millimetre-wave frequencies. Indicate the most suitable transmission line technology, for both the carrier and MMIC, in each of these frequency bands. **[25%]**

7 (a) Draw the simplified block diagram of a scalar network analyser and a vector network analyser (VNA), clearly identifying all blocks. Explain how transmission measurements are performed by the VNA and list some of the advantages and disadvantages of both instruments. **[30%]**

(b) Compare and contrast test-fixture measurements with on-wafer probing. **[10%]**

(c) Briefly explain the basic principles by which a VNA can perform synthetic-pulse time domain reflectometry. Sketch the measured transmission and reflection responses (in both the time and frequency domains) for a slightly mismatched MMIC through-line embedded within a non-ideal test fixture. With a sketch of the time-domain response, describe how the frequency response of $|S_{11}|$ can be emphasised for the embedded MMIC. Is this 'de-embedding' process needed with on-wafer probing? **[30%]**

(d) Explain why a VNA needs to be calibrated. With the aid of suitable flow diagrams, describe how a 2-port VNA calibration is undertaken. **[30%]**

8 (a) (i) Describe, with the aid of a diagram, the principle behind ground-probing radar. **[15%]**

(ii) Discuss the main problems associated with soil composition **[15%]**

(iii) If the dynamic range of the ground-probing radar is 100 dB and at 6 GHz the attenuation of dry sand is 8 dB/m, calculate the maximum depth the radar can detect an ideal target. Comment on the results of this depth if these measurements are repeated in the rain. Ignore the effects of impedance mismatches at the surface. **[15%]**

(iv) Discuss the main problems associated with non-ideal buried targets. **[15%]**

(b) Describe the principles behind remote sensing and state the main problems that must be overcome when implementing remote sensing by satellite. **[40%]**

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