DEDAN KIMATHI UNIVERSITY OF TECHNOLOGY UNIVERSITY

UNIVERSITY EXAMINATION 2021/2022

FIRST YEAR SECOND SEMESTER EXAMINATION FOR THE DEGREE OF MASTER OF SCIENCE IN TELECOMMUNICATION ENGINEERING

EEE 6107: MICROWAVE ENGINEERING

DATE: SEPTEMBER 2021 **TIME 3HRS**

INSTRUCTIONS: This examination paper contains five questions. Answer Question **ONE** and any other **TWO** questions. Question **ONE** is **COMPULSORY** and carries **30 Marks** and ALL the other questions carry **20 Marks** each.

Take free space constants as

- $\mu_0 = 4\pi \times 10^{-7}$ H/m
- $\epsilon_0 = \frac{10^{-9}}{36\pi}$ F/m
- c = 3×10^8 m/s

Question 1:

a). Waveguide depicts a highpass filter, explain. **(2 marks)**

b). Differentiate between lossless and lossy microwave networks. **(2 marks)**

c). Define the term over-mode as used in microwave engineering and explain why it is discouraged. What do you think would happen if dimensions a and b are made equal in a rectangular waveguide? **(3 marks)**

d). A rectangular waveguide of dimension a and b is to be operated in a single mode. Determine the smallest ratio of a/b dimension that will allow the largest bandwidth of the single mode operation. State the dominant mode and the largest bandwidth of single mode operation. **(5 marks)** e). A waveguide of dimension $20mm \times 10mm$ that is filled with air carries a TE_{10} mode at a frequency of 10GHz. The total power being transferred down the guide is 1W. What is the peak electric field amplitude in the waveguide? **(4 marks)**

f). With neat diagram, explain the operation of a branch-line coupler. Write its scattering matrix. **(4 marks)**

g). Show that:

$$\begin{aligned} S &= S^{\top} \\ S^H S &= I \end{aligned}$$

for a reciprocal and lossless network respectively. **(4 marks)**

h). How different are microwave filters from low frequency equivalents? **(2 marks)**

i). Show that the maximum range for an active transponder is expressed as

$$R_{\max} = \left[\frac{A_{eff;r} W_b G_b}{(4\pi l) W_{\min}} \right]^{1/2}$$

(4 marks)

Question 2:

a). Starting with the expression of the propagation constant in a parallel plate waveguide with a lossy dialectic medium, derive the attenuation due to the lossy dielectric medium for the TEn mode. **(6 marks)**

b). A waveguide is formed from two perfect conductors. The conductors are spaced 50mm with a dielectric of $\epsilon_r = 2.25$. For an operating frequency of 10GHz calculate β, v_p, v_g, Z_{TX} and λ_g for the following modes:

i). TEM **(2 marks)**

ii). TM_1 **(2 marks)**

iii). TE_2 **(2 marks)**

c). A parallel plate waveguide is to be designed so that only TEM modes can propagate in the frequency $0 < f < 2GHz$. The dielectric between the plates has a relative dielectric constant of $\epsilon_r = 9$ and a magnetic permeability of free space μ_0:

i). What is the maximum allowed spacing d_{max} between the parallel plate waveguide plates? **(2 Marks)**

ii). If the plate spacing is 2.1cm and f= 10GHz, what TE_n and TM_n modes will propagate? **(2 Marks)**

iii). For TE_2 and TM_2, plot the **E** and **H** field pattern in the xy(cross-section) plane. **(4 Marks)**

Question 3:

a). An air filled rectangular waveguide has dimensions 1cm and 2cm. Determine;

i). The range of frequencies over which the guide will operate in single mode

ii). Wave impedance for the TE_{01} mode **(2 marks)**

iii). Guide wavelength for the TE_{01} mode **(2 marks)**

iv). Phase velocity for the TE_{01} mode **(2 marks)**

v). Over what frequency range will the guide support both TE_{10} and TE_{01} modes only and no other? **(2 marks)**

vi). Also determine the other modes that can propagate below 25GHz **(2 marks)**

b). A rectangular waveguide of dimension $50mm \times 20mm$ filled with air is being operated at 1.1 times its cut-off frequency for the TE10 mode. The TE wave reaches a section of the waveguide that is now completely filled with a lossless dielectric with $\epsilon_r = 3$. Find the mode impedance for the two sections and use these values to calculate the reflection coeffcient in magnitude and phase, VSWR and the fraction of the incident power that passes into the loaded waveguide section. **(5 marks)**

c). An attenuator is designed using a section of waveguide operating below cutoff as shown in Figure 1 below. If a = 2.286 cm and the operating frequency is 12 GHz, determine the required length of the below-cutoff section of waveguide to achieve an attenuation of 100 dB between the input and output guides. Ignore the effect of reflections at the step discontinuities. **(5 marks)**

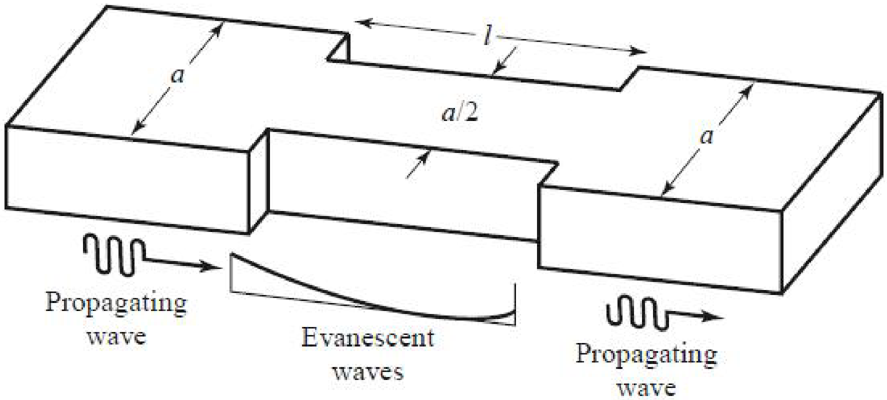

Figure 1: Microwave attenuator

Question 4:

a). Find the scattering parameters of the 3dB attenuator circuit shown in Figure 2 below given that $Z_0 = 50\Omega$. **(5 marks)**

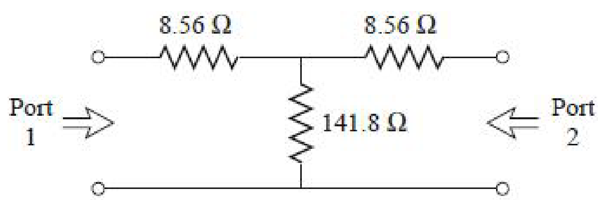

Figure 2: Two-port network

b). A four port network has the scattering matrix shown below

$$S = \begin{bmatrix} 0.6\angle 90^\circ & 0 & 0 & 0.8\angle 0^\circ \\ 0 & 0.7071\angle 45^\circ & 0.7071\angle 45^\circ & 0 \\ 0 & 0.8\angle 45^\circ & 0.7071\angle -45^\circ & 0 \\ 0.8\angle 0^\circ & 0 & 0 & 0.6\angle 90^\circ \end{bmatrix}$$

i). Is this network lossless? **(2 marks)**

ii). Is this network reciprocal? **(2 marks)**

iii). What is the return loss at port 1 when all other ports are terminated with matched loads? **(2 marks)**

iv). What is the reflection coefficient seen at port1 if a short circuit is placed at the terminal plane of port 3, and all other ports are terminated with matched loads? **(2 marks)** v). What is the reflection coefficient seen at port1 if an open circuit is placed at the terminal plane of port 2, and all other ports are terminated with matched loads? **(2 marks)**

c). A lossless, reciprocal 3 port device has s-parameters of $S_{11} = 1/2$, $S_{31} = 1/\sqrt{2}$ and $S_{33} = 0$ as shown below.

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{23} & S_{33} \end{bmatrix}$$

It is likewise known that all scattering parameters are real.

i). Find the remaining six scattering parameters. **(3 marks)**

ii). Write the S matrix of the network if all the ports are matched. **(2 marks)**

Question 5:

a). Derive the frii's equation from the first principles and express the final form in dB. **(6 marks)**

b). A half wavelength dipole antenna (max gain = 2.14 dBi) is used to communicate from an old satellite phone to a low orbiting Iridium communication satellite in the L band (1.6 GHz). Assume the communication satellite has antenna that has a maximum directivity of 24 dBi and is orbiting at a distance of 781 km above the earth. Assuming that the power at the input terminals of the transmitting antenna is 1.0 W, and the antennas are aligned for maximum radiation between them. The transmitter antenna is circularly polarized while the receiver is linearly polarized while the reflection coefficients of the transmitter and receiver feeder are 0.12 and 0.09 respectively. Find the power delivered to the receiver. **(6 marks)**

c). The electric field intensity of a left-hand circularly polarized electromagnetic wave of frequency 200MHz is $10Vm^{-1}$. This wave propagates in air and impinges normally on a poor conductor with $\epsilon_r = 2.25$, $\mu_r = 1$ and $\sigma = 10^{-4}Sm^{-1}$ that is located in the region $z \geq 0$. The x component of the incident electric field phasor has a maximum at $z = 0$ when $t = 0$.

i). Determine the electric field phasor of the incident wave. **(2 marks)** ii). Find the reflection and transmission coefficients. **(2 marks)**

iii). Obtain the electric field phasors of the reflected and transmitted waves, and of the total field in the region $z \geq 0$. **(2 marks)**

iv). Find the fraction of the incident average power that is reflected by the interface and the one that is transmitted to the dielectric medium. **(2 marks)**

Question 6:

a). Explain with practical examples the importance of having linear phase response in microwave filter design. **(4 marks)**

b). A magnitude plot of the impedance of a 30 pF chip capacitor is shown in Figure 3 below. The marker on the plot shows that the capacitor has a self-resonant frequency of 1.775 GHz. At this frequency, $|\mathbf{Z}| = 0.083\Omega$.

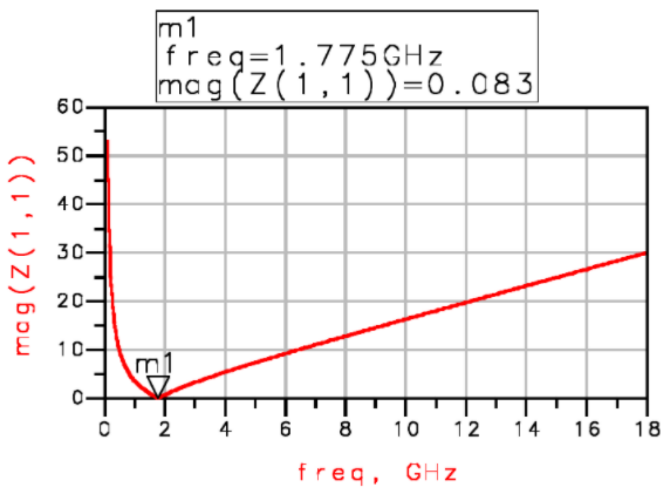

Figure 3: 30 pF chip capacitor impedance magnitude plot

i). Sketch an equivalent circuit that could be used to model this component. Calculate the equivalent circuit element values, assuming that the capacitance is 30 pF. **(3 marks)**

ii). For the equivalent circuit sketched in part above, explain the physical origin of each of the equivalent circuit components. **(3 marks)** iii). Over what frequency range could this component be used as a DC Block in a 50Ω system? Explain the reasoning used to arrive at your answer. **(4 marks)**

c). Design a stepped impedance low-pass filter, which has a Butterworth response. The filter is to have a cut-off frequency of 2.2 GHz and is to have at least 40 dB of attenuation at 5.7 GHz. The filter terminations are 50Ω, and the high impedance lines are to have a characteristic impedance of 125Ω and the low impedance lines are to have a characteristic impedance of 25Ω. The first element in the filter is to be a low impedance line and the filter must be an odd order (i.e. N = 1 or 3 or 5 or $\cdots$) Clearly show the electrical length of the transmission lines (in degrees) at the cut-off frequency of 2.2 GHz. Attenuation curves and low-pass prototype element values are given below. **(6 marks)**

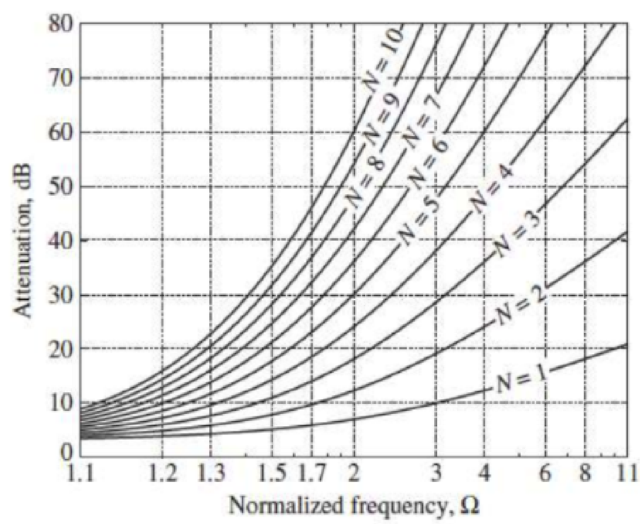

Figure 4: Attenuation responses for Butterworth filters