Université d'Ottawa
Faculté de génie

École de science informatique
et de génie électrique

uOttawa
L'Université canadienne
Canada's university

University of Ottawa
Faculty of Engineering

School of Electrical Engineering
and Computer Science

ELG 3106 / 3506 <u>Electromagnetic Engineering / Électromagnétisme Appliqué</u>
Fall/Automne 2014

FINAL EXAMINATION (3 hours) / EXAMEN FINAL (3 heures)

Professors H. Schriemer, K. Hinzer **Nom/Name:** ______________________________

Date Dec. 17th, 17 déc. 2014 **St./Étudiant#:**______________________________

- This booklet contains 17 pages, including the cover page.
- DO NOT SEPARATE THE PAGES OF THIS BOOKLET!
- Answer all the questions.
- This is a closed-book exam. Equations are provided on the last pages of this booklet.
- Calculators are permitted, but must not be pre-programmable.
- Remember to provide units.
- Write down any assumptions that you make.

- Ce livret contient 17 pages, incluant la page couverture.
- NE PAS SÉPARER LES PAGES DE CE LIVRET !
- Répondre à toutes les questions.
- Cet examen est à livres fermés. Les équations sont fournies à la fin de ce livret.
- Les calculatrices sont permises, mais ne doivent pas être pré-programmables.
- Ne pas oublier de préciser les unités.
- Écrire lisiblement toute supposition que vous faites.

Q1	**/ 4**
Q2	**/ 7**
Q3	**/ 9**
Q4	**/ 9**
Q5	**/ 5**
Q6	**/ 10**
Q7	**/ 4**

Final Mark / Note finale:

/ 48

Question 1

In free space, your source emits a wave having $\mathbf{E}(z,t) = \hat{\mathbf{a}}_y 10^3 \sin(\omega t - \beta z)$ V/m. Determine $\mathbf{H}(z,t)$.

Dans le vide, votre source émet une onde ayant $\mathbf{E}(z,t) = \hat{\mathbf{a}}_y 10^3 \sin(\omega t - \beta z)$ V/m. Déterminez $\mathbf{H}(z,t)$.

Solution:

$$
\begin{aligned}
\mathbf{H}(z,t) &= \frac{\hat{\mathbf{k}} \times \mathbf{E}}{\eta} = \frac{\hat{\mathbf{z}} \times \hat{\mathbf{y}} 10^3 \sin(\omega t - \beta z)}{120\pi} \\
&= -\hat{\mathbf{x}} 2.65 \sin(\omega t - \beta z) = \hat{\mathbf{x}} 2.65 \sin(\omega t - \beta z + \pi) \\
&= \hat{\mathbf{x}} 2.65 \cos\left(\omega t - \beta z + \pi/2\right)
\end{aligned}
$$

Question 2

You have a conducting media, in which $\sigma = 5.8\times10^{7}$ S/m, μ_r = 1 and the frequency is f =100 MHz, calculate:

Vous avez un milieu conducteur, dans lequel $\sigma = 5.8\times10^{7}$ S/m, μ_r = 1 et la fréquence est f =100 MHz, calculez :

(a) the propagation constant γ / la constante de propagation γ;

Solution: $\gamma = \alpha + j\beta$

$$\alpha = \beta = \sqrt{\pi f \mu\sigma} = \sqrt{\pi\left(100\times10^{6}\right)\left(4\pi\times10^{-7}\right)\left(5.8\times10^{7}\right)} = 1.513\times10^{5}$$

Therefore $\gamma = 1.513\times10^{5}\left(1+j\right)\ \mathrm{m}^{-1}$

(b) the intrinsic impedance η / l'impédance intrinsèque η;

Solution:

$$\eta_c = \left(1+j\right)\frac{\alpha}{\sigma} = \left(1+j\right)\frac{1.513\times10^{5}}{5.8\times10^{7}} = 0.00261\left(1+j\right)\Omega$$

(c) the propagation velocity u_p / la vitesse de propagation u_p.

Solution:

$$u_p = \sqrt{\frac{4\pi f}{\mu\sigma}} = \sqrt{\frac{4\pi\left(100\times10^6\right)}{\left(4\pi\times10^{-7}\right)\left(5.8\times10^7\right)}} = 4152 \text{ m/s}$$

Question 3

A wave in medium 1, travelling in the z-direction, is normally incident on medium 2 at z = 0. The media are nonmagnetic. The electric fields in the two media are

Une onde dans le milieu 1 se propage dans la direction z. Cette onde est incidente à la normale du milieu 2 à z = 0. Les milieux sont non-magnétiques. Les champs électriques pour les deux milieux sont

$$\mathbf{E}_1(z,t) = \hat{\mathbf{a}}_x 7\cos\left(2\pi\times10^8 t - 2\pi z\right) - \hat{\mathbf{a}}_x \cos\left(2\pi\times10^8 t + 2\pi z\right) \text{ V/m},$$
$$\mathbf{E}_2(z,t) = \hat{\mathbf{a}}_x 6\cos\left(\omega t - kz\right) \text{ V/m}$$

(a) What is the reflection coefficient? / Quel est le coefficient de réflexion?

Solution:

$$\Gamma = \frac{E_{r0}}{E_{i0}} = -\frac{1}{7}$$

(b) What is the transmission coefficient? / Quel est le coefficient de transmission ?

Solution:

$$\tau = \frac{E_{t0}}{E_{i0}} = \frac{6}{7}$$

(c) What is the frequency in medium 2? / Quelle est la fréquence dans le milieu 2?

Solution:

$$f = 100 \text{ MHz}$$

(d) What is the wavelength in medium 2? / Quelle est la longueur d'onde dans le milieu 2?

Solution:

$$\Gamma = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1},\ \tau = \frac{2\eta_2}{\eta_2 + \eta_1}, \text{ so } \frac{\Gamma}{\tau} = \frac{\eta_2 - \eta_1}{2\eta_2} = \frac{-1/7}{6/7} = -\frac{1}{6}, \text{ so } \eta_2 - \eta_1 = -\frac{2}{6}\eta_2 \quad \Rightarrow \quad \frac{\eta_1}{\eta_2} = \frac{4}{3}$$

$$k = \omega\sqrt{\mu\varepsilon} = \frac{\omega}{c}\sqrt{\mu_r\varepsilon_r}, \text{ so } \frac{k_2}{k_1} = \sqrt{\frac{\varepsilon_{r2}}{\varepsilon_{r1}}}$$

$$\eta = \sqrt{\frac{\mu}{\varepsilon}} = 120\pi\sqrt{\frac{\mu_r}{\varepsilon_r}}, \text{ so } \frac{\eta_2}{\eta_1} = \sqrt{\frac{\varepsilon_{r1}}{\varepsilon_{r2}}}$$

Therefore $\frac{k_2}{k_1} = \frac{\eta_1}{\eta_2} = \frac{4}{3} \quad \Rightarrow \quad k_2 = \frac{4}{3}k_1 = \frac{4}{3}(2\pi) = \frac{2\pi}{3/4}$

Since $k = \frac{2\pi}{\lambda}$, then $\lambda_2 = \frac{3}{4}$ m

NB. $\varepsilon_{r1} = 9$, $\varepsilon_{r2} = 16$

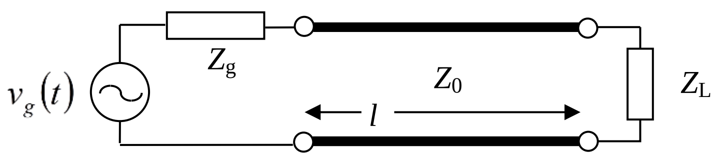
Question 4

All parts of this question must be done using formulae. Explain what you are doing.

Toutes les parties de cette question doivent être résolues avec les formules. Expliquer ce que vous faites.

A 6-m section of 1.5-Ω lossless line has a phase velocity of 3×10^8 m/s and is driven by a source with $v_g(t)=5\cos(6\pi\times10^7 t-30^\circ)$ V and $Z_g=1.5\Omega$, as shown below.
If the line is terminated in a load impedance of $Z_L=(1.5-j0.5)\Omega$, find the following:

Une section de 6 m d'une ligne de transmission sans pertes de $1.5\,\Omega$ a une vitesse de phase de 3×10^8 m/s et est actionnée par une source $v_g(t)=5\cos(6\pi\times10^7 t-30^\circ)$ V et $Z_g=1.5\Omega$, comme montré ci-dessous.
Si la ligne est terminée par une charge d'impédance $Z_L=(1.5-j0.5)\Omega$, déterminer ce qui suit :



(a) The wavelength λ / La longueur d'onde λ ;

Solution:

$$\lambda=\frac{u_p}{f}=\frac{2\pi u_p}{\omega}=\frac{2\pi\left(3\times10^8\right)}{6\pi\times10^7}=10\text{ m}$$

(b) The input impedance, written as a magnitude and phase;
L'impédance d'entrée, écrite sous la forme d'amplitude et phase,

Solution: $\beta l = \frac{2\pi}{10} \cdot 6 = 1.2\pi$

$$Z_{in} = Z_0 \left\{ \frac{Z_L + jZ_0 \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)} \right\}$$

$$= (1.5)\left(\frac{(1.5 - j0.5) + j1.5 \tan(1.2\pi)}{1.5 + j(1.5 - j0.5)\tan(1.2\pi)} \right)$$

$$= (1.5)\left(\frac{(1.5 - j0.5) + j(1.5)(0.727)}{1.5 + j(1.5 - j0.5)(0.727)} \right)$$

$$= (1.5)\left(\frac{1.5 + j0.5905}{1.8635 + j1.0905} \right)$$

$$= \frac{2.063 + j0.812}{1.709 + j}$$

$$= \left(\frac{2.063 + j0.812}{3.92} \right)(1.709 - j)$$

$$= 1.107 - j0.172$$

$$\Rightarrow Z_{in} = 1.12 \exp(-j8.8^\circ)$$

(c) The phasor input voltage, written as a magnitude and phase; and
Le phaseur de la tension d’entrée, écrite sous la forme d’amplitude et phase, et

Solution:

$$V_i = \frac{V_g Z_{in}}{Z_g + Z_{in}} = \frac{\left(5e^{-j30^\circ}\right)\left(1.12e^{-j8.8^\circ}\right)}{1.5 + 1.107 - j0.172} = \frac{5.6e^{-j38.8^\circ}}{2.61e^{-j3.8^\circ}} = 2.1e^{-j35^\circ} \text{ V}$$

(d) The time domain input voltage.
La tension d’entrée dans le domaine temporel.

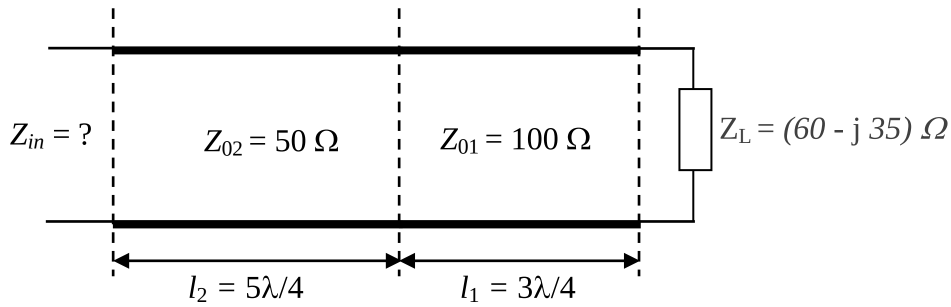
Solution:

$$v_i\left(t\right) = \mathrm{Re}\left\{V_i \exp\left(j\omega t\right)\right\} = \mathrm{Re}\left\{V_i e^{j\omega t}\right\} = \mathrm{Re}\left\{\left(2.1e^{-j35^\circ}\right)e^{j\omega t}\right\} = 2.1\cos\left(6\pi \times 10^7 t - 35^\circ\right) \text{ V}$$

Question 5

Two lossless transmission lines are connected in series as shown in the figure below. Determine the input impedance Z_{in}. *This question must be done analytically. YOU MUST EXPLAIN what you are doing.*

Deux lignes de transmission sans pertes sont connectées tel que montré ci-dessous. Calculer l'impédance d'entrée Z_{in}. *Cette question doit être résolue analytiquement. VOUS DEVEZ EXPLIQUER ce que vous faites.*



Solution:

$$Z(l) = \frac{V(l)}{I(l)} = Z_o \left(\frac{Z_L + j Z_o \tan(\beta l)}{Z_o + j Z_L \tan(\beta l)} \right)$$

Since $\tan(\beta l_1) = \tan(3\pi/2) \to \infty$, $Z_1 = \frac{Z_{01}^2}{Z_L} = \frac{100^2}{60 - j35} = \frac{100^2}{4825}(60 + j35) = (124.35 + j72.54)\,\Omega$

Since $\tan(\beta l_2) = \tan(5\pi/2) \to \infty$,

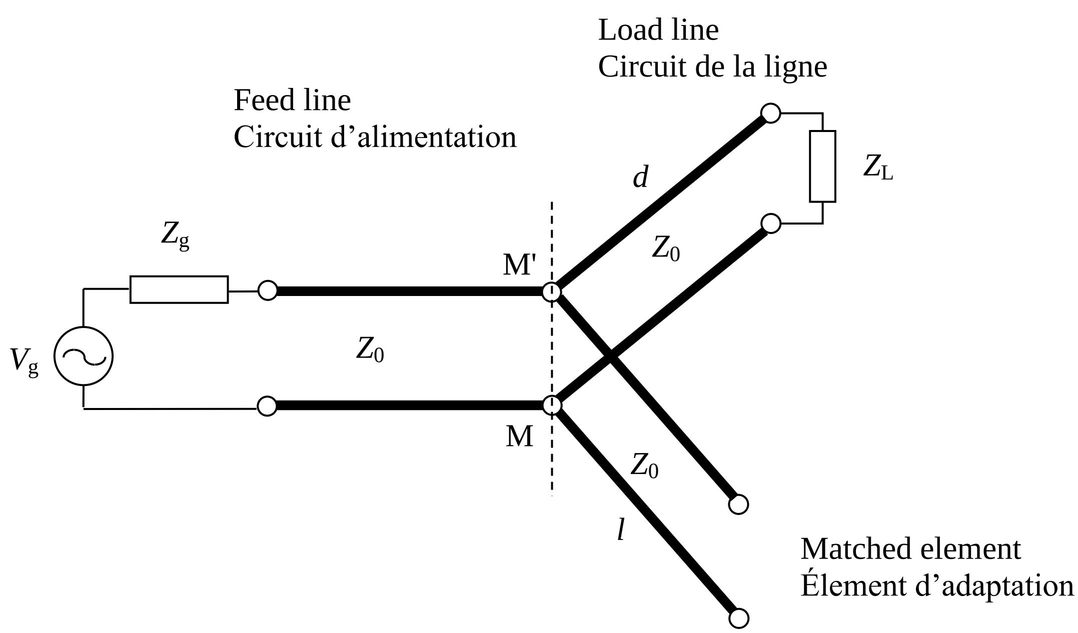
$$Z_{in} = \frac{Z_{02}^2}{Z_1} = \frac{50^2}{124.35 + j72.54} = \frac{50^2}{20725}(124.35 - j72.54) = (15 - j8.75)\,\Omega$$

Question 6

This question must be done using the Smith chart.
Cette question doit être résolue en utilisant l'abaque de Smith.

An open-ended shunt stub is placed a distance $d = 0.236\lambda$ from a load impedance $Z_L = 40 + j\,100\ \Omega$ on a 50-Ω transmission line, as shown below. The stub admittance is $-j1.85$. A Smith chart is given on which there are two constant-|Γ| circles that describe this circuit. Using this Smith chart, answer the following questions:

Un stub en circuit ouvert est place à une distance $d = 0.236\lambda$ de l'impédance de charge $Z_L = 40 + j\,100\ \Omega$ sur une ligne de transmission de 50-Ω, comme vu plus bas. L'admittance du stub est $-j1.85$. Une abaque de Smith est donnée sur laquelle il y a deux cercles de |Γ| constants qui décrivent notre circuit. Utilisant l'abaque de Smith, répondez aux questions suivantes:



(a) What is the normalized load impedance?
Quelle est l'impédance de la charge normalisée?

Solution: $Z_L = (40 + j100)\,\Omega,\ Z_0 = 50\,\Omega$, therefore

$$z_L = \frac{40 + j100}{50} = 0.8 + j2$$

(b) What is the normalized load admittance?
Quelle est l’admittance de la charge normalisée ?

Solution: From the Smith chart: $y_L = 0.175 - j0.43$

(c) On the load line at M'M, what is the phase as noted from the position on the WTG scale?
Sur la ligne de la charge à M’M, quelle est la phase comme dénotée par la position sur l’échelle ‘Longueur d’onde vers la génératrice (WTG)’ ?

Solution: From the Smith chart: $0.434\lambda + 0.236\lambda - 0.5\lambda = 0.170\lambda$

(d) What is the input admittance of the through line at M'M?
Quelle est l’admittance d’entrée sur la ligne principale à M’M ?

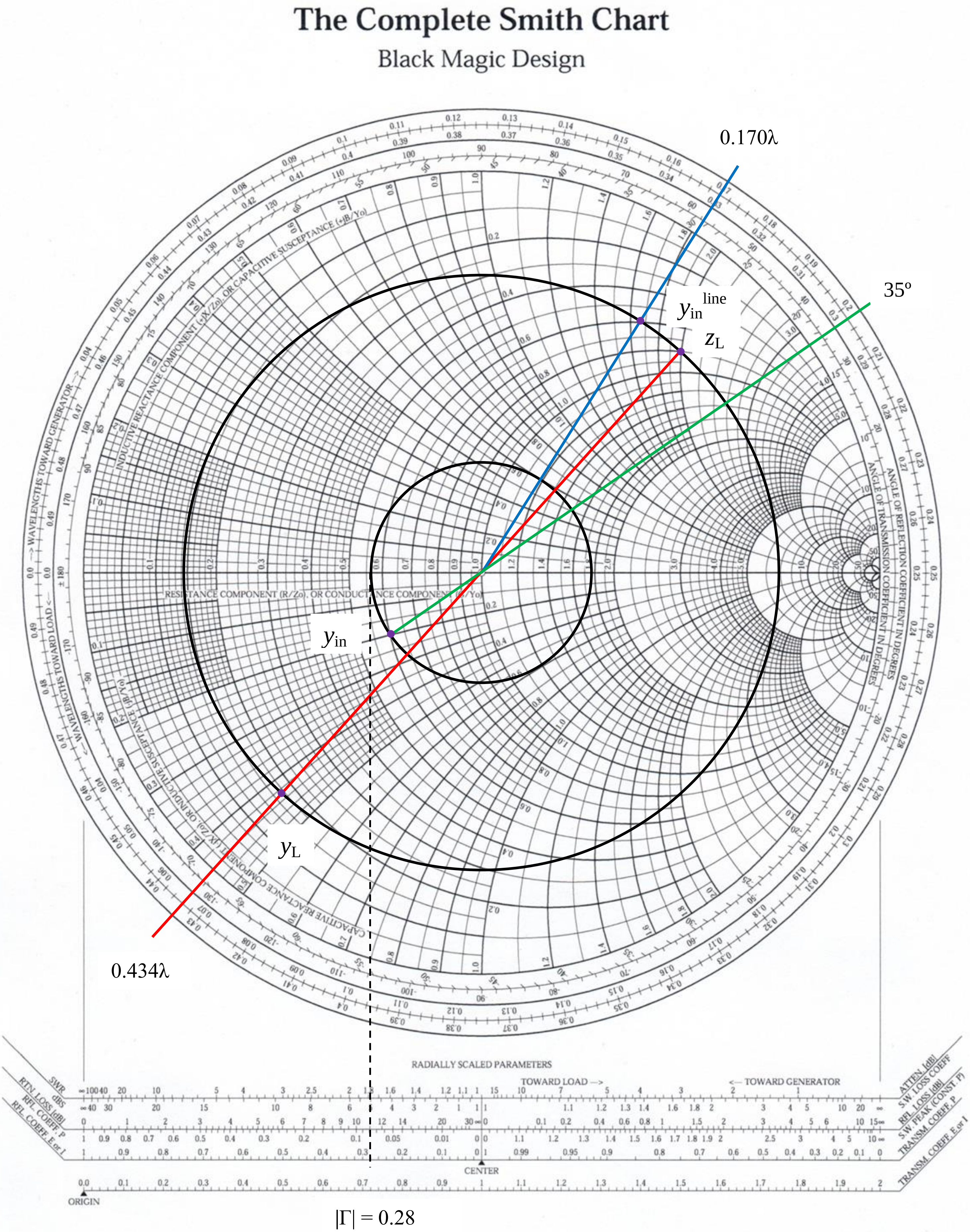
Solution: From the Smith chart: $y_{in}^{line} = 0.6 + j1.65$

(e) What is the input admittance of the parallel combination of line and stub at M'M?
Quelle est l’admittance d’entrée de la combinaison parallèle du circuit de la ligne et du stub ?

Solution: $y_{in} = y_{in}^{line} + y_{in}^{stub} = (0.60 + j1.65) - j1.85 = 0.60 - j0.20$

(f) What is the reflection coefficient (magnitude and phase) at M'M?
Quel est le coefficient de réflexion (amplitude et phase) à M’M?

Solution: $\Gamma = 0.28\angle 35^{\circ}$



The Complete Smith Chart
Black Magic Design
0.170λ
35º
y_in^line
z_L
y_in
y_L
0.434λ
|Γ| = 0.28
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
WAVELENGTHS TOWARD GENERATOR
WAVELENGTHS TOWARD LOAD
ANGLE OF REFLECTION COEFFICIENT IN DEGREES
ANGLE OF TRANSMISSION COEFFICIENT IN DEGREES
RADIALLY SCALED PARAMETERS
TOWARD LOAD
TOWARD GENERATOR
CENTER
ORIGIN

Question 7

You have a hollow metallic rectangular waveguide that operates at f = 1 GHz and it has dimensions of 5 cm × 2 cm. Does the TE_{21} mode propagate in the waveguide? Explain your answer.

Vous avez un guide d'onde rectangulaire métallique vide qui opère à f = 1 GHz et qui a des dimensions de 5 cm × 2 cm. Est-ce que le mode TE_{21} peut se propager dans le guide d'onde? Expliquez votre réponse.

Solution:

For a mode to propagate, $\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 < \left(\frac{2f}{u}\right)^2$ must be satisfied.

Here, m = 2, n = 1, a = 5 cm, b = 2 cm, $u = c = 3\times10^{10}$ cm/s

$$\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 = \left(\frac{2}{5}\right)^2 + \left(\frac{1}{2}\right)^2 = 0.41, \quad \left(\frac{2f}{u}\right)^2 = \left(\frac{2\times10^9}{3\times10^{10}}\right)^2 = 0.0044$$

Therefore the TE_{21} mode does not propagate.

Additional page / page additionelle

Equation sheet / Page de formules

$$\Gamma=\frac{V_o^-}{V_o^+}=\frac{Z_L-Z_o}{Z_L+Z_o}=|\Gamma|e^{j\theta_\Gamma} \qquad S=\frac{|V_{max}|}{|V_{min}|}=\frac{1+|\Gamma|}{1-|\Gamma|} \qquad Z(l)=\frac{V(l)}{I(l)}=Z_o\frac{Z_L+Z_o\tanh(\gamma l)}{Z_o+Z_L\tanh(\gamma l)}$$

$$\nabla\times\mathbf{E}=-\frac{\partial\mathbf{B}}{\partial t} \qquad \nabla\times\mathbf{H}=\mathbf{J}+\frac{\partial\mathbf{D}}{\partial t} \qquad \nabla\cdot\mathbf{D}=\rho_v \qquad \nabla\cdot\mathbf{B}=0$$

$$\nabla\times\tilde{\mathbf{E}}=-j\omega\mu\tilde{\mathbf{H}} \qquad \nabla\times\tilde{\mathbf{H}}=+j\omega\varepsilon_c\tilde{\mathbf{E}} \qquad \nabla\bullet\tilde{\mathbf{E}}=0 \qquad \nabla\bullet\tilde{\mathbf{B}}=0 \qquad c\cong 3\times10^8\ \text{m/s}$$

$$\frac{\sin\theta_t}{\sin\theta_i}=\frac{k_1}{k_2} \qquad \eta=\sqrt{\frac{\mu}{\varepsilon}} \qquad k=\omega\sqrt{\mu\varepsilon} \qquad \Gamma=\frac{E_o^r}{E_o^i}=\frac{\eta_2-\eta_1}{\eta_2+\eta_1} \qquad \tau=\frac{E_o^{tr}}{E_o^i}=\frac{2\eta_2}{\eta_2+\eta_1} \qquad \tau=1+\Gamma$$

$$\Gamma_\perp=\Gamma_{TE}=\frac{E_o^r}{E_o^i}=\frac{\eta_2\cos\theta_i-\eta_1\cos\theta_t}{\eta_2\cos\theta_i+\eta_1\cos\theta_t} \qquad \tau_\perp=\tau_{TE}=\frac{E_o^{tr}}{E_o^i}=\frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_i+\eta_1\cos\theta_t} \qquad \varepsilon_0=8.85\times10^{-12}\ \text{F/m}$$

$$\Gamma_\parallel=\Gamma_{TM}=\frac{E_o^r}{E_o^i}=\frac{\eta_2\cos\theta_t-\eta_1\cos\theta_i}{\eta_2\cos\theta_t+\eta_1\cos\theta_i} \qquad \tau_\parallel=\tau_{TM}=\frac{E_o^{tr}}{E_o^i}=\frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_t+\eta_1\cos\theta_i} \qquad \mu_0=4\pi\times10^{-7}\ \text{H/m}$$

Dans l'air/ in air $\eta = 120\ \pi = 377\ \Omega$ $\qquad \varepsilon=\varepsilon_r\varepsilon_0 \qquad \beta=\frac{2\pi}{\lambda} \qquad n=\sqrt{\mu_r\varepsilon_r}=\sqrt{\frac{\mu\,\varepsilon}{\mu_0\varepsilon_0}}=\frac{c}{u_p}$

$$\mathbf{D}=\varepsilon\mathbf{E} \qquad \mathbf{B}=\mu\mathbf{H} \qquad \mathbf{J}=\sigma\mathbf{E} \qquad \omega=2\pi f \qquad f=u/\lambda$$

$$\nabla^2\mathbf{E}+k_c{}^2\mathbf{E}=0 \qquad \nabla^2\mathbf{H}+k_c{}^2\mathbf{H}=0 \qquad k_c=\omega\sqrt{\mu\varepsilon_c} \qquad \mathbf{H}=\frac{1}{\eta}\hat{\mathbf{a}}_{\mathbf{k}}\times\mathbf{E}$$

$$\mathbf{S}=\mathbf{E}\times\mathbf{H} \qquad Z(l)=\frac{V(l)}{I(l)}=Z_o\left(\frac{Z_L+jZ_o\tan(\beta l)}{Z_o+jZ_L\tan(\beta l)}\right) \qquad \tilde{\mathbf{S}}_{av}=\tfrac{1}{2}\text{Re}[\tilde{\mathbf{E}}\times\tilde{\mathbf{H}}^*]\ (\text{W/m}^2)$$

$l_{max}=\frac{\theta_r\lambda_1}{4\pi}+n\frac{\lambda_1}{2}$ $(n=0,1,2\ldots.)$ where/où $\theta_r=0$ if/si $\eta_1>\eta_2$ and/et $\theta_r=\pi$ if/si $\eta_1<\eta_2$

	General Case *Cas général*	*Lossless* *Milieu sans pertes*	*Low loss* *Milieu à faibles pertes*	*Good conductor* *Bon conducteur*
α (Np/m)	$\omega\left\{\frac{1}{2}\mu\varepsilon'\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right]\right\}^{1/2}$	0	$\frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\pi f\mu\sigma}$
β (rad/m)	$\omega\left\{\frac{1}{2}\mu\varepsilon'\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}+1\right]\right\}^{1/2}$	$\omega\sqrt{\mu\varepsilon}$	$\omega\sqrt{\mu\varepsilon}$	$\sqrt{\pi f\mu\sigma}$
η_c (Ω)	$\sqrt{\frac{\mu}{\varepsilon'}}\left(1-j\frac{\varepsilon''}{\varepsilon'}\right)^{-1/2}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$(1+j)\frac{\alpha}{\sigma}$
u_p (m/s)	$\frac{\omega}{\beta}$	$\frac{1}{\sqrt{\mu\varepsilon}}$	$\frac{1}{\sqrt{\mu\varepsilon}}$	$\sqrt{\frac{4\pi f}{\mu\sigma}}$

$$\tilde{\mathbf{S}}_{av}^{i}(z)=\hat{\mathbf{z}}\frac{\left|E_{i0}\right|^2}{2\eta_1^*}\qquad \tilde{\mathbf{S}}_{1av}(z)=\hat{\mathbf{z}}\frac{\left|E_{i0}\right|^2}{2\eta_1^*}\left(1-\left|\Gamma\right|^2\right)\qquad \tilde{\mathbf{S}}_{2av}(z)=\hat{\mathbf{z}}\frac{\left|\tau\right|^2\left|E_{i0}\right|^2}{2\eta_2^*}$$

$$S=\frac{\left|\tilde{\mathbf{E}}_i\right|_{\max}}{\left|\tilde{\mathbf{E}}_i\right|_{\min}}=\frac{1+\left|\Gamma\right|}{1-\left|\Gamma\right|}\qquad \beta^2=k^2-h^2\qquad h^2=\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2$$

$$f_c^{m,n}=\frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(m/a\right)^2+\left(n/b\right)^2}\qquad \beta=k\sqrt{1-\left(f_c^{m,n}/f\right)^2}\qquad u_p=\frac{u}{\sqrt{1-\left(f_c^{m,n}/f\right)^2}}$$

$$Z_{TM}=\frac{\tilde{E}_x}{\tilde{H}_y}=-\frac{\tilde{E}_y}{\tilde{H}_x}=\eta\sqrt{1-\left(\frac{f_c^{m,n}}{f}\right)^2},\quad Z_{TE}=\frac{\tilde{E}_x}{\tilde{H}_y}=-\frac{\tilde{E}_y}{\tilde{H}_x}=\frac{\eta}{\sqrt{1-\left(\frac{f_c^{m,n}}{f}\right)^2}},\quad \frac{1}{\lambda^2}=\frac{1}{\lambda_g^2}+\frac{1}{\lambda_c^2}$$

Table 6-2: Boundary conditions for the electric and magnetic fields.

Field Components	General Form	Medium 1 Dielectric / Medium 2 Dielectric	Medium 1 Dielectric / Medium 2 Conductor	
Tangential E	$\hat{\mathbf{n}}_2\times(\mathbf{E}_1-\mathbf{E}_2)=0$	$E_{1t}=E_{2t}$	$E_{1t}=E_{2t}=0$	
Normal D	$\hat{\mathbf{n}}_2\cdot(\mathbf{D}_1-\mathbf{D}_2)=\rho_s$	$D_{1n}-D_{2n}=\rho_s$	$D_{1n}=\rho_s$	$D_{2n}=0$
Tangential H	$\hat{\mathbf{n}}_2\times(\mathbf{H}_1-\mathbf{H}_2)=\mathbf{J}_s$	$H_{1t}=H_{2t}$	$H_{1t}=J_s$	$H_{2t}=0$
Normal B	$\hat{\mathbf{n}}_2\cdot(\mathbf{B}_1-\mathbf{B}_2)=0$	$B_{1n}=B_{2n}$	$B_{1n}=B_{2n}=0$	

Notes: (1) ρ_s is the surface charge density at the boundary; (2) $\mathbf{J}_s$ is the surface current density at the boundary; (3) normal components of all fields are along $\hat{\mathbf{n}}_2$, the outward unit vector of medium 2; (4) $E_{1t}=E_{2t}$ implies that the tangential components are equal in magnitude and parallel in direction; (5) direction of $\mathbf{J}_s$ is orthogonal to $(\mathbf{H}_1-\mathbf{H}_2)$.

Paramètre (Parameters)	*Coaxiale (Coaxial)*	*Bifilaire (Twin lead)*	*Plaques parallèles (Parallel Plate)*
R' (Ω/m)	$\frac{R_S}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$	$\frac{R_S}{\pi a}$	$\frac{2R_S}{w}$
L' (H/m)	$\frac{\mu}{2\pi}\ln\left(b/a\right)$	$\frac{\mu}{\pi}\ln(D)$	$\frac{\mu d}{w}$
G' (S/m)	$\frac{2\pi\sigma}{\ln\left(b/a\right)}$	$\frac{\pi\sigma}{\ln(D)}$	$\frac{\sigma w}{d}$
C' (F/m)	$\frac{2\pi\varepsilon}{\ln\left(b/a\right)}$	$\frac{\pi\varepsilon}{\ln(D)}$	$\frac{\varepsilon w}{d}$

where/où $R_S=\sqrt{\dfrac{\pi f\mu_c}{\sigma_c}}$, $\qquad D=\dfrac{d}{2a}+\sqrt{\left(\dfrac{d}{2a}\right)^2-1}$