Electromagnetic fields and biological tissues: effects and medical applications

Please **initialize** individual items of the declaration, and **sign** it at bottom.

Upon my word of honor, and aware of the consequences of a false declaration under the Italian law, as well as those deriving from unfair conduct at Politecnico,

I, the undersigned Tong Lin

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Hereby declare (*dichiarazione sostitutiva di atto notorio*) that the home assignment n. 5

Has been carried out in a strictly individual manner from beginning to end; in particular,

TL I have not obtained help from any classmate or external person to carry out in part or whole the assignment;

TL I have not employed any paper or electronic material directly related to the assignment; (note: textbooks are indirectly related only)

TL I have not employed scripts, computer programs or any other such procedures that have not been entirely developed by myself, or provided as course material (by the Instructor and/or the Teaching Assistant), and that are not commercial, or cannot be referenced in the open literature or internet; please note that *all employed software not personally and individually developed must be referenced in the submitted papers*. In particular, I have not employed any script, programs etc. developed by my classmates, and that the employed scripts, programs etc. have not been developed in cooperation with my classmates.

TL I have discussed this assignment with the following persons: (enter "none" if appropriate):

Tong Lin — Tong Lin

(Complete name, please print) — signature

Torino, 2022/6/8 (date)

Note: Use of commercial software, of free-ware or shareware, or otherwise publicly available software (e.g. via Internet) is allowed, but usage of all software not developed personally and individually by the student, or provided as course material, MUST be clearly stated and precisely referenced in the submitted paper.

Problem 1

1) Amplitude of the wave along the propagation direction:

Along the propagation, where $\underline{k} = k \cdot \hat{r}$, $\underline{k} \cdot \underline{r} = k \cdot r$, therefore,

$$\underline{E} = \frac{e^{-jkr}}{4\pi r} \underline{e}(\theta, \varphi)$$
$$= \underline{E}_0 \cdot \exp(-j\underline{k}\underline{r}).$$

The amplitude, $|\underline{E}| = |E_0| = \frac{e(\theta, \varphi)}{4\pi r}.$

2)

a. Expression of the wavevector:

As z lies along the propagation vector,

$$\hat{k} = \hat{z}$$

Thus, the wavevector can be expressed as,

$$\underline{k} = k \cdot \hat{z}$$
$$= (k' + jk'') \hat{z}$$

b. Values of the wavevectors:

According to the expression of the wavevector,

$$k = \sqrt{w^2 \cdot \tilde{\varepsilon} \cdot \mu}$$

where, w – related with the frequencies,
$\tilde{\varepsilon}$ – complex permitivity, where the imaginary part can be obtained with the tangent loss,
μ – permeability, which can simply use the value of μ_0.

The parameters of each tissue for each frequency, along with the results are listed in the table below.

Tissue	Frequency	Conductivity [S/m]	Relative permittivity	Loss tangent	Wavevector (k)
Muscle	435MHz	0.80536	56.859	0.5853	71.4 - 19.4i
	2.45GHz	1.7388	52.729	0.24194	375.5 - 44.8i
	26GHz	31.595	25.848	0.84508	2976.9 - 1089.4i
Skin Dry	435MHz	0.70272	46.039	0.63073	64.6 - 18.7i
	2.45GHz	1.464	38.007	0.28262	319.6 - 44.3i
	26GHz	24.408	17.709	0.95287	2502.2 - 1001.2i

3) Depths of L_e and L_{10}:

According to the expression of SAR,

$$SAR = \frac{1}{2}\sigma|\underline{E}|^2 \cdot \frac{1}{\rho}$$

The general function for calculating the depths can be then expressed as,

$$\frac{SAR(L)}{SAR(0)} = \frac{\frac{1}{2}\sigma|\underline{E}(L)|^2\frac{1}{\rho}}{\frac{1}{2}\sigma|\underline{E}(0)|^2\frac{1}{\rho}} = \frac{|\underline{E}(L)|^2}{|\underline{E}(0)|^2}$$

$$= [|\exp(-jk\cdot L)|]^2$$

Where k is complex, $k = k' + jk''$, which is already obtained in question 2.

The values of L_e and L_{10} can therefore be obtained by,

$$L_e: \ |\exp(-2jk\cdot L_e)| = \exp(-2)$$

$$L_{10}: \ |\exp(-2jk\cdot L_{10})| = -10dB = 0.1$$

The resulted calculated using MATLAB are listed as follows,

Tissue	Frequency	L_e [m]	L_{10} [m]
Muscle	435MHz	0.0516	0.0595
	2.45GHz	0.0223	0.0257
	26GHz	0.0009	0.0011
Skin Dry	435MHz	0.0535	0.0616
	2.45GHz	0.0226	0.0260
	26GHz	0.0010	0.0011

Problem 2

1)

a. Wavevectors for incidents and transmitted waves:

The incident wave in the (x, z) plane is expressed as,

$$\underline{k_i} = k_1(\hat{x} \cdot \sin\theta_i + \hat{z}\cos\theta_i)$$

where k_1 is a real value, $k_1 = \omega\sqrt{\varepsilon_1\mu_1}$

The transmitted wavevector in the (x, z) plane can be expressed as,

$$\underline{k_t} = \tilde{k}_2(\hat{x} \cdot \sin\theta_t + \hat{z}\cos\theta_t).$$

where k_2 indicates a complex value, $k_2 = \omega\sqrt{\tilde{\varepsilon}_2\mu_2}$

A relationship exist between the incident and transmitted values lays on, $k_{xt} = k_1\sin\theta_i$, that is,

$$\tilde{k}_2\sin\theta_t = k_1\sin\theta_i$$

b. $L_{10}(\theta)$ and $L_e(\theta)$ for the two incidences:

Assuming that the propagation direction is along z-axis as in the previous problem, where $\underline{r} = L \cdot \hat{z}$

$$\underline{k_i} \cdot \underline{r} = k_1(\hat{x}\sin\theta_i + \hat{z}\cos\theta_i) \cdot L \cdot \hat{z}$$

$$= k_1\cos\theta_i \cdot L$$

As discussed in Problem 1, $L_{10}(\theta)$ and $L_e(\theta)$ can be obtained from,

$$L_e: \ |\exp[-2j\, k_i(\theta) \cdot L_e]| = \exp(-2)$$

$$L_{10}: \ |\exp[-2j\, k_i(\theta) \cdot L_{10}]| = 0.1$$

The results calculated using MATLAB are as shown in the table below.

		$\vartheta=0°$		$\vartheta=45°$	
Tissue	**Frequency**	**L_e [m]**	**L_{10} [m]**	**L_e [m]**	**L_{10} [m]**
Muscle	435MHz	0.0516	0.0595	0.0514	0.0592
	2.45GHz	0.0223	0.0257	0.0222	0.0256
	26GHz	0.0009	0.0011	0.0009	0.0010
Skin Dry	435MHz	0.0535	0.0616	0.0533	0.0614
	2.45GHz	0.0226	0.0260	0.0224	0.0258
	26GHz	0.0010	0.0011	0.0010	0.0011

2) Power transmission:

a. The ratio between the incident power density and the total dissipated power per unit area ~~is~~ has been discribed as,

$$T(\theta) \equiv \frac{S_{diss}}{S_{inc}}$$

where, $S_{diss} = \frac{1}{2}\sigma_2 |\underline{E}_t(0)|^2 \frac{1}{2\alpha_2}$

$$S_{inc} = \frac{1}{2}\cdot\frac{1}{Z_0}|\underline{E}_i(0)|^2$$

Therefore,

$$T(\theta) = \frac{Z_0\sigma_2}{2\alpha_2}\frac{|\underline{E}_t(0)|^2}{|\underline{E}_i(0)|^2}$$

where, $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$, σ_2 is the conductivity of medium 2, α_2 indicates the imaginary part of k_t.

b. For the case of TE polarization,

$$\frac{|E_t^{TE}(0)|^2}{|E_i^{TE}(0)|^2} = |1 + \Gamma^{TE}|^2$$

$$\Gamma^{TE} = \frac{k_{z1} - k_{z2}}{k_{z1} + k_{z2}}$$

For the case of TM polarization,

$$\frac{|E_t^{TM}(0)|^2}{|E_i^{TM}(0)|^2} = \frac{\varepsilon_1^2}{\tilde{\varepsilon}_2^2} \frac{|k_{x2}|^2 + |k_{z2}|^2}{|k_{x1}|^2 + |k_{z1}|^2} \cdot |1 - \Gamma^{TM}|^2$$

$$\Gamma^{TM}(\theta) = \frac{\frac{k_{z2}}{\omega\tilde{\varepsilon}_2} - \frac{k_{z1}}{\omega\varepsilon_1}}{\frac{k_{z2}}{\omega\tilde{\varepsilon}_2} + \frac{k_{z1}}{\omega\varepsilon_1}} = \frac{\frac{k_{z2}}{\tilde{\varepsilon}_2} - \frac{k_{z1}}{\varepsilon_1}}{\frac{k_{z2}}{\tilde{\varepsilon}_2} + \frac{k_{z1}}{\varepsilon_1}}$$

Where,
$$k_{z1} = k_1 \cdot \cos\theta_i$$
$$k_{z2} = k_2 \cdot \cos\theta_t$$
$$k_{x1} = k_1 \cdot \sin\theta_i$$
$$k_{x2} = k_2 \cdot \sin\theta_t$$

The plots of $T(\theta)$ respectively with TE and TM are as shown in the figures as follows.

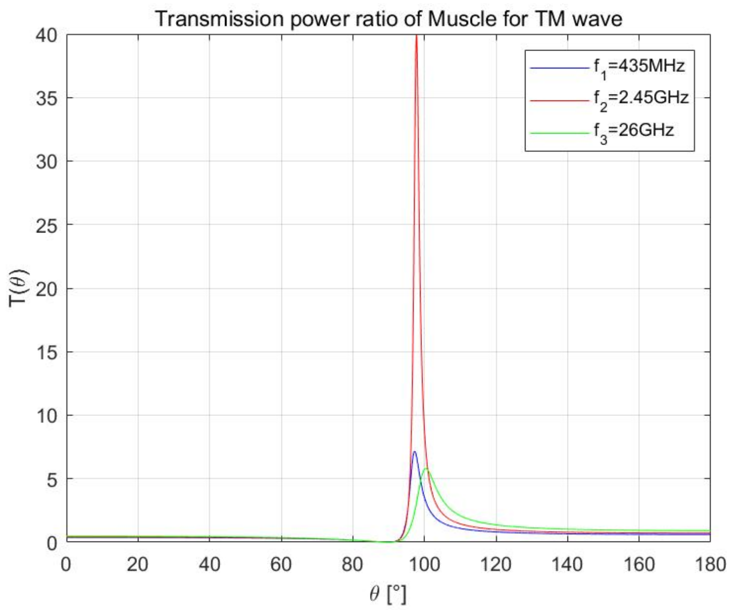

Figure 2.1: Power transmission for Muscle of TM polarization

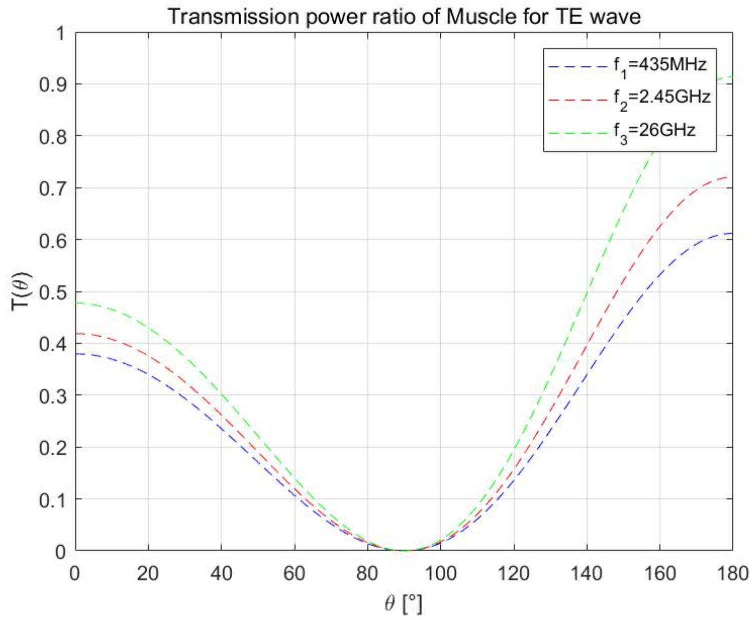

Figure 2.2: Power transmission for Muscle of TE polarization

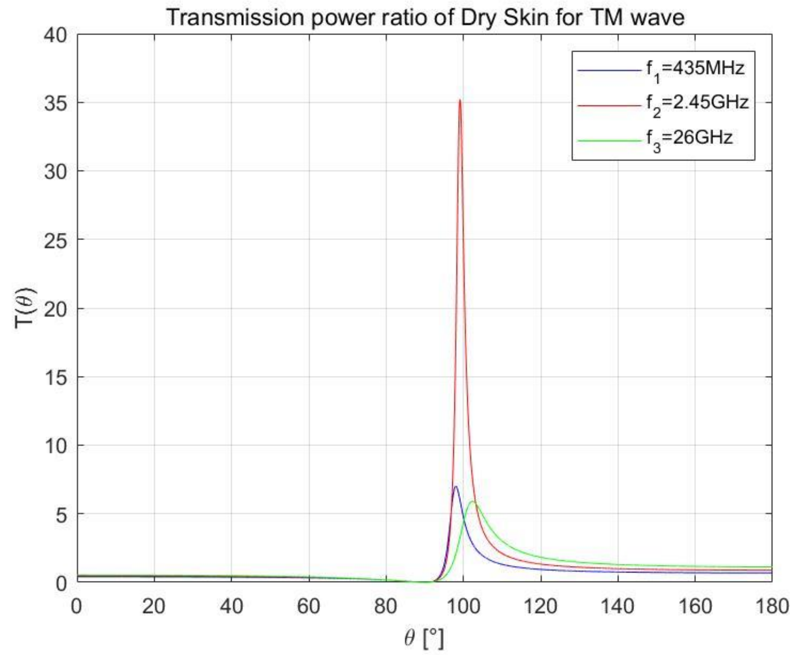

Figure 2.3: Power transmission for Dry Skin of TM polarization

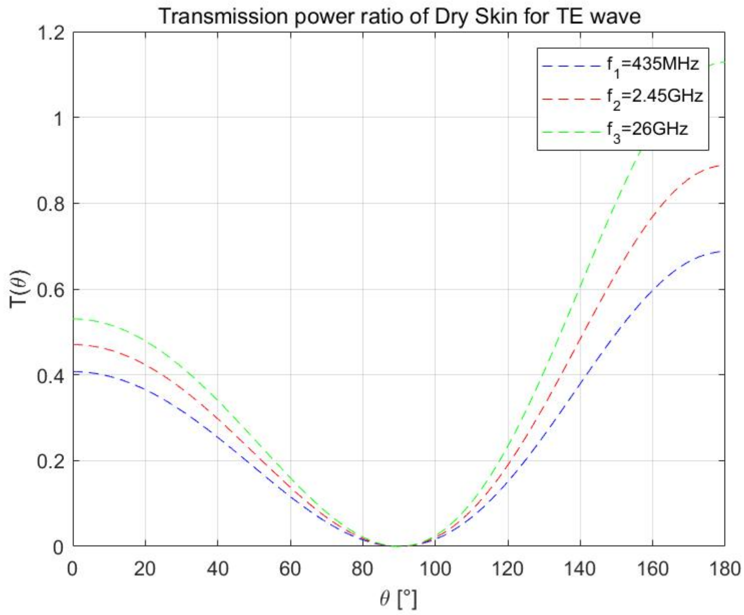

Figure 2.4: Power transmission for Dry Skin of TE polarization

3)

a. As shown in Figure 2.1, the worst case for penetration appears in the TM polarization with the angle approximately as 97.79° and 99.14° respectively for the medium of muscle and for the dry skin, where the frequency lies on $f = 2.45$ GHz, and with $T(\theta)$ equal to 39.92 and 35.21.

b. E-field:

Taking the worst case of Muscle with $f = 2.45$GHz as an example, where $\theta_i = 97.79°$.

The value of E-field along z-axis can be calculated using the function. $\underline{E} = |E_0| \cdot \exp(-j\underline{k} \cdot \underline{r})$

$$E_{0t} = \sqrt{\frac{|E_t^{TM}|^2}{|E_i^{TM}|^2}} \cdot E_{0i}$$

$$E_{0t} = \sqrt{\frac{|E_t^{TE}|^2}{|E_i^{TE}|^2}} \cdot E_{0i}$$

respectively for the TM and TE polarization.

where the functions of the ratio is the same as in question 2b. with specific values in this condition.

The plot of the E-field is as shown in figure below, which is obvious to obtain, that the maximum E-field stays at begining of the interface, where $z=0$.

The result is same with the medium of dry skin.

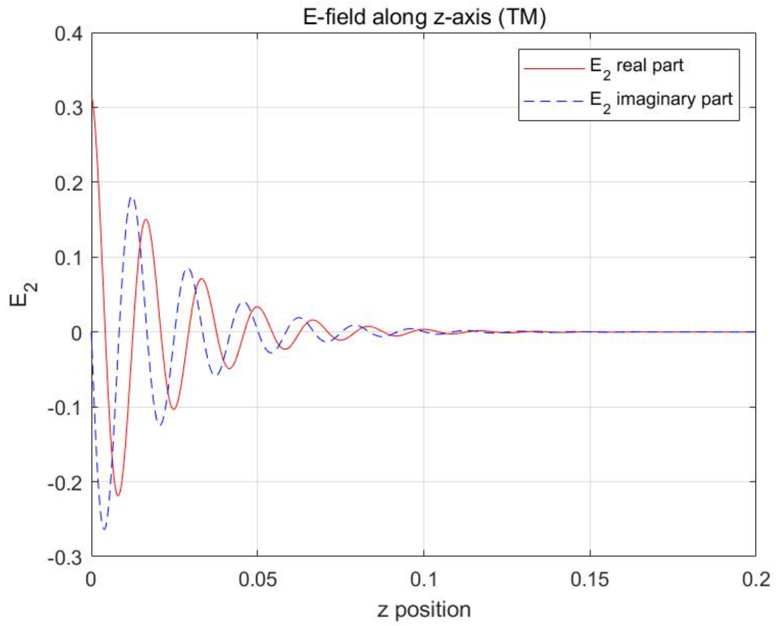

Figure 2.5: E-field of TM polarization

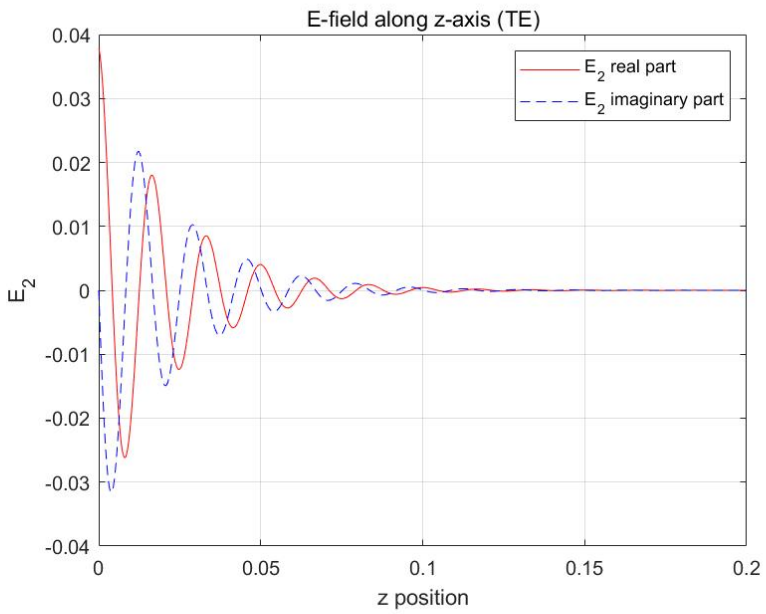

Figure 2.6: E-field of TE polarization

4) Calculation of E-field with given SAR:

According to the expression of SAR,

$$SAR = \frac{1}{2}\sigma |E_t|^2 \cdot \frac{1}{\rho}$$

The transmission E-field can be obtained. The value of the incident E-field can be calculated with the ratio of the E-fields.

TM: $$|E_i| = \frac{|E_t|}{\sqrt{\frac{|E_t TM|^2}{|E_i TM|^2}}}$$

TE: $$|E_i| = \frac{|E_t|}{\sqrt{\frac{|E_t TE|^2}{|E_i TE|^2}}}$$

The results are listed as follows.

When SAR = 2W/kg,

For muscle, TM: $|E_i| = 108.89$ [V/m]

TE: $|E_i| = 909.91$ [V/m]

For dry skin, TM: $|E_i| = 99.13$ [V/m]

TE: $|E_i| = 771.24$ [V/m]

When SAR = 0.08 W/kg,

For musle, TM: $|E_i| = 21.78$ [V/m]

TE: $|E_i| = 181.98$ [V/m]

For dry skin, TM: $|E_i| = 19.82$ [V/m]

TE: $|E_i| = 142.24$ [V/m]

5) Maximum SAR:

With the given value of the incident field, the transmitted E-field can be then calculated, along with the function of SAR.

TM. $$|E_t| = |E_i| \sqrt{\frac{|E_t^{TM}|^2}{|E_i^{TM}|^2}}$$

TE: $$|E_t| = |E_i| \sqrt{\frac{|E_t^{TE}|^2}{|E_i^{TE}|^2}}$$

$$E_t = |E_t| \cdot exp(-j \cdot \underline{k} \cdot \underline{r})$$

where $\underline{k} \cdot \underline{r} = k_2 \cdot z$.

$$SAR = \frac{1}{2} \sigma |E_t|^2 \cdot exp(-2j k_2 \cdot z) \cdot \frac{1}{\rho}$$

The plots of SAR are shown in the figures below, (Figure 2.5.1 ~ 2.5.4), where is easy to observe that the maximum value of SAR lays on the points of $z=0$, thus the maximum values are,

For muscle, TM: $SAR_{max} = 0.003 [W/kg]$

TE: $SAR_{max} = 4.35 \times 10^{-5} [W/kg]$

For dry skin, TM: $SAR_{max} = 0.0037 [W/kg]$

TE: $SAR_{max} = 7.12 \times 10^{-5} [W/kg]$

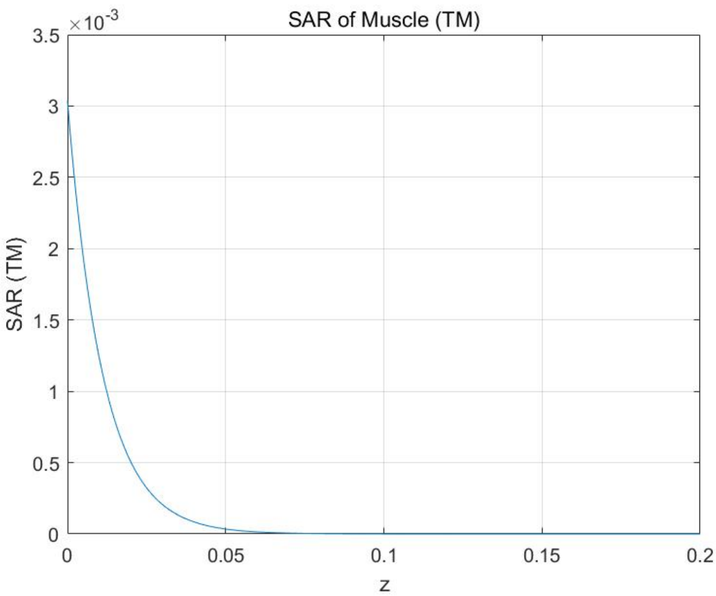

Figure 2.7: SAR for muscle of TM polarization

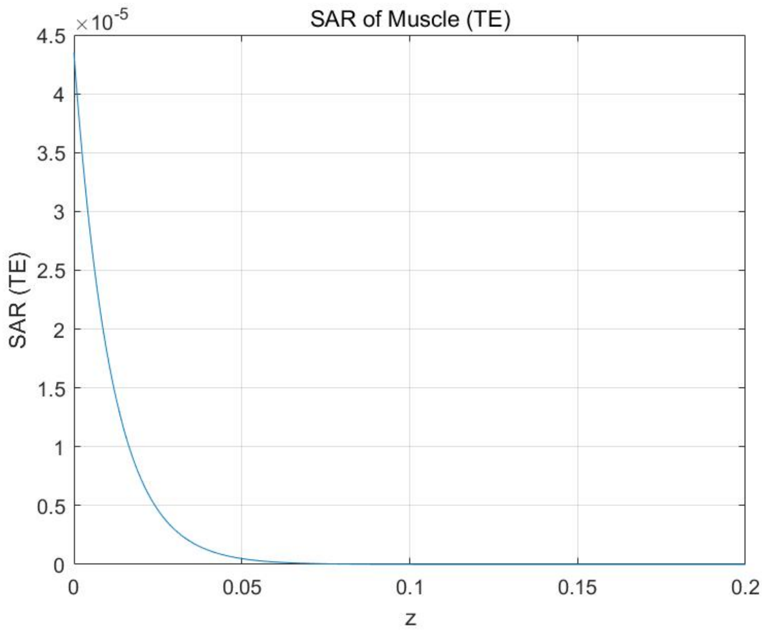

Figure 2.8: SAR for muscle of TE polarization

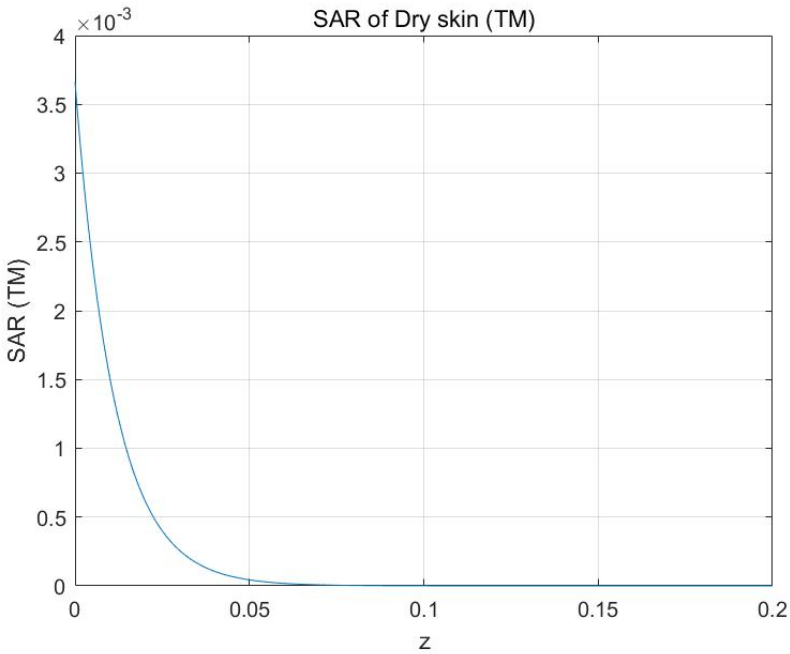

Figure 2.9: SAR for dry skin of TM polarization

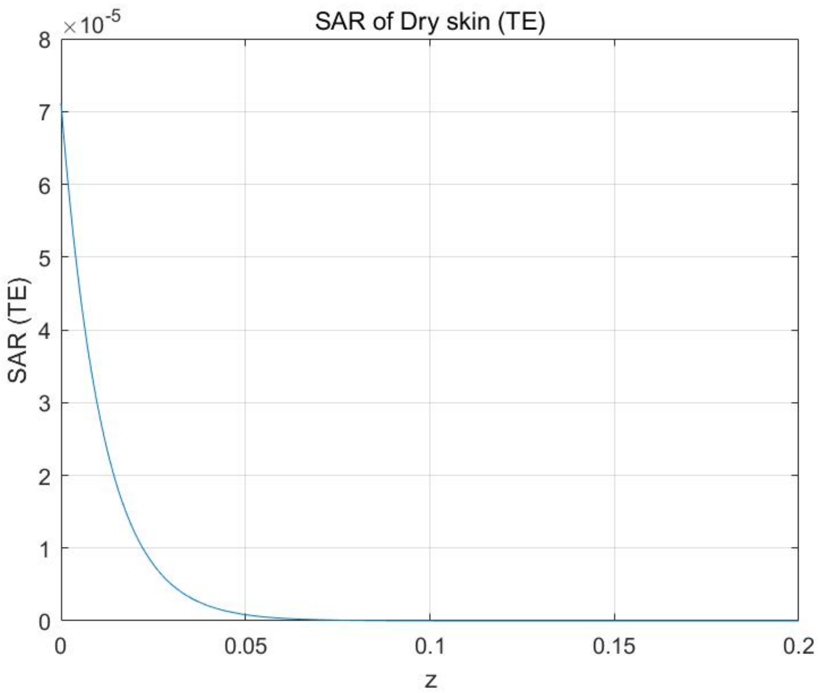

Figure 2.10: SAR for dry skin of TE polarization

Appendix: MATLAB codes

<u>Problem 1:</u>

```
clear all;
close all;
clc

sts =
textread('D:\EE\Electromagnetic_Fields_and_Biological_Tissues\Assignm
ent\A5\statistics.txt');
j = sqrt(-1);

%% P1_2
f = sts(:,1);   %[Hz]
omg = 2*pi*f;
miu0 = pi*4e-7;   %[H/m]
sigma = sts(:,2);   %Conductivity, [S/m]
yp0 = 8.85418782e-12;    %Perimittivity free space, [F/m]
yp1 = sts(:,3)*yp0;    %Permittivity, real part
yp2 = sts(:,4).*yp1;   %Permittivity, imaginary part
yp = yp1-j*yp2;
k = omg.*sqrt(yp.*miu0)

%% P1_3
Le = [];
L10 = [];

for i = 1:1:length(k)
    syms Lei L10i
    eq1 = abs(exp(-2*j*k(i)*Lei)) == exp(-2);
    eq2 = 10*log10(abs(exp(-2*j*k(i)*L10i))) == -10;
    Lei = solve(eq1,Lei); Le = [Le double(Lei)];
    L10i = solve(eq2,L10i); L10 = [L10 double(L10i)];
end

Le
L10
```

Problem 2:

```
clear all;
close all;
clc

sts =
textread('D:\EE\Electromagnetic_Fields_and_Biological_Tissues\Assignm
ent\A5\statistics.txt');
j = sqrt(-1);

%% P2_1b
f = sts(:,1);   %[Hz]
omg = 2*pi*f;
miu0 = pi*4e-7;   %[H/m]
sigma = sts(:,2);   %Conductivity, [S/m]
yp0 = 8.85418782e-12;     %Perimittivity free space, [F/m]
yp1 = sts(:,3)*yp0;    %Permittivity, real part
yp2 = sts(:,4).*yp1;   %Permittivity, imaginary part
yp_2 = yp1-j*yp2;
yp_1 = yp0;
k1 = omg.*sqrt(1*yp0*miu0);
k2 = omg.*sqrt(yp_2.*miu0);

%% Theta1 = 0¡ã
theta1 = 0;
theta2 = k1*sin(theta1)./k2;
Le_0 = [];
L10_0 = [];
for i = 1:1:length(k2)
    syms Lei L10i
    eq1 = abs(exp(-2*j*k2(i)*cos(theta2(i))*Lei)) == exp(-2);
    eq2 = 10*log10(abs(exp(-2*j*k2(i)*cos(theta2(i))*L10i))) == -10;
    Lei = solve(eq1,Lei); Le_0 = [Le_0 double(Lei)];
    L10i = solve(eq2,L10i); L10_0 = [L10_0 double(L10i)];
end
%% Theta1 = 45¡ã
theta1 = 45*pi/180;
theta2 = k1*sin(theta1)./k2;
Le_45 = [];
L10_45 = [];
for i = 1:1:length(k2)
    syms Lei L10i
    eq1 = abs(exp(-2*j*k2(i)*cos(theta2(i))*Lei)) == exp(-2);
```

```
    eq2 = 10*log10(abs(exp(-2*j*k2(i)*cos(theta2(i))*L10i))) == -10;
    Lei = solve(eq1,Lei); Le_45 = [Le_45 double(Lei)];
    L10i = solve(eq2,L10i); L10_45 = [L10_45 double(L10i)];
end

%% P2_2
theta1 = linspace(0,pi,10000);
theta2 = asin(k1.*sin(theta1)./k2);
alp2 = -imag(k2);
kx1 = k1.*sin(theta1);
kz1 = k1.*cos(theta1);
kx2 = k2.*sin(theta2);
kz2 = k2.*cos(theta2);
gammaTM = (kz2./yp_2-kz1./yp_1)./(kz2./yp_2+kz1./yp_1);
gammaTE = (kz1-kz2)./(kz1+kz2);
yp_2ab = sqrt(conj(yp_2).*yp_2);
gammaTMab = sqrt(conj(1-gammaTM).*(1-gammaTM));   % |1-gammaTM|
kx2ab = sqrt(conj(kx2).*kx2);
kz2ab = sqrt(conj(kz2).*kz2);
kx1ab = sqrt(conj(kx1).*kx1);
kz1ab = sqrt(conj(kz1).*kz1);
Eratio_TM =
(gammaTMab.^2.*((kx2ab.^2+kz2ab.^2)./(kx1ab.^2+kz1ab.^2))).*(yp_1^2./
yp_2ab.^2);

gammaTEab = sqrt(conj(1+gammaTE).*(1+gammaTE));   % |1+gammaTE|
Eratio_TE = gammaTEab.^2;

Z0 = sqrt(miu0/yp0);
const = Z0*sigma./(2*alp2);
T_TM = const.*Eratio_TM;
T_TE = const.*Eratio_TE;

theta1 = theta1*180/pi;

figure   %Muscle TM
plot(theta1,T_TM(1,:),'b',theta1,T_TM(2,:),'r',theta1,T_TM(3,:),'g')
grid on
xlabel('\theta [¡ã]');
ylabel('T(\theta)')
title('Transmission power ratio of Muscle for TM wave');
legend('f_1=435MHz','f_2=2.45GHz','f_3=26GHz')

figure   %Muscle TE
```

```
plot(theta1,T_TE(1,:),'b--',theta1,T_TE(2,:),'r--
',theta1,T_TE(3,:),'g--')
grid on
xlabel('\theta [¡ã]');
ylabel('T(\theta)')
title('Transmission power ratio of Muscle for TE wave');
legend('f_1=435MHz','f_2=2.45GHz','f_3=26GHz')

figure  %Skin TM
plot(theta1,T_TM(4,:),'b',theta1,T_TM(5,:),'r',theta1,T_TM(6,:),'g')
grid on
xlabel('\theta [¡ã]');
ylabel('T(\theta)')
title('Transmission power ratio of Dry Skin for TM wave');
legend('f_1=435MHz','f_2=2.45GHz','f_3=26GHz')

figure  %Skin TE
plot(theta1,T_TE(4,:),'b--',theta1,T_TE(5,:),'r--
',theta1,T_TE(6,:),'g--')
grid on
xlabel('\theta [¡ã]');
ylabel('T(\theta)')
title('Transmission power ratio of Dry Skin for TE wave');
legend('f_1=435MHz','f_2=2.45GHz','f_3=26GHz')
%% Check
figure
plot(theta1,gammaTMab(5,:))
hold on
plot(theta1,abs(gammaTM(5,:)))
axis([0 90 0 2])
grid on
xlabel('\theta');
ylabel('gammaTM');
legend('|1-\Gamma_{TM}|','|\Gamma_{TM}|')
title('Reflection coefficient')

figure
plot(theta1,abs(gammaTM(5,:)))
hold on
grid on
plot(theta1,abs(gammaTE(5,:)))
hold on
plot(theta1,sqrt(Eratio_TM(5,:)))
hold on
```

```
plot(theta1,sqrt(Eratio_TE(5,:)))
axis([0 90 0 1])
xlabel('\theta');
title('Dry skin, f=2.45GHz')
legend('|\Gamma_{TM}|','|\Gamma_{TE}|','Eratio_{TM}','Eratio_{TE}')
%% P2_3
% a. power dissipation along theta in medium 2 -- as shown in figures
above
% b. E-field along z -- worst case when f=2.45[GHz] in Muscle (2,;)
%----------------------- ratio calculation ----------------------------
-
theta_wi = 97.79*pi/180;
kxi = k1(2)*sin(theta_wi); kxiab = sqrt(conj(kxi)*kxi);
kzi = k1(2)*cos(theta_wi);
theta_wt = k1(2)*sin(theta_wi)/k2(2);
kxt = k2(2)*sin(theta_wt); kxtab = sqrt(conj(kxt)*kxt);
kzt = k2(2)*cos(theta_wt);
yp_2ab = sqrt(conj(yp_2(2))*yp_2(2));
gammaTM = (kzt/yp_2(2)-kzi/yp_1)/(kzt/yp_2(2)+kzi/yp_1);
gammaTMab = sqrt(conj(1-gammaTM)*(1-gammaTM));   %|1-gammaTM|
Eratio_TMsq = gammaTMab^2*(kxtab^2/kxiab^2)*(yp_1^2/yp_2ab^2);
gammaTE = (kzi-kzt)./(kzi+kzt);
gammaTEab = sqrt(conj(1+gammaTE).*(1+gammaTE));   % |1+gammaTE|
Eratio_TEsq = gammaTEab.^2;
%---------------------------------------------------------------------
-
E0_1 = 1;   %normalized
z = linspace(0,0.2,1000);
E0_2TM = sqrt(Eratio_TMsq)*E0_1;
E2TM = E0_2TM*exp(-j*k2(2)*z);
E0_2TE = sqrt(Eratio_TEsq)*E0_1;
E2TE = E0_2TE*exp(-j*k2(2)*z);

figure   %TM
plot(z,real(E2TM),'r',z,imag(E2TM),'b--');
xlabel('z position');
ylabel('E_2');
legend('E_2 real part','E_2 imaginary part')
grid on
title('E-field along z-axis (TM)')

figure   %TE
plot(z,real(E2TE),'r',z,imag(E2TE),'b--');
xlabel('z position');
```

```
ylabel('E_2');
legend('E_2 real part','E_2 imaginary part')
grid on
title('E-field along z-axis (TE)')

%% P2_4/P2_5
%Muscle
rou_m = 1.03e3;   %Mass density of muscle, [kg/m3]
Et_2 = sqrt(2*rou_m/sigma(2));   %[V/m]
Ei_2TM_m = Et_2/sqrt(Eratio_TMsq)
Ei_2TE_m = Et_2/sqrt(Eratio_TEsq)
Et_008 = sqrt(0.08*rou_m/sigma(2));
Ei_008TM_m = Et_008/sqrt(Eratio_TMsq)
Ei_008TE_m = Et_008/sqrt(Eratio_TEsq)

Ei0 = 6;   %[V/m]
Et0_TM = sqrt(Eratio_TMsq)*Ei0;
Et_TM = Et0_TM*exp(-j*k2(2)*z); EtTMab = sqrt(conj(Et_TM).*Et_TM);
SAR_TM = 0.5*sigma(2)*EtTMab.^2/rou_m;
Et0_TE = sqrt(Eratio_TEsq)*Ei0;
Et_TE = Et0_TE*exp(-j*k2(2)*z); EtTEab = sqrt(conj(Et_TE).*Et_TE);
SAR_TE = 0.5*sigma(2)*EtTEab.^2/rou_m;

SAR_TMmax_m = 0.5*sigma(2)*Et0_TM^2/rou_m
SAR_TEmax_m = 0.5*sigma(2)*Et0_TE^2/rou_m
figure
plot(z,SAR_TM)
xlabel('z');
ylabel('SAR (TM)')
title('SAR of Muscle (TM)')
grid on
figure
plot(z,SAR_TE)
xlabel('z');
ylabel('SAR (TE)')
title('SAR of Muscle (TE)')
grid on

%Dry skin
%-----------------------ratio calculation-----------------------
theta_wi = 99.14*pi/180;
kxi = k1(5)*sin(theta_wi); kxiab = sqrt(conj(kxi)*kxi);
kzi = k1(5)*cos(theta_wi);
theta_wt = k1(5)*sin(theta_wi)/k2(5);
```

```
kxt = k2(5)*sin(theta_wt); kxtab = sqrt(conj(kxt)*kxt);
kzt = k2(5)*cos(theta_wt);
yp_2ab = sqrt(conj(yp_2(5))*yp_2(5));
gammaTM = (kzt/yp_2(5)-kzi/yp_1)/(kzt/yp_2(5)+kzi/yp_1);
gammaTMab = sqrt(conj(1-gammaTM)*(1-gammaTM));   %|1-gammaTM|
gammaTE = (kzi-kzt)./(kzi+kzt);
gammaTEab = sqrt(conj(1+gammaTE).*(1+gammaTE));   % |1+gammaTE|
Eratio_TMsq_s = gammaTMab^2*(kxtab^2/kxiab^2)*(yp_1^2/yp_2ab^2);
Eratio_TEsq_s = gammaTEab.^2;
%-------------------------------------------------------------------
rou_s = 1.02e3;   %Mass density of muscle, [kg/m3]
Et_2_s = sqrt(2*rou_s/sigma(5));   %[V/m]
Ei_2TM_s = Et_2_s/sqrt(Eratio_TMsq_s)
Ei_2TE_s = Et_2_s/sqrt(Eratio_TEsq_s)
Et_008_s = sqrt(0.08*rou_s/sigma(5));
Ei_008TM_s = Et_008_s/sqrt(Eratio_TMsq_s)
Ei_008TE_s = Et_008_s/sqrt(Eratio_TEsq_s)

Ei0 = 6;   %[V/m]
Et0_TM_s = sqrt(Eratio_TMsq_s)*Ei0;
Et_TM_s = Et0_TM_s*exp(-j*k2(5)*z); EtTMab_s =
sqrt(conj(Et_TM_s).*Et_TM_s);
SAR_TM_s = 0.5*sigma(5)*EtTMab_s.^2/rou_s;
Et0_TE_s = sqrt(Eratio_TEsq_s)*Ei0;
Et_TE_s = Et0_TE_s*exp(-j*k2(5)*z); EtTEab_s =
sqrt(conj(Et_TE_s).*Et_TE_s);
SAR_TE_s = 0.5*sigma(5)*EtTEab_s.^2/rou_s;

SAR_TMmax_s = 0.5*sigma(5)*Et0_TM_s^2/rou_s
SAR_TEmax_s = 0.5*sigma(5)*Et0_TE_s^2/rou_s
figure
plot(z,SAR_TM_s)
xlabel('z');
ylabel('SAR (TM)')
title('SAR of Dry skin (TM)')
grid on
figure
plot(z,SAR_TE_s)
xlabel('z');
ylabel('SAR (TE)')
grid on
title('SAR of Dry skin (TE)')
```

Plots of check: