FACULTY OF ELECTRICAL

AND ELECTRONIC ENGINEERING

2020 – 2021

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REPORT EXERCISE

TOPIC 4

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I. INTRODUCTION

Topic: for 2 antennas with size (radius a1, a2, length l1, l2), operating frequency f, amplitude of input current I0 and distance R between 2 antennas. Calculate the power density S, Smax, transmit power Prad, efficiency, directivity D, gain G of the two antennas. Calculate the received power at antenna 2 (using Friis's formula).

Solution: Write a program to compute the basic information of an antenna, with the input from the user, we use the python code with the basic function (as l,R,I,f,a) and an external library is math (to define pi with math.pi and compute the square root)

II. RECOUNT CONSTANT VALUES

Calculate some basic constants to make it more convenient for coding

Code:

```
c = 3e8    # light velocity, m/s unit
D_Hertzian = 1.5    # directivity of Hertzian dipole
D_halfwave = 1.64    # directivity of halfwave dipole
mu = 4 * math.pi * 1e-7    # Magnetic permeability of vacuum (=copper), H/m unit
sigma = 5.8 * 1e7    # electrical conductivity of copper, S/m unit
Rrad_halfwave = 73    # radiation resistance of halfwave dipole, Ohm unit
```

In which

$c = 3 \cdot 10^{8} \left(m/s \right)$

$\sigma_c = 4\pi \cdot 10^{-7} \left(H/m \right)$

$\mu_c = 5.8 \cdot 10^{7} \left(S/m \right)$

$D_{Hertzian} = 1.5$

$D_{halfwave} = 1.64$

$R_{rad\_halfwave} = 73 (\Omega)$ used when antenna is half-wave dipole

Describe the calculation formula used

Code:

```
lamda = c / f
def Smax_Hertzian(l):    # maximum power density of Hertzian dipole
    return 15 * math.pi * (I**2) * (l**2) / (R**2 * lamda**2)
def Prad_Hertzian(l):    # total radiated power of Hertzian dipole
    return 40 * (math.pi**2) * (I**2) * (l**2) / (lamda**2)
def Rloss(l, a):    # Rloss of the antenna
    return (l / (2 * math.pi * a)) * math.sqrt(math.pi * mu * f / sigma)
def Rrad_Hertzian(l):    # Rrad of Hertzian dipole
    return 80 * (math.pi**2) * (l/lamda)**2
def Smax_halfwave(l):    # maximum power density of half-wave dipole
```

```
        return 15 * (I**2) / (math.pi * R**2)
def Prad_halfwave():    # total radiated power of half-wave dipole
        return 36.6 * (I**2)
def efficiency(Rrad, Rloss):    # radiation efficiency
        return Rrad / (Rrad + Rloss)
def gain(e, D):    # antenna gain
        return e * D
def eff_area(D):    # effective area
        return lamda**2 * D / (4 * math.pi)
def Ptrans(Rrad, Rloss):    # transmitting power
        return 1/2 * (I**2) * (Rrad + Rloss)
def Prec(Ptrans, G_trans, G_rec):    # receiving power
      return Ptrans * G_trans * G_rec * (lamda/(4*math.pi*R))**2
```

In which:

$\lambda = \dfrac{c}{f}$

$S_{max} = S_0 = \dfrac{15\pi \cdot I_0^2}{R^2}\left(\dfrac{l}{\lambda}\right)^2$ used when antenna is Hertzian dipole

$P_{rad} = 40\pi \cdot I_0^2\left(\dfrac{l}{\lambda}\right)^2$ used when antenna is Hertzian dipole

$R_{loss} = \dfrac{l}{2\pi \cdot a}\sqrt{\dfrac{\pi \cdot f \cdot \mu_c}{\sigma_c}}$ used when antenna is Hertzian dipole

$R_{rad} = 80\pi^2\left(\dfrac{l}{\lambda}\right)^2$ used when antenna is half-wave dipole

$S_{max} = \dfrac{15 \cdot I_0^2}{\pi \cdot R^2}$ used when antenna is half-wave dipole

$P_{rad} = 36.6 \cdot I^2$ used when antenna is half-wave dipole

Efficiency = E = $\dfrac{R_{rad}}{R_{rad} + R_{loss}}$

G = Gain = $E \cdot D$

E = $\dfrac{\lambda^2 \cdot D}{4 \cdot \pi}$

$P_{trans} = \dfrac{1}{2} \cdot I^2 (R_{rad} + R_{loss})$

$P_{rec} = P_{trans} \cdot G_{trans} \cdot G_{rec} \cdot \left(\dfrac{\lambda}{4\pi R}\right)^2$

III. BASIC PARAMETER CALCULATION

1. When transmitting antenna is Hertzian dipole

Code :

```
def Hertzian_trans():
	Smax = Smax_Hertzian(l1)
	Rloss_trans = Rloss(l1, a1)
	Rrad_trans = Rrad_Hertzian(l1)
	Prad = Prad_Hertzian(l1)
	Pt = Ptrans(Rrad_trans, Rloss_trans)
	eff_trans = efficiency(Rrad_trans, Rloss_trans)
	D_trans = D_Hertzian
	G_trans = gain(eff_trans, D_trans)
	return Smax, Rloss_trans, Rrad_trans, Prad, Pt, eff_trans, D_trans, G_trans
```

Using the formula codes applicable to the Transmission antenna as Hertzian dipole, we have

$$S_{max} = \frac{15\pi \cdot I_0^2}{R^2}\left(\frac{l_1}{\lambda}\right)^2$$

$$R_{loss\_trans} = \frac{l}{2\pi \cdot a_1}\sqrt{\frac{\pi \cdot f \cdot \mu_c}{\sigma_c}}$$

$$R_{rad\_trans} = 80\pi^2\left(\frac{l_1}{\lambda}\right)^2$$

$$P_{rad\_trans} = 40\pi \cdot I_0^2\left(\frac{l_1}{\lambda}\right)^2$$

$$P_{trans} = \frac{1}{2} \cdot I^2\left(R_{rad\_trans} + R_{loss\_trans}\right)$$

$$E_{trans} = \frac{R_{rad\_trans}}{R_{rad\_trans} + R_{loss\_trans}}$$

$G_{trans} = E_{trans} \cdot D$ with D = 1.5

2. When transmitting antenna is Half-wave dipole

Code :

```
def Halfwave_trans():
    Smax = Smax_halfwave(l1)
    Rloss_trans = Rloss(l1, a1)
    Rrad_trans = Rrad_halfwave
    Prad = Prad_halfwave()
    Pt = Ptrans(Rrad_trans, Rloss_trans)
    eff_trans = efficiency(Rrad_trans, Rloss_trans)
    D_trans = D_halfwave
    G_trans = gain(eff_trans, D_trans)
    return Smax, Rloss_trans, Rrad_trans, Prad, Pt, eff_trans, D_trans, G_trans
```

Use the formula codes applicable to the Transmission antenna as Half-wave dipole

$S_{max} = \frac{15 \cdot {I_0}^2}{\pi \cdot R^2}$

$R_{loss} = \frac{l}{2\pi \cdot a_1}\sqrt{\frac{\pi \cdot f \cdot \mu_c}{\sigma_c}}$

$P_{rad\ trans} = 36.6 \cdot I^2$

$R_{rad\_trans} = 73(\Omega)$

Calculate transmitting power

$P_{trans} = \frac{1}{2} \cdot I^2 (R_{rad\_trans} + R_{loss\_trans})$

$E_{trans} = \frac{R_{rad\_trans}}{R_{rad\_trans} + R_{loss\_trans}}$

$G_{trans} = E_{trans} \cdot D$ with D = 1.6.4

3. When receiving antenna is Hertzian dipole

Code :

```
def Hertzian_rec():
    Rloss_rec = Rloss(l2, a2)
    Rrad_rec = Rrad_Hertzian(l2)
    eff_rec = efficiency(Rrad_rec, Rloss_rec)
    D_rec = D_Hertzian
    G_rec = gain(eff_rec, D_rec)
    return Rloss_rec, Rrad_rec, eff_rec, D_rec, G_rec
```

Use recipe codes that apply to receiving antenna as Hertzian dipole

$R_{loss\_rec} = \frac{l}{2\pi \cdot a_2}\sqrt{\frac{\pi \cdot f \cdot \mu_c}{\sigma_c}}$

$R_{rad\_rec} = 80\pi^2\left(\frac{l_2}{\lambda}\right)^2$

$E_{rec} = \frac{R_{rad\_rec}}{R_{rad\_rec} + R_{loss\_rec}}$

$G_{rec} = E_{rec} \cdot D$ with D = 1.5

4. **When receiving antenna is Half-wave dipole**

Code :

```
def Halfwave_rec():
	Rloss_rec = Rloss(l2, a2)
	Rrad_rec = Rrad_halfwave
	eff_rec = efficiency(Rrad_rec, Rloss_rec)
	D_rec = D_halfwave
	G_rec = gain(eff_rec, D_rec)
	return Rloss_rec, Rrad_rec, eff_rec, D_rec, G_rec
```

Use recipe codes applicable to receiving antenna as Half-wave dipole

$R_{loss\_rec} = \frac{l}{2\pi \cdot a_2}\sqrt{\frac{\pi \cdot f \cdot \mu_c}{\sigma_c}}$

$P_{rad\ rec} = 36.6 \cdot I^2$

$E_{rec} = \frac{R_{rad\_rec}}{R_{rad\_rec} + R_{loss\_rec}}$

$G_{rec} = E_{rec} \cdot D$ with D = 1.64

IV. SPECIFIC CASES

In this problem, there will be 4 cases for (transmitting - receiving antenna)

1. Where transmitting - receiving antenna is Hertzian – Hertzian

Code:

```
if 0 < l1/lamda < 1/50 and 0 < l2/lamda < 1/50:
        # 2 antennas are Hertzian dipoles.
        Smax, Rloss_trans, Rrad_trans, Prad, Pt, eff_trans, D_trans, G_trans =
Hertzian_trans()
        Rloss_rec, Rrad_rec, eff_rec, D_rec, G_rec = Hertzian_rec()
        Pr = Prec(Pt, G_trans, G_rec)
        print('Both antennas are Hertzian dipoles')
        print('Power density: ' + str(Smax) + ' * sin(theta)^2 (W/m^2)')
        print_valid_antennas(Smax, Prad, eff_trans, D_trans, G_trans,
                                            eff_rec, D_rec, G_rec, Pr)
```

The condition for this case is when $0 < l_1 < \frac{\lambda}{50}$ và $0 < l_2 < \frac{\lambda}{50}$

When the Hertzian_trans() and Hertzian_rec() commands are executed and the two antennas are determined to be Hertzian dipoles.Power density have values:

$S = S_{\max} \cdot (\sin(\theta))^2$(W/m^2)

Output the values to the screen

2. **When transmitting - receiving antenna is Hertzian – Halfwave**

Code:

```
elif 0 < l1/lamda < 1/50 and abs(2*l2 - lamda) < 1e-4:
        # transmitting antenna is Hertzian dipole,
        # receiving antenna is half-wave length dipole.
        Smax, Rloss_trans, Rrad_trans, Prad, Pt, eff_trans, D_trans, G_trans =
Hertzian_trans()
        Rloss_rec, Rrad_rec, eff_rec, D_rec, G_rec = Halfwave_rec()
        Pr = Prec(Pt, G_trans, G_rec)
        print('Transmitting antenna is a Hertzian dipoles. Receiving antenna is a
half-wave length dipole.')
        print('Power density: ' + str(Smax) + ' * sin(theta)^2 (W/m^2)')
        print_valid_antennas(Smax, Prad, eff_trans, D_trans, G_trans,
                                    eff_rec, D_rec, G_rec, Pr)
```

The condition for this case is when: n $0 < l_1 < \frac{\lambda}{50}$ và $l_2 = \frac{\lambda}{2}$

to calculate easier, we note it by $\left|\frac{\lambda}{2} - l_2\right| < 10^{-4}$

When the Hertzian_trans() and Hertzian_rec() commands are executed and determine that transmitting antenna is Hertzian dipole, receiving antenna is half-wave length dipole

Power density have value: $S = S_{\max} \cdot (\sin(\theta))^2$(W/m^2)

Output the values to the screen

3. When transmitting - receiving antenna is Halfwave – Hertzian

Code:

```
elif abs(2*l1 - lamda) < 1e-4 and 0 < l2/lamda < 1/50:
        # transmitting antenna is half-wave length dipole,
        # receiving antenna is Hertzian dipole.
        Smax, Rloss_trans, Rrad_trans, Prad, Pt, eff_trans, D_trans, G_trans =
Halfwave_trans()
        Rloss_rec, Rrad_rec, eff_rec, D_rec, G_rec = Hertzian_rec()
        Pr = Prec(Pt, G_trans, G_rec)
        print('Transmitting antenna is half-wave length dipoles. Receiving antenna is a
Hertzian dipole.')
        print('Power density: ' + str(Smax) + ' * cos[pi/2 * cos(theta)]^2 / sin(theta)^2
(W/m^2)')
        print_valid_antennas(Smax, Prad, eff_trans, D_trans, G_trans,
                                              eff_rec, D_rec, G_rec, Pr)
```

The condition for this case is when $l_1 = \frac{\lambda}{2}$ và $0 < l_2 < \frac{\lambda}{50}$

to calculate easier, we note it by $\left|\frac{\lambda}{2} - l_1\right| < 10^{-4}$

When the Hertzian_trans() and Hertzian_rec() commands are executed and specifying that transmitting antenna is half-wave length dipole, receiving antenna is Hertzian dipole

Power density have values: $S = S_{\max} \cdot \left(\frac{\cos\left(\pi/2 - \cos(\theta)\right)}{\sin(\theta)} \right)^2$ (W/m^2)

Output the values to the screen

4. **When transmitting - receiving antenna is Halfwave – Halfwave**

Code:

```
elif abs(2*l1 - lamda) < 1e-4 and abs(2*l2 - lamda) < 1e-4:
	# 2 antennas are half-wave length dipoles.
	Smax, Rloss_trans, Rrad_trans, Prad, Pt, eff_trans, D_trans, G_trans = 
Halfwave_trans()
	Rloss_rec, Rrad_rec, eff_rec, D_rec, G_rec = Halfwave_rec()
	Pr = Prec(Pt, G_trans, G_rec)
	print('Both antenna are half-wave length dipoles.')
	print('Power density: ' + str(Smax) + ' * cos[pi/2 * cos(theta)]^2 / sin(theta)^2 
(W/m^2)')
	print_valid_antennas(Smax, Prad, eff_trans, D_trans, G_trans,
					eff_rec, D_rec, G_rec, Pr)
```

The condition for this case is when $l_1 = \frac{\lambda}{2}$ và $l_2 = \frac{\lambda}{2}$

to calculate easier, we note it by $\left|\frac{\lambda}{2} - l\right| < 10^{-4}$

When the Hertzian_trans() and Hertzian_rec() commands are executed and the two antennas are half-wave length dipole defined.

Power density have values $S = S_{\max} \cdot \left(\frac{\cos\left(\pi/2 - \cos(\theta)\right)}{\sin(\theta)} \right)^2$ (W/m^2)

Output the values to the screen

Special

When transmitting - receiving antenna is neither half-wave length dipole nor Hertzian dipole

Code:

```
else:
     print('Please check the length of antennas as some requirements for Hertzian and 
Half-wave length antenna are not met.')
```

Condition for this case is the remaining cases
Printed text is “not eligible to be Hertzian and Half-wave length antenna”

V. EXAMPLE

```
---INPUT SECTION---
Current amplitude I (in Ampere): I = 10
Frequency (in Hertz): 50000
Distance R between 2 antennas (in meter): R = 1000
Radius a1 of transmitting antenna (in meter): a1 = 0.05
Length l1 of transmitting antenna (in meter): l1 = 6
Radius a2 of receiving antenna (in meter): a2 = 0.03
Length l2 of receiving antenna (in meter): l2 = 8
```

When you run the program, and input parameter from the keyboard, as requiment in the INPUT SECTION

```
---OUTPUT SECTION---
Both antennas are Hertzian dipoles
Power density: 4.71238898038469e-09 * sin(theta)^2 (W/m^2)
Maximum power density:  4.71238898038469e-09 (W/m^2)
```

Then we will define type of dipole and do the calculation in OUTPUT SECTION

```
****Assume two antennas are oriented in the direction of maximum power.****
Radiation power:  0.039478417604357434 (W)
Efficiency of transmitting antenna:  0.4147458129823432
Directivity of transmitting antenna:  1.5
Gain of transmitting antenna:  0.6221187194735148

Efficiency of receiving antenna:  0.3618083500422928
Directivity of receiving antenna:  1.5
Gain of receiving antenna:  0.5427125250634391

Receiving power:  0.007326619088356429 (W)
```

All the basic parameter need to calculate.

Another example, when the transmitting antenna is half-wave length dipoles. Receiving antenna is a Hertzian dipole.

```
---INPUT SECTION---
Current amplitude I (in Ampere): I = 10
Frequency (in Hertz): 50000
Distance R between 2 antennas (in meter): R = 10000
Radius a1 of transmitting antenna (in meter): a1 = 0.05
Length l1 of transmitting antenna (in meter): l1 = 3000
Radius a2 of receiving antenna (in meter): a2 = 0.06
Length l2 of receiving antenna (in meter): l2 = 115
```

The INPUT SECTION

```
---OUTPUT SECTION---
Transmitting antenna is half-wave length dipoles. Receiving antenna is a Hertzian dipole.
Power density: 4.774648292756861e-06 * cos[pi/2 * cos(theta)]^2 / sin(theta)^2 (W/m^2)
Maximum power density:  4.774648292756861e-06 (W/m^2)

****Assume two antennas are oriented in the direction of maximum power.****
Radiation power:  3660.0 (W)
Efficiency of transmitting antenna:  0.9924264806463228
Directivity of transmitting antenna:  1.64
Gain of transmitting antenna:  1.6275794282599692

Efficiency of receiving antenna:  0.9421937367962626
Directivity of receiving antenna:  1.5
Gain of receiving antenna:  1.4132906051943939

Receiving power:  19.2863905608615 (W)
```

And all the OUTPUT SECTION will tell you the type and calculate the number