Bioelectromagnetism

Basic Concepts

1- True or False: The magnitude of the force exerted on one charge by another charge is inversely proportional to the square of the distance between the two charges.

2- True or False: By definition, the *electric field strength* at point P is given by **E** = **F**/Q_{test}.

3- True or False: The units of **E** are volts (V).

4- True or False: Because **E** fields exert forces on charges, work is required to move a charge from one point in space to another in the presence of an **E** field. The work done per unit charge is called *electric potential difference*.

5- True or False: When **E** does not vary with time, or when it varies slowly with time the frequency is low.

6- True or False: When charges are moving, they exert another kind of force on each other that is not along a line between the charges. Magnetic fields are used to account for this other kind of force.

7- True or False: Moving charges produce an electric current. This current **I** produces a magnetic field **B.**

8- True or False: Maxwell’s equations, which are a fundamental set of equations that form the framework of all of classical electromagnetic field theory.

9- The shape of the wave as a function of time is called the *waveform*.

10- True or False: The simplest type of electrical waveform is constant with time. This is called *direct current* or *DC* (also called *static* fields).

11- True or False: Many applications in electromagnetics use waves that are single-frequency sine waves. These waves are often called *alternating current* or *AC* waves, because the current alternates from positive to negative and back again. A major characteristic of AC waves is that the electric and magnetic fields can generate each other and are therefore coupled and cannot be analyzed separately.

12- Electromagnetic radiation of frequency f, when waves propagate in free space or in the human body wavelength is maintained. The wavelength does not depend on the medium where spreads.

13- Consider a signal of frequency f=2.45 GHz. Calculate its lambda in free space. Place it in the spectrum.

14- Consider a signal of frequency f=433 MHz. Calculate its lambda in free space. Place it in the spectrum.

15- What are ISM frequency bands?

EM Propagation in Biological Media

1. A plane wave travels from semi-infinite medium 1 to semi-infinite medium 2 and propagates normal to the boundary between the two media.

Show that the reflection coefficient of a plane wave with normal incidence on a flat boundary is given as:

$$\Gamma = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}$$

2. A plane wave travels from semi-infinite air medium to semi-infinite skin medium. Find the reflection and transmission coefficients assuming an incident signal of f=1.8 GHz. Take into consideration permittivity and conductivity values from Table I.

TABLE I

RELATIVE PERMITIVITY ε_R, CONDUCTIVITY σ (S/M) OF THE BODY TISSUES

Frrequency		skin	fat	muscle	bone
10 MHz	ε_r	361.66	13.77	170.73	36.77
	σ	0.19	0.03	0.62	0.04
433 MHz	ε_r	46.08	5.57	56.87	13.07
	σ	0.70	0.04	0.80	0.09
0.9 GHz	ε_r	41.4	5.46	55.03	12.45
	σ	0.86	0.05	0.94	0.14
1.8 GHz	ε_r	38.87	5.35	53.55	11.78
	σ	1.18	0.08	1.34	0.27
2.45 GHz	ε_r	38.01	5.28	52.73	11.38
	σ	1.46	0,10	1.74	0.39
5 GHz	ε_r	35.77	5.03	49.54	10.04
	σ	3.06	0.24	4.04	0.96
10 GHz	ε_r	31.29	4.60	42.76	8.12
	σ	8.01	0.58	10.63	2.14
17 GHz	ε_r	24.54	4.15	34.06	6.49
	σ	16.09	1.07	20.71	3.48

3. Assume that a plane wave with E_0=200V/m and f=1.8 GHz is propagating in the z direction though the air and arrives to our body. How much field will be transmitted?

4. Repeat problem 2 for frequencies of 10 MHz, 433 MHz, 900 MHz, 2.45 GHz, 5 GHz and 17 GHz. Discuss the results.

5. Find the penetration depth for the media of problem 2 at the specified frequency.

6. Repeat problem 5 for frequencies of 10 MHz, 433 MHz, 900 MHz, 1,8 GHz, 2.45 GHz, 5 GHz, 10 GHz and 17 GHz. Discuss the results.

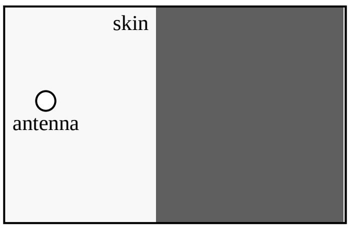
7. The complex permittivity of skin, fat, and muscle at 915 MHz, 2.45 GHz and 10 GHz, respectively, is given in the following table:

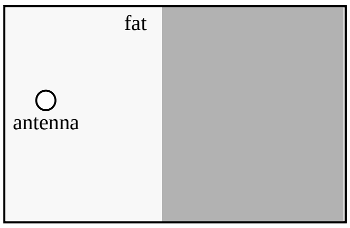
	915 MHz		2.45 MHz		10 GHz	
	ε’	ε’’	ε’	ε’’	ε’	ε’’
skin	41.5	17	38	11	31	14.5
fat	11.3	2.2	10.9	2	8.8	3.1
muscle	55	19	53	12.5	43	19

Calculate the loss tangent at the specified frequencies.

8. Find the reflection coefficients of the skin-fat and fat-muscle interfaces at the specified frequencies of problem 7.

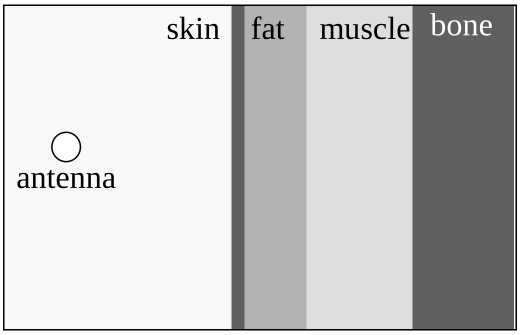
9. Assume that a plane wave with frequency of 1.8 GHz is propagating in the z direction through the air and arrives to a skin or fat tissue. Which tissue will absorb more energy? Take into consideration permittivity and conductivity values from Table I.





10. Assume that a plane wave with E_0=200V/m and f=1.8 GHz is propagating in the z direction though the air and arrives to the skin tissue of problem 9. Calculate the electric field strength 1 cm below the air-skin interface. Take into consideration permittivity and conductivity values from Table I. Repeat the calculation for a signal of 17 GHz.

11. Assume that a plane wave with frequency of 1.8 GHz is propagating in the z direction though the air and arrives to the following tissue sequence:



Which tissue will now absorb more energy? Take into consideration permittivity and conductivity values from Table I.

12. Consider now a plane wave with E_0=50V/m and f=1.8 GHz is propagating in the z direction though the air and arrives to the tissue sequence of problem 11. If we assume a skin and fat thicknesses of 3 mm and 5 mm respectively, calculate the electric field maximum amplitude that could reach the muscle tissue. Ignore the influence of standing waves.

Dosimetry

1. A plane wave with E_0=100 V/m travels from semi-infinite air medium to semi-infinite skin medium. Find the maximum local SAR in the skin assuming an incident signal of f=1.8 GHz. Take into consideration constant values from Tables I and II.

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	σ	16.09	1.07	20.71	3.48

TABLE II

DENSITY OF THE BODY TISSUES (kg/m^3)

skin	fat	muscle	bone
1100	916	1041	1990

2. A plane wave with E_0=100 V/m travels from semi-infinite air medium to semi-infinite skin medium. Find the maximum local SAR in the skin assuming incident signals of frequencies 10 MHz and 5 GHz. Take into consideration constant values from Tables I and II.

3. A plane wave with E_0=100 V/m travels from semi-infinite air medium to semi-infinite skin medium. Find the 1 g average SAR in the skin assuming an incident signal of f=1.8 GHz. Take into consideration constant values from Tables I and II. Repeat the calculation for with E_0=100V/m an incident signal of f=5 GHz.