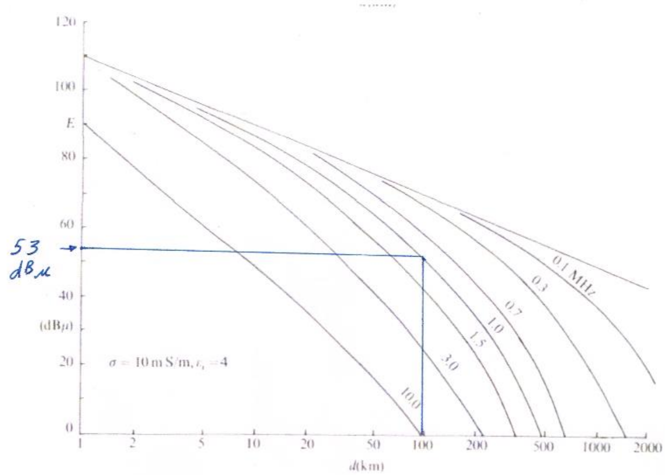
Ministry of Higher Education & Scientific Research
University of Technology
Communication Eng. Department
Final Examination (2016/2017)

Subject: **Radio wave propagation** Date: **11 / 6 / 2017**
Division: **Wireless** Time: **180 min.**
Year: **Second** Examiner: **Assist. Prof. R.T. Hussein**
Number of pages: **6 with solutions**

Attempt **five** questions only

Q1: Estimate from appropriate propagation chart the electric field strength at $d = 100$ km from a vertical monopole of effective height $h_e = 0.5\lambda$ with $f = 1$ MHz and input current $I_o = 10$A (rms) over a land path with conductivity $\sigma = 10$ mS/m and relative permittivity $\epsilon_r = 4$. Determine the induced voltage in the whip antenna with an effective height 60 m at that distance. **[12 Marks]**

<u>Solution:</u> $d = 100$ km, $h_e = 0.5\lambda$, $f = 1$ MHz, $I_o = 10$A,
From the chart at $d = 100$ km, $E = 53\ dB\mu$



$$E_1\ (\text{mV/m}) = 120\pi\frac{I_o h_{et}}{\lambda} = 120\pi\frac{10 \times 0.5\lambda}{\lambda}$$
$$= 942.5\ (\text{mV/m})$$

Correction factor $CF = 20\log\frac{E_1}{300} = 20\log\frac{942.5}{300} = 9.94\ dB$

$$E_T = 53 + 9.94 = 62.94\ dB\mu \quad \rightarrow \quad E_T = 10^{\frac{62.94}{20}} = 1.403\ mV/m$$

$\sigma = 10$ mS/m and relative permittivity $\epsilon_r = 4$, $h_{er} = 60m$

$$\frac{E_\rho}{E_z} = \frac{J_S Z_S}{H\eta_o} = \frac{Z_S}{\eta_o} = \frac{1}{120\pi}\sqrt{\frac{\omega\mu}{\sqrt{\sigma^2+\omega^2\epsilon^2}}}\ \angle\left(\frac{1}{2}\ tan^{-1}\frac{\sigma}{\omega\epsilon}\right)$$

$$\omega\epsilon = 2 \times \pi \times 10^6 \times 8.854 \times 10^{-12} \times 4 = 2.23 \times 10^{-4}$$

$$\frac{E_\rho}{E_z} = 0.0745\angle 44.36^o$$

$$\psi = tan^{-1}0.0745 = 4.26^o$$
$$\boldsymbol{V_{ind}} = E_T\ l_{er}\cos\psi = 1.403 \times 10^{-3} \times 60 \times \cos 4.26 = 84\ \text{mV}$$

Q2: Explain in details the following terms; gyro-magnetic frequency, maximum usable frequency, LUF, critical frequency, Maximum Usable Frequency Factor (MUFF), sporadic E-layer, Ionosonde, and collision frequency in ionospheric layers, and Negative Index Media., **[12 Marks]**

Q3: a) The electric field intensity of a linearly polarized uniform plane wave propagation in the $+z$ direction in sea water is **[8 Marks]**

$\mathbf{E} = \mathbf{a}_x 100\cos(10^7\pi t)$ (V/m) at $z = 0$.

The constitutive parameters of sea water are $\epsilon_r = 80$, $\mu_r = 1$, and $\sigma = 4$ (S/m). Determine the attenuation constant, the phase constant, the intrinsic impedance, the phase velocity, wavelength, and the skin depth. Find the distance at which the amplitude of **E** is 1% of its value at $z = 0$.

Solution:

$\omega = 10^7\pi$ (rad/s), $\quad f = \frac{\omega}{2\pi} = 5\times 10^6$ (Hz),

$$\frac{\sigma}{\omega\epsilon} = \frac{\sigma}{\omega\epsilon_o\epsilon_r} = \frac{4}{10^7\pi\times 80\times\frac{1}{36\pi}\times 10^{-9}} = 180 \gg 1,$$

Hence we can use the formulas for good conductors:

The attenuation constant $\alpha = \sqrt{\pi f\mu\sigma}$

$$= \sqrt{5\pi\times 10^6(4\pi 10^{-7})4} = 8.89 \quad (\text{Np/m})$$

The phase constant $\beta = \sqrt{\pi f\mu\sigma}$

$$= \sqrt{5\pi\times 10^6(4\pi 10^{-7})4} = 8.89 \qquad (\text{rad/m})$$

The intrinsic impedance $\eta = [1+j]\sqrt{\frac{\pi f\mu}{\sigma}}$

$$= [1+j]\sqrt{\frac{5\pi\times 10^6(4\pi 10^{-7})}{4}} = \pi e^{j\pi/4} \quad (\Omega)$$

The phase velocity $v_p = \frac{\omega}{\beta} = \frac{10^7\pi}{8.89} = 3.53\times 10^6$ (m/s)

Wavelength $\quad \lambda = \frac{2\pi}{\beta} = \frac{2\pi}{8.89} = 0.707$ (m)

The skin depth $\delta_s = 1/\alpha = 1/8.89 = 0.112$ (m)

Distance z_1 at which the amplitude of decreases to 1% of its value at $z = 0$:

$e^{-\alpha z_1} = 0.01 \quad$ or $\quad e^{\alpha z_1} = 100$

$$z_1 = \frac{1}{\alpha}\ln 100 = \frac{4.605}{8.89} = 0.518 \text{ (m)}$$

b) Show that the highest value of a maximum usable frequency is equal to 3.6 ×critical frequency. **[4 Marks]**

or $\sin\phi_i = \sqrt{1-\left(\frac{f_{cr}}{f_{MUF}}\right)^2}$ — — (4-14)

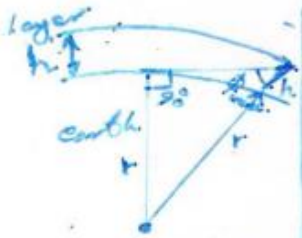
where f_{MUF} is called the maximum usable freq.

Eq. (4-14) can be rewritten as

$f_{MUF} = f_{cr} \cdot \sec\phi_i$ — — (4-15)

where $\sec\phi_i = \frac{1}{\cos\phi_i}$ — — (4-16)

and for the idealized horizontally stratified ionosphere is become



$f_{MUF}(max) = f_{cr} \sec(\phi_{i,max})$

Ex: if $\phi_{i,max} = \sin^{-1}\left(\frac{r}{r+h}\right) = 74^\circ$

$f_{MUF}(max) = \frac{f_{cr}}{\cos 74} = 3.6 f_{cr}$

Then ... so that

Q4: a) Consider application of a 5.2 GHz wireless LAN in an office building. If the longest link is 100m, what is the maximum path loss? The office building the value of $N = 31$, and the floor penetration loss factor for a single floor $Lf = 16$ dB. **[6 Marks]**

Solution:

$$L_{total} = 20\log_{10}(f) + N\log_{10}(d) + Lf(n) - 28 \text{ dB}$$

N is the distance power loss coefficient

f in the frequency in MHz

d is the distance in meters (d > 1m)

Lf(n) is the floor penetration loss factor

N is the number of floors between the transmitter and the receiver.

Where f = 5200 MHz, N = 31, d = 100, Lf = 16,

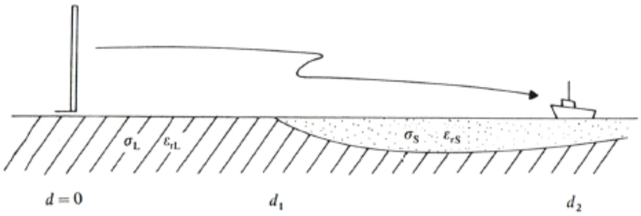
Thus the maximum path loss

$L_{total} = 20\log_{10}(5200) + 31\log_{10}(100) + 16 - 28 \text{ dB} = 124.3\ dB$

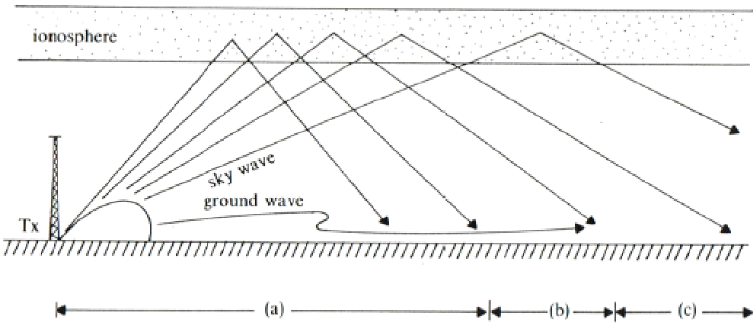
b) Explain with aid of drawing the propagation problems of a ground surface wave. **[6 Marks]**

Solution:

1) *Land – sea boundary*. In the case of a mixed land-sea path there is a very abrupt and drastic change in both conductivity and relative permittivity at the boundary between land and sea. When propagation over sea water (good conductor), particularly at f <100 kHz, surface absorption for E field is small. And when propagation over a ground (good dielectric) the surface absorption for E field is high.



2) *Transmitter coverage for broadcasting*. For radio broadcasting using LF and MF, it is useful to be able to estimate the range of each transmitter under specified conditions. One way of overcoming the problem of frequency limited is to operate several transmitters in various locations at the same frequency provided the coverage of each transmitter does not overlap with the others; a much larger region can receive the radio broadcasts.
3) *Sky-wave interference***.** LF and MF transmitting antennas propagate both a ground wave and a sky wave is effectively by D-layer. After sunset, when the D-layer has diminished, the transmitting antenna produces two modes of propagation as shown in figure below.

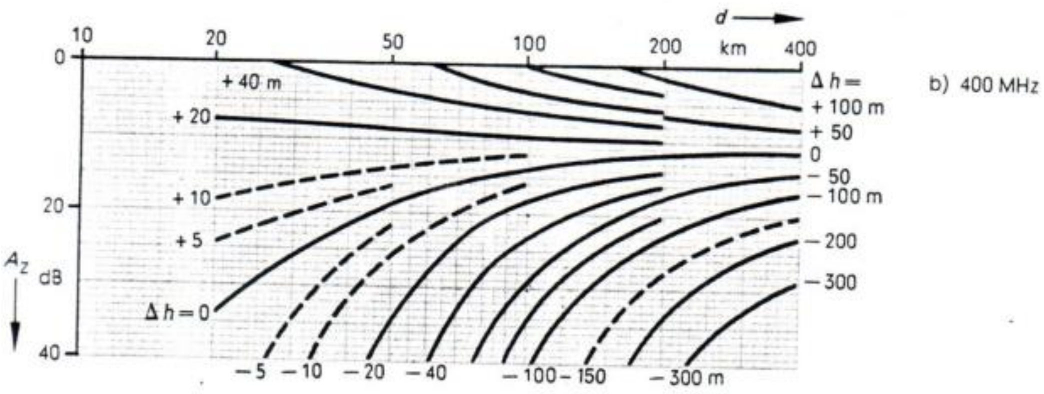


Q5: a) A link is to be established between two points with a $d = 100$ km spacing, at an operating frequency of 400MHz. Determine the obstruction loss for the given value of $\Delta h = +40$ m at $d_1 = 30$ km and $d_2 = 70$ km. **[6 Marks]**

<u>Solution</u>

$d' = \frac{4d_1d_2}{d} = \frac{4\times30\times70}{100} = 84km$

The obstruction loss A_z from the chart is $A_z \approx 5.5$dB for $d' = 84km$ and $\Delta h = +40$ m



b) Explain with aid of equations and drawing the group velocity and phase velocity of an EM waves which propagate through the atmospheric regions. **[6 Marks]**

Solution:

In general, the *phase velocity* $\upsilon_p = \frac{\omega}{\beta}$ and

The *group velocity* $\upsilon_g = \frac{\upsilon_p}{1 - \frac{\omega}{\upsilon_p}\frac{d\upsilon_p}{d\omega}}$.

a) In tropospheric region, $\sigma = 0$, $\boldsymbol{\mu_r} = 1$, and

$\epsilon_r = 1 + \frac{155.1}{T}\left[P + \frac{4810p}{T}\right] \times 10^{-6}$.

The *phase velocity* $\upsilon_p = \frac{c}{n} = \frac{c}{\sqrt{\epsilon_r}}$

So, $n = \sqrt{\epsilon_r} = 1 + \frac{77.6}{T}\left[P + \frac{4810p}{T}\right] \times 10^{-6} \quad > 1 \quad \rightarrow \upsilon_p < c$

And with increasing the height, the value of $n \rightarrow 1$ and $\upsilon_p \rightarrow c$.

While, the *group velocity* $\upsilon_g < c$,

and with increasing the height, the $\upsilon_g \rightarrow c$.

b) In stratospheric region, $\sigma = 0$, $\boldsymbol{\mu_r} = 1$, and $\epsilon_r = 1$.

The $\upsilon_p = \upsilon_g = c$

c) In Ionospheric region

$v_{p1} = \frac{c}{\sqrt{1 - \frac{\omega_c^2}{\omega^2 + \omega\omega_H}}} \quad < c$, while $\upsilon_g > c$.

Q6: a) A sinusoidal electric intensity of amplitude 100 (V/m) and frequency 1.5 (GHz) exists in a lossy dielectric medium that has a relative permittivity of 5 and a loss tangent of 0.001. Find the average power dissipated in the medium per cubic meter. **[6 Marks]**

Solution:

First we must find the effective conductivity of the lossy medium:

$$\tan\delta = 0.001 = \frac{\sigma}{\omega\epsilon_o\epsilon_r}$$

$$\sigma = 0.001(2 \times \pi \times 1.5 \times 10^9)\left(\frac{10^{-9}}{36\pi}\right)(5) = 4.167 \times 10^{-4}\ (\text{S/m})$$

The average power dissipated per unit volume is

$$p = \frac{1}{2}JE = \frac{1}{2}\sigma E^2\ , \quad p = \frac{1}{2} \times (4.167 \times 10^{-4}) \times 100^2 = 2.084\ (\text{W/m}^3)$$

b) Determine the values of attenuation rate (α) at height $h = 85\ km$ in the D-layer if the corresponding free electron density is $N = 5 \times 10^6/m^3$ during the night and $N = 10^9/m^3$ during the day, and the effective electron collision frequency is $\upsilon = 8 \times 10^6/s$, and operating frequency (i) $f = 0.8\ MHz$, and (ii) $f = 8\ MHz$. Ignoring the effect of earth's magnetic field. **[6 Marks]**

Solution:

$$\alpha = \frac{60\,\pi\,\sigma}{\sqrt{\varepsilon_r}}\ \text{Np/m} \qquad \text{or} \qquad \alpha = 1.637 \times 10^6 \frac{\sigma}{\sqrt{\varepsilon_r}}\ \text{dB/km}$$

Where

$$\sigma = \frac{Ne^2\upsilon}{m(\upsilon^2+\omega^2)}\ \text{S/m} \qquad \text{and} \qquad \varepsilon_r = 1 - \frac{Ne^2}{\varepsilon_o m(\upsilon^2+\omega^2)}$$

At f = 0.8 MHz

(i) $\text{N} = 5 \times 10^6/\text{m}^3$ during the night

$$\sigma = \frac{(5\times10^6)(1.59\times10^{-19})^2(8\times10^6)}{9.1\times10^{-31}((8\times10^6)^2+(2\pi\times0.8\times10^6)^2)} = 14.06\ \times 10^{-10}\text{S/m}$$

$$\varepsilon_r = 1 - \frac{5\times10^6(1.59\times10^{-19})^2}{8.854\times10^{-12}\times9.1\times10^{-31}\times((8\times10^6)^2+(2\pi\times0.8\times10^6)^2)} = 1$$

$$\alpha = \frac{60\,\pi\,\sigma}{\sqrt{\varepsilon_r}} = \frac{60\,\pi\times 14.06\ \times10^{-10}}{\sqrt{1}} = 26.503\ \times 10^{-8}\text{Np/m}$$

$$\alpha = 1.637 \times 10^6 \frac{\sigma}{\sqrt{\varepsilon_r}} = 1.637 \times 10^6 \times \frac{14.06\times10^{-10}}{\sqrt{1}} = 2.302\ \text{mdB/km}$$

(ii) $\text{N} = 10^9/\text{m}^3$ during the day

$$\sigma = \frac{(10^9)(1.59\times10^{-19})^2(8\times10^6)}{9.1\times10^{-31}((8\times10^6)^2+(2\pi\times0.8\times10^6)^2)} = 2.812\ \times 10^{-7}\text{S/m}$$

$$\varepsilon_r = 1 - \frac{10^9(1.59\times10^{-19})^2}{8.854\times10^{-12}\times9.1\times10^{-31}\times((8\times10^6)^2+(2\pi\times0.8\times10^6)^2)} = 1$$

$$\alpha = \frac{60\,\pi\,\sigma}{\sqrt{\varepsilon_r}} = \frac{60\,\pi\times 2.812\times10^{-7}}{\sqrt{1}} = 5.3\ \times 10^{-5}\text{Np/m}$$

$$\alpha = 1.637 \times 10^6 \frac{\sigma}{\sqrt{\varepsilon_r}} = 1.637 \times 10^6 \times \frac{2.812\times10^{-7}}{\sqrt{1}} = 0.46\ \text{dB/km}$$

At f = 8 MHz

(iii) $\text{N} = 5 \times 10^6/\text{m}^3$ during the night

$$\sigma = \frac{(5\times10^6)(1.59\times10^{-19})^2(8\times10^6)}{9.1\times10^{-31}((8\times10^6)^2+(2\pi\times8\times10^6)^2)} = 2.7\ \times 10^{-10}\text{S/m}$$

$$\varepsilon_r = 1 - \frac{5\times10^6(1.59\times10^{-19})^2}{8.854\times10^{-12}\times9.1\times10^{-31}\times((8\times10^6)^2+(2\pi\times8\times10^6)^2)} = 1$$

$$\alpha = \frac{60\,\pi\,\sigma}{\sqrt{\varepsilon_r}} = \frac{60\,\pi\times 2.7\ \times10^{-10}}{\sqrt{1}} = 5.09\ \times 10^{-8}\text{Np/m}$$

$$\alpha = 1.637 \times 10^6 \frac{\sigma}{\sqrt{\varepsilon_r}} = 1.637 \times 10^6 \times \frac{2.7\times10^{-10}}{\sqrt{1}} = 0.442\ \text{mdB/km}$$

(iv) $\text{N} = 10^9/\text{m}^3$ during the day

$$\sigma = \frac{(10^9)(1.59\times10^{-19})^2(8\times10^6)}{9.1\times10^{-31}((8\times10^6)^2+(2\pi\times8\times10^6)^2)} = 0.54\ \times 10^{-7}\text{S/m}$$

$$\varepsilon_r = 1 - \frac{10^9(1.59\times10^{-19})^2}{8.854\times10^{-12}\times9.1\times10^{-31}\times((8\times10^6)^2+(2\pi\times8\times10^6)^2)} = 1$$

$$\alpha = \frac{60\,\pi\,\sigma}{\sqrt{\varepsilon_r}} = \frac{60\,\pi\times 0.54\times10^{-7}}{\sqrt{1}} = 1.02\ \times 10^{-5}\text{Np/m}$$

$$\alpha = 1.637 \times 10^6 \frac{\sigma}{\sqrt{\varepsilon_r}} = 1.637 \times 10^6 \times \frac{0.54\times10^{-7}}{\sqrt{1}} = 0.088\ \text{dB/km}$$