Telecommunication Systems
June 26th, 2019

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SURNAME AND NAME ______________________________

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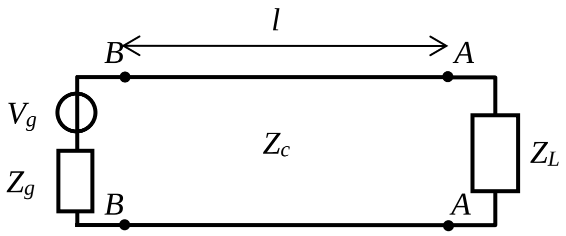
Problem 1

A source with voltage V_g = 50 V and internal impedance Z_g = 100 Ω is connected to a load Z_L = 25 Ω by a transmission line with characteristic impedance Z_C = 50 Ω, the frequency is f = 300 MHz and the length of the line is l = 4.25 m

Calculate:

a) The power absorbed by the load
b) The temporal trend of the voltage at the beginning of the line (section BB below), V_B



Solution

a) The wavelength is:

$$\lambda = \lambda_0 = c/f = 1 \text{ m}$$

As a consequence, the length of the line normalized to the wave length is:

$$l/\lambda = 4.25 = 4 + 0.25 \text{ m}$$

In other terms, the line is a $\lambda/4$.

As a result, the load at section BB can be easily calculated as:

$$Z_{BB} = \frac{Z_C^2}{Z_L} = 100\ \Omega$$

The reflection coefficient for the source is:

$$\Gamma_g = \frac{Z_{BB} - Z_g}{Z_{BB} + Z_g} = 0$$

Therefore, the power absorbed by the load is:

$$P_L = P_{AV} = \frac{|V_g|^2}{8\,\mathrm{Re}\left[Z_g\right]} = 3.125 \text{ W}$$

b) The voltage at the beginning of the line is:

$$V_{BB} = V_g \frac{Z_{BB}}{Z_{BB} + Z_g} = 25 \text{ V}$$

c) The trend of V_{BB} in time is given by:

$$v_{BB}(t) = \mathrm{Re}\left[V_{BB}\, e^{j\omega t}\right] = 25\cos(\omega t) \text{ V}$$

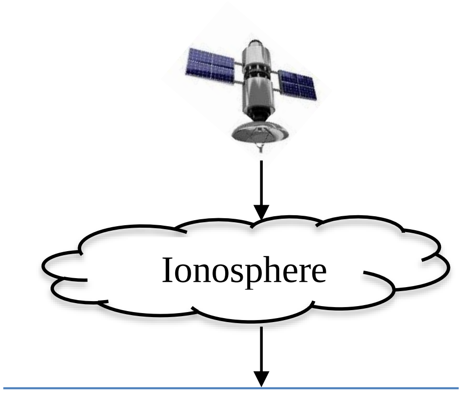
Problem 2

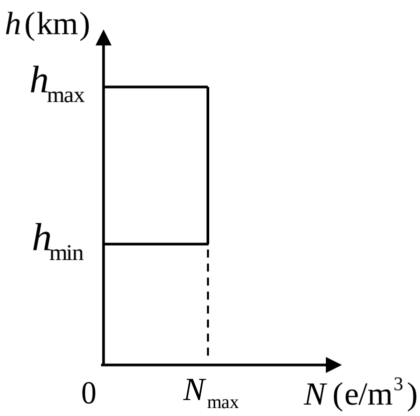
Making reference to the figure below, a satellite transmits Earth observation data to a ground station using two channels centered around the carrier frequencies f_1 = 20 MHz and f_2 = 25 MHz (zenithal link). The ionosphere can be modelled with the electron density profile sketched in the figure (right side), where h_{max} = 450 km and h_{min} = 50 km.

1) Determine the satellite altitude H (> h_{max}) and the peak electron content N_{max}, knowing that the data travel time is T_1 = 2.9 ms at f_1 and T_2 = 2.7 ms at f_2.

2) What happens to the communication system if, due to a sudden ionospheric anomaly, the value of N_{max} determined at point 1) doubles?

Assumption: no effects induced by the troposphere (neither delay, nor attenuation).





Solution

1) The total travel time T is due to the free space and to the ionosphere, the latter being frequency dependent. T is defined as:

$$T = T_{FS} + T_{IONO} = \frac{H}{c} + \frac{1}{2c}\frac{81}{f^2}TEC$$

where TEC is the total electron content. As a result, taking the difference between T_1 and T_2:

$$\Delta T = T_1 - T_2 = \frac{81}{2c}TEC\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)$$

$$TEC = \frac{2c}{81}\Delta T \frac{1}{\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)} = 1.646 \cdot 10^{18} \text{ e/m}^2$$

N_{max} can be obtained from:

$$N_{max} = \frac{TEC}{(h_{max} - h_{min})} = 4.11 \cdot 10^{12} \text{ e/m}^3$$

Finally, the height of the satellite is given, for example, by:

$$H = c\left(T_1 - \frac{1}{2c}\frac{81}{f_1^2}TEC\right) \approx 700 \text{ km}$$

2) If the values of the maximum electron content becomes $N'_{\max} = 8.22 \cdot 10^{12}$ e/m^3, the critical frequency of the link becomes $f_C \approx 9\sqrt{N'_{\max}} = 25.8$ MHz. Being both carrier frequencies lower than the critical frequency, the signal transmitted by the satellite will be completely reflected by the ionosphere.

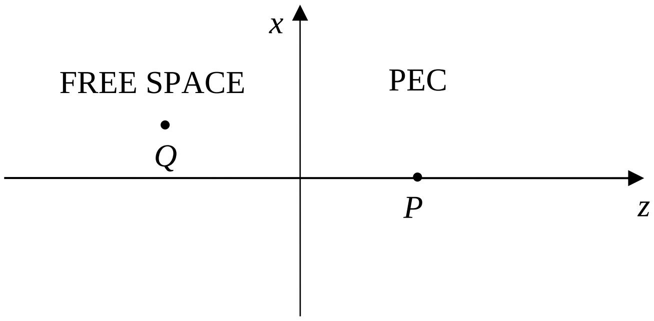
Problem 3

A uniform plane wave propagates in free space and impinges on a perfect electric conductor (PEC). The incident electric field is

$$\vec{E}_i = e^{-j41.888z}\ \vec{\mu}_y \ \text{V/m}$$

Calculate:

a) The frequency of the wave
b) The wavelength of the wave in the first medium
c) The electric field in P(0,0,0.6375)
d) The electric field in Q(0.6375,0.6375,-0.6375)



Solution

a) The information on the frequency of the wave is embedded in phase constant β = 41.888 rad/m. In free space its expression is:

$$\beta = \frac{2\pi f}{c}$$

Therefore f = 2 GHz.

b) In free space, the wavelength is given by:

$$\lambda = \frac{c}{f} = 0.15 \ \text{m}$$

c) The electric field in P is zero: no EM wave can be transmitted into a PEC.

d) Following point c), the incident electric field is totally reflected. Thus, the electric field in Q is a combination of the incident and of the reflected field. The second one is found by studying the reflection coefficient. For the discontinuity of the problem:

$$\Gamma = \frac{\eta_{PEC} - \eta_{FS}}{\eta_{PEC} + \eta_{FS}} = \frac{0-377}{0+377} = -1$$

The reflected field is therefore (note the change of sign at the exponent):

$$\vec{E}_r = -e^{j41.888z}\ \vec{\mu}_y \ \text{V/m}$$

The total electric field in Q is found by summing up both the incident and reflected fields and by setting z = -0.6375 (the other two coordinates are not important as the wave is a plane wave):

$$\vec{E}_T(Q) = \vec{E}_i(Q) + \vec{E}_R(Q) = \vec{\mu}_y + \vec{\mu}_y = j2 \ \text{V/m}$$

This is one of the points where the two fields interact constructively by providing the maximum absolute value of the electric field.

Problem 4

Consider a link from the moon to a ground station. The carrier frequency is f = 30 GHz. The atmospheric attenuation A can be modelled using the following Complementary Cumulative Distribution Function (probability expressed in percentage values, A expressed in dB):

$$P(A) = 100e^{-1.15A}$$

Design the ground antenna to guarantee a minimum SNR of 10 dB for 99.99% of the yearly time. Use the following data:

- the gain of the antenna on the moon is G_M = 30 dB
- assume that both antennas are optimally pointed
- the transmitted power is P_T = 1 kW
- the distance between the ground station and the satellite is H = 390000 km
- the receiver LNA equivalent noise temperature is T_{LNA} = 120 K
- the mean radiating temperature of the troposphere is T_{mr} = 278 K
- assume that there are no additional losses in the transmitter and receiver chains, nor antenna pointing inaccuracies
- the bandwidth is B = 100 MHz

Solution

In order to guarantee the target SNR for 99.99% of the time, the atmospheric attenuation needs to be lower than a given value. This value can be determined by setting $P(A)$ = 100%-99.99% = 0.01%. As a result, A = 8 dB = 0.1582. This value can be included in the link budget to determine the gain of the ground atenna (the wavelength is $\lambda = c/f$ = 0.01 m):

$$SNR = \frac{P_T G_G \left(\frac{\lambda}{4\pi H}\right)^2 G_M A}{k T_{sys} B}$$

where f_S and f_R are assumed to be 1, as antennas are optimally pointed.

The noise power depends on the total system equivalent noise temperature:

$$T_{sys} = T_A + T_{LNA} = T_{mr}(1-A) + T_C A_R + T_{LNA} = 354.5 \text{ K}$$

By inverting the SNR equation, G_G can be determined.

$G_G = 7.428 \cdot 10^6$ = 68.7 dB

Considering the relationship between the gain and the antenna effective area:

$$A_{eff} = \eta A = \frac{\lambda^2}{4\pi} G_G = 59.11 \text{ m}^2$$

η is the antenna efficiency and A is its physical area. Assuming a reasonable value for η, i.e. 0.6:

$$A = \left(\frac{D}{2}\right)^2 \pi = \frac{A_{eff}}{\eta} = 98.52 \text{ m}^2$$

D is the antenna diameter (we assume to use a parabolic antenna, given the very high gain required), which turns out to be:

D = 11.2 m

Problem 5

Design a multi-beam geostationary system providing broadband Internet (Mb/s) via satellite over Europe: system architecture, typical frequencies to be employed, main features of the ground stations (both user and operator side), user access scheme, etc.

Solution

A geostationary system aimed at providing broadband Internet access via satellite makes use of multiple beams of limited aperture, which allows to improve the satellite-user link budget (thanks to a better antenna gain aboard the satellite) and to implement a frequency reuse scheme.

The system architecture consists in a forward link (from the operator ground station to the user through the satellite) and a return link (from the user back to the operator ground station through the satellite) because the service includes information originating from the user (e.g. webpage request, packet feedbacks, …).

The operator ground station, the gateway, is characterized by a large antenna (high gain) to guarantee the link availability for at least 99.999% of the time. The frequency of the links between the gateway and the satellites are higher (e.g. 28 GHz) than those of the links between the satellite and the users (e.g. 19 GHz), as the gateway needs to simultaneously upload a large amount of information to the satellite.

The users that are illuminated by the same satellite beam will have access to the satellite simultaneously using an access scheme such as (typical user link availability of 99.99%):

- Time Division Multiple Access (TDMA): each user transmits the information always in a given portion of the frame (time is shared)
- Frequency Division Multiple Access (FDMA): each user transmits the information always in a given portion of the available bandwidth, i.e. a channel (frequency is shared)
- Code Division Multiple Access (CDMA): each user transmits the information multiplied by a specific pseudo-random code, that is (almost) orthogonal to those associated to the other users