Telecommunication Systems
January 24th, 2019

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SURNAME AND NAME ______________________________

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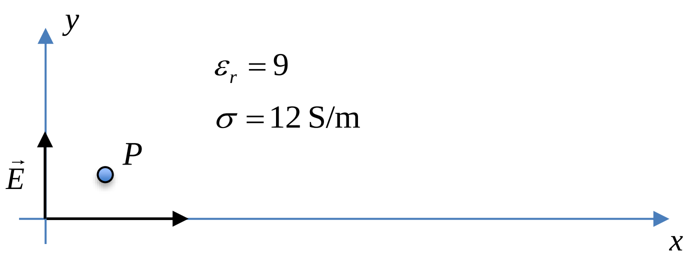
Problem 1

A uniform sinusoidal plane wave with frequency f = 800 MHz propagates in a medium characterized by relative electric permittivity ε_r = 9, magnetic permeability μ_r = 1 and conductivity σ = 12 S/m. The expression of the electric field is (E_0 = 10 V/m):

$$\vec{E} = E_0\, e^{-\alpha x} e^{-j\beta x} \vec{\mu}_y \text{ V/m}$$

For such a wave, calculate:

1. the attenuation constant α and the phase constant β
2. the coordinates, in meters, of point P(λ,λ), where λ is the wavelength
3. the power received by an antenna located at P with equivalent reception area A_e = 1 m^2



Solution

1) Let us first check the loss tangent for the wave:

$$\tan\delta = \frac{\sigma}{\omega\varepsilon} \approx 30$$

The medium can be considered as a good conductor, which is very dissipative. As a consequence, the following approximations can be used to calculate the propagation constant ($\mu = \mu_0$):

$$\gamma = \alpha + j\beta = \sqrt{\frac{\omega\mu\sigma}{2}} + j\sqrt{\frac{\omega\mu\sigma}{2}} = 194.68 + j194.68 \text{ 1/m}$$

2) The wavelength is:

$$\lambda = \frac{2\pi}{\beta} = 0.0323 \text{ m}$$

Therefore P is in (0.0323 m, 0.0323 m).

3) The power received at P by the antenna is:

$$P = SA_e = \frac{1}{2}\frac{\left|\vec{E}(P)\right|^2}{|\eta|}\cos\left(\measuredangle\eta\right) A_e = \frac{1}{2}\frac{\left|E_0\right|^2}{|\eta|} e^{-2\alpha x_P} \cos\left(\measuredangle\eta\right) A_e \text{ W}$$

where x_P = 0.0323 m and (considering the good conductor approximations):

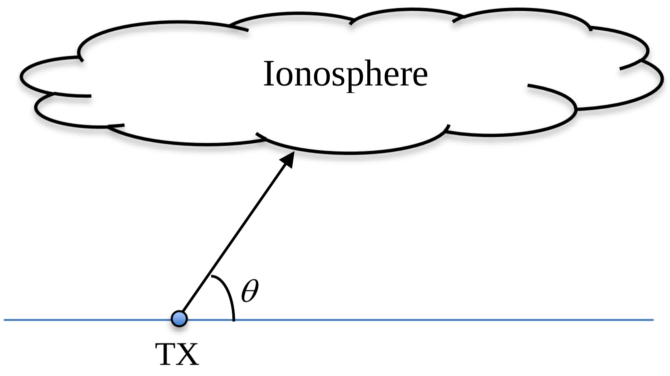
$$\eta = \sqrt{\frac{\mu\omega}{2\sigma}}(1+j) = 16.22(1+j) \ \Omega$$

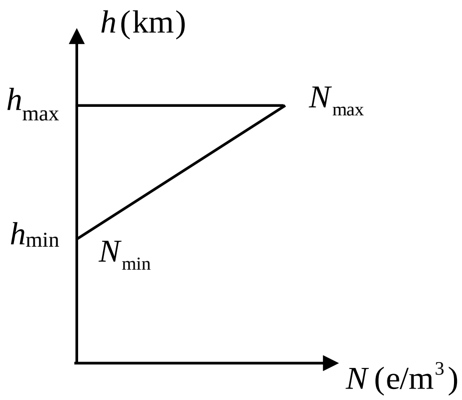
Therefore:

$$P = 5.37 \ \mu\text{W}$$

Problem 2

Making reference to the figure below, the ionosphere is modelled with the sketched electron density profile, where $N_{\max} = 4\times10^{12}$ e/m^3, $N_{\min} = 1\times10^{12}$ e/m^3, $h_{\min} = 100$ km and $h_{\max} = 400$ km. Determine the minimum operational frequency f_{GEO} to reach a geostationary satellite, seen at $\theta = 50°$ elevation from the ground station in TX.





Solution

1) The minimum frequency necessary to reach the geostationary satellite f_{GEO}, for a given elevation angle θ, is obtained by inverting:

$$\cos\theta = \sqrt{1-\left(\frac{f_C}{f_{GEO}}\right)^2} = \sqrt{1-\left(\frac{9\sqrt{N_{\max}}}{f_{GEO}}\right)^2}$$

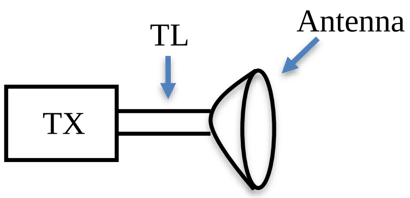
which yields (assuming $\theta = 50°$):

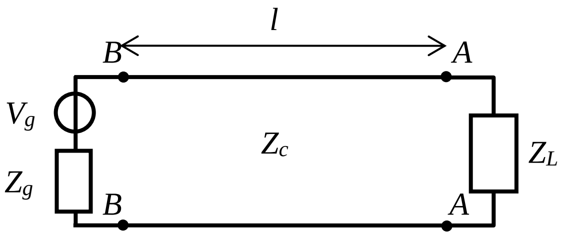
$$f_C = \sqrt{\frac{81 N_{\max}}{1-\left[\cos(\theta_{GEO})\right]^2}} \approx 23.5 \text{ MHz}$$

For any frequency higher than f_C, TX will reach the GEO satellite.

Problem 3

A transmitter TX with voltage V_g = 100 V and internal impedance Z_g = 50 Ω is connected to a transmitting antenna acting as a load (Z_L) by a lossless transmission line TL with characteristic impedance Z_C = 150 Ω. The line length is l = 6 m and the frequency is f = 300 MHz.
Calculate the power radiated by the antenna (i.e. absorbed by the load), P_L, if the antenna radiation resistance is Z_L = 50 Ω.





Solution

The wavelength is:

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

There is a discontinuity at the load section, but the line length l is a multiple of the wavelength. Therefore, the input impedance at section BB is Z_{BB} = 50 Ω. In fact:

$$\Gamma_A = \frac{Z_L - Z_C}{Z_L + Z_C} = -0.5$$

The reflection coefficient at section BB is:

$$\Gamma_B = \Gamma_A e^{-j2\beta l} = \Gamma_A e^{-j2\left(\frac{2\pi}{\lambda}\right)6\lambda} = \Gamma_A e^{-j24\pi} = -0.5$$

Therefore, the input impedance is:

$$Z_B = Z_C \frac{1+\Gamma_B}{1+\Gamma_B} = 50 \ \ \Omega$$

The reflection coefficient at the generator section is:

$$\Gamma_g = \frac{Z_B - Z_g}{Z_B + Z_g} = 0$$

Therefore, the power crossing section BB, i.e. reaching the load is:

$$P_L = P_{AV}(1 - |\Gamma_g|^2) = \frac{|V_g|^2}{8\,\mathrm{Re}\left[Z_g\right]} = 25 \text{ W}$$

All the power made available by the transmitter is radiated by the antenna.

Problem 4

Consider the downlink from a GEO satellite to a ground station: the elevation angle is $\theta = 40°$ and link operating frequency is f = 30 GHz. Calculate the signal-to-noise ratio (SNR) using the following data:

- both the ground and satellite antenna have directivity function that can be modelled as:

$$f(\theta) = \left[\cos(\theta)\right]^5$$

  where θ is the angle defining any deviation from the antenna axis (the antenna is parabolic with circular symmetry)
- the equivalent area of the both antennas is A_e = 1 m^2
- the ground antenna is optimally pointed to the satellite, while the satellite is mispointed by an angle $\theta = 20°$
- the power transmitted by the satellite is P_T = 100 W
- the distance between the ground station and the satellite is H = 38000 km
- the receiver LNA equivalent noise temperature is T_{LNA} = 150 K
- the antenna equivalent noise temperature T_A = 85 K
- on-board losses L_{SAT} = 0.3 dB
- receiver waveguide losses L_R = 0.8 dB (waveguide temperature T_{WG} = 40°)
- system bandwidth B = 500 MHz
- cloud and gases attenuation A_{GC} = 1.5 dB

What happens to the SNR if rain starts to fall? Which terms of the SNR equation will be affected by the additional presence of rain?

Solution

1) The wavelength is $\lambda = c/f$ = 0.01 m. The gain of the two antennas is:

$$G_T = G_R = \frac{4\pi}{\lambda^2} A_e \approx 125664 = 51 \text{ dB}$$

The on-board and ground losses are:

L_{SAT} = 0.3 dB = 0.93

L_R = 0.8 dB = 0.83

The atmospheric attenuation is:

A_{GC} = 1.5 dB = 0.71

The received power is:

$$P_R = P_T G_T f_T L_{SAT} \left(\frac{\lambda}{4\pi H}\right)^2 G_R f_R L_R A_{GC}$$

where $f_T(20°) = \left[\cos(20°)\right]^5 = 0.73$ and f_R = 1 (the ground antenna is optimally pointed to the satellite). As a result:

$$P_R \approx 2.78 \times 10^{-10} \text{ W}$$

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

$$T_{sys} \approx T_A + T_{LR} + T_{LNA}$$

The noise introduced by the waveguide T_{LR} is given by:

$T_{LR} = T_{WG}\,(1-L_R) = 52.7$ K

Thus $T_{sys} \approx 287.7\ \text{K}$

The SNR is:

$$SNR = \frac{P_R}{P_N} = \frac{P_R}{kT_{sys}B} = 138.9 = 21.4\ \text{dB}$$

where k is the Boltzmann's constant (1.38×10^{-23} J/K).

The presence of rain will increase the atmospheric attenuation, thus reducing the received power, and, at the same time, it will also increase the noise power through the increase in T_A. Both effects will concur to reducing the SNR.

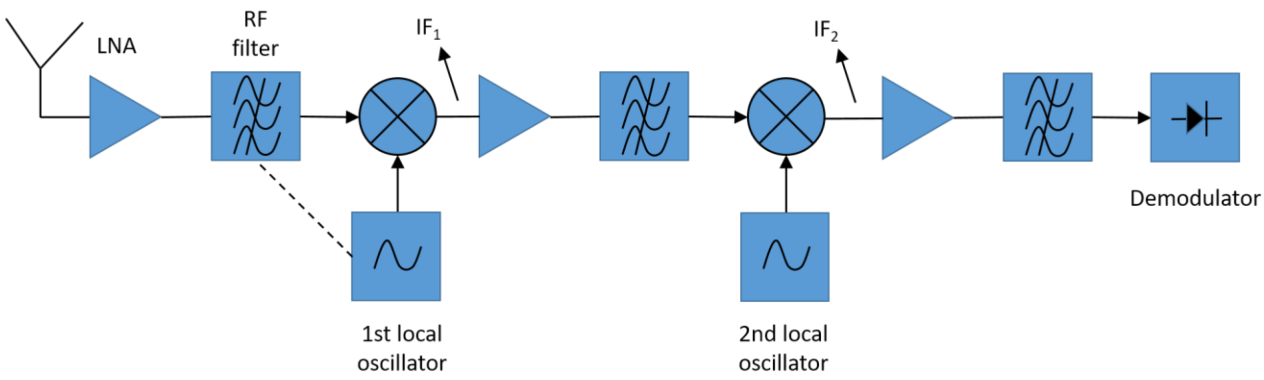
Problem 5

A superheterodyne receiver (double conversion) is used in a satellite system operating at 10 GHz with 5 MHz channel bandwidth.

1. Show the block diagram of the receiver and briefly comment the general characteristics of each subsystem.
2. Propose a frequency plan (f_{IF1}, f_{IF2}, f_{osc1}, f_{osc2}) and justify the choice.
3. Evaluate the total gain of the receiver chain assuming that the input voltage at the RF section is 25 μV and the demodulator requires 0.5 V as input.

Solution

1) The typical block diagram is composed by an RF stage (Low Noise Amplified plus filter to reject the image frequency), a first downconverter (mixer with local oscillator plus amplifier and filter) producing an intermediate frequency high enough to facilitate the rejection of the image frequency using the RF filter, and a second downconverter (mixer with very stable local oscillator plus amplifier and filter) tuned to obtain a lower intermediate frequency but high enough to facilitate the post processing of the signal (sampling).



2) A good choice for the mixer frequencies is:

f_{LO1} = 9.9 GHz

f_{LO2} = 90 MHz

This yields:

f_{IF1} = 100 MHz

f_{IF2} = 10 MHz

3) The gain is given by:

$$G = 20\log_{10}\left(\frac{0.5}{25\cdot 10^{-6}}\right) = 86 \text{ dB}$$

We need to add the loss due to the filters (1 dB) and to the mixers (12 dB). Therefore the total gain is 99 dB.