Delivery Exercise A

1) Propagation basics

1a) What is EIRP?

Effective isotropic radiated power (EIRP) is the equivalent power of a transmitted signal in terms of an isotropic (omnidirectional) radiator. Normally the effective isotropic radiated power equals the product of the transmitter power and the antenna gain (reduced by any coupling losses between the transmitter and antenna.)

1b) Select three to four very important characteristics of any antenna and describe these including clear definitions if applicable.

Directivity
The directivity is the ratio between the antenna's radiation intensity in a direction and the average radiation intensity.

Gain
The power gain, or simply gain, is the ratio between the radiation intensity in a direction and the radiation intensity to an isotropic loss free antenna with the same input power.

Efficiency
The antenna efficiency is the ratio of radiated power to the power accepted by the antenna

Bandwidth
The antenna frequency bandwidth is the frequency range it operates satisfactory. Sometimes defined as the range where the gain remains within 3 dB, or the VSWR is no greater than 2:1, whichever the smaller.

1c) Derive an expression for free space loss. What is the fee-space loss in dB for a 20 GHz link from the geostationary orbit to Kjeller in Norway?

Power P_t radiates from a point. At distance r consider an effective aperture A_e.
Power received P_r

$$P_r = SA_e$$

where S is the Received power with physical antenna area A power density (W/m^2).
For the wave length λ the antenna gain is related to A_e

$$A_e = \frac{G}{4\pi}\lambda^2$$

Receivedpower with physical antenna area A is received power P_r

$$P_r = \frac{P_t}{4\pi r^2} G_t \cdot A_e$$

A_e is the "effective" area

$$P_r = \frac{P_t G_t}{4\pi r^2} \cdot \frac{G_r \lambda^2}{4\pi} = P_t G_t G_r \left(\frac{\lambda}{4\pi r}\right)^2$$

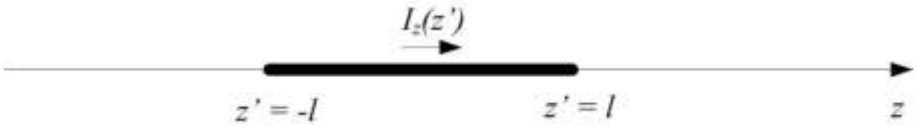
The term $(4\pi r/\lambda)^2$ is called free space loss.

Distance to geostationary orbit can be estimated knowing that it is about 36 000 km above equator and that Kjeller is located at 60° latitude and the earth radios about 6370 km. The speed of the wave is set to speed of light c = 3·10^8 *m/s. The free space loss becomes 211 dB.*

1d) Why is it important to model the noise in the receiver? A satellite receiver usually has an amplifier very close to the antenna. Why? Discuss it in terms of a cascaded network.

The signal must be above the receiver threshold in order to detect the content, not dealing with spread spectrum systems. In the case of very weak signals it is important to amplify as soon as possible after the antenna since an antenna cable will attenuate and add noise. It becomes convenient with a cascaded receiver network with and amplifier and downconverter at the antenna itself. In such a case the first network element dominates completely the system noise, and for satellite case it should be a low noise amplifier.

2) Wire antenna

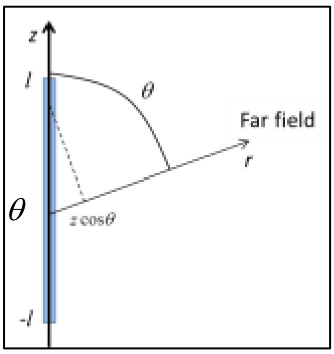


The figure shows a straight wire antenna of length 2l from z'=–l to z' = l. The current distribution on the antenna is

$$I_z(z') = I_0 e^{-jk_0 z'}$$

where I_0 is constant and k_0 is the wave number in free space.

2a) Find the electric far-field.



Assume far-field in as function of distance r and angle θ *to the observation point.*

From Lecture 3 (p. 42) or text book (Eq. 4.27) focusing on

$$dE_\theta = jZ_0 \frac{k_0 I(z) e^{-jk_0 r}}{4\pi r} e^{jk_0 z\cos\theta} \sin\theta dz$$

$$E_\theta = jZ_0 \frac{k_0 e^{-jk_0 r}}{4\pi r} \sin\theta \int_{-l}^{l} I(z) e^{jk_0 z\cos\theta} dz = \frac{jZ_0 k_0 e^{-jk_0 r}}{4\pi r} \sin\theta \int_{-l}^{l} I_0 e^{-jk_0 z} e^{jk_0 z\cos\theta} dz$$

$$= \frac{jZ_0 k_0 e^{-jk_0 r}}{4\pi r} \sin\theta I_0 \int_{-l}^{l} e^{-jk_0(1-\cos\theta)z} dz = \frac{jZ_0 k_0 e^{-jk_0 r}}{4\pi r} I_0 \sin\theta \left[\frac{e^{-jk_0(1-\cos\theta)z}}{-jk_0(1-\cos\theta)} \right]_{-l}^{l}$$

$$= \frac{jZ_0 k_0 e^{-jk_0 r}}{4\pi r} I_0 \sin\theta \left[\frac{e^{-jk_0(1-\cos\theta)l}}{-jk_0(1-\cos\theta)} - \frac{e^{-jk_0(1-\cos\theta)(-l)}}{-jk_0(1-\cos\theta)} \right]$$

$$= \frac{jZ_0 k_0 e^{-jk_0 r}}{4\pi r} 2lI_0 \sin\theta \frac{\sin(k_0(1-\cos\theta)l)}{k_0(1-\cos\theta)l}$$

2b) How long must the antenna be to get N lobes within $0 < \theta < \pi$? N is a positive whole number. Find an approximate simple expression for the number of lobes as function of l/λ, where λ is the wave length.

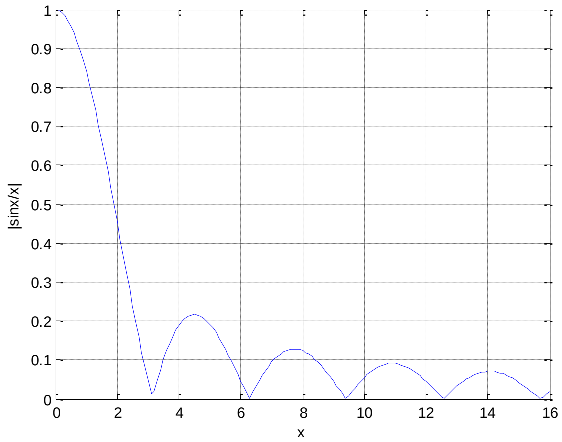
The number of lobes is determined from the factor sinx/x where $x=k_0(1-\cos\theta)l$. When θ varies from 0 to π will x vary from 0 to $2k_0l$, sketched to the right.

It will be N lobes if $(N-1)\pi<2k_0l<N\pi$. By using $k_0 = 2\pi/\lambda$ and solve

$$(N-1)\pi < \frac{4\pi}{\lambda} < N\pi, \quad \frac{N-1}{4} < \frac{l}{\lambda} < \frac{N}{4}$$

Set simply

$$\frac{l}{\lambda} \approx \frac{N}{4}, \quad N \approx \frac{4l}{\lambda}$$



2c) Sketch the radiation diagram, i.e., the E-field relative amplitude as function of the angle θ for the cases $l/\lambda = 1$ and $l/\lambda = 3$.

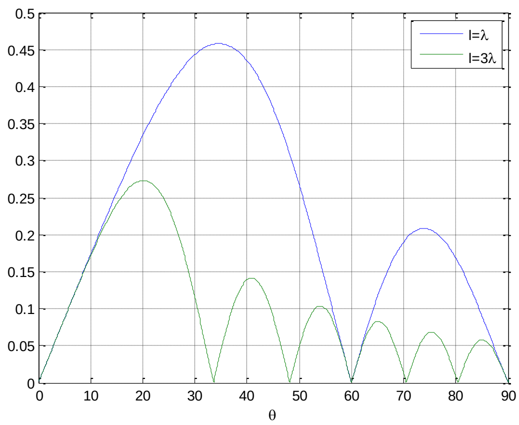
The radiation diagram is given by

$$\sin\theta \frac{\sin(k_0(1-\cos\theta)l)}{k_0(1-\cos\theta)l}.$$

With $l/\lambda = 1$ and $l/\lambda = 3$ it becomes

$$\sin\theta \frac{\sin(2\pi(1-\cos\theta))}{2\pi(1-\cos\theta)} \text{ and } \sin\theta \frac{\sin(6\pi(1-\cos\theta))}{6\pi(1-\cos\theta)}$$

Diagram sketched to the right.



3) Macro cell coverage

A mobile network operator wishes to provide 95 % successful communication at the fringe of macro cell coverage and analyses two cases of 6 dB and 10 dB location variability.

3a) What are the required fade margins?

For σ_L =6 dB
The location loss is called L_S due to shadowing, with a variability σ_L. It comes on top of path loss. The fade margin required such that 95 % of the cases get successful communication is z such that $p(L_S > z) = 0.05$, i.e., same as $Q(z/\sigma_L) = 0.05$.
Using Eq. 9.7 (erfcinv in Matlab) or Figure 9.5: $z/\sigma L=1.65$, or fade margin z = 13.2 dB. This margin must be added to the path loss.

For σ_L =10 dB
Repeat steps above.

3b) What is the average availability over the whole cell, assuming a path loss exponent of 4?

For σ_L =6 dB
The edge p_e is 0.95, and the local variability is 8 dB with path loss model with power law factor of 4. Using Figure 9.8, p_{cell} is close to 0.97 (Eq. 9.14: p_{cell}=0.974).

For σ_L =10 dB
Repeat steps above.

3c) Discuss the effects in link budget calculations if shadowing is neglected.

If shadowing is neglected the system link calculation it will be designed considering path loss only. There will be now margin added for local variability and therefore half the terminals cannot be served. The link budget is easier to set up, but the result will be poor service.