Problem 1.1:
If a transmitter produces 50 W of power, express the transmit power in units of

a) dBm,

b) dBW.

Problem 1.2:
If 50 watts are transmitted by a unity gain antenna at 900 MHz carrier frequency, find the received power (assuming unity gain receiver antenna) in [dBm] and [W] at a free space distance of:

a) 100 m from antenna,

b) 10 km from antenna.

Problem 1.3:
Assume an air-filled metallic rectangular waveguide of cross-section 22.86 mm x 10.16 mm. Calculate

a) the monomode frequency range,

b) the guided wavelength at 10 GHz,

c) group velocity and phase velocity at 10 GHz.

Problem 1.4:
A hypothetical isotropic antenna is radiating in free space. At a distance of 100 m from the antenna, the total electric field is measured to be 5 V/m.

a) Find the power density at this location.

b) Determine the total power radiated by the antenna.
**Problem 1.5:**
A dipole of length $3\lambda/2$ is resonant at $f = 150$ MHz. Calculate its mechanical length

a) in air,

b) in water ($\varepsilon_{rel} = 81$).

**Problem 2.4:**
The power radiated by a lossless antenna is 10 Watts. The directional characteristics of the antenna are represented by the radiation intensity of

\[ U = B_0 \cos^3 \theta \quad (W/\text{sr}) \quad 0 \leq \theta \leq \pi/2, \quad 0 \leq \phi \leq 2\pi \]

a) Find the maximum power density (in watts per square meter) at a distance of 1000 m (assume far field distance). Specify the angle where this occurs.

b) Find the directivity of the antenna (dimensionless and in dB).

c) Calculate the half-power beamwidth (HPBW).

d) Find the first-null beamwidth (FNBW).

**Problem 2.5:**
The normalized radiation intensity of a given antenna is given by:

1. \[ U_1 = \sin \theta \cdot \sin \phi \]
2. \[ U_2 = \sin \theta \cdot \sin^2 \phi \]
3. \[ U_3 = \sin^2 \theta \cdot \sin \phi \]

The intensity exists only in $0^\circ \leq \theta \leq 180^\circ$, $0^\circ \leq \phi \leq 180^\circ$ region, and is zero elsewhere.

a) Find the exact directivity (dimensionless and in dB).
b) Find the Azimuthal and elevation plane half-power beamwidths (in degrees).

(c) Find the directivity by using approximate formulas.

**Problem 9.1:**
A microstrip line is used as a feed line to a microstrip patch. The substrate of the line is alumina (\( \varepsilon_{\text{rel}} = 10 \)) while the dimensions of the line are \( w_0 / h = 1.2 \).

a) Determine the effective dielectric constant \( \varepsilon_{\text{reff}} \) and 

b) the characteristic impedance \( Z_0 \) of the line.

c) Calculate the reflection coefficient if a line of the computed characteristic impedance is connected to a 50 \( \Omega \) line.

d) Calculate the respective lengths of half-wavelength long lines of impedance \( Z_0 \) on alumina, of a line in free-space, and of a line fully embedded in alumina halfspace, at \( f = 1.5 \) GHz.

**Problem 9.4:**
Design a patch antenna working at the frequency 1.575 GHz and etched on Duroid 6010 substrate (\( \varepsilon_r = 10 \)) of thickness \( h = 0.508 \)mm.

a) Determine \( W \) and \( L \),

b) Determine the inset length \( L_1 \) needed for matching of antenna to the microstrip feed line (50\( \Omega \))
Proposition

Problem 4
The spacecraft Pioneer 10 has been launched in 1972 to explore outer planets of our solar system. By the time of its last contact with earth, in 2003, the distance between earth and Pioneer 10 was about 12.3 x 10^9 km. Let's explore the conditions of the downlink (spacecraft to earth) operating at 2192 MHz.

The parabolic dish antenna of Pioneer 10 has a diameter of 274 cm and a depth of 46 cm. On earth, the signal is received by a 70 m diameter dish antenna. For each dish antenna, assume an aperture efficiency of 70%.

1 point a) How much time takes the signal to propagate from spacecraft to earth?

3 points b) Assume a transmit power of 8 Watt. Calculate the received power.

The spacecraft dish is illuminated by a circular horn antenna. For simplification, assume a circular aperture in infinite ground and uniform distribution for illumination of the dish. The first null in the radiation pattern of this aperture shall coincide with the edge of the dish. The directivity of this aperture is 19.5 dBi.

3 points c) Calculate the distance between the feed aperture and the dish. For clarity, make a simple drawing (e.g., in cross section) indicating that distance

1 point d) Why it is not suitable to use a feedhorn with much higher gain, e.g., 29 dBi?

1 point e) In reality, the aperture distribution of the feedhorn is non-constant. In particular, the fundamental mode of a circular waveguide, TE11, has no circular symmetry, leading to a radiation pattern without circular symmetry. What can be done to realize a radiation pattern with circular symmetry for the feed horn?
3 points f) The large dish on earth is motorized at huge cost, allowing it to “follow” the spacecraft as earth rotates. Assume now that the earth dish is fixed, looking normal to the earth surface, is installed on the earth equator, and at a certain moment, it is pointing perfectly to the spacecraft. Calculate approximately the time after which the received power is reduced to 50 %. Explain why your calculation is approximate.

3 points g) The aperture efficiency of a typical parabolic dish antenna is in the range of 50 % to 75 %. It is impossible to reach 100 %. What factors are degrading the aperture efficiency of a dish antenna?

Problem 11.1:
A mobile phone is located 5 km away from a base station. It uses a vertical 1/4 monopole antenna with a gain of 2.55 dB to receive cellular radio signals. The free space E-field at 1 km from the transmitter is measured to be 10-3 V/m. The carrier frequency used for this system is f = 900MHz.

a) Find the length and effective aperture of the receiving antenna.

b) Find the received power at the mobile using the 2-ray ground reflection model assuming the height of the transmitting antenna is 50 m, and the receiving antenna is 1.5 m above ground.

Problem 11.2:
Compute the diffraction loss for the scenario shown in the figure below. Assume l = 1/3 m, d1 = 1 km, d2 = 1 km, and

a) h = 25 m,

b) h = 0,

c) h = −25 m.
Problem 11.3:
A base station transmits a power of 10 W into a feeder cable with a loss of 10 dB. The transmit antenna has a gain of 12 dBd (dBd refers to a 1/2 dipole) in the direction of a mobile receiver, with antenna gain 0 dBd and feeder loss 2 dB. The mobile receiver has a sensitivity of -104 dBm.

a) Determine the maximum acceptable path loss.

b) Calculate the maximum range of the communication system, assuming $h_1 = 1.5m$, $h_2 = 30m$, $f = 900MHz$ and that propagation takes place over a plane earth.

c) How does this range change if the base station height is doubled?