Problem 1 Wavelengths in Radio Applications (12 points)

Radio waves propagate in free space (and in our atmosphere) at the speed of electromagnetic waves (e.g., light waves) – an EM wave velocity of \( v = 2.99792 \times 10^8 \) meters per second. \textbf{For this problem use} \( v = 3.00 \times 10^8 \) \textit{meters per second (m/sec)}. An important wave parameter for electromagnetic waves is the wavelength \( \lambda \) which is inversely related to the wave frequency \( f \) (cycles per second in units of Hertz). The relationship is (as you know) velocity equals wavelength times frequency \( (v = \lambda f) \).

The reason wavelength \( \lambda \) is important is because the wavelength is approximately the spatial resolving dimension of radar and antenna sizes scale with wavelength (e.g., long wavelengths requires large antennas where the antenna will be of the order of the wavelength in size for best transmission and reception).

To get a feel for the size of the free space wavelength \( \lambda \) for various radio communication systems, fill out the table below: [Express all \textit{wavelengths in meters}.]

<table>
<thead>
<tr>
<th>Radio Application</th>
<th>Frequency Band</th>
<th>Wavelength Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM broadcast radio</td>
<td>535 kHz to 1605 kHz</td>
<td></td>
</tr>
<tr>
<td>FM broadcast radio</td>
<td>88 MHz to 108 MHz</td>
<td></td>
</tr>
<tr>
<td>VHF Civil Aviation Band</td>
<td>108 MHz to 136 MHz</td>
<td>2.778 meters to 2.206 meters (example)</td>
</tr>
<tr>
<td>(example)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSM Cellular (Uplink)</td>
<td>890 MHz to 915 MHz</td>
<td></td>
</tr>
<tr>
<td>Wi-Fi 802.11b/g/n</td>
<td>2.400 GHz to 2.497 GHz</td>
<td></td>
</tr>
<tr>
<td>K-band Radar Sensor</td>
<td>24.125 GHz (narrowband)</td>
<td></td>
</tr>
<tr>
<td>Wi-Fi 802.11ad</td>
<td>60 GHz</td>
<td></td>
</tr>
</tbody>
</table>
Problem 2 Height of an AM Broadcast Antenna (8 points)

In problem 1 you found that radio wavelengths cover a very broad span of values. For example, in broadcast AM radio (which has been around since the 1920s), the wavelengths covering its band are very large. The photo of a AM broadcast antenna is designed to be one-quarter of a wavelength ($\lambda/4$). Radio station KSRO (News/Talk) in Santa Rosa broadcasts at frequency $f = 1350$ kHz. Given that its broadcast antenna is a quarter wavelength, what is the height of KSRO’s antenna expressed in feet? (Note that 1 meter = 3.2808 feet).

Problem 3 Frequency Requirement for a Cell Phone (10 points)

For this problem we want to estimate how high a frequency must be to have a handheld cellular telephone without a separate antenna extruding from the case of the cell phone. Again, let us assume that we can use a quarter wavelength antenna in the direction of the height of the cell phone case (such as using the side of the case itself). Using the dimension of the height of your personal cell phone, and setting that dimension equal to one-quarter wavelength, what frequency $f$ meets this requirement? [Note: This would be the lowest frequency you would allow for operation.]
Problem 4  Voltage Gain & Power Gain (20 points)

Electrical engineers often specify, or characterize, circuit blocks and/or networks in terms of voltage gain and power gain. Voltage and power gains can be expressed either numerically or in decibels (see Handout #1 for a discussion of decibels). In this problem you are presented with the amplifier circuit shown diagrammatically shown below with input and output resistances and voltages levels as labeled.

\[ V_{in} = 0.35 \text{ volt} \quad V_{out} = 10 \text{ volts} \]

Assume the amplifier is impedance matched at output and input. Calculate:

(a) The numerical voltage gain ratio.

(b) The voltage gain expressed in decibels (dB).

(c) The power gain ratio.

(d) The power gain ratio expressed in decibels (dB).
Problem 5 Voltage Gain & Power Gain continued (10 points)

Consider a similar amplifier with a higher output resistance $R_{out} = 150$ ohms (it is no longer 75 ohms). This is illustrated in the diagram below. Again, assume input and output impedance matching.

Write an expression for the power gain (expressed in decibels) in terms of $V_{in}$, $V_{out}$ and the ratio of $R_{in}$ to $R_{out}$.

![Diagram of amplifier with $V_{in} = 0.4$ volt, $V_{out} = 10$ volts, $R_{in} = 75$ Ω, and $R_{out} = 150$ Ω.]

Problem 6 Cable Attenuation (14 points)

Transmission losses in cables (such as coaxial cables) are generally expressed in decibels per kilometer (dB/km). Suppose you have a 50-ohm coaxial cable with a specified loss of –1.5 dB/km. If you input 10 milliwatts (i.e., +10 dBm) into a cable of 5 kilometers in length, what is the output power (express it in both milliwatts and dBm)?
**Problem 7 Voltage Gain & Power Gain continued** (12 points)

We have four circuit components cascaded together as shown in the block diagram below.

\[
\begin{array}{c|c|c|c}
\text{Component 1} & \text{Component 2} & \text{Component 3} & \text{Component 4} \\
\frac{P_1}{P_{in}} = \frac{1}{4} & \frac{P_2}{P_1} = 20 & \frac{P_3}{P_2} = \frac{1}{2.4} & \frac{P_{out}}{P_3} = 7.3 \\
\end{array}
\]

(a) Express the gains and losses in decibels (use the second column in the table below):

<table>
<thead>
<tr>
<th>Numerical power ratio</th>
<th>Power ration in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{P_1}{P_{in}} = \frac{1}{4} )</td>
<td>dB</td>
</tr>
<tr>
<td>( \frac{P_2}{P_1} = 20 )</td>
<td>dB</td>
</tr>
<tr>
<td>( \frac{P_3}{P_2} = \frac{1}{2.4} )</td>
<td>dB</td>
</tr>
<tr>
<td>( \frac{P_{out}}{P_3} = 7.3 )</td>
<td>dB</td>
</tr>
</tbody>
</table>

(b) What is ratio of \( \frac{P_{out}}{P_{in}} \) (both numerically and in decibels)?

(c) If \( P_{in} = 30 \text{ mW} \), what is \( P_{out} \) in watts (W)?
Problem 8  Communication Link: Gain & Loss (14 points)

You are given the receiver block as schematically shown below. It consists of a receiving antenna which delivers a signal to a bandpass filter. The antenna feed has a loss of -1.15 dB and the filter’s loss is -2.4 dB. The filter’s output drives an amplifier with gain of +42.7 dB and the RF signal is input to a mixer which performs a frequency translation to an IF signal (but the mixer has a loss of -7.2 dB). Finally, the IF signal travels through another bandpass filter with a nominal loss of -1.6 dB. If the signal strength output by the last filter is $P_{\text{sig}} = -86.3$ dBm, what is the signal strength of the signal $P_{\text{ant}}$ at the antenna? How many milliwatts is this signal power?
EXTRA CREDIT PROBLEM  Wheatstone Bridge  (up to 10 points extra)

In class the instructor mentioned the Wheatstone Bridge (1843) named after Charles Wheatstone who was co-inventor of the “Wheatstone-Cook” telegraph discussed in class. The Wheatstone Bridge circuit schematic shown below is a way to accurately measure the unknown resistor designated as $R_x$ in the circuit schematic drawing. Resistors $R_1$ and $R_2$ are fixed resistors and resistor $R_3$ is variable (such as a multi-turn potentiometer). A battery is used for the applied voltage across nodes C and D. The voltage is measured when operating the bridge between nodes A and B.

Explain how this bridge works and write an expression for the value of resistor $R_x$ in terms of the other three resistors when the bridge is balanced.