Antennas

Radio Frequency Wave Propagation

References

- *Digital and Analog Communication Systems*, Couch, Chapter 8
Point-Source Radiator

- Consider a source of electro-magnetic radiation that radiates in all directions equally.
- Such a source is call isotropic.
- Let the total power radiated by the source be $P_T$.
- Let the source be surrounded by a sphere or radius $d$. If there are no objects inside the sphere to absorb or reflect the radiation, all of the power from the source will hit or cross the sphere.
- The surface area of a sphere is $4 \pi d^2$.

\[
\text{power density at } d = \frac{P_T}{4\pi d^2}
\]

Concentrate the Power

- If a reflector were added to the point source, more of the power would go in one direction that the others.
- This increase in power (over isotropic) can be expressed as the power gain $G_T$ of the antenna.
- Since the antenna is a passive device, it cannot actually increase the total power radiated.
- The higher the gain of the antenna, the more focused is the power in one direction.
- The gain only applies along the bore sight of the antenna.
Antenna Gain

• The antenna power gain is defined as

\[ G_T = \frac{\text{radiation power density of the actual antenna in the direction of maximum radiation (bore sight)}}{\text{radiation power density of an isotropic antenna with the same power input}} \]

• Since an antenna is a passive device, it has the same gain whether it is transmitting or receiving.

Effective Isotropic Radiated Power

• The Effective Isotropic Radiated Power (EIRP) of an antenna is power input required of an isotropic antenna to produce the same power density on the bore sight as the actual antenna.

• The EIRP is the transmitted power multiplied by the gain of the transmitting antenna.

\[ P_{\text{ERIP}} = P_T G_T \]

power density at \( d \) = \( \frac{P_{\text{ERIP}}}{4\pi d^2} = \frac{P_T G_T}{4\pi d^2} \)
Effective Area

- If the receiving antenna is placed $d$ meters from the transmitting antenna, it will act like a catcher’s mitt and intercept the power in an effective area of $A_e$ (m$^2$).

$$P_R = G_T \left( \frac{P_T}{4\pi d^2} \right) A_e$$

Antenna Gain and Effective Area

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Power Gain</th>
<th>Effective Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isotropic</td>
<td>1</td>
<td>$\lambda^2/(4\pi)$</td>
</tr>
<tr>
<td>Small Dipole or Loop</td>
<td>1.5</td>
<td>$(1.5\lambda^2)/(4\pi)$</td>
</tr>
<tr>
<td>Half-Wave Dipole</td>
<td>1.64</td>
<td>$(1.64\lambda^2)/(4\pi)$</td>
</tr>
<tr>
<td>Horn, mouth area $A$</td>
<td>$10A/\lambda^2$</td>
<td>0.81$A$</td>
</tr>
<tr>
<td>Parabola, face area $A$</td>
<td>$7A/\lambda^2$</td>
<td>0.56$A$</td>
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<tr>
<td>Turnstile</td>
<td>1.15</td>
<td>$(1.15\lambda^2)/(4\pi)$</td>
</tr>
</tbody>
</table>
**Effective Area Formula**

- The gain and the effective area of an antenna are related by
  \[ G_R = \frac{4\pi A_e}{\lambda^2} \]

- \( \lambda = \text{wavelength} = \frac{c}{f} \)
- \( c = \text{speed of light} = 3 \times 10^8 \text{ m/s} \)
- \( f = \text{operating frequency in Hz} \)

**Received Power**

- Combining equations yields an expression for the received power in terms of the transmitted power and the gains of both antennas.
  \[ P_R = P_T G_T \left( \frac{\lambda}{4\pi d} \right)^2 G_R \]

- The middle term is called the free-space gain (1.0 / loss) of the system.
  \[ G_{FS} = \left( \frac{\lambda}{4\pi d} \right)^2 = \frac{1}{L_{FS}} \]
### TV Relay Satellite Exercise

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Receiver</th>
</tr>
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<tbody>
<tr>
<td>Galaxy I Satellite</td>
<td>Antenna</td>
</tr>
<tr>
<td>Geostationary</td>
<td>Noise Temp</td>
</tr>
<tr>
<td>Frequency</td>
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<tr>
<td>EIRP</td>
<td>Feedline</td>
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<tr>
<td>Slant Range</td>
<td>Gain</td>
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<tr>
<td></td>
<td>36 dBw</td>
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<tr>
<td></td>
<td>0.98</td>
</tr>
</tbody>
</table>

Low-Noise Amplifier

- Noise Temp: 40 K
- Gain: 50 dB

Receiver

- Noise Temp: 2610 K
- Bandwidth: 30 MHz
- Threshold: 8 dB S/N