Given: WLAN with

\[ f_c = 5.0 \text{ GHz} \]
\[ f_w = 2.0 \text{ MHz} \]
\[ G_{\text{Tx}} = 2 \text{ dBi} \]
\[ G_{\text{Rx}} = 2 \text{ dBi} \]

Find: Max Allowed Noise Figure

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>20 dBm</td>
<td>Given</td>
</tr>
<tr>
<td>Transmit Antenna Gain</td>
<td>2.0 dBi</td>
<td>Given</td>
</tr>
<tr>
<td>Transmitter Losses</td>
<td>3.0 dB</td>
<td>Given</td>
</tr>
<tr>
<td>Net Transmitted Power</td>
<td>( P_{\text{TX}} = 20 \text{ dBm} + 2 \text{ dB} - \frac{PL}{3} )</td>
<td>19 dBm</td>
</tr>
<tr>
<td>Path Loss</td>
<td>90 dB</td>
<td>Given</td>
</tr>
<tr>
<td>Diffraction Loss</td>
<td>N/A</td>
<td>No Diffraction</td>
</tr>
<tr>
<td>Fading Margin</td>
<td>N/A</td>
<td>Mobility based fading. N/A in this example</td>
</tr>
<tr>
<td>Shadowing Margin</td>
<td>16 dB</td>
<td>Given</td>
</tr>
<tr>
<td>Net Propagation Losses</td>
<td>Losses = ( PL + \gamma )</td>
<td>106 dB</td>
</tr>
<tr>
<td>Receiver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receiver Antenna Gain</td>
<td>2.0 dB</td>
<td>Given</td>
</tr>
<tr>
<td>Receiver Losses</td>
<td>0.0 dB</td>
<td>No cable, connector, etc. losses at RX</td>
</tr>
<tr>
<td>Net Receiver Gain</td>
<td>( RX_{\text{Gain}} = 2.0 \text{ dB} )</td>
<td>Net gain/loss provided by the receiver</td>
</tr>
<tr>
<td>Net Received Power</td>
<td>( P_{\text{RX}} = P_{\text{TX}} - \text{Losses} + RX_{\text{Gain}} )</td>
<td>-85.0 dBm</td>
</tr>
<tr>
<td>System Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum SNR</td>
<td>5.0 dB</td>
<td>Given</td>
</tr>
<tr>
<td>Max MDS</td>
<td>( MDS = kT_B ) = P_{\text{RX}} - \text{SNR} )</td>
<td>Solve</td>
</tr>
</tbody>
</table>

\[ MDS = -85.0 \text{ dBm} - 5.0 \text{ dB} = -90.0 \text{ dBm} \]

\[ L \Rightarrow T_m = \frac{MDS}{kT_B} = \frac{1.0 \times 10^{-6} W}{(1.38 \times 10^{-23} J/K)(20 \text{ MHz})} = 3623 K \]

\[ n_f = 1 + \frac{T_m}{290} = 1 + \frac{3623K}{290} = 13.43 \]

\[ NF = 11.3 \text{ dB} \]
Given: \( f_c = 900 \text{ MHz} \)
\( TX/RX \) antennas, 15 m dish
\( d = 500 \text{ m} \)
\( P_{tx} = 100 \text{ mW} \)
\( N_{DS} = -105 \text{ dBm} \)

**Find:**

a) Can Friis be used to calculate Rx power?

b) Calculate link budget, compare TX/Rx power.

a) Far Field Distance:
\[
\frac{d_{ff}}{\lambda} \approx 20^2 = \frac{2(15\text{ m})^2}{(0.333 \text{ m})} = 1350 \text{ meters}
\]

At a distance of 500 m, the antennas are in the Near Field.

Friis is Not Valid.

b) Gains of antennas are not explicitly given, however we can approximate gains using the effective area.

\[
g_r \approx g_r \approx 4\pi A_e = \frac{4\pi \left(\frac{\lambda}{4\pi}\right)^2}{\lambda^2} \approx \frac{4\pi \left(\frac{0.75\text{ m}}{0.333 \text{ m}}\right)^2}{(0.333 \text{ m})^2} = 19.986
\]

\[
G_t \approx G_r \approx 43 \text{ dB}
\]

Free Space Path Loss:
\[
PL = -10 \log_{10} \left( \frac{d^2}{(4\pi)^2} \right) = -10 \log_{10} \left( \frac{(0.333 \text{ m})^2}{(4\pi(500 \text{ m}))^2} \right)
\]

\[
PL = 85.5 \text{ dB}
\]

From there, Fill in the Link Budget.
<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>20 dBm</td>
<td>Given</td>
</tr>
<tr>
<td>Transmit Antenna Gain</td>
<td>43 dB</td>
<td>Estimated based on dish size</td>
</tr>
<tr>
<td>Transmitter Losses</td>
<td>0 dB</td>
<td></td>
</tr>
<tr>
<td>Net Transmitted Power</td>
<td>63 dBm</td>
<td>Net TX Power</td>
</tr>
<tr>
<td>Channel Losses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Path Loss</td>
<td>85.5 dB</td>
<td>Free Space Path Loss</td>
</tr>
<tr>
<td>Diffraction Loss</td>
<td>0 dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Fading Margin</td>
<td>0 dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Shadowing Margin</td>
<td>0 dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Net Propagation Losses</td>
<td>85.5 dB</td>
<td>$Losses = \sum Losses$</td>
</tr>
<tr>
<td>Receiver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receiver Antenna Gain</td>
<td>43 dB</td>
<td>Net gain/loss provided by the receiver</td>
</tr>
<tr>
<td>Receiver Losses</td>
<td>0 dB</td>
<td></td>
</tr>
<tr>
<td>Net Receiver Gain</td>
<td>43 dB</td>
<td></td>
</tr>
<tr>
<td>Net Received Power</td>
<td>20.5 dBm</td>
<td>$P_{RX} = P_{TX} - Losses + RX_{Gain}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$P_{RX} = MDS + SNR$</td>
</tr>
<tr>
<td>System Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum SNR</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Max MDS</td>
<td>-105 dBm</td>
<td>Given</td>
</tr>
</tbody>
</table>

$$P_{RX} = 20.5 \text{ dBm}$$

$$P_{TX} = 20 \text{ dBm}$$

$$P_{RX} > P_{TX}$$  Why? The model is not valid for this configuration.
Given: The Navy’s SPN-43 Air Traffic Control Radar operates at 3.5 GHz with a transmit power of 1.0 MW and a Transmitter Antenna Gain of 32 dB. Bandwidth is 1.6 MHz, TX Height is 16 meters, RX Height is 1.5 meters. If you have a receiver with a noise figure of 3.0 dB, antenna gain of 2 dB, and a 10 dB SNR is required to received the signal, generate a link budget to calculate the following:

Find: Develop a link budget to calculate the following:

(a) Maximum distance for free-space propagation.
(b) Maximum distance for two-ray propagation.
(c) Maximum distance for Log-Distance propagation with parameters \( n = 3.8 \) and \( \sigma = 15 \) dB.
(d) Maximum distance for the Hata Model, using the standard Hata parameters.
(e) If you were the Radar Operating Officer, and the Radar was located at coordinates of (38.144818, -76.434097), which model would you choose and why?

MDS

\[
MDS = k T_n B \\
T_n = 290 (nf - 1) = 290 (1.995 - 1) = 288.6 K \\
MDS = k T_n B = (1.38 \times 10^{-23} \text{ J/K})(288.6 \text{ K})(1.6 \text{ MHz}) \\
MDS = -112.0 \text{ dBm}
\]
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>90 dBm</td>
<td>1 MW Radar TX Power</td>
</tr>
<tr>
<td>Transmit Antenna Gain</td>
<td>32 dB</td>
<td></td>
</tr>
<tr>
<td>Transmitter Losses</td>
<td>0 dB</td>
<td></td>
</tr>
<tr>
<td>Net Transmitted Power</td>
<td>122 dBm</td>
<td></td>
</tr>
<tr>
<td>Path Loss</td>
<td></td>
<td>Calculated</td>
</tr>
<tr>
<td>Diffraction Loss</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Fading Margin</td>
<td>N/A: No Mobility in this scenario.</td>
<td></td>
</tr>
<tr>
<td>Shadowing Margin</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Channel Losses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Propagation Losses</td>
<td>226 dB</td>
<td>Maximum based on Net RX Power</td>
</tr>
<tr>
<td>Receiver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receiver Antenna Gain</td>
<td>2.0 dB</td>
<td>Given</td>
</tr>
<tr>
<td>Receiver Losses</td>
<td>0 dB</td>
<td></td>
</tr>
<tr>
<td>Net Receiver Gain</td>
<td>2.0 dB</td>
<td></td>
</tr>
<tr>
<td>Net Received Power</td>
<td>-102 dBm</td>
<td></td>
</tr>
<tr>
<td>System Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum SNR</td>
<td>10 dB</td>
<td>Given</td>
</tr>
<tr>
<td>Max MDS</td>
<td>-112.0 dBm</td>
<td>Based on NF and 2.0 MHz BW</td>
</tr>
</tbody>
</table>
Free Space Path Loss

\[ \bar{PL}(d) = 226 \text{ dB} \]

\[ d_{\text{max}} = \frac{\lambda^2}{4\pi} \sqrt{\frac{1}{10 \cdot \frac{\bar{PL}(d)}{10}}} = \frac{1}{4\pi} \sqrt{\frac{(0.0857\text{m})^2}{10 \cdot \frac{226\text{ dB}}{10}}} = 1,360,000 \text{ km} \]

Two Ray Path Loss

\[ \bar{PL}(d) = 226 \text{ dB} \]

\[ PL(d) = 40 \log_{10}(d) + 20 \log_{10}(h_r) + 20 \log_{10}(h_t) \]

\[ d_{\text{max}} = 10^{\frac{-20 \log_{10}(h_r) - 20 \log_{10}(h_t) + \bar{PL}(d)}{40}} = 10^{\frac{-20 \log_{10}(1.6\text{m}) - 20 \log_{10}(1.5\text{m}) + 226\text{ dB}}{40}} = 91.2 \text{ km} \]

Average Path Loss (Log-Distance Model)

\[ \bar{PL}(d) = PL(d_0) + 10 n \log_{10} \left( \frac{d}{d_0} \right) + X_{\sigma} \]

\[ PL(d_0 = 1\text{m}) = -10 \log_{10} \left( \frac{\lambda^2}{(4\pi d_0)^2} \right) = -10 \log_{10} \left( \frac{(0.0857\text{m})^2}{(4\pi (1\text{m}))^2} \right) = 43.3 \text{ dB} \]

\[ d_{\text{max}} = 10^{\frac{PL(d) - PL(d_0)}{10n}} = 10^{\frac{226\text{ dB} - 43.3\text{ dB}}{10(3.8)}} = 64.2 \text{ km} \]
Average Path Loss (Hata Model)

\[ PL(d) = 69.55 - 26.16 \log_{10}(f) - 13.82 \log_{10}(h_r) - a(h_r) + \]
\[ \left(44.9 - 6.55 \log_{10}(h_r)\right)\log_{10}(d) - 2\left(\log_{10}\left(\frac{f}{28}\right)\right)^2 - 5.4 \]

\[ a(h_r) = (1.1 \log_{10}(f) - 0.7)h_r - (1.56 \log_{10}(f) - 0.8) \]

\[ PL(d) = 69.55 - 26.16 \log_{10}(3500) - 13.82 \log_{10}(16) - a(1.5) + \]
\[ \left(44.9 - 6.55 \log_{10}(1.5)\right)\log_{10}(d) - 2\left(\log_{10}\left(\frac{3500}{28}\right)\right)^2 - 5.4 \]

\[ a(h_r) = (1.1 \log_{10}(3500) - 0.7)(1.5) - (1.56 \log_{10}(3500) - 0.8) = 0.07 \]

\[ PL(d) = -39.80 + 43.75 \log_{10}(d) - 14.19 \]
\[ + 43.75 \log_{10}(d) = +54.0 + PL(d) \]

\[ \log_{10}(d) = \frac{54.0 + 226}{43.75} \]
\[ d_{\text{max}} = 2,510,000 \text{ km} \]