Wireless Communication Technology

Tutorial-I Solution

1. A base station transmits a power of 10W into a feeder cable with a loss of 10dB. The transmit antenna has a gain of 12 dBd 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 effective isotropic radiated power (Ans: EIRP = 26W)
   b) Determine the maximum acceptable path loss (Ans: 148.3 dB)

Solution:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value in original units</th>
<th>Value in consistent units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_T$: transmitted power</td>
<td>10 W</td>
<td>10 dBW</td>
</tr>
<tr>
<td>$G_T$: gain of transmitting antenna</td>
<td>12 dBd</td>
<td>14.15 dBi</td>
</tr>
<tr>
<td>$G_R$: gain of receiving antenna</td>
<td>0 dBd</td>
<td>2.15 dBi</td>
</tr>
<tr>
<td>$P_R$: received power</td>
<td>-104 dBm</td>
<td>-134 dBW</td>
</tr>
<tr>
<td>$L_T$: transmitter feeder loss</td>
<td>10 dB</td>
<td>10 dB</td>
</tr>
<tr>
<td>$L_R$: receiver feeder loss</td>
<td>2 dB</td>
<td>2 dB</td>
</tr>
</tbody>
</table>

   a) \[ EIRP = P_T + G_T - L_T = 10 \text{dBW} + (12 + 2.15) - 10 = 14.15 \text{dBW} = 26 \text{Watts} \]

   b) \[ L = P_T + G_T + G_R - P_R - L_T - L_R \]
   \[ G_T = 12 + 2.15 \]
   \[ G_R = 2.15 \]
   \[ P_R = -104 \text{dBm} = -134 \text{dBW} \]
   \[ L = 10 + 14.15 + 2.15 - (-134) - 10 - 2 = 148 \text{dB} \]

2. A receiver in a digital mobile communication system has a noise bandwidth of 200 kHz and requires that its input SNR should be at least 10 dB when the input signal is -104 dBm.

   a) What is the maximum permitted value of the receiver noise figure? (Ans: F (dB) = 7.0 dB)
   b) What is the equivalent input noise temperature of such a receiver? (Ans: $T_e = 1164 \text{K}$)

Solution:

a) \[ \text{SNR} = P_s - N \]
   \[ N = 10 \log (F k T B) \]
   \[ \text{SNR} = P_s - N = P_s - \text{FdB} - 10 \log (k T B) \]
\[ F_{dB} = P_s - SNR - 10 \log (kT) \]
\[ F_{dB} = (-104-30) - 10 - 10 \log (1.38 \times 10^{-23} \times 290 \times 20000) \]
\[ F_{dB} = 7 \text{ dB} \]

b) \[ T_e = T(F-1) = 290 \left( 10^{\frac{7}{10}} - 1 \right) = 1163 \text{ K} \]

3. A receiver is made up of three main elements: a preamplifier, a mixer and an IF amplifier with noise figures 3 dB, 6 dB and 10 dB, respectively.
   a) If the overall gain of the receiver is 30 dB and the IF amplifier gain is 10 dB, determine the minimum gain of the preamplifier to achieve an overall noise figure of no more than 5 dB.
   b) If its gain is set to this minimum, what would the system noise figure become if the noise figure of the IF amplifier is increased to 20 dB? (Ans: a) \( G_1 = 2.7 \) = 4.3 dB minimum b) \( F = 4.1 = 6.1 \) dB

Solution:

The receiver is modeled as a three-element network, with individual noise factors \( F_1 = 2 \), \( F_2 = 4 \) and \( F_3 = 10 \), where subscripts 1, 2 and 3 represent the preamplifier, mixer and IF amplifier, respectively. Since the overall gain is 30 dB, we have \( G_1G_2G_3 = 1000 \) and \( G_3 = 10 \), so \( G_1G_2 = 100 \).

From Eq. (5.19), the overall noise factor is

\[ F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1G_2} \]

Thus

\[ 3.2 = 2.0 + \frac{4.0 - 1}{G_1} + \frac{10.0 - 1}{100} \]

Rearranging,

\[ G_1 = \frac{3.0}{3.2 - 2.0 - \frac{9.0}{100}} = 2.7 = 4.3 \text{ dB minimum} \]

If the noise figure of the IF amplifier is now increased to 20 dB, i.e. \( F_3 = 100 \), we have

\[ F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1G_2} = 2.0 + \frac{4.0 - 1}{2.7} + \frac{100 - 1}{100} = 4.1 = 6.1 \text{ dB} \]

This is clearly a very small increase on the previous figure, since the result is highly insensitive to the noise figure of the final element in the cascade.
a) Model receiver as a three-element network.

F1 = 2
F2 = 4
F3 = 10

G = G1G2G3 = 30 dB = 1000
G3 = 10, so G1G2 = 100

Then

F = F1 + (F2 - 1)/G1 + (F3 - 1)/(G1G2)

F = 5 dB = 10^(-5) = 3.2 = 2 + (4 - 1)/G1 + (10 - 1)/100

Solve for G1:
G1 = 2.7 = 10 log(2.7) = 4.3 dB, minimum

b) Increase F3 to 20 dB = 10^1

Then

F = F1 + (F2 - 1)/G1 + (F3 - 1)/(G1G2) = 2 + (4 - 1)/2.7 + (100 - 1)/100

F = 4.1 = 6.1 dB

4. The communication system described in above question number 1 is operated under free space propagation condition at 900 MHz and at 1800 MHz. Determine its maximum range. (Ans: 693 Km for 900 MHz)

Solution:

From question 1, Path loss L = 148 dB

From Friis equation,

L = 20 log(f, Mhz) + 20 log(d, miles) + 36.6

20 log(d, miles) = L - 36.6 - 20 log(900) = 148 - 36.6 - 59.1 = 52.3

d, miles = 416 miles

d, km = 694 km

5. Calculate the maximum range of the communication system in above question 4 assuming h = 1.5 m, h = 30 m, f = 900 MHz and that propagation takes place over a plane earth. How does this range change if the base station antenna height is doubled? (Ans: r = 34 Km, if height is doubled then r = 48 Km)

Solution:

Assuming that the range is large enough to use the simple form of the plane earth model then,

r = (h + 20 h + 20 log h) 1/40 = 148.3 + 3.5 + 29.5/40 ≈ 4.53

Hence, r = 34 km, a substantial reduction from the free space case described in question 4. If the antenna height is doubled, the range may be increased by a factor of \(\sqrt{2}\) for the same propagation loss.

Hence r = 48 km.
6. If a transmitter produces 50 W of power, express the transmit power in units of a) dBm, and b) dBW. If 50 W is applied to a unity gain antenna with a 900 MHz carrier frequency, c) find the receiver power in dBm at a free space distance of 100 m from the antenna d) What is (10 km)? Assume unity gain for the receiver antenna. (Ans: a) 47 dBm b) 17 dBW c) -64.5 dBm)

**Solution:**

a) and b) 

Note: For the unit dBmW, the abbreviation dBm is commonly used.

Transmitter power is \( P_t = 50 \text{ W} \).

\[
\begin{align*}
a) & \quad P_{t, \text{dBm}} = 10 \cdot \log \left( \frac{P_t [\text{mW}]}{1 \text{ mW}} \right) = 10 \cdot \log [50 \cdot 10^3] = 47.0 \text{ dBm} \\
b) & \quad P_{t, \text{dBW}} = 10 \cdot \log \left( \frac{P_t [\text{W}]}{1 \text{ W}} \right) = 10 \cdot \log [50] = 17.0 \text{ dBW}
\end{align*}
\]

c) and d) 

Power density as a function of distance: \( S = \frac{\text{power}}{\text{area}} = \frac{P_t}{4\pi R^2} \)

Unity-gain/isotropic receive antenna described by its effective area: \( A_{\text{isotropic}} = \frac{\lambda^2}{4\pi} \)

Received power: \( P_{\text{rec}} = S \cdot A = P_t \left( \frac{\lambda}{4\pi R} \right)^2 \)

c) 

\[ \text{received power} = 3.5 \times 10^{-6} \text{ W} \equiv -24.5 \text{ dBm} \]

d) 

\[ \text{received power} = 3.5 \times 10^{-10} \text{ W} \equiv -64.5 \text{ dBm} \]