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Chapter 2 Solutions

1. From Equation 2.12, the minimum SNR required to decode a signal depends on both the bit rate and the energy-per-bit to noise-density ratio, $\mathbf{E_b/N_o}$. The value, $\mathbf{E_b/N_o}$ is determined from solving Equation 2.7 in terms of $\mathbf{P_e}$ which was given as one part per million or 10^{-6}.

[BT]Solving Equation 2.7 gives,

[DISP]

$$E_b/N_o = - 2 \ln (2 P_e)$$

[DISPX]

[FT]Substituting for P_e gives,

[DISP]

$$\mathbf{E_b/N_o} = 26.24 \text{ or } 14.19 \text{ dB.}$$

[DISPX]

[FT]Substituting this value into Equation 2.12 give the minimum SNR as,

[DISP]

$$SNR_{min} = 1000 \text{ x } 26.24 = 30 \text{ dB} + 14.19 \text{ dB} = 44.19 \text{ Db}$$

[DISPX]

[FT]The signal power received is one microwatt or equivalently, -30 dBm. Therefore, the sensitivity required is,

[DISP]

Sensitivity = Received Signal Level – SNR = -30 dBm – 44.19 dB = -74.19 dBm

[DISPX]

[FT]This result assumes a theoretical receiver that is designed with the specified sensitivity level and bandwidth to correctly demodulate the one kbps ASK modulated signal within the specified BER.

2. The link margin provides a signal degradation budget that can be used to determine the theoretical maximum separation distance between a transmitter and a corresponding receiver system. The range can also be easily determined from solving the Friis formula as given in Equation 2.4 and replacing the contents under the square root with the link margin.

[BT]From the FCC regulatory reference, the maximum allowed EIRP at 433.92 MHz per FCC Part 15.231(e) is calculated by interpolating between 260 MHz to 470 MHz as given by formula in the referenced power table. This interpolation for 433.92 MHz gives a maximum electric field density of 72.87 dBμV/m measured at 3 meters. It is easier to convert this quantity to power by using a 50-ohm reference, thereby yielding approximately 6 microwatts EIRP or -22.26 dBm.

[DISP]

EIRP = -22.36 dBm

RX Sensitivity = -74.19 dBm – 2.2 dB (antenna gain) = -76.39 dB.

Link Margin = EIRP – RX Sensitivity = -22.36 dBm + 76.39 dB = 54.03 Db

[DISPX]

[FT]It is important to note that the maximum allowed EIRP includes any gain from the antenna, and so the antenna gain is included only for the receiver path.

3. Looking up the FCC regulations Part 15.517(c) reveals a table showing that within the specified 3.1 GHz to 10.6 GHz band, the transmitted signal power shall be no greater than -41.3 dBm/MHz EIRP. Integrating across the entire band from 3.1 GHz to 10.6 GHz gives a total EIRP level of 0.56 mW or -2.55 dBm.

[BT]Therefore,

[DISP]

Link Margin = EIRP – RX Sensitivity = -2.55 dBm + 76.39 dB = 73.84 dB.

[DISPX]

4. The range can be determined from Equation 2.4 by replacing the contents under the square root with the link margin and using a value for λ, the wavelength, that is at the center of the specified frequency band. The wavelength is calculated from C/f where C is the speed of light and f is the frequency. The results are summarized in the table below.

Parameter	Active RFID	UWB
Center frequency, f	433.92 MHz	6.85 GHz
Wavelength	0.691 meters	0.044 meters
Link margin	54.03 dB	73.84 dB
Range	27.7 meters	17.1 meters

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[BT]The UWB system is at a significant disadvantage for a few reasons. First, the FCC severely restricts the EIRP. This is because the UWB transmission occupies a wide segment of licensed frequency bands and must, therefore, fall below the established noise emission levels. Second, the shorter wavelength implies a much smaller effective aperture for collecting the signal. Note that when solving the Friis formula for range, it is evident that range is linearly proportional to the wavelength.