jammer noise density by

$$\text{sinc}^2\left[(f-f_0)\frac{2}{W}\right] = \frac{\sin(\pi/2)}{\pi/2} = 0.637 = 1.96 \text{ dB}$$

With the worst case frequency error, the jammer loses only 2 dB in effective power when using a very narrowband jammer. If the jammer resorted to a wideband strategy, it would immediately pay a 3 dB penalty. Thus, a pulse narrowband jammer is most effective.

Problem 6-3

The bit error probability for binary FH/FSK in partial band jamming is given by (6-48):

$$(\overline{P_b})_{\max} = \begin{cases} \dfrac{e^{-1}}{2(P/J)(W/R)}, & 1.0 < \dfrac{P}{J}\dfrac{W}{R} \\ \dfrac{1}{2}\exp\left\{-\dfrac{P}{J}\dfrac{W}{R}\right\}, & \dfrac{P}{J}\dfrac{W}{R} < 1.0 \end{cases}$$

The jammer is 30 dB or 1000 times more powerful tahn the communicator signal. Therefore, $P/J = 10^{-3}$. Also, $R = 32\times10^3$. Solve both equations above for W.

$$10^{-3} = \frac{e^{-1}(32\times10^3)}{2(10^{-3})W} \rightarrow W = 5.89 \text{ GHz}$$

Also,

$$10^{-3} = \frac{1}{2}\exp\left[-\frac{10^{-3}W}{32\times10^3}\right] \rightarrow W = 199 \text{ MHz}$$

Observe that in the first case

$$\frac{P}{J}\frac{W}{R} = 184 \geq 1$$

so that the equation is valid. In the second case

$$\frac{P}{J}\frac{W}{R} = 6.22$$

so that the equation is not valid. The first result is the required bandwidth. The bandwidth of the data signal is about $2R = 64\times10^3$ Hz. Therefore, the frequency hopper must generate

$$\frac{5.89\times10^9}{64\times10^3} = 92{,}000 \text{ frequencies}$$

This is clearly a very difficult jammer to defeat.

Problem 6-4

The number of hops in the FH/DPSK system is only 10 if we assume that the data modulation bandwidth is 2 MHz. Therefore, the partial band jammer's fractional bandwidth is in the range $0.1 \le \rho \le 1.0$. Fractional bandwidths smaller than $\rho = 0.1$ could be used but they would be no more effective than $\rho = 0.1$. In contrast, the pulse jammer can reduce its duty factor to any desired value (assuming the jammer is not peak power limited). Thus, for low P_b, the pulse jammer is more effective than the partial band jammer.

Problem 6-5

For BPSK/BPSK modulation, partial band jamming is at most 3 dB more effective than wideband jamming as discussed in Section 6.2-2. In contrast, the pulsed jammer can be much more effective than the wideband jammer as illustrated in Figure 6-19. Again, pulsed noise is a good choice for the jammer if he is not peak power limited.

Problem 6-6

The image rejection filter bandwidth must be large enough to pass the direct-sequence spread signal with minimum distortion. Usually a bandwidth equal to the null-to-null signal bandwidth is adequate; thus, choose 200 MHz for the image reject filter bandwidth. Larger bandwidths are also okay. However, they will not reject interferers that are only slightly out of band. The IF bandpass filter must have a bandwidth adequate to pass the data modulated IF carrier. In this case, an IF bandwidth of 2 MHz is reasonable; larger bandwidths would not seriously degrade performance. Assume that the jammer is within the image reject filter bandwidth. The receiver despreader spreads the tone jammer; the power spectral density of the despreader output due to jamming is

$$S_J(f) = \frac{1}{2} J T_c \left\{ \text{sinc}^2[(f - f_{IF} - \Delta f) T_c] + \text{sinc}^2[(f - f_{IF} - \Delta f) T_c] \right\}$$

and the power spectral density at $f = f_{IF}$ is

$$S_J(f_{IF}) = \frac{1}{2} J T_c \text{sinc}^2(\Delta f T_c)$$

After despreading, the entire signal power passes through the IF bandpass filter. Therefore, the ratio of signal power to jammer power spectral density at the IF filter output is

$$\frac{P}{N_J'} = \frac{P}{J T_c \text{sinc}^2(\Delta f T_c)}$$

But $(P/J)_{dB} = -10$ dB which implies $P/J = 0.1$. Also, $T_c = R_c^{-1} = 10$ ns. This gives

$$\frac{P}{N_J'} = \frac{0.1}{10^{-8}\text{sinc}^2(10^{-8}\Delta f)}$$

Since $P = E_b R$, $P/N_J' = E_b R/N_J'$, or

$$\frac{E_b}{N_J'} = \frac{0.1}{10^{-2}\text{sinc}^2(10^{-8}\Delta f)} = \frac{10}{\text{sinc}^2(10^{-8}\Delta f)}$$

A table of values for the specified values of Δf is given below:

Δf, MHz	E_b/N_J'	$P_b = Q\left(\sqrt{\frac{2E_b}{N_J'}}\right)$
1.5	10.0	4.05×10^{-6}
5.0	10.1	3.65×10^{-6}
10.0	10.3	2.96×10^{-6}
50.0	24.7	1.06×10^{-12}

Problem 6-7

The image rejection filter must pass the entire spread signal. A bandwidth much wider than necessary will permit out-of-band interferers to pass. Therefore, make the image rejection filter bandwidth about 1024x200 kHz = 204.8 MHz. The post-despreading bandwidth must pass the data modulation. Therefore, use a bandwidth of 100 kHz + 2x0.5x100 kHz = 200 kHz. The jammer power is 10 times as large as the signal power. The optimum jamming strategy places a single interferer in any hop band. The power of each interferer should equal the signal power. Thus, the optimal number of jamming tones is $J/P = 10P/P = 10$. The tone spacing is 200 kHz (1 per band). The jammer tone power level is $J_q = J/q = 10P/10 = P$. The frequency hop rate is arbitrary except for requiring that the system must be a slow hopper. It must be such because the hop spacing is determined by the data bandwidth and not by the duration of the hop chip. In order that hop transitions not affect performance, choose a hop rate equal to 1/10 of the data rate or 10 khops/s. The bit error probability is calculated by noting that an error is made with probability 1/2 on the hops which are jammed, and no errors are made on the remaining 1024 - 10 = 1014 hop tones. Thus,