```
%%%%%%%%%%%%%%%%%%%%%%%%%
%                       %
%       p4_24.m         %
%                       %
%  Chapter 4    4.24    %
%                       %
%%%%%%%%%%%%%%%%%%%%%%%%%

d0 = 1000;          % reference distance (m)
Prd0 = 10^(-6);     % received power at d0 (Watt)
f = 1800*10^6;      % carrier frequency (Hz)
ht = 40;            % transmitter antenna height (m)
hr = 3;             % receiver antenna height (m)
Gt = 1;             % transmitter antenna gain (0 dB)
Gr = 1;             % receiver antenna gain (0 dB)
lambda = 3*10^8/f;  % wavelength of carrier (m)

Pt = Prd0*(4*pi)^2*d0^2/(Gt*Gr*lambda^2);  % transmitte power
d = 1000:100:20000;     % distance of interest

PrAppr = Pt*Gt*Gr*ht^2*hr^2./d.^4;    %  approximate expression of received power
PrAppr_dBm = 10*log10(PrAppr*1000);  %  power in dBm
sita_delta = 4*pi*ht*hr./(lambda*d); %  phase difference between two rays
PrExa = (Pt*Gt*Gr*lambda^2./((4*pi)^2*d.^2))*4.*(sin(sita_delta/2)).^2;
                                     %  exact expression of received power
PrExa_dBm = 10*log10(PrExa*1000);    %  power in dBm
PrExa2 = (Pt*Gt*Gr*lambda^2./((4*pi)^2*d.^2))*4.*(cos(sita_delta/2)).^2;
                                     %  for gama = 1
PrExa2_dBm = 10*log10(PrExa2*1000);     %  power in dBm

figure(1);
plot(d/1000,PrExa_dBm,'-',d/1000,PrAppr_dBm,'--',d/1000,PrExa2_dBm,'-.');
grid;
title('exact and approximate receive power');
xlabel('d(km)');
ylabel('Pr(d) (dBm)');
legend('Exact','Approximate','gamma = 1');
axis([1 20 -80 -10]);
```

4.27 Given noise figure $F = 8dB \doteq 6.3$, receiver bandwidth $B_W = 30KHz$.

$\Rightarrow$ noise floor $= K \cdot B_W \cdot F \cdot T_0$, where K is Boltzman constant, $T_0 = 290°K$

$\Rightarrow$ noise floor $= 1.38 \times 10^{-23} \times 30 \times 10^3 \times 6.3 \times 290$

$\doteq 7.56 \times 10^{-16} (W) \doteq -121.2\ (dBm)$

$\Rightarrow$ threshold γ = noise floor (dBm) + SNR (dB)

$= -121.2 + 20 = -101.2\ (dBm)$

Since $Pr[P_r(d_{max}) > \gamma] = Q\left(\frac{\gamma - \overline{P_r(d_{max})}}{\sigma}\right) = 0.95$, we have

$$\frac{\gamma - \overline{P_r(d_{max})}}{\sigma} \doteq -1.645$$

$\Rightarrow \overline{P_r(d_{max})} = \gamma + 1.645\sigma = -101.2 + 1.645 \times 8 = -88.04 (dBm)$

Given $P_t = 15\ W$, $\lambda = \frac{c}{f} \doteq 0.1667\ m$, $G_t = 12dB \doteq 15.85$, $G_r = 3\ dB = 2$

$\Rightarrow$ $$P_r(d_0) = \frac{P_t \cdot G_t \cdot G_r \cdot \lambda^2}{(4\pi)^2 \cdot d_0^2}$$

4.27 Cont'd

$$= \frac{15 \times 15.85 \times 2 \times 0.1667^2}{(4\pi)^2 \times (1000)^2} \doteq 8.373 \times 10^{-8} (W) \doteq -40.77\ dBm$$

Since $\overline{P_r(d_{max})} = P_r(d_0)\ (dBm) - 10 \cdot n \log_{10}\left(\frac{d_{max}}{d_0}\right)$, we have

$10 \times 4 \log_{10}\left(\frac{d_{max}}{d_0}\right) = P_r(d_0) - \overline{P_r(d_{max})} = -40.77 - (-88.04)$

$\Rightarrow \log_{10} \frac{d_{max}}{d_0} \doteq 1.182$

$\Rightarrow d_{max} \doteq \underline{\underline{15.2\ (Km)}}$

4.29

(a) Find the minimum mean square error (MMSE) estimate for the path loss exponent, n.

First note that $P_r(100m) = 0\ dBm = P_r(d_0)$
$P_r(d) = P_r(d_0) - PL(d)$

d	P_r (dBm)
100	0
200	-25
1000	-35
2000	-38

$$J_n = \sum_{i=1}^{4}\left[P_i - \hat{P}_i\right]^2 = \underbrace{[0-0]^2}_{100m} + \underbrace{\left[-25-\left(0-10n\log\tfrac{200}{100}\right)\right]^2}_{200m}$$
$$+\left[-35-\left(0-10n\log\tfrac{1000}{100}\right)\right]^2 + \left[-38-\left(0-10n\log\tfrac{2000}{100}\right)\right]^2$$

$$= 625-150n+9n^2$$
$$+\ 1225-700n+100n^2$$
$$+\ 1444-988n+169n^2$$

$$\therefore J_n = 278n^2 - 1838n + 3294$$

$$\frac{dJ_n}{dn} = 556n - 1838 \Rightarrow \boxed{n = 3.30}$$

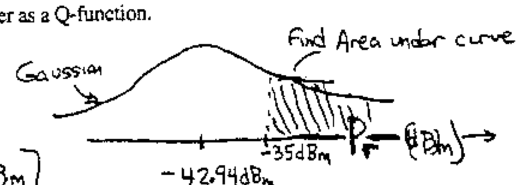
(b) Calculate the standard deviation of shadowing about the mean value.

$$\sigma = \sqrt{\sigma^2} = \left.\sqrt{\frac{J_n}{4}}\right|_{n=3.30}$$
$$= \sqrt{278(3.3)^2 - 1838(3.3) + 3294}\,/\sqrt{4}$$
$$= \frac{\sqrt{3027 - 6065.4 + 3294}}{\sqrt{4}} = \frac{\sqrt{255.6}}{\sqrt{4}} = \boxed{8\ dB}$$

(c) Estimate the received power at d = 2 km using the resulting model.

$$P_r(d) = P_r(d_0) - PL(d) = 0\ dBm - 10[3.3]\log_{10}\left(\frac{2000}{100}\right)$$
$$= (0 - 42.94)\ dBm = \boxed{-42.94\ dBm}$$

(d) Predict the likelihood that the received signal level at 2 km will be greater than –35 dBm. Express your answer as a Q-function.



$$P_r\left[P_r(2km) \geq -35\ dBm\right]$$
$$= Q\left[\frac{-35-(-42.94)}{8}\right]$$

Avg. PWR at 2km using Model

$$= Q\left(\frac{7.93}{8}\right) = Q(0.99) \approx Q(1)$$