RADAR JAMMING SIMULATION

1. Introduction

The program *radjam.m* simulates the performance of a radar in the presence of a standoff jammer. The geometry is illustrated in Figure 1. The jammer location is fixed but the target location is allowed to change. In the simulation, the target is stepped through positions in a specified range window of radius $R_{t_{max}}$. The target echo signal-to-jammer-plus-noise ratio (SJNR) is calculated for each position, and a series of contours are generated. If the minimum SJNR (simply referred to as SNR_{min}) is specified, then detection contours can be drawn. By varying the radar and jammer parameters and geometry, the user can study the effect of the jammer on the radar's performance.

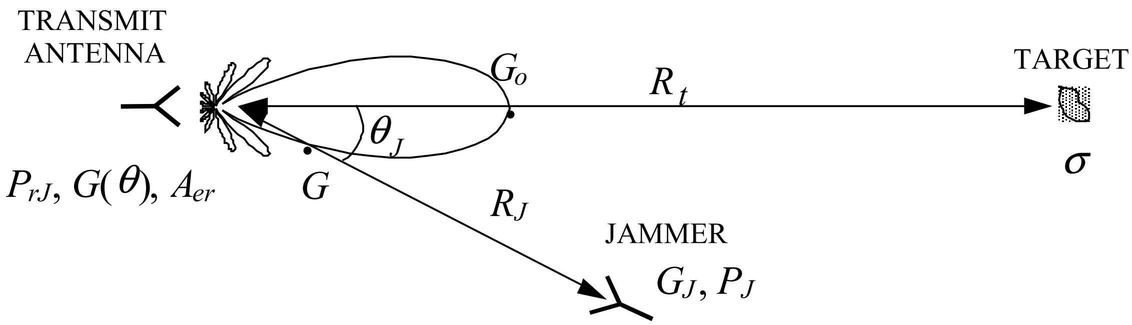

Figure 1: Jammer and radar geometry and parameters (top view).

The simulation is based on the radar range equation and the jammer burnthrough equation. The jammer power received by the radar is

$$P_{rJ} = \left(\frac{P_J G_J}{4\pi R_J^2} \right) \left(\frac{\lambda^2 G(\theta_J)}{4\pi} \right) = \frac{P_J G_J \lambda^2 G(\theta_J)}{(4\pi R_J)^2}$$

As the target moves throughout the range window, it is assumed that the radar antenna's maximum gain is on the target. Defining $G_o \equiv G(\theta = 0) = G_{\max}$ as the main beam gain, the target return is

$$P_r = \frac{P_t G_o^2 \lambda^2 \sigma G_p}{(4\pi)^3 R_t^4}$$

G_p is a generalized processing gain to account for the increase in SNR due to correlation, integration, matched receiver performance, etc. The signal-to-jam ratio is

$$\text{SJR} = \frac{S}{J} = \frac{P_r}{P_{rJ}} = \left(\frac{P_t G_o}{P_J G_J}\right)\left(\frac{R_J^2}{R_t^4}\right)\left(\frac{\sigma}{4\pi}\right)\left(\frac{G_o}{G(\theta_J)}\right)$$

The burnthrough range for the jammer is the range at which its signal is equal to the target return (SJR=1). Important points to note are that:

1. R_J^2 vs R_t^4 is a big advantage for the jammer.
2. G vs $G(\theta_J)$ is usually a big disadvantage for the jammer. Low sidelobe radar antennas reduce jammer effectiveness.
3. Given the geometry, the only parameter that the jammer has control of is the ERP (the product $P_J G_J$).

If a broadband jammer is present, then the jammer's transmitted power will be spread over a bandwidth wider than the radar's bandwidth. Thus, the radar sees only a fraction of the jammer's transmitted power

$$P_J\left(\frac{B_n}{B_J}\right)$$

A general rule of thumb is that $B_n \approx \frac{1}{\tau}$, where τ is the pulsewidth.

The jammer can be modeled as a noise source at temperature T_J

$$N_o \equiv P_{rJ} = k\mathrm{T}_J B_n$$

From our earlier result the jammer power received by the radar is

$$P_{rJ} = \frac{P_J G_J G(\theta_J)\lambda^2}{(4\pi R_J)^2}\left(\frac{B_n}{B_J}\right)$$

which gives an equivalent jammer temperature of

$$\mathrm{T}_J = \frac{P_{rJ}}{kB_n} = \frac{P_J G_J G(\theta_J)\lambda^2}{(4\pi R_J)^2 kB_J}$$

This temperature is used in the radar equation to access the impact of jammer power on the radar's SNR.

The thermal noise introduced by the receiver and antenna can also be included

$$N_o = kT_s B_n$$

where $T_s = T_A + T_e$ is the system noise temperature, T_A is the antenna temperature, and T_e is the effective temperature of the receiver. Therefore the total noise temperature is $T_s + T_J$. In as severe jamming environment $T_J >> T_s$.

2. Antenna Model

The antenna model in version 2.0 has been modified from that in version 1. The antenna is a rectangular aperture of width W_{az} in azimuth and W_{el} in elevation. In antenna coordinates, the normal to the aperture is the positive *z* direction, azimuth is $\phi = 90^\circ$ and elevation is $\phi = 0^\circ$. Therefore the antenna z axis is always pointed at the target. Mechanical scanning is assumed. That is, the antenna beamwidth does not increase as the beam is scanned off of broadside.

The aperture is uniformly illuminated in elevation and is represented by a sampled aperture (i.e., array) with a Taylor distribution in azimuth. The aperture is sampled at 0.5 wavelength intervals, and a minimum of 5 samples is taken. The Taylor parameters are the sideloble level in decibels (*Slldb*) and *nbar*. The parameter *nbar* controls the rate of fall off of the sidelobes. For example, a Taylor distribution with *nbar*=5 and *Slldb*=-30 has approximately the first 5 sidelobes at the –30 dB level, and then they gradually decrease from there. If the specified *Slldb* is greater than –15 dB then a uniform distribution is used in azimuth.

To suppress the backlobe, a cosine-squared-on-a-pedestal of the form

$$\mathrm{EF} = (1\text{-}Bll)\cos^2(\theta/2) + Bll$$

is applied, where $Bll = 10^{(Blldb/20)}$ and *Blldb* is the relative backlobe level in dB. The antenna efficiency is *e*. The Taylor distribution tapering (aperture) efficiency e_A is included in the gain calculation in addition to the efficiency input by the user. Therefore the gain can be written as

$$G(\theta_{el}, \phi_{az}) = \underbrace{\frac{4\pi (W_{az} W_{el})\, e \cdot e_A}{\lambda^2}}_{\equiv G_{\max}} \underbrace{\times \mathrm{Taylor}^2\left(W_{az}, k\sin\theta\sin\phi, nbar, Slldb\right) \cdot \mathrm{EF}^2 \cdot \mathrm{sinc}^2\left(\frac{kW_{el}}{2}\sin\theta\cos\phi\right)}_{\equiv f_t^2}$$

where f_t is the normalized electric field pattern[1]. Figure 2 shows a typical antenna azimuth pattern for a 3 m by 1 m antenna at 1 GHz for *Slldb*=-35 and *Blldb*=-50.

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[1] Assuming that the Taylor coefficients are properly scaled.

3. Multipath

Multipath (that is, the interference of a ground-reflected wave with the direct wave) can significantly affect the radar's performance. The multipath can be included in the radar range equation by using a path gain factor (PGF) or pattern propagation factor (PPF). A simple flat earth model is shown in Figure 3.

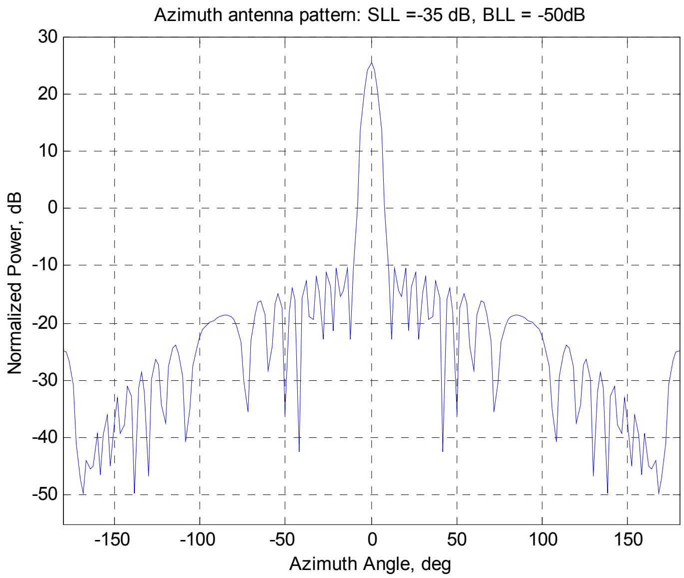

Figure 2: Sample antenna pattern.

The path gain factor (F) relates the total electric field with the reflection to the electric field that would be present for the direct path only

$$|E_{\text{tot}}| = \underbrace{|E_{\text{ref}}}_{\text{REFLECTED}} + \underbrace{E_{\text{dir}}|}_{\text{DIRECT}} = \left| f_t(\theta_A) \frac{e^{-jkR_o}}{4\pi R_o} \overbrace{\left[1 + \rho e^{j\phi_\Gamma} \frac{f_t(\theta_B)}{f_t(\theta_A)} e^{-jk\Delta R} \right]}^{\equiv F} \right|$$

If the antenna main beam is on the target then $f_t(\theta_A) = 1$. The difference between the direct and reflected paths is $\Delta R = (R_1 + R_2) - R_o$ and the reflection coefficient of the surface at the reflection point is $\rho e^{j\phi_\Gamma}$. Note that the two-way power for a monostatic radar will vary as $|F|^4$.

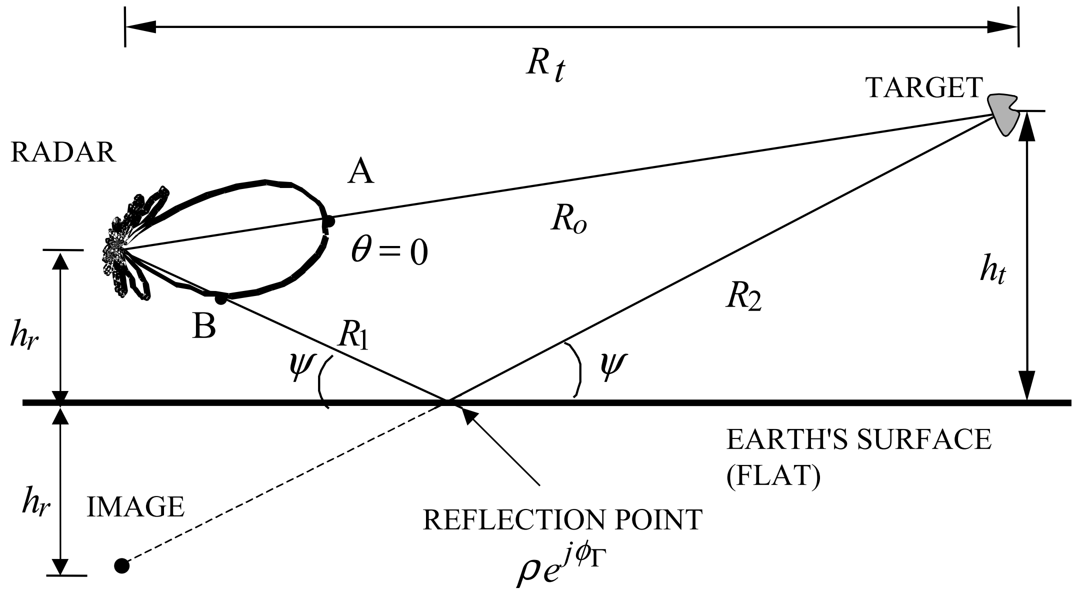

Figure 3: Flat earth multipath model (side view of radar-target geometry, $\phi = 0^\circ$).

If the radar is near the ground and the target is at a low altitude ($h_r, h_t << R_t$), then the path difference is approximately $\Delta R \approx \frac{2h_r h_t}{R_t}$. Furthermore, when the ground is a good conductor $\Gamma \approx -1$ for both polarizations and the path gain factor is approximately

$$|F| = \left|1 - e^{-jk2h_r h_t / R_t}\right| = \left|e^{jkh_r h_t / d}\left(e^{-jkh_r h_t / R_t} - e^{jkh_r h_t / R_t}\right)\right| = 2\left|\sin\left(kh_r h_t / R_t\right)\right|$$

The received (round trip) target power depends on the forth power of the path gain factor

$$P_r \propto |F|^4 = 4\sin^4\left(\frac{kh_t h_r}{R_t}\right) \approx 4\left(\frac{kh_t h_r}{R_t}\right)^4$$

4. Sample Calculations

Several sample calculations are shown to illustrate the typical input and output formats of *radjam*. Shown below are the data assignment statements in the non-GUI version of the code. Figure 4 shows the corresponding input in the GUI version.

```
% RADAR PARAMETERS
**************************************************************
Pt=1e3;          % radar transmitter power
Waz=3;           % radar antenna az aperture in m (sinc pattern)
Wel=1;           % radar antenna el aperture in m (sinc pattern)
TA=1000;         % antenna temperature
Te=1000;         % effective temperature of radar receiver
Ts=TA+Te;        % radar system noise temperature
er=0.9;          % radar antenna efficiency
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freq=1e9;         % frequency
c=3e8;            % velocity of light
Gpdb=20;          % radar processing gain in db
tau=1e-6;         % radar pulse width
Bn=1/tau;         % radar noise bandwidth
No=boltz*Ts*Bn;   % noise power
SNRmindb=0;       % threshold SNR
Smin=SNRmin*No;   % minimum detectable signal

% TARGET PARAMETERS
**************************************************************
rcsdb=10;         % target rcs
rcs=10^(rcsdb/10);

% JAMMER PARAMETERS
**************************************************************
Gjdb=3;           % jammer gain in direction of radar (in db)
Bj=2e6;           % jammer bandwidth
Pj=10             % jammer transmitter power

% compute contours of Rmax by computing the SNR over a rectangular grid
% target range and angle change; jammer location fixed
   Rj=5000;       % jammer range fixed
   angj=0*rad;  % jammer angle fixed
   xj=Rj*cos(angj); yj=Rj*sin(angj);
   Rtmax=10000;  % max/min target range for display window (i.e.,PPI radius)
   dRt=100;      % increment in target range
```

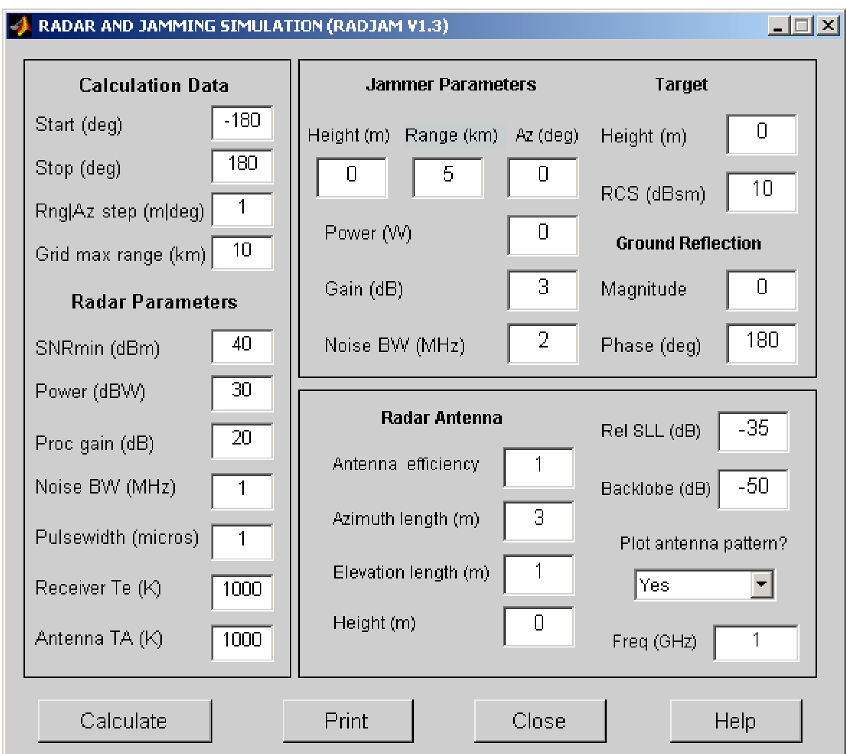

Figure 4: Input parameters, GUI version.

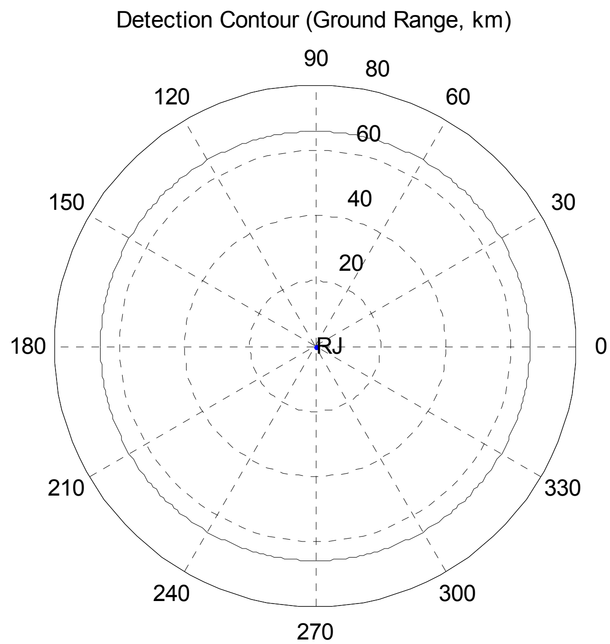

Figure 5: Detection contour for radar with no jamming.

For reference, the program displays the maximum range with no jammer present (only thermal noise) in the Matlab command window. For the above parameters, the program displays:

```
Max detection range without jamming = 65.8674 km
```

Figure 5 shows the detection range for this case. As expected, the detection contour is a circle. The jammer location is denoted by a J in the figure; the radar location is at the center of the plot and denoted by a R. With the jammer present and the parameters listed in Figure 4 the contour of Figure 6 results. Larger detection ranges occur when the jammer is in the null of the radar antenna. Note that the radar is rendered nonfunctional when the jammer is in the antenna main beam with the target (near 0 degrees).

Another example is based on the data in Figure 7, which models a relatively low power radar and jammer. The detection range with no multipath is shown in Figure 8. There is some reduction in detection when the jammer is in the mainbeam and the higher sidelobes at ± 90 degrees and in the backlobe. Figure 9 shows the detection range when multipath is included. Detection rings occur due to the fact that there are ranges where the reflected wave completely cancels the direct wave. Note that in Figure 9 the maximum detection range is actually larger than that in Figure 8 due to constructive interference of the direct and reflected waves. The width of the rings (in range) increases with range due to the non-uniform separation in nulls of the path gain factor. (A typical path gain factor is plotted in Figure 10.) As the ground range increases, the grazing angle decreases and it takes a larger change in ground range to obtain a half wavelength difference between the direct and reflected paths.

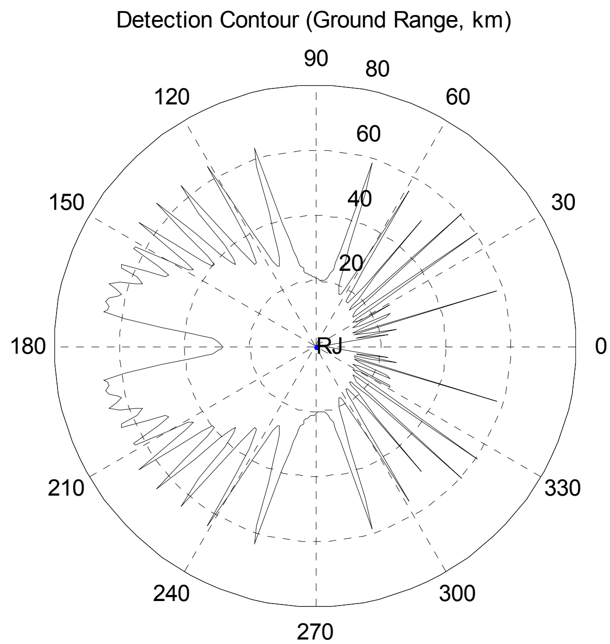

Figure 6: Radar detection contour with jamming (parameters in Figure 4), no multipath.

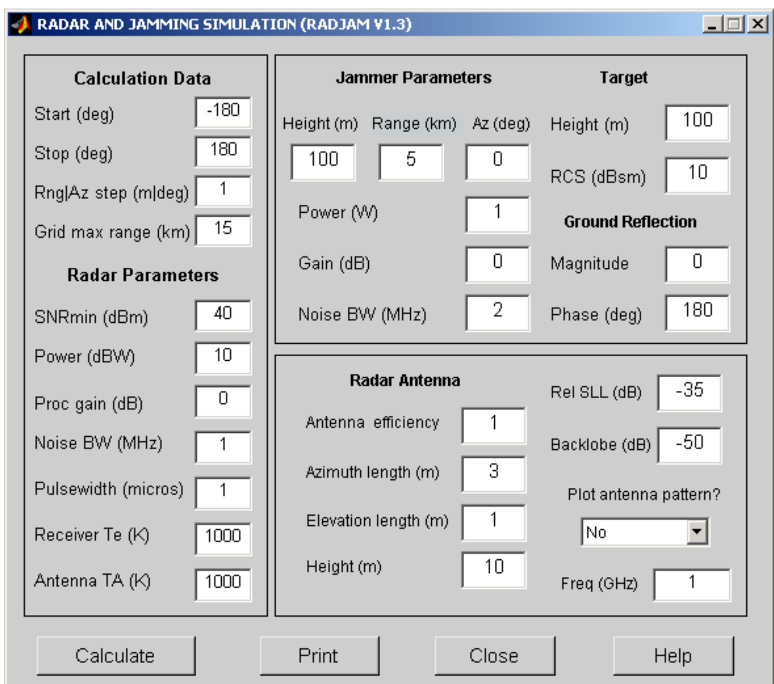

Figure 7: Data for the plots in Figures 8 and 9.

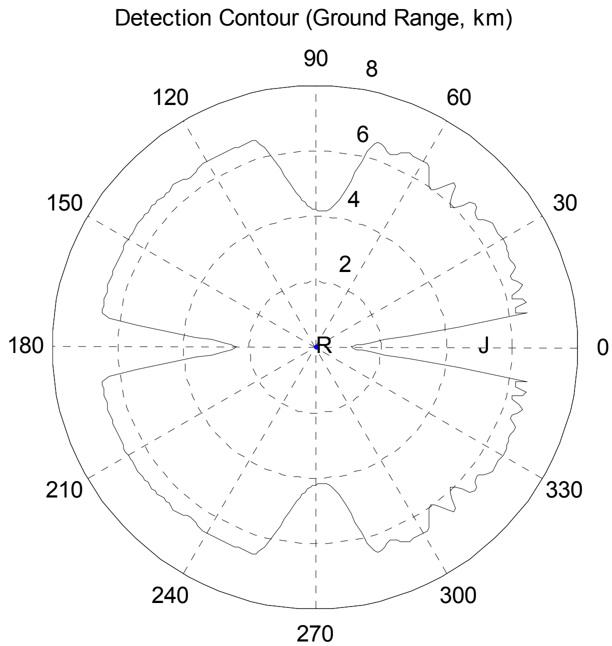

Figure 8: Detection contour for jamming but no multipath.

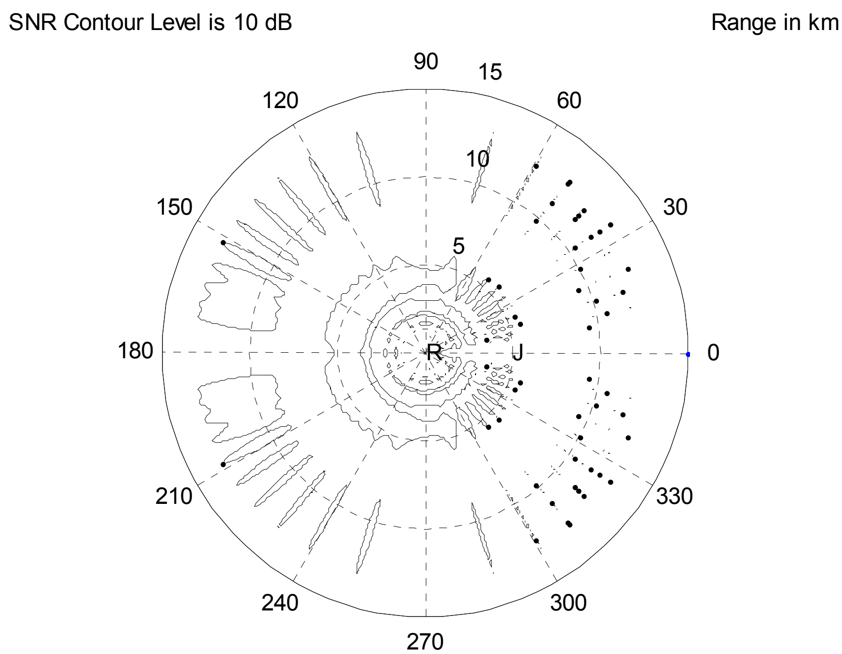

Figure 9: Detection range when the jammer is turned on. Multipath is present (reflection coefficient of –1).

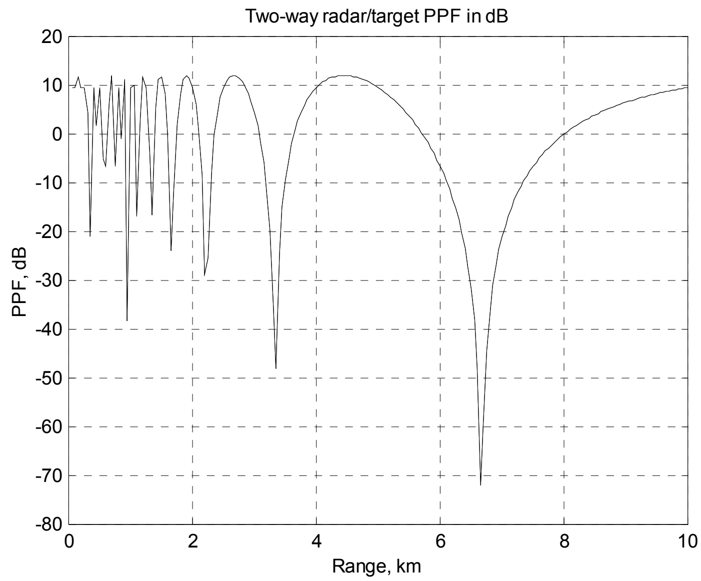

Figure 10: Example of a path gain factor for a perfectly conducting flat earth.

5. Hints

If *Magnitude* is zero then there is no multipath and *Start*, *Stop*, and *Az Step* are used to determine the angles at which to compute the detection range. *Grid max range* is not used. If an antenna pattern plot is requested *Start*, *Stop*, and *Az Step* are used for the pattern calculation.

If *Magnitude* is greater than zero then multipath is included. The required detection SNR is computed throughout a square grid of size *Grid max range*. The grid cell size is *Rng step*. The parameters *Start* and *Stop* are not used. All heights must be greater than zero or the direct and reflected rays will cancel everywhere.

SLL should be < - 15 dB or else a uniform distribution is used (-13 dB sidelobe level). The backlobe level should be less than or equal to the specified sidelobe level (BLL ≤ SLL).

Note that the jammer power is in W but the radar power is in dBw. The minimum SNR is in dBm.

If your computer is having problems displaying the GUI (only the header bar is visible), then it may be necessary to run Matlab in the 256 color mode.

(8 July 2002)