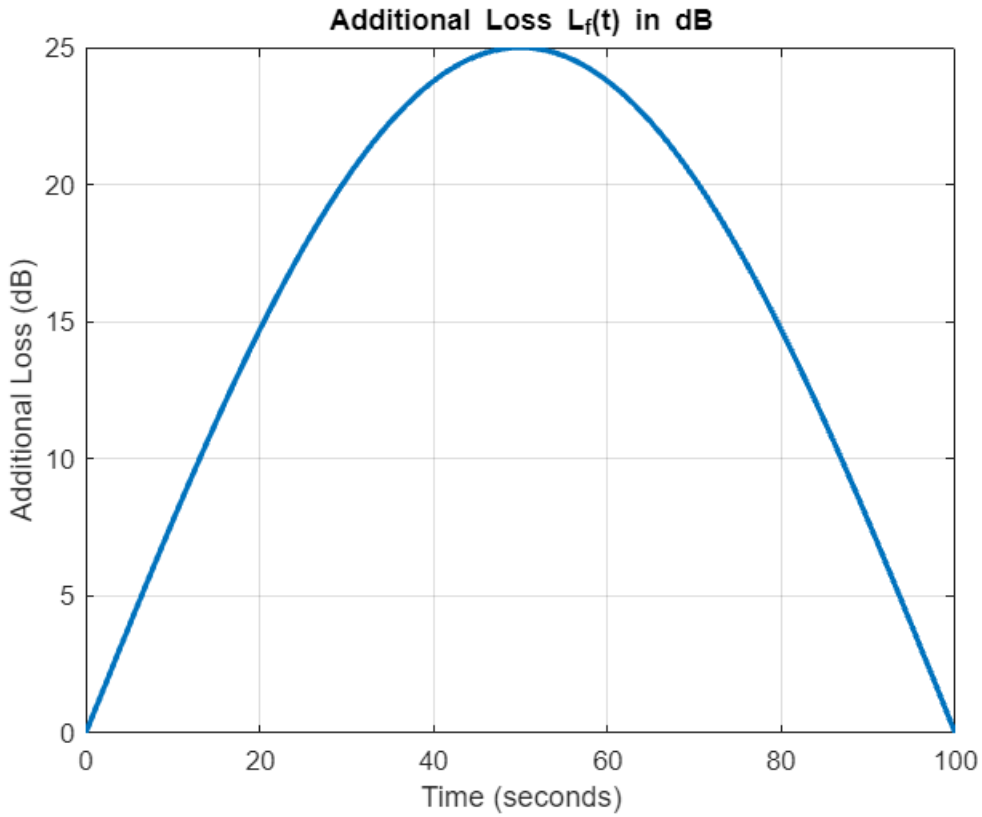
```
% Question 4
% (a)

time = 0:1:100; % 1 sample/sec sample rate for additional loss function
freq = 0.005;
L_f=25*sin(2*pi*freq.*time);
plot(time,L_f,'LineWidth',2);
title('Additional Loss L_f(t) in dB');
xlabel('Time (seconds)');
ylabel('Additional Loss (dB)');
ylim([0 25]);
grid on;
```




```
% (b)

disp('Answer of (b) part starts here');
```

```
Answer of (b) part starts here
```

```
distance=1000;
frequency=6e9;
t_total=100;
t=0:1:100;

% initializing required arrays for storing variables for each sample
```

```
eirp_array = zeros(size(t));
fspl_array = zeros(size(t));
tpl_array = zeros(size(t));
rip_array = zeros(size(t));
ps_array = zeros(size(t));
pn_array = zeros(size(t));
snr_array = zeros(size(t));

%Declaration of Constants and various calculations and conversions.
c=299792458; % speed of light
ff=0.005; % frequency of additional power loss temporal profile
transmit_power=-40; % in dbW

eta_t=0.55; %Antenna Efficiency of Transmitter
eta_r = 0.5; %Antenna Efficiency of Receiver

diameter_t=1; %Antenna Diameter of Transmitter
diameter_r =0.1; %Antenna Diamter of Receiver

gain_lin_t = eta_t*(pi*diameter_t*frequency/c)^2; %Gain of Transmitter Antenna in
linear scale
gain_db_t= 10*log10(gain_lin_t); % Gain of Transmitter Antenna in dB scale
gain_lin_r = eta_r*(pi*diameter_r*frequency/c)^2; %Gain of Receiver Antenna in
linear scale
gain_db_r= 10*log10(gain_lin_r); % Gain of Receiver Antenna in dB scale

temp_c=25; % Ambient Temperature at the receiver in degree Celsius
temp_k=273.15+temp_c; %Ambient Temperature at receiver in Kelvin
temp_k_db = 10*log10(temp_k); % Ambient Temperature at receiver in Kelvin in dB

k = 1.380649e-23; %Boltzmann Constant
k_db = 10*log10(k); %Boltzmann Constant in dB
N_0 = k_db+temp_k_db; % Spectral Density of Noise in dB

B = 125e6; %Bandwidth
B_db = 10*log10(B); %Bandwidth in dB

% Loop to calculate transmit EIRP, Total FSPL, L_f(t), RIP(t), P_s(t), P_n
% and SNR
for i = 1:length(t)
    disp(['Sample ' num2str(i) ':']);
    fspl_array(i) = (4*pi*distance*frequency/c)^2;
    fspl_array(i) = 10*log10(fspl_array(i));
    disp(['  Free Space Path Loss (FSPL): ' num2str(fspl_array(i)) ' dB']);
    Lf_db(i)=25 * sin(2*pi*ff*t(i));
    disp(['  Additional Loss (Lf): ' num2str(Lf_db(i)) ' dB']);
    tpl_array(i)=Lf_db(i)+fspl_array(i);
    disp(['  Total Path Loss (TPL): ' num2str(tpl_array(i)) ' dB']);
    eirp_array(i)=transmit_power+gain_db_t;
    disp(['  Transmit EIRP: ' num2str(eirp_array(i)) ' dBW']);
```

```
    rip_array(i) = eirp_array(i)-Lf_db(i)-fspl_array(i);
    disp(['  Received Isotropic Power: ' num2str(rip_array(i)) ' dBW']);
    ps_array(i) = rip_array(i)+gain_db_r;
    disp(['  Received power at receiver antenna (Ps): ' num2str(ps_array(i)) '
dBW']);
    pn_array(i) = N_0+B_db;
    disp(['  Received Noise power: ' num2str(pn_array(i)) ' dBW']);
    snr_array(i) = ps_array(i)-pn_array(i);
    disp(['  SNR = P_S/P_N: ' num2str(snr_array(i)) ' dBW']);
    disp(' ');
end
```

```
Sample 1:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 0 dB
  Total Path Loss (TPL): 108.0108 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -114.6376 dBW
  Received power at receiver antenna (Ps): -101.6783 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 21.2075 dBW

Sample 2:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 0.78527 dB
  Total Path Loss (TPL): 108.7961 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -115.4228 dBW
  Received power at receiver antenna (Ps): -102.4635 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 20.4222 dBW

Sample 3:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 1.5698 dB
  Total Path Loss (TPL): 109.5806 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -116.2073 dBW
  Received power at receiver antenna (Ps): -103.248 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 19.6377 dBW

Sample 4:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 2.3527 dB
  Total Path Loss (TPL): 110.3635 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -116.9903 dBW
  Received power at receiver antenna (Ps): -104.031 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 18.8547 dBW

Sample 5:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 3.1333 dB
  Total Path Loss (TPL): 111.1441 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -117.7709 dBW
  Received power at receiver antenna (Ps): -104.8116 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 18.0741 dBW
```

```
Sample 6:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 3.9109 dB
  Total Path Loss (TPL): 111.9217 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -118.5484 dBW
  Received power at receiver antenna (Ps): -105.5891 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 17.2966 dBW

Sample 7:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 4.6845 dB
  Total Path Loss (TPL): 112.6953 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -119.3221 dBW
  Received power at receiver antenna (Ps): -106.3628 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 16.5229 dBW

Sample 8:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 5.4536 dB
  Total Path Loss (TPL): 113.4644 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -120.0912 dBW
  Received power at receiver antenna (Ps): -107.1318 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 15.7539 dBW

Sample 9:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 6.2172 dB
  Total Path Loss (TPL): 114.2281 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -120.8548 dBW
  Received power at receiver antenna (Ps): -107.8955 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 14.9902 dBW

Sample 10:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 6.9748 dB
  Total Path Loss (TPL): 114.9856 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -121.6124 dBW
  Received power at receiver antenna (Ps): -108.653 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 14.2327 dBW

Sample 11:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 7.7254 dB
  Total Path Loss (TPL): 115.7362 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -122.363 dBW
  Received power at receiver antenna (Ps): -109.4037 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 13.482 dBW

Sample 12:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 8.4684 dB
```

```
  Total Path Loss (TPL): 116.4793 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -123.106 dBW
  Received power at receiver antenna (Ps): -110.1467 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 12.739 dBW

Sample 13:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 9.2031 dB
  Total Path Loss (TPL): 117.2139 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -123.8407 dBW
  Received power at receiver antenna (Ps): -110.8814 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 12.0043 dBW

Sample 14:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 9.9287 dB
  Total Path Loss (TPL): 117.9395 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -124.5663 dBW
  Received power at receiver antenna (Ps): -111.607 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 11.2788 dBW

Sample 15:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 10.6445 dB
  Total Path Loss (TPL): 118.6553 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -125.2821 dBW
  Received power at receiver antenna (Ps): -112.3227 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 10.563 dBW

Sample 16:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 11.3498 dB
  Total Path Loss (TPL): 119.3606 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -125.9873 dBW
  Received power at receiver antenna (Ps): -113.028 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 9.8577 dBW

Sample 17:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 12.0438 dB
  Total Path Loss (TPL): 120.0547 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -126.6814 dBW
  Received power at receiver antenna (Ps): -113.7221 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 9.1636 dBW

Sample 18:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 12.726 dB
  Total Path Loss (TPL): 120.7368 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -127.3636 dBW
  Received power at receiver antenna (Ps): -114.4043 dBW
```

```
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 8.4814 dBW

Sample 19:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 13.3957 dB
  Total Path Loss (TPL): 121.4065 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -128.0332 dBW
  Received power at receiver antenna (Ps): -115.0739 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 7.8118 dBW

Sample 20:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 14.0521 dB
  Total Path Loss (TPL): 122.0629 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -128.6897 dBW
  Received power at receiver antenna (Ps): -115.7303 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 7.1554 dBW

Sample 21:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 14.6946 dB
  Total Path Loss (TPL): 122.7054 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -129.3322 dBW
  Received power at receiver antenna (Ps): -116.3729 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 6.5128 dBW

Sample 22:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 15.3227 dB
  Total Path Loss (TPL): 123.3335 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -129.9602 dBW
  Received power at receiver antenna (Ps): -117.0009 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 5.8848 dBW

Sample 23:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 15.9356 dB
  Total Path Loss (TPL): 123.9464 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -130.5732 dBW
  Received power at receiver antenna (Ps): -117.6139 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 5.2719 dBW

Sample 24:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 16.5328 dB
  Total Path Loss (TPL): 124.5436 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -131.1704 dBW
  Received power at receiver antenna (Ps): -118.2111 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 4.6747 dBW

Sample 25:
```

```
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 17.1137 dB
  Total Path Loss (TPL): 125.1245 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -131.7513 dBW
  Received power at receiver antenna (Ps): -118.7919 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 4.0938 dBW

Sample 26:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 17.6777 dB
  Total Path Loss (TPL): 125.6885 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -132.3152 dBW
  Received power at receiver antenna (Ps): -119.3559 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 3.5298 dBW

Sample 27:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 18.2242 dB
  Total Path Loss (TPL): 126.235 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -132.8618 dBW
  Received power at receiver antenna (Ps): -119.9025 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 2.9832 dBW

Sample 28:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 18.7528 dB
  Total Path Loss (TPL): 126.7636 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -133.3903 dBW
  Received power at receiver antenna (Ps): -120.431 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 2.4547 dBW

Sample 29:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 19.2628 dB
  Total Path Loss (TPL): 127.2736 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -133.9004 dBW
  Received power at receiver antenna (Ps): -120.9411 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 1.9446 dBW

Sample 30:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 19.7539 dB
  Total Path Loss (TPL): 127.7647 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -134.3914 dBW
  Received power at receiver antenna (Ps): -121.4321 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 1.4536 dBW

Sample 31:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 20.2254 dB
  Total Path Loss (TPL): 128.2362 dB
  Transmit EIRP: -6.6268 dBW
```

```
  Received Isotropic Power: -134.863 dBW
  Received power at receiver antenna (Ps): -121.9037 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 0.98203 dBW

Sample 32:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 20.677 dB
  Total Path Loss (TPL): 128.6878 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -135.3146 dBW
  Received power at receiver antenna (Ps): -122.3553 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 0.53044 dBW

Sample 33:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 21.1082 dB
  Total Path Loss (TPL): 129.119 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -135.7458 dBW
  Received power at receiver antenna (Ps): -122.7865 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 0.099256 dBW

Sample 34:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 21.5186 dB
  Total Path Loss (TPL): 129.5294 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -136.1561 dBW
  Received power at receiver antenna (Ps): -123.1968 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -0.3111 dBW

Sample 35:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 21.9077 dB
  Total Path Loss (TPL): 129.9185 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -136.5452 dBW
  Received power at receiver antenna (Ps): -123.5859 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -0.70021 dBW

Sample 36:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 22.2752 dB
  Total Path Loss (TPL): 130.286 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -136.9127 dBW
  Received power at receiver antenna (Ps): -123.9534 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -1.0677 dBW

Sample 37:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 22.6207 dB
  Total Path Loss (TPL): 130.6315 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -137.2582 dBW
  Received power at receiver antenna (Ps): -124.2989 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -1.4132 dBW
```

```
Sample 38:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 22.9439 dB
  Total Path Loss (TPL): 130.9547 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -137.5814 dBW
  Received power at receiver antenna (Ps): -124.6221 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -1.7364 dBW

Sample 39:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 23.2444 dB
  Total Path Loss (TPL): 131.2552 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -137.882 dBW
  Received power at receiver antenna (Ps): -124.9227 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.037 dBW

Sample 40:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 23.522 dB
  Total Path Loss (TPL): 131.5328 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.1596 dBW
  Received power at receiver antenna (Ps): -125.2003 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.3146 dBW

Sample 41:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 23.7764 dB
  Total Path Loss (TPL): 131.7872 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.414 dBW
  Received power at receiver antenna (Ps): -125.4547 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.569 dBW

Sample 42:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.0073 dB
  Total Path Loss (TPL): 132.0182 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.6449 dBW
  Received power at receiver antenna (Ps): -125.6856 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.7999 dBW

Sample 43:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.2146 dB
  Total Path Loss (TPL): 132.2254 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.8522 dBW
  Received power at receiver antenna (Ps): -125.8928 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.0071 dBW

Sample 44:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.3979 dB
```

```
  Total Path Loss (TPL): 132.4087 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.0355 dBW
  Received power at receiver antenna (Ps): -126.0762 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.1905 dBW

Sample 45:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.5572 dB
  Total Path Loss (TPL): 132.568 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.1948 dBW
  Received power at receiver antenna (Ps): -126.2354 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.3497 dBW

Sample 46:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.6922 dB
  Total Path Loss (TPL): 132.703 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.3298 dBW
  Received power at receiver antenna (Ps): -126.3705 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.4848 dBW

Sample 47:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.8029 dB
  Total Path Loss (TPL): 132.8137 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.4404 dBW
  Received power at receiver antenna (Ps): -126.4811 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.5954 dBW

Sample 48:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.889 dB
  Total Path Loss (TPL): 132.8999 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.5266 dBW
  Received power at receiver antenna (Ps): -126.5673 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.6816 dBW

Sample 49:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.9507 dB
  Total Path Loss (TPL): 132.9615 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.5882 dBW
  Received power at receiver antenna (Ps): -126.6289 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.7432 dBW

Sample 50:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.9877 dB
  Total Path Loss (TPL): 132.9985 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.6252 dBW
  Received power at receiver antenna (Ps): -126.6659 dBW
```

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  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.7802 dBW

Sample 51:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 25 dB
  Total Path Loss (TPL): 133.0108 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.6376 dBW
  Received power at receiver antenna (Ps): -126.6783 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.7925 dBW

Sample 52:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.9877 dB
  Total Path Loss (TPL): 132.9985 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.6252 dBW
  Received power at receiver antenna (Ps): -126.6659 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.7802 dBW

Sample 53:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.9507 dB
  Total Path Loss (TPL): 132.9615 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.5882 dBW
  Received power at receiver antenna (Ps): -126.6289 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.7432 dBW

Sample 54:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.889 dB
  Total Path Loss (TPL): 132.8999 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.5266 dBW
  Received power at receiver antenna (Ps): -126.5673 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.6816 dBW

Sample 55:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.8029 dB
  Total Path Loss (TPL): 132.8137 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.4404 dBW
  Received power at receiver antenna (Ps): -126.4811 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.5954 dBW

Sample 56:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.6922 dB
  Total Path Loss (TPL): 132.703 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.3298 dBW
  Received power at receiver antenna (Ps): -126.3705 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.4848 dBW

Sample 57:
```

```
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.5572 dB
  Total Path Loss (TPL): 132.568 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.1948 dBW
  Received power at receiver antenna (Ps): -126.2354 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.3497 dBW

Sample 58:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.3979 dB
  Total Path Loss (TPL): 132.4087 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -139.0355 dBW
  Received power at receiver antenna (Ps): -126.0762 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.1905 dBW

Sample 59:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.2146 dB
  Total Path Loss (TPL): 132.2254 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.8522 dBW
  Received power at receiver antenna (Ps): -125.8928 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -3.0071 dBW

Sample 60:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 24.0073 dB
  Total Path Loss (TPL): 132.0182 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.6449 dBW
  Received power at receiver antenna (Ps): -125.6856 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.7999 dBW

Sample 61:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 23.7764 dB
  Total Path Loss (TPL): 131.7872 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.414 dBW
  Received power at receiver antenna (Ps): -125.4547 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.569 dBW

Sample 62:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 23.522 dB
  Total Path Loss (TPL): 131.5328 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -138.1596 dBW
  Received power at receiver antenna (Ps): -125.2003 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.3146 dBW

Sample 63:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 23.2444 dB
  Total Path Loss (TPL): 131.2552 dB
  Transmit EIRP: -6.6268 dBW
```

```
  Received Isotropic Power: -137.882 dBW
  Received power at receiver antenna (Ps): -124.9227 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -2.037 dBW

Sample 64:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 22.9439 dB
  Total Path Loss (TPL): 130.9547 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -137.5814 dBW
  Received power at receiver antenna (Ps): -124.6221 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -1.7364 dBW

Sample 65:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 22.6207 dB
  Total Path Loss (TPL): 130.6315 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -137.2582 dBW
  Received power at receiver antenna (Ps): -124.2989 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -1.4132 dBW

Sample 66:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 22.2752 dB
  Total Path Loss (TPL): 130.286 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -136.9127 dBW
  Received power at receiver antenna (Ps): -123.9534 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -1.0677 dBW

Sample 67:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 21.9077 dB
  Total Path Loss (TPL): 129.9185 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -136.5452 dBW
  Received power at receiver antenna (Ps): -123.5859 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -0.70021 dBW

Sample 68:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 21.5186 dB
  Total Path Loss (TPL): 129.5294 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -136.1561 dBW
  Received power at receiver antenna (Ps): -123.1968 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: -0.3111 dBW

Sample 69:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 21.1082 dB
  Total Path Loss (TPL): 129.119 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -135.7458 dBW
  Received power at receiver antenna (Ps): -122.7865 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 0.099256 dBW
```

```
Sample 70:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 20.677 dB
  Total Path Loss (TPL): 128.6878 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -135.3146 dBW
  Received power at receiver antenna (Ps): -122.3553 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 0.53044 dBW

Sample 71:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 20.2254 dB
  Total Path Loss (TPL): 128.2362 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -134.863 dBW
  Received power at receiver antenna (Ps): -121.9037 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 0.98203 dBW

Sample 72:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 19.7539 dB
  Total Path Loss (TPL): 127.7647 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -134.3914 dBW
  Received power at receiver antenna (Ps): -121.4321 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 1.4536 dBW

Sample 73:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 19.2628 dB
  Total Path Loss (TPL): 127.2736 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -133.9004 dBW
  Received power at receiver antenna (Ps): -120.9411 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 1.9446 dBW

Sample 74:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 18.7528 dB
  Total Path Loss (TPL): 126.7636 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -133.3903 dBW
  Received power at receiver antenna (Ps): -120.431 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 2.4547 dBW

Sample 75:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 18.2242 dB
  Total Path Loss (TPL): 126.235 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -132.8618 dBW
  Received power at receiver antenna (Ps): -119.9025 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 2.9832 dBW

Sample 76:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 17.6777 dB
```

```
  Total Path Loss (TPL): 125.6885 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -132.3152 dBW
  Received power at receiver antenna (Ps): -119.3559 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 3.5298 dBW

Sample 77:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 17.1137 dB
  Total Path Loss (TPL): 125.1245 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -131.7513 dBW
  Received power at receiver antenna (Ps): -118.7919 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 4.0938 dBW

Sample 78:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 16.5328 dB
  Total Path Loss (TPL): 124.5436 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -131.1704 dBW
  Received power at receiver antenna (Ps): -118.2111 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 4.6747 dBW

Sample 79:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 15.9356 dB
  Total Path Loss (TPL): 123.9464 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -130.5732 dBW
  Received power at receiver antenna (Ps): -117.6139 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 5.2719 dBW

Sample 80:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 15.3227 dB
  Total Path Loss (TPL): 123.3335 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -129.9602 dBW
  Received power at receiver antenna (Ps): -117.0009 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 5.8848 dBW

Sample 81:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 14.6946 dB
  Total Path Loss (TPL): 122.7054 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -129.3322 dBW
  Received power at receiver antenna (Ps): -116.3729 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 6.5128 dBW

Sample 82:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 14.0521 dB
  Total Path Loss (TPL): 122.0629 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -128.6897 dBW
  Received power at receiver antenna (Ps): -115.7303 dBW
```

```
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 7.1554 dBW

Sample 83:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 13.3957 dB
  Total Path Loss (TPL): 121.4065 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -128.0332 dBW
  Received power at receiver antenna (Ps): -115.0739 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 7.8118 dBW

Sample 84:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 12.726 dB
  Total Path Loss (TPL): 120.7368 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -127.3636 dBW
  Received power at receiver antenna (Ps): -114.4043 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 8.4814 dBW

Sample 85:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 12.0438 dB
  Total Path Loss (TPL): 120.0547 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -126.6814 dBW
  Received power at receiver antenna (Ps): -113.7221 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 9.1636 dBW

Sample 86:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 11.3498 dB
  Total Path Loss (TPL): 119.3606 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -125.9873 dBW
  Received power at receiver antenna (Ps): -113.028 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 9.8577 dBW

Sample 87:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 10.6445 dB
  Total Path Loss (TPL): 118.6553 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -125.2821 dBW
  Received power at receiver antenna (Ps): -112.3227 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 10.563 dBW

Sample 88:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 9.9287 dB
  Total Path Loss (TPL): 117.9395 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -124.5663 dBW
  Received power at receiver antenna (Ps): -111.607 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 11.2788 dBW

Sample 89:
```

```
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 9.2031 dB
  Total Path Loss (TPL): 117.2139 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -123.8407 dBW
  Received power at receiver antenna (Ps): -110.8814 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 12.0043 dBW

Sample 90:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 8.4684 dB
  Total Path Loss (TPL): 116.4793 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -123.106 dBW
  Received power at receiver antenna (Ps): -110.1467 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 12.739 dBW

Sample 91:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 7.7254 dB
  Total Path Loss (TPL): 115.7362 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -122.363 dBW
  Received power at receiver antenna (Ps): -109.4037 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 13.482 dBW

Sample 92:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 6.9748 dB
  Total Path Loss (TPL): 114.9856 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -121.6124 dBW
  Received power at receiver antenna (Ps): -108.653 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 14.2327 dBW

Sample 93:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 6.2172 dB
  Total Path Loss (TPL): 114.2281 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -120.8548 dBW
  Received power at receiver antenna (Ps): -107.8955 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 14.9902 dBW

Sample 94:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 5.4536 dB
  Total Path Loss (TPL): 113.4644 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -120.0912 dBW
  Received power at receiver antenna (Ps): -107.1318 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 15.7539 dBW

Sample 95:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 4.6845 dB
  Total Path Loss (TPL): 112.6953 dB
  Transmit EIRP: -6.6268 dBW
```

```
  Received Isotropic Power: -119.3221 dBW
  Received power at receiver antenna (Ps): -106.3628 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 16.5229 dBW

Sample 96:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 3.9109 dB
  Total Path Loss (TPL): 111.9217 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -118.5484 dBW
  Received power at receiver antenna (Ps): -105.5891 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 17.2966 dBW

Sample 97:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 3.1333 dB
  Total Path Loss (TPL): 111.1441 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -117.7709 dBW
  Received power at receiver antenna (Ps): -104.8116 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 18.0741 dBW

Sample 98:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 2.3527 dB
  Total Path Loss (TPL): 110.3635 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -116.9903 dBW
  Received power at receiver antenna (Ps): -104.031 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 18.8547 dBW

Sample 99:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 1.5698 dB
  Total Path Loss (TPL): 109.5806 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -116.2073 dBW
  Received power at receiver antenna (Ps): -103.248 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 19.6377 dBW

Sample 100:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): 0.78527 dB
  Total Path Loss (TPL): 108.7961 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -115.4228 dBW
  Received power at receiver antenna (Ps): -102.4635 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 20.4222 dBW

Sample 101:
  Free Space Path Loss (FSPL): 108.0108 dB
  Additional Loss (Lf): -8.0406e-15 dB
  Total Path Loss (TPL): 108.0108 dB
  Transmit EIRP: -6.6268 dBW
  Received Isotropic Power: -114.6376 dBW
  Received power at receiver antenna (Ps): -101.6783 dBW
  Received Noise power: -122.8857 dBW
  SNR = P_S/P_N: 21.2075 dBW
```

```
% (c)

%To simplify our variable names we have renamed the file as modcod and the
%table columns as SNR and etab.

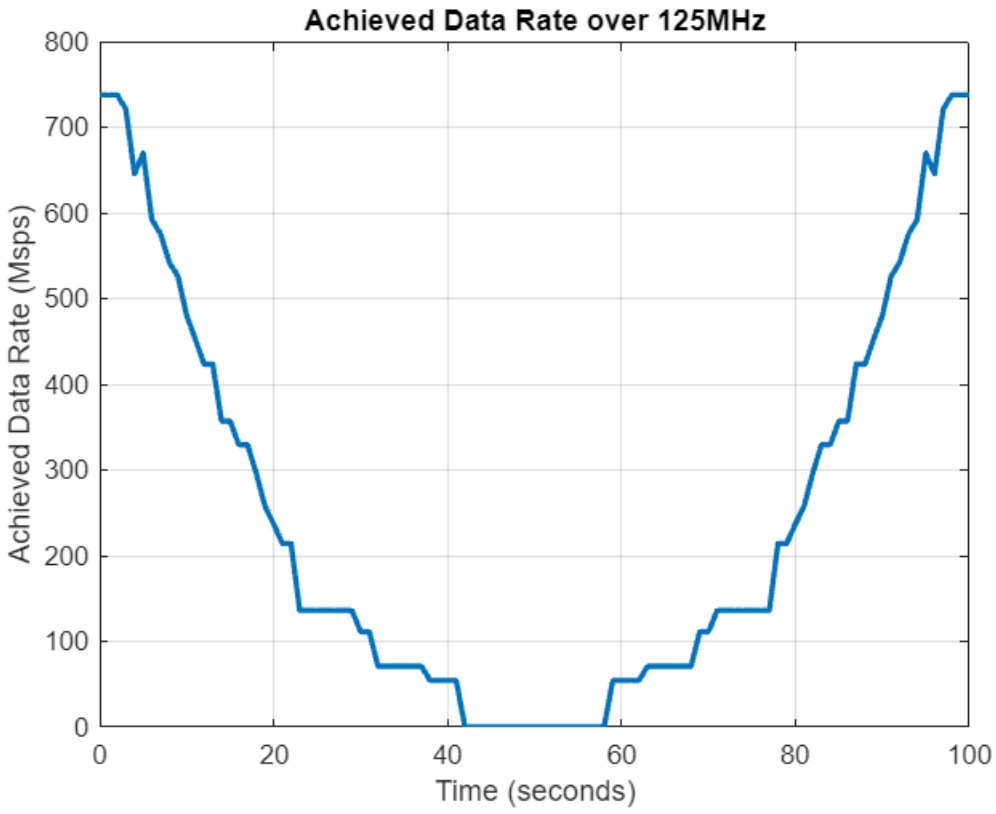
modcod = readtable('modcod.xlsx', 'VariableNamingRule', 'preserve');
etab = zeros(size(t));
achievedDataRate = zeros(size(t));

bandwidth = 125e6;
for i = 1:length(t)
    [~, idx] = max(modcod.SNR(modcod.SNR <= snr_array(i)));
    etab(i) = modcod.etab(idx);
    achievedDataRate(i) = etab(i) * bandwidth;
end
```

```
% (d)

% Convert achieved data rate to Mbps
achievedDataRateMbps = achievedDataRate / 1e6;

plot(t, achievedDataRateMbps,'LineWidth',2);
xlabel('Time (seconds)');
ylabel('Achieved Data Rate (Msps)');
title('Achieved Data Rate over 125MHz');
grid("on");
```




```
disp(" ");
```

```
% Question 5
% MIMO CONCEPT

%1)
% Specify the number of receive antennas (N_R) and transmit antennas (N_T)
NR = 8;  % Number of receive antennas
NT = 16;  % Number of transmit antennas

% Generate a random complex-valued matrix with dimensions (N_R, N_T)
real_part = randn(NR, NT);
imag_part = randn(NR, NT);
H = real_part + 1i * imag_part;  % Complex matrix
H=H/sqrt(2);

% Display the generated MIMO channel matrix
disp('MIMO Channel Matrix H:');
```

```
MIMO Channel Matrix H:
```

```
disp(H);
```

```
   0.7655 + 0.4944i  -0.0388 - 0.2050i  -0.4607 + 0.5788i  -0.0501 - 0.0451i   0.4787 - 0.1840i  -0.0933 - 0.2311i
   0.7114 + 0.1907i   0.6443 + 0.8921i   0.8429 - 0.2069i  -1.7581 + 0.4323i   0.6065 + 0.4244i  -0.1041 + 0.5744i
  -0.4603 + 0.3495i   0.4204 + 0.3362i  -1.1397 - 0.3824i   0.4110 + 0.0773i  -0.4887 + 0.4200i   0.7126 + 0.3858i
   0.1818 - 1.0487i   0.2476 + 0.8302i  -0.0173 - 0.2182i  -1.5503 + 1.2827i   0.3178 - 1.5458i  -1.5017 - 0.7436i
  -0.6678 - 0.7214i   0.8841 + 0.0898i  -1.3780 - 0.7754i  -1.6400 + 0.2206i   0.0712 - 0.9384i  -0.3568 + 0.2811i
  -0.9346 - 0.3161i   0.6575 - 0.4644i   0.7216 - 0.3486i   0.0565 + 1.2760i   0.5841 - 1.0190i  -0.8984 - 0.5317i
   0.6540 + 0.0775i   0.1695 - 1.0475i   0.6093 - 0.1278i  -0.6707 - 0.5113i   0.3791 + 0.2841i  -0.2705 + 1.0722i
   0.0000 + 0.7981i  -0.4882 + 0.1099i   0.0008 + 0.0324i   0.2910 + 0.3723i   0.6349 + 1.0396i   0.4587 - 0.0230i
```

```
%2)
% Using M-PSK method to generate symbols
%Add a file which contains the function pskModulator for generating a set
%of M-ary Phase Shift Keying Modulation Scheme.

symbols_PSK=pskModulator(16,1);
```

```
%3)
% N_R generated randomly from M symbols
all_indices = 1:length(symbols_PSK);
selected_indices = all_indices(randperm(length(all_indices), NR));
selected_symbols = symbols_PSK(selected_indices);

% N_T*1 Matrix
x = zeros(NT, 1);
x(1:NR) = selected_symbols;
```

```
%4)
% Received signal vector
y = H * x;

%5)
%The elements of y do not match with the elements of x before peforming
%operation with MIMO channel matrix.
disp('Before performing smart MIMO scheme')
```

```
Before performing smart MIMO scheme
```

```
disp('Transmitted Symbol Vector x:');
```

```
Transmitted Symbol Vector x:
```

```
disp(x.');
```

```
  -0.7071 + 0.7071i  -0.9239 - 0.3827i  -0.3827 + 0.9239i   0.7071 + 0.7071i  -0.3827 - 0.9239i   0.3827 - 0.9239i
```

```
disp('Received Signal Vector y:');
```

```
Received Signal Vector y:
```

```
disp(y.');
```

```
  -0.5229 + 0.3393i  -2.1959 - 2.9969i   1.5385 - 0.5987i  -3.1053 + 0.7981i  -1.5388 - 3.9138i  -2.0506 + 1.0852i
```

```
% 6)
% Performing SVD and obtaining matrices on left U and right V singular
% vectors and a diagonal matrix of the singular values S.
%Performing a Smary MIMO Scheme
[U, S, V] = svd(H);

%Verifying that U and V matrices are unitary
tolerance = 1e-10;  % Set a small tolerance value
is_U_unitary = norm(U' * U - eye(NR)) < tolerance;
is_V_unitary = norm(V' * V - eye(NT)) < tolerance;

% Collecting these non-zero elements in S
nonzero_elements_S = diag(S);
num_nonzero_elements_S = sum(nonzero_elements_S ~= 0); % equal to NR
```

```
%7)
% Display the results and verifying whether U and V are unitary and
% Non-zero elements in S equals NR
disp('SVD Results:');
```

```
SVD Results:
```

```
disp(['U is unitary: ', num2str(is_U_unitary)]);
```

```
U is unitary: 1
```

```
disp(['V is unitary: ', num2str(is_V_unitary)]);
```

```
V is unitary: 1
```

```
disp(['Number of nonzero elements in S: ', num2str(num_nonzero_elements_S)]);
```

```
Number of nonzero elements in S: 8
```

```
disp('Nonzero elements of S:');
```

```
Nonzero elements of S:
```

```
disp(nonzero_elements_S.');
```

```
    5.8991    5.7249    4.2700    3.4637    3.0313    2.4774    2.1908    1.3276
```

```
%(a)
x_prime= V*x;

%(b)
y_prime=H*x_prime;

%(c)
U_herm=U';
y=U_herm* y_prime;
```

```
%(d)
% Element by element division
y_S=y./nonzero_elements_S;

%(e)
% Display the results
disp('Transmitted Vector x:');
```

```
Transmitted Vector x:
```

```
disp(x.');
```

```
  -0.7071 + 0.7071i  -0.9239 - 0.3827i  -0.3827 + 0.9239i   0.7071 + 0.7071i  -0.3827 - 0.9239i   0.3827 - 0.9239i
```

```
disp('Transmitted Vector x'' (after MIMO):');
```

```
Transmitted Vector x' (after MIMO):
```

```
disp(x_prime.');
```

```
   0.2672 - 0.0340i   0.1819 + 0.2649i   0.0593 + 0.4289i  -0.4736 - 0.3641i   1.1709 - 0.5082i   0.8539 - 0.1097i
```

```
disp('Received Vector y'' (after MIMO):');
```

```
Received Vector y' (after MIMO):
```

```
disp(y_prime.');
```

```
   3.4818 - 2.0644i   1.9058 + 3.1088i   4.4510 + 3.0100i  -0.4823 - 4.0465i  -1.6276 - 0.8347i  -0.1388 - 4.7917i
```

```
disp('Received Vector y (after receive side "beamforming"):');
```

```
Received Vector y (after receive side "beamforming"):
```

```
disp(y.');
```

```
  -4.1713 + 4.1713i  -5.2891 - 2.1908i  -1.6341 + 3.9450i   2.4492 + 2.4492i  -1.1600 - 2.8005i   0.9481 - 2.2888i
```

```
disp('Element-by-element Division Result y_s:');
```

```
Element-by-element Division Result y_s:
```

```
disp(y_S.');
```

```
  -0.7071 + 0.7071i  -0.9239 - 0.3827i  -0.3827 + 0.9239i   0.7071 + 0.7071i  -0.3827 - 0.9239i   0.3827 - 0.9239i
```

```
disp('We can see that y_S and x are identical from the output which is desired
as interference introduced by the MIMO channel has been entirely removed thereby
increasing the channel capacity by factor or N_R.');
```

```
We can see that y_S and x are identical from the output which is desired as interference introduced by the MIMO chan
```

CT216
20220426
Lab - 2

Q1

$$\frac{E_b}{N_0} \geq \frac{2^{\eta_B} - 1}{\eta_B}$$

$\eta_B \to 0$ ($\frac{0}{0}$ indeterminate form)

$$\lim_{\eta_B \to 0} \frac{2^{\eta_B} - 1}{\eta_B}$$

Applying L'Hospital Rule

$$\left[\frac{2^{\eta_B} \ln 2}{1}\right]_{\eta_B = 0} \Rightarrow \boxed{\ln 2}$$

∴ Min. possible $\frac{E_b}{N_0}$ in dB → $10 \log_{10}(\ln 2)$

$\Rightarrow -1.59$ dB

Q.2

$$\frac{E_b}{N_0} \geq \frac{2^{\eta_B} - 1}{\eta_B}$$

Multiplying η_B both sides ⇒

$$\eta_B \frac{E_b}{N_0} \geq 2^{\eta_B} - 1$$

$$\frac{E_s}{N_0} \geq 2^{\eta_B} - 1$$

$$\lim_{\eta_B \to 0} (2^{\eta_B} - 1) = 0$$

in dB

$10 \log_{10}(0)$ = undefined

The minimum value of $\frac{E_s}{N_0}$ is not specifically defined as meaningful when $\frac{E_s}{N_0} \to 0$

Teacher's Signature:

Q3 Instead of multiplicative channel in SISO if LTI channel is used.

$y(t) = h_t * x(t) + n(t)$

(* : convolution)

As mentioned that the receiver observes multiple echoes of $x(t)$ with delay k-th echo to be τ_k.

Therefore equation can be written as :-

$$y(t) = \sum_{<k>} h_k x(t - \tau_k) + n(t) \qquad 1 \le k \le K$$

Q.4.

$y = h * x + n$

By property of convolution;

$h * x = x * h$

$x * h = x(h(t - \tau))$

Here → Discrete time domain : Therefore :-

$$y(n) = \sum_{\tau=0}^{\tau=\infty} x(\tau) h(N - \tau) + n$$

~~$y(n) = x_0 h(N) + x_1 h(N-1) + x_2 h(N-2) + \dots + x_N h(0) + n$~~

→ Now we can break y at any instant say n_0.

$$y(n_0) = \underbrace{\sum x(\tau) h(n_0 - \tau)}_{\text{(i)}} + n$$

Teacher's Signature:.....

→ We can see (i) as matrix multiplication.

$x = \begin{bmatrix} x(\tau_1) \\ x(\tau_2) \\ \vdots \\ x(\tau) \end{bmatrix}$ | h can be broken and written as $H = \begin{bmatrix} - & -h(n_1-\tau_0) & - \\ - & h(n_2-\tau_0) & - \\ & \vdots & \\ - & \cdots & - \end{bmatrix}$

as $x[\tau_1]$ get multiplied with $h(n_1-\tau_1)$, $h_2(n_2-\tau_1)$

Hence to represent it has a matrix multiplicat^n

$$H: \begin{bmatrix} h(n_1-\tau_1) & h(n_1-\tau_2) & - & - \\ h(n_2-\tau_1) & h(n_2-\tau_2) & - & - \\ \vdots & & & \end{bmatrix} \quad -(a)$$

Hence $H \cdot x$ would give us the desired convolution output.

(b) For H matrix as given in (a) we can further break it down by taking into consideration appropriate values.

Let us say $y(0) = \sum_{\tau} x(0)\, h(0-\tau_1) + n$

τ varies from (let us say) 0 to N-1

$\therefore y(0) = x(0)h(0) + x(0)h(-1) \cdots$

But $h(-1)$ to $h(-N+1)$ all have negative i/p which is not in real scenario true as we are talking abt communication so $h(-1) \cdots h(-N+1)$ would be

Teacher's Signature:

eventually 0

So, H can be reduced to =

$$H = \begin{bmatrix} h(0) & 0 & 0 & \cdots & 0 \\ h(1) & h(0) & 0 & & 0 \\ \vdots & h(1) & h(0) & & 0 \\ & \vdots & \vdots & & 0 \\ h(N-1) & h(N-2) & h(N-3) & \cdots & h[0] \end{bmatrix}$$

→ So SISO LSI channel represent the MIMO channel equation as discussed in the class which also satisfies "convolut^n as well.

Using concepts of linear Algebra H can be represented as:

$H = S \Lambda S^{-1}$ (Diagonalizat^n concept) where Λ is a diagonal matrix & S is the matrix of eigenvectors (diagonal)

Λ actually represents eigenvalue matrix

This is similar to what we studied in class that H can be represented as $U \Sigma V^H$ where $\Sigma = \text{diag}(\lambda_1, \lambda_2, \ldots)$ is a diag. matrix of singular value (i.e. eigenvalues)

And U & V are singular vectors (i.e. eigenvector matrix)

→ As it was noted by S.R in the class, if we have consider H (square matrix) when full rank i.e. full set of linearly independent eigenvectors SVD & EVD are of MIMO of H

Teacher's Signature:

related as U-V & Σ-λ.

→ We know that eigenvalues of matrix represent the scaling factor for a linear transformation. Which corresponds to our understanding of Σ too as singular value denoting the factor/magnitude of transform

Teacher's Signature

```
%{
for question 4 part (b) it is also important to note that EVD is possible
when H is a square matrix.

Also it is analytically difficult to obtain the eigen values and eigen
vectors for H but can be done computationally in MATLAB if provided with
proper values.

Furthermore eigen vectors here in this case may represent the directions in
which communication is done.


%}
```