Wireless Communication Systems Final Project – Angular-domain ULA Radiation/Reception

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1. Problem description

Ref. Chap 7, Fundamentals of Wireless Communication 2005.

Chap 2, Wireless Communication Systems lecture handouts

- *According to the angular domain model, evaluate the Radiation and Reception patterns of uniform linear arrays (ULA)*
- *Input parameters:*
  - *The number of antennas N*
  - *The normalized antenna separation Δ (normalized to wavelength λ_c)*
  - *SIMO (reception) or MISO (radiation)*
  - *The radiation or reception directions of the desired signals*
  - *The radiation or reception direction of the interference signal*
- *Output results:*
  - *The angular domain radiation/reception basis*
  - *The correlation between different basis vectors*
  - *The gain pattern of the ULA*
  - *The gain of desired signal for different radiation/reception beams*
  - *The signal to interference power ratio (SINR) for different beams*
  - *The SINR of multiple input signals (multiple reception directions) with diversity combining (consider fading for signals and interference)*
  - *(Any results that can present your work better)*

2. Simulation results

The number of antenna N = 16, The normalized antenna separation Δ = 0.5

Case 1 = SIMO with combining, The number of multipaths = 4

The multipaths directions = 20°, 25.714°, 90°, 45°, The interference directions = 36°

(direction 都是 randi()隨機產生)

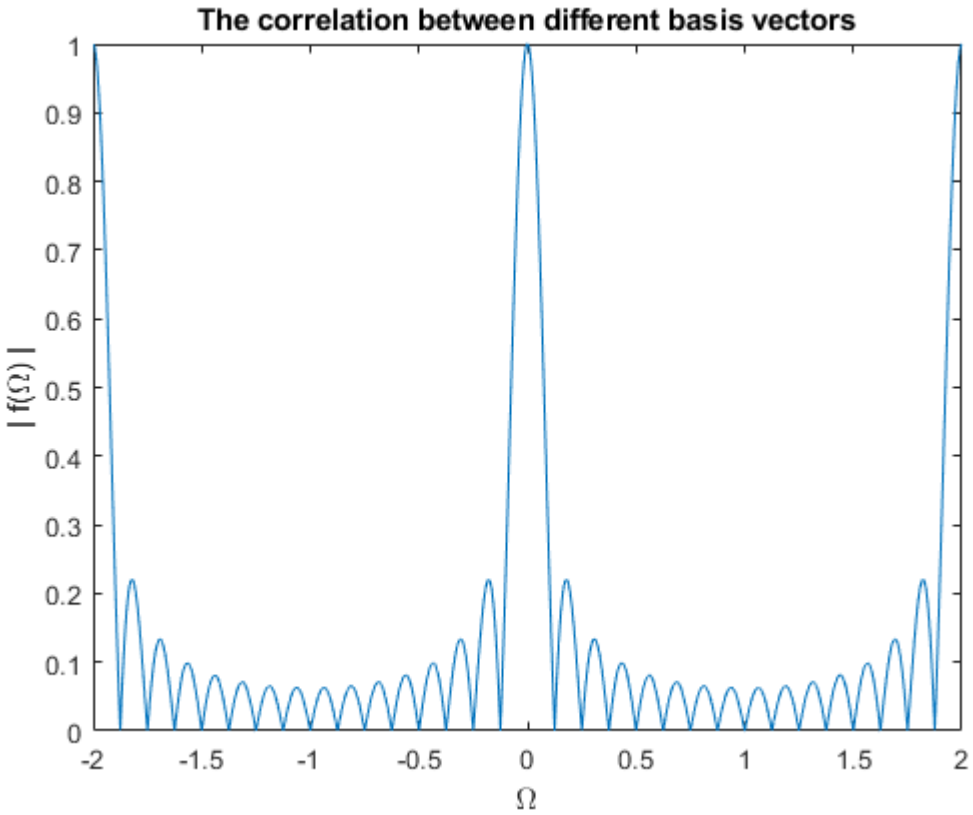
(1) The angular-domain radiation/reception basis:

```
-----------------Input-----------------
N = 16
delta = 0.500000
case 1. SIMO with combining
number of reception directions of desired signal = 4
reception direction of desired signal(in degree) = 20.000000 25.714286 90.000000 45.000000
reception direction of interference signal(in degree) = 36.000000
L = 8
-----------------Output-----------------
First part
  Columns 1 through 6

   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i
   0.2500 + 0.0000i   0.2310 - 0.0957i   0.1768 - 0.1768i   0.0957 - 0.2310i   0.0000 - 0.2500i  -0.0957 - 0.2310i
   0.2500 + 0.0000i   0.1768 - 0.1768i   0.0000 - 0.2500i  -0.1768 - 0.1768i  -0.2500 - 0.0000i  -0.1768 + 0.1768i
   0.2500 + 0.0000i   0.0957 - 0.2310i  -0.1768 - 0.1768i  -0.2310 + 0.0957i  -0.0000 + 0.2500i   0.2310 + 0.0957i
   0.2500 + 0.0000i   0.0000 - 0.2500i  -0.2500 - 0.0000i  -0.0000 + 0.2500i   0.2500 + 0.0000i   0.0000 - 0.2500i
   0.2500 + 0.0000i  -0.0957 - 0.2310i  -0.1768 + 0.1768i   0.2310 + 0.0957i   0.0000 - 0.2500i  -0.2310 + 0.0957i
   0.2500 + 0.0000i  -0.1768 - 0.1768i  -0.0000 + 0.2500i   0.1768 - 0.1768i  -0.2500 - 0.0000i   0.1768 + 0.1768i
   0.2500 + 0.0000i  -0.2310 - 0.0957i   0.1768 + 0.1768i  -0.0957 - 0.2310i  -0.0000 + 0.2500i   0.0957 - 0.2310i
   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i
   0.2500 + 0.0000i  -0.2310 + 0.0957i   0.1768 - 0.1768i  -0.0957 + 0.2310i   0.0000 - 0.2500i   0.0957 + 0.2310i
   0.2500 + 0.0000i  -0.1768 + 0.1768i   0.0000 - 0.2500i   0.1768 + 0.1768i  -0.2500 - 0.0000i   0.1768 - 0.1768i
   0.2500 + 0.0000i  -0.0957 + 0.2310i  -0.1768 - 0.1768i   0.2310 - 0.0957i  -0.0000 + 0.2500i  -0.2310 - 0.0957i
   0.2500 + 0.0000i  -0.0000 + 0.2500i  -0.2500 - 0.0000i   0.0000 - 0.2500i   0.2500 + 0.0000i  -0.0000 + 0.2500i
   0.2500 + 0.0000i   0.0957 + 0.2310i  -0.1768 + 0.1768i  -0.2310 - 0.0957i  -0.0000 - 0.2500i   0.2310 - 0.0957i
   0.2500 + 0.0000i   0.1768 + 0.1768i  -0.0000 + 0.2500i  -0.1768 + 0.1768i  -0.2500 - 0.0000i  -0.1768 - 0.1768i
   0.2500 + 0.0000i   0.2310 + 0.0957i   0.1768 + 0.1768i   0.0957 + 0.2310i  -0.0000 + 0.2500i  -0.0957 + 0.2310i

  Columns 7 through 12

   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i
  -0.1768 - 0.1768i  -0.2310 - 0.0957i  -0.2500 - 0.0000i  -0.2310 + 0.0957i  -0.1768 + 0.1768i  -0.0957 + 0.2310i
  -0.0000 + 0.2500i   0.1768 + 0.1768i   0.2500 + 0.0000i   0.1768 - 0.1768i   0.0000 - 0.2500i  -0.1768 - 0.1768i
   0.1768 - 0.1768i  -0.0957 - 0.2310i  -0.2500 - 0.0000i  -0.0957 + 0.2310i   0.1768 + 0.1768i   0.2310 - 0.0957i
  -0.2500 - 0.0000i  -0.0000 + 0.2500i   0.2500 + 0.0000i   0.0000 - 0.2500i  -0.2500 - 0.0000i  -0.0000 + 0.2500i
   0.1768 + 0.1768i   0.0957 - 0.2310i  -0.2500 - 0.0000i   0.0957 + 0.2310i   0.1768 - 0.1768i  -0.2310 - 0.0957i
   0.0000 - 0.2500i  -0.1768 + 0.1768i   0.2500 + 0.0000i  -0.1768 - 0.1768i  -0.0000 + 0.2500i   0.1768 - 0.1768i
  -0.1768 + 0.1768i   0.2310 - 0.0957i  -0.2500 - 0.0000i   0.2310 + 0.0957i  -0.1768 - 0.1768i   0.0957 + 0.2310i
   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i
  -0.1768 - 0.1768i   0.2310 + 0.0957i  -0.2500 - 0.0000i   0.2310 - 0.0957i  -0.1768 + 0.1768i   0.0957 - 0.2310i
  -0.0000 + 0.2500i  -0.1768 - 0.1768i   0.2500 + 0.0000i  -0.1768 + 0.1768i  -0.0000 - 0.2500i   0.1768 + 0.1768i
   0.1768 - 0.1768i   0.0957 + 0.2310i  -0.2500 - 0.0000i   0.0957 - 0.2310i   0.1768 + 0.1768i  -0.2310 + 0.0957i
  -0.2500 - 0.0000i  -0.0000 - 0.2500i   0.2500 + 0.0000i  -0.0000 + 0.2500i  -0.2500 - 0.0000i   0.0000 - 0.2500i
   0.1768 + 0.1768i  -0.0957 + 0.2310i  -0.2500 + 0.0000i  -0.0957 - 0.2310i   0.1768 - 0.1768i   0.2310 + 0.0957i
  -0.0000 - 0.2500i   0.1768 - 0.1768i   0.2500 + 0.0000i   0.1768 + 0.1768i  -0.0000 + 0.2500i  -0.1768 + 0.1768i
  -0.1768 + 0.1768i  -0.2310 + 0.0957i  -0.2500 - 0.0000i  -0.2310 - 0.0957i  -0.1768 - 0.1768i  -0.0957 - 0.2310i
```

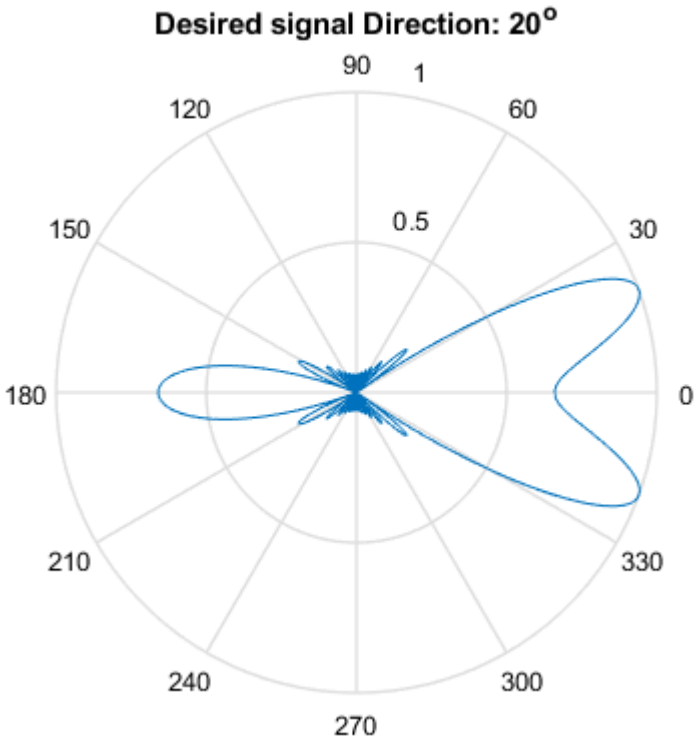
```
Columns 13 through 16

 0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i
-0.0000 + 0.2500i   0.0957 + 0.2310i   0.1768 + 0.1768i   0.2310 + 0.0957i
-0.2500 - 0.0000i  -0.1768 + 0.1768i  -0.0000 + 0.2500i   0.1768 + 0.1768i
 0.0000 - 0.2500i  -0.2310 - 0.0957i  -0.1768 + 0.1768i   0.0957 + 0.2310i
 0.2500 + 0.0000i  -0.0000 - 0.2500i  -0.2500 - 0.0000i  -0.0000 + 0.2500i
-0.0000 + 0.2500i   0.2310 - 0.0957i  -0.1768 - 0.1768i  -0.0957 + 0.2310i
-0.2500 - 0.0000i   0.1768 + 0.1768i  -0.0000 - 0.2500i  -0.1768 + 0.1768i
-0.0000 - 0.2500i  -0.0957 + 0.2310i   0.1768 - 0.1768i  -0.2310 + 0.0957i
 0.2500 + 0.0000i  -0.2500 + 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i
-0.0000 + 0.2500i  -0.0957 - 0.2310i   0.1768 + 0.1768i  -0.2310 - 0.0957i
-0.2500 - 0.0000i   0.1768 - 0.1768i  -0.0000 + 0.2500i  -0.1768 - 0.1768i
 0.0000 - 0.2500i   0.2310 + 0.0957i  -0.1768 + 0.1768i  -0.0957 - 0.2310i
 0.2500 + 0.0000i  -0.0000 + 0.2500i  -0.2500 + 0.0000i   0.0000 - 0.2500i
 0.0000 + 0.2500i  -0.2310 + 0.0957i  -0.1768 - 0.1768i   0.0957 - 0.2310i
-0.2500 + 0.0000i  -0.1768 - 0.1768i   0.0000 - 0.2500i   0.1768 - 0.1768i
 0.0000 - 0.2500i   0.0957 - 0.2310i   0.1768 - 0.1768i   0.2310 - 0.0957i
```

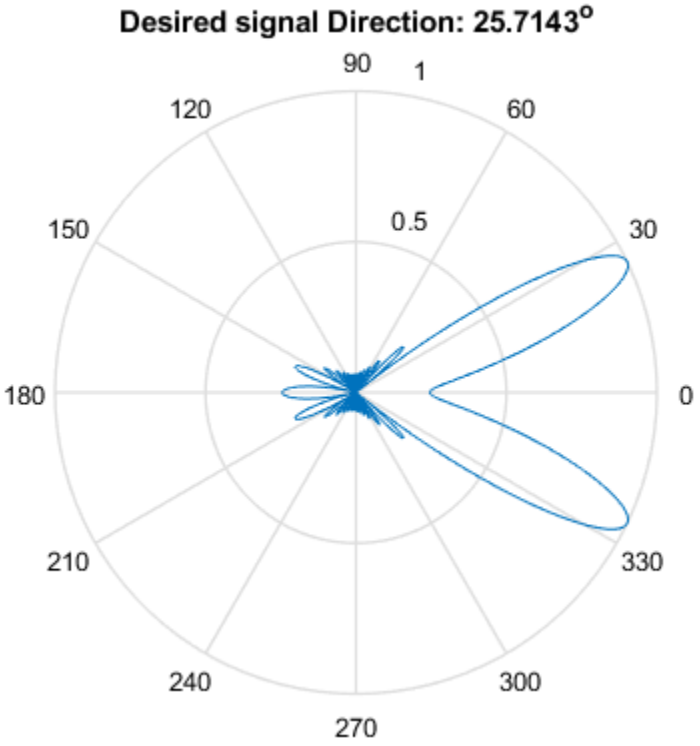
```
----------------------------------------
Secnod part
     Plot in figure 1
----------------------------------------
Third part
     Plot in figure 2
----------------------------------------
Forth part
     Plot in figure 3
----------------------------------------
Fifth part
     Plot in figure 4
----------------------------------------
Sixth part
     SINR with MRC = 60.3696
     SINR with EGC = 53.0815
     SINR with SC  = 29.0511
```

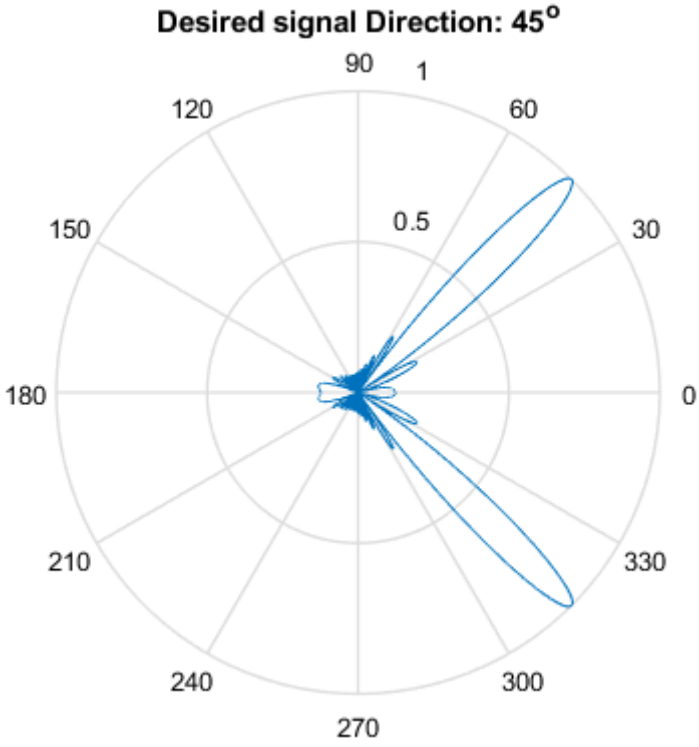
(2) The correlation between different basis vectors

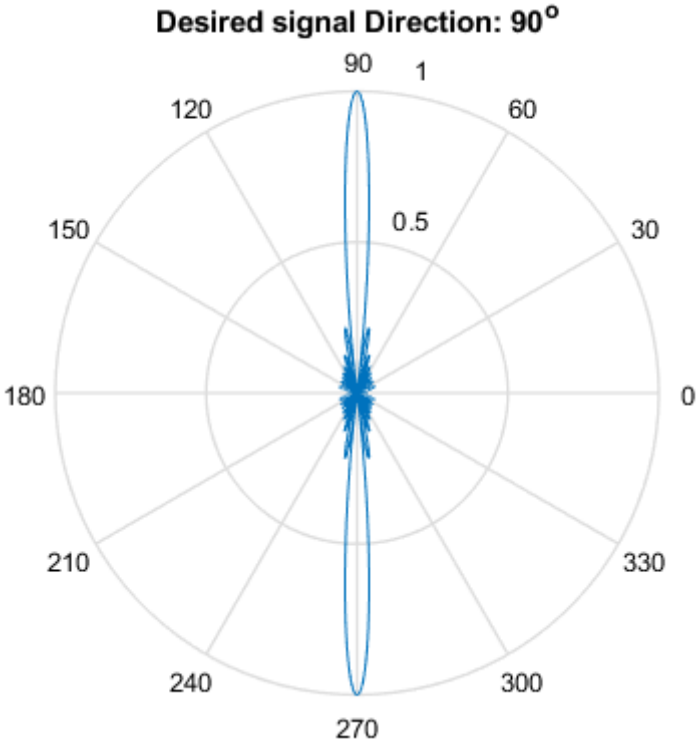


(3) The power gain pattern of the ULA

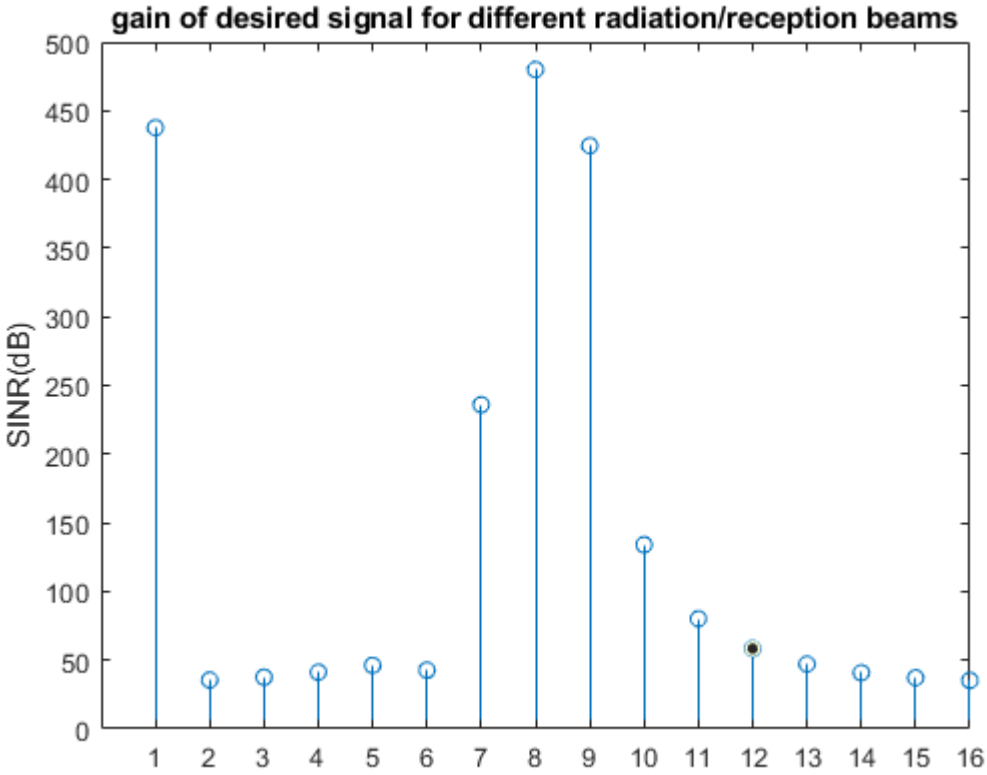




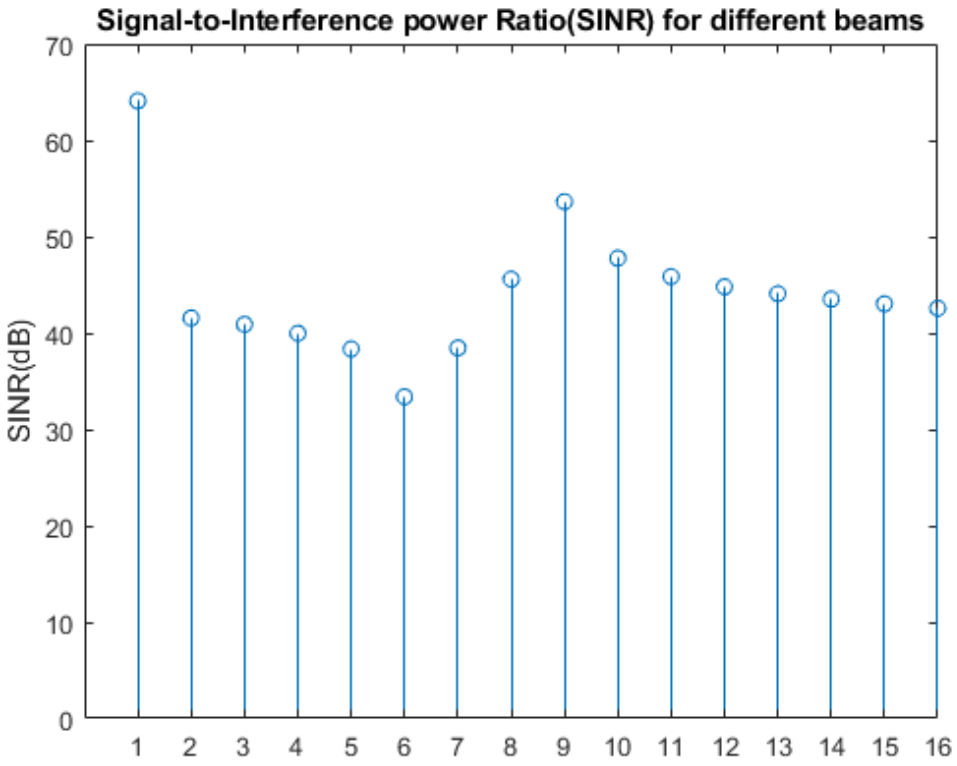




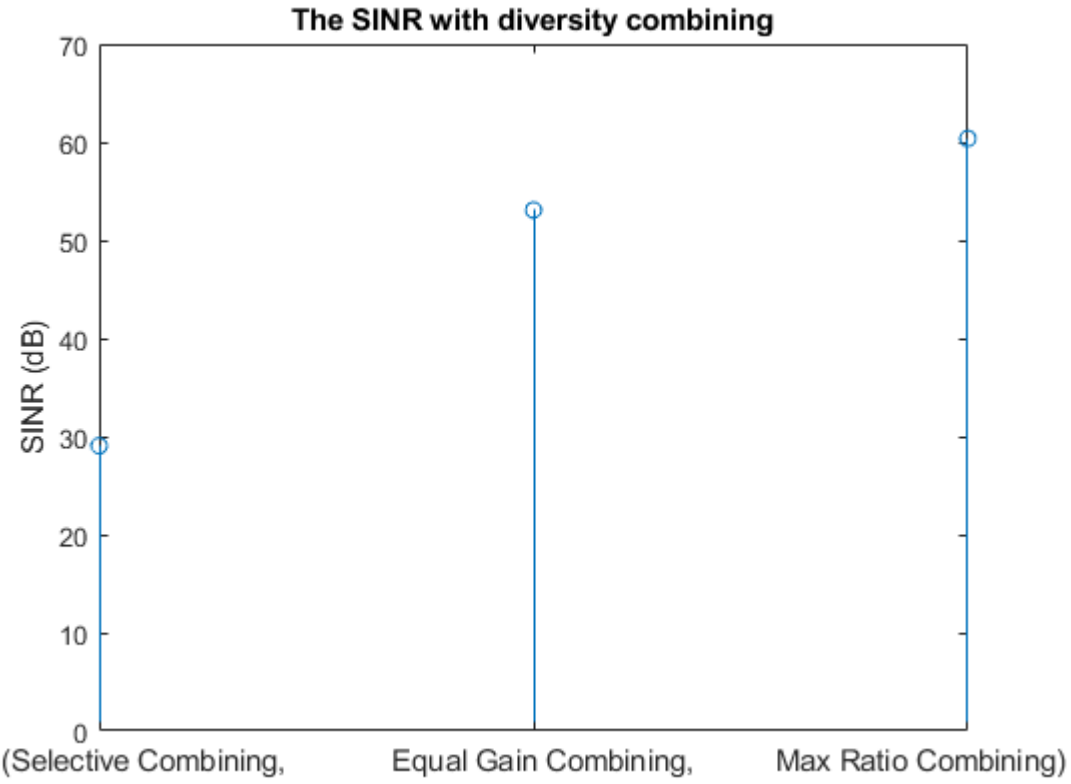
(4) The power gain of the desired signal for using different radiation beams



(5) The signal-to-interference power ratio (SIR) for using different beams



(6) The SIR of multiple input signals (multiple reception directions) with diversity combining (considering fading for the signals and interferences)



SC 的 SINR = 29.0511, EGC 的 SINR = 53.0815, MRC 的 SINR = 60.3696 (dB)

The number of antenna N = 16, The normalized antenna separation Δ = 0.5

Case 2 = MISO without combining, The number of multipaths = 4

The multipaths directions = 30°, 18°, 36°, 18°, The interference directions = 45°

(direction 都是 randi()隨機產生)

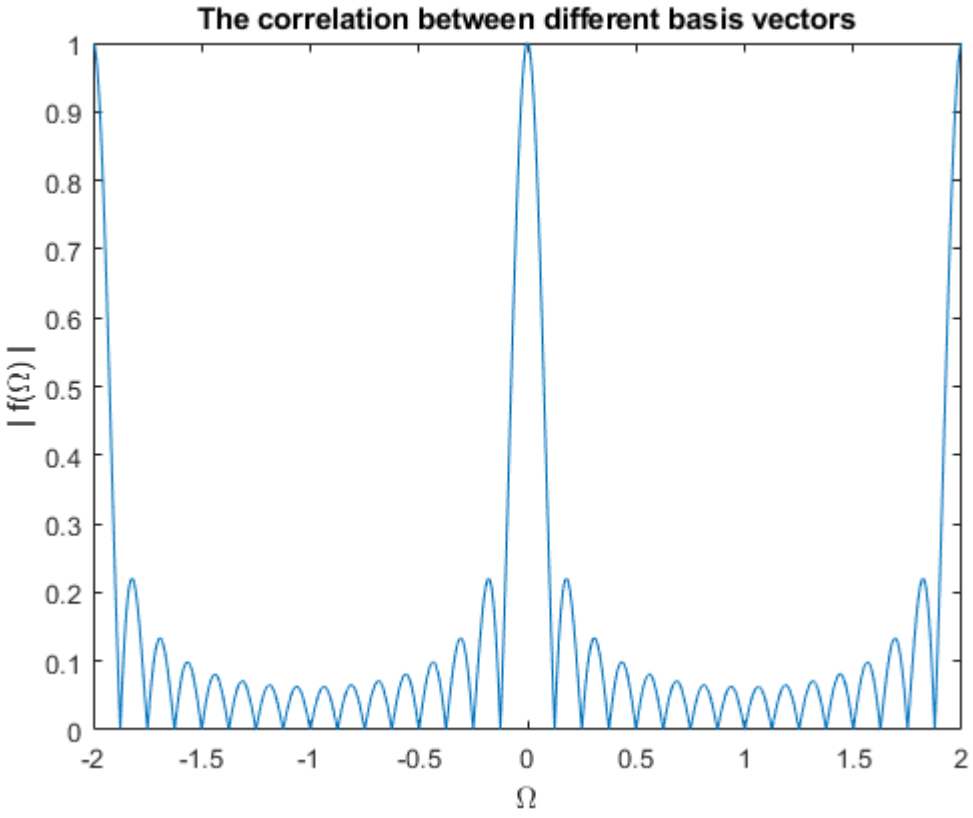
```
-----------------Input-----------------
N = 16
delta = 0.500000
case 2. MISO without combining
number of reception directions of desired signal = 4
reception direction of desired signal(in degree) = 30.000000 18.000000 36.000000 18.000000
reception direction of interference signal(in degree) = 45.000000
L = 8
```

(1) The angular-domain radiation/reception basis:

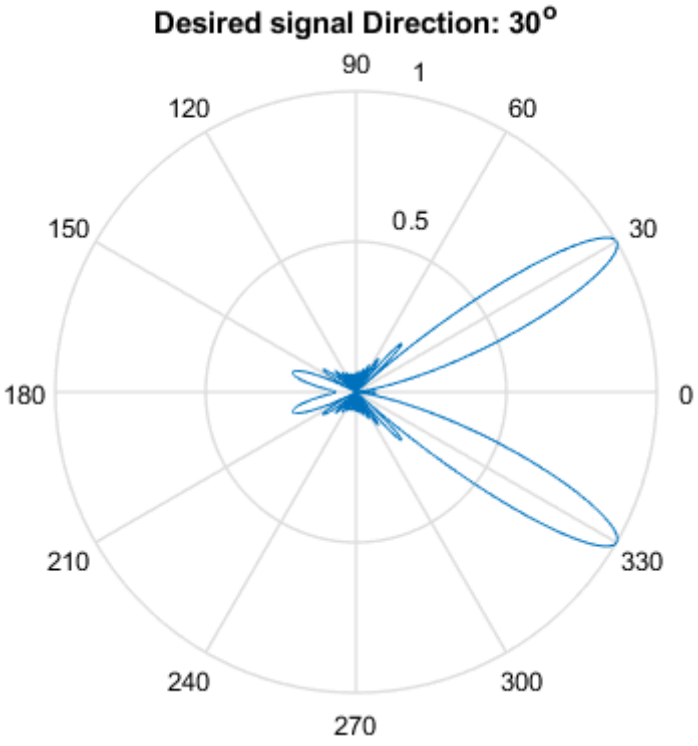
```
-----------------Output-----------------
First part
  Columns 1 through 6

   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i
   0.2500 + 0.0000i   0.2310 - 0.0957i   0.1768 - 0.1768i   0.0957 - 0.2310i   0.0000 - 0.2500i  -0.0957 - 0.2310i
   0.2500 + 0.0000i   0.1768 - 0.1768i   0.0000 - 0.2500i  -0.1768 - 0.1768i  -0.2500 - 0.0000i  -0.1768 + 0.1768i
   0.2500 + 0.0000i   0.0957 - 0.2310i  -0.1768 - 0.1768i  -0.2310 + 0.0957i  -0.0000 + 0.2500i   0.2310 + 0.0957i
   0.2500 + 0.0000i   0.0000 - 0.2500i  -0.2500 - 0.0000i  -0.0000 + 0.2500i   0.2500 + 0.0000i   0.0000 - 0.2500i
   0.2500 + 0.0000i  -0.0957 - 0.2310i  -0.1768 + 0.1768i   0.2310 + 0.0957i   0.0000 - 0.2500i  -0.2310 + 0.0957i
   0.2500 + 0.0000i  -0.1768 - 0.1768i  -0.0000 + 0.2500i   0.1768 - 0.1768i  -0.2500 - 0.0000i   0.1768 + 0.1768i
   0.2500 + 0.0000i  -0.2310 - 0.0957i   0.1768 + 0.1768i  -0.0957 - 0.2310i  -0.0000 + 0.2500i   0.0957 - 0.2310i
   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i
   0.2500 + 0.0000i  -0.2310 + 0.0957i   0.1768 - 0.1768i  -0.0957 + 0.2310i   0.0000 - 0.2500i   0.0957 + 0.2310i
   0.2500 + 0.0000i  -0.1768 + 0.1768i   0.0000 - 0.2500i   0.1768 + 0.1768i  -0.2500 - 0.0000i   0.1768 - 0.1768i
   0.2500 + 0.0000i  -0.0957 + 0.2310i  -0.1768 - 0.1768i   0.2310 - 0.0957i  -0.0000 + 0.2500i  -0.2310 - 0.0957i
   0.2500 + 0.0000i  -0.0000 + 0.2500i  -0.2500 - 0.0000i   0.0000 - 0.2500i   0.2500 + 0.0000i  -0.0000 + 0.2500i
   0.2500 + 0.0000i   0.0957 + 0.2310i  -0.1768 + 0.1768i  -0.2310 - 0.0957i  -0.0000 - 0.2500i   0.2310 - 0.0957i
   0.2500 + 0.0000i   0.1768 + 0.1768i  -0.0000 + 0.2500i  -0.1768 + 0.1768i  -0.2500 - 0.0000i  -0.1768 - 0.1768i
   0.2500 + 0.0000i   0.2310 + 0.0957i   0.1768 + 0.1768i   0.0957 + 0.2310i  -0.0000 + 0.2500i  -0.0957 + 0.2310i


  Columns 7 through 12

   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i
  -0.1768 - 0.1768i  -0.2310 - 0.0957i  -0.2500 - 0.0000i  -0.2310 + 0.0957i  -0.1768 + 0.1768i  -0.0957 + 0.2310i
  -0.0000 + 0.2500i   0.1768 + 0.1768i   0.2500 + 0.0000i   0.1768 - 0.1768i   0.0000 - 0.2500i  -0.1768 - 0.1768i
   0.1768 - 0.1768i  -0.0957 - 0.2310i  -0.2500 - 0.0000i  -0.0957 + 0.2310i   0.1768 + 0.1768i   0.2310 - 0.0957i
  -0.2500 - 0.0000i  -0.0000 + 0.2500i   0.2500 + 0.0000i   0.0000 - 0.2500i  -0.2500 - 0.0000i  -0.0000 + 0.2500i
   0.1768 + 0.1768i   0.0957 - 0.2310i  -0.2500 - 0.0000i   0.0957 + 0.2310i   0.1768 - 0.1768i  -0.2310 - 0.0957i
   0.0000 - 0.2500i  -0.1768 + 0.1768i   0.2500 + 0.0000i  -0.1768 - 0.1768i  -0.0000 + 0.2500i   0.1768 - 0.1768i
  -0.1768 + 0.1768i   0.2310 - 0.0957i  -0.2500 - 0.0000i   0.2310 + 0.0957i  -0.1768 - 0.1768i   0.0957 + 0.2310i
   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i
  -0.1768 - 0.1768i   0.2310 + 0.0957i  -0.2500 - 0.0000i   0.2310 - 0.0957i  -0.1768 + 0.1768i   0.0957 - 0.2310i
  -0.0000 + 0.2500i  -0.1768 - 0.1768i   0.2500 + 0.0000i  -0.1768 + 0.1768i  -0.0000 - 0.2500i   0.1768 + 0.1768i
   0.1768 - 0.1768i   0.0957 + 0.2310i  -0.2500 - 0.0000i   0.0957 - 0.2310i   0.1768 + 0.1768i  -0.2310 + 0.0957i
  -0.2500 - 0.0000i  -0.0000 - 0.2500i   0.2500 + 0.0000i  -0.0000 + 0.2500i  -0.2500 - 0.0000i   0.0000 - 0.2500i
   0.1768 + 0.1768i  -0.0957 + 0.2310i  -0.2500 + 0.0000i  -0.0957 - 0.2310i   0.1768 - 0.1768i   0.2310 + 0.0957i
  -0.0000 - 0.2500i   0.1768 - 0.1768i   0.2500 + 0.0000i   0.1768 + 0.1768i  -0.0000 + 0.2500i  -0.1768 + 0.1768i
  -0.1768 + 0.1768i  -0.2310 + 0.0957i  -0.2500 - 0.0000i  -0.2310 - 0.0957i  -0.1768 - 0.1768i  -0.0957 - 0.2310i

  Columns 13 through 16

   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i   0.2500 + 0.0000i
  -0.0000 + 0.2500i   0.0957 + 0.2310i   0.1768 + 0.1768i   0.2310 + 0.0957i
  -0.2500 - 0.0000i  -0.1768 + 0.1768i  -0.0000 + 0.2500i   0.1768 + 0.1768i
   0.0000 - 0.2500i  -0.2310 - 0.0957i  -0.1768 + 0.1768i   0.0957 + 0.2310i
   0.2500 + 0.0000i  -0.0000 - 0.2500i  -0.2500 - 0.0000i  -0.0000 + 0.2500i
  -0.0000 + 0.2500i   0.2310 - 0.0957i  -0.1768 - 0.1768i  -0.0957 + 0.2310i
  -0.2500 - 0.0000i   0.1768 + 0.1768i  -0.0000 - 0.2500i  -0.1768 + 0.1768i
  -0.0000 - 0.2500i  -0.0957 + 0.2310i   0.1768 - 0.1768i  -0.2310 + 0.0957i
   0.2500 + 0.0000i  -0.2500 + 0.0000i   0.2500 + 0.0000i  -0.2500 - 0.0000i
  -0.0000 + 0.2500i  -0.0957 - 0.2310i   0.1768 + 0.1768i  -0.2310 - 0.0957i
  -0.2500 - 0.0000i   0.1768 - 0.1768i  -0.0000 + 0.2500i  -0.1768 - 0.1768i
   0.0000 - 0.2500i   0.2310 + 0.0957i  -0.1768 + 0.1768i  -0.0957 - 0.2310i
   0.2500 + 0.0000i  -0.0000 + 0.2500i  -0.2500 + 0.0000i   0.0000 - 0.2500i
   0.0000 + 0.2500i  -0.2310 + 0.0957i  -0.1768 - 0.1768i   0.0957 - 0.2310i
  -0.2500 + 0.0000i  -0.1768 - 0.1768i   0.0000 - 0.2500i   0.1768 - 0.1768i
   0.0000 - 0.2500i   0.0957 - 0.2310i   0.1768 - 0.1768i   0.2310 - 0.0957i
```

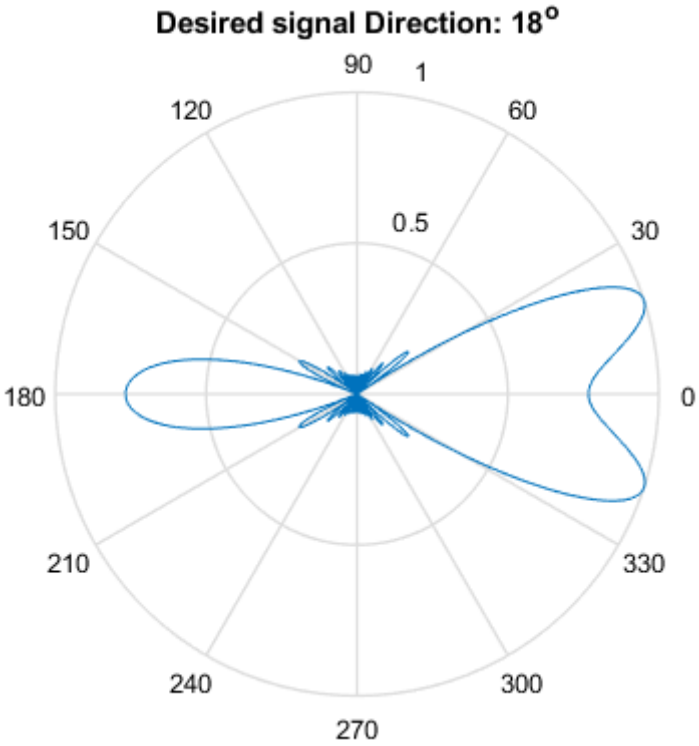
```
----------------------------------------
Secnod part
     Plot in figure 1
----------------------------------------
Third part
     Plot in figure 2
----------------------------------------
Forth part
     Plot in figure 3
----------------------------------------
Fifth part
     Plot in figure 4
----------------------------------------
Sixth part
MISO cannot peform combining techniques.
```

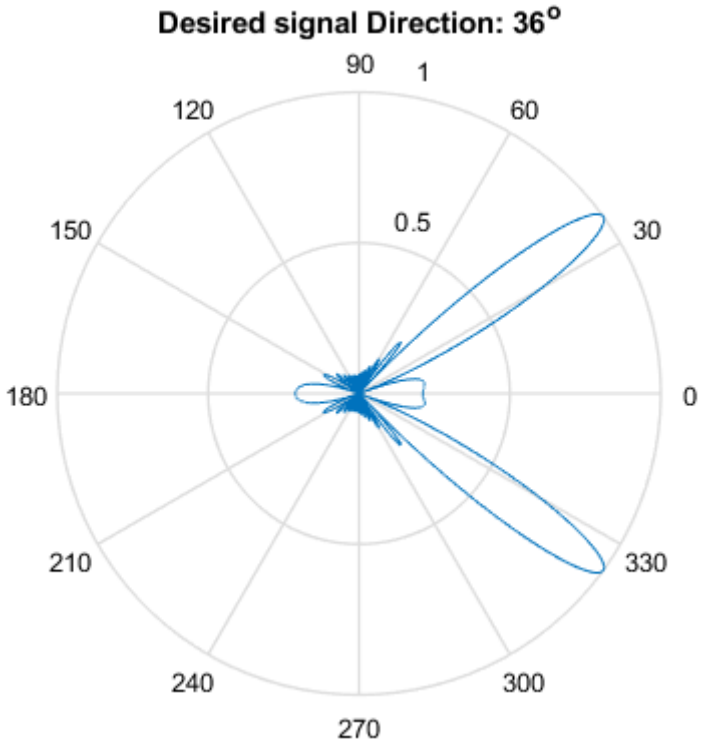
(2) The correlation between different basis vectors

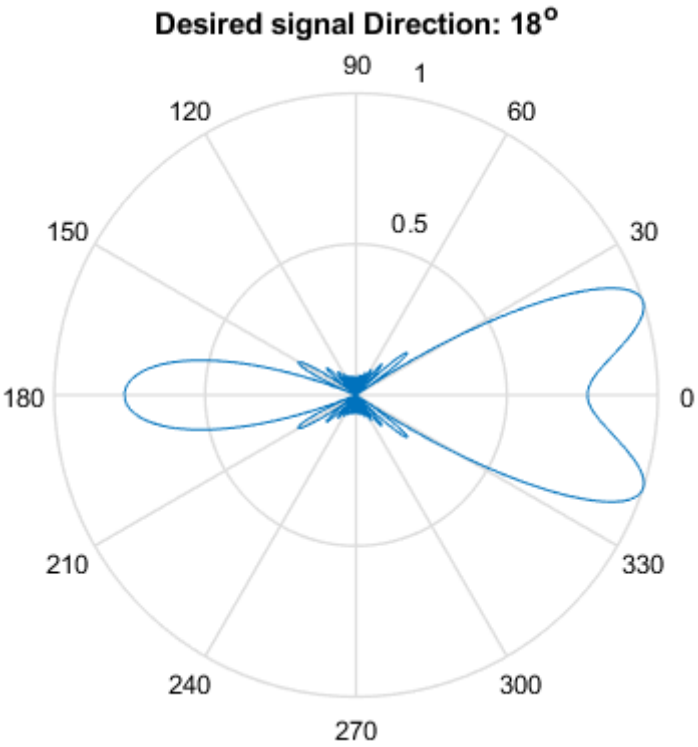


(3) The power gain pattern of the ULA

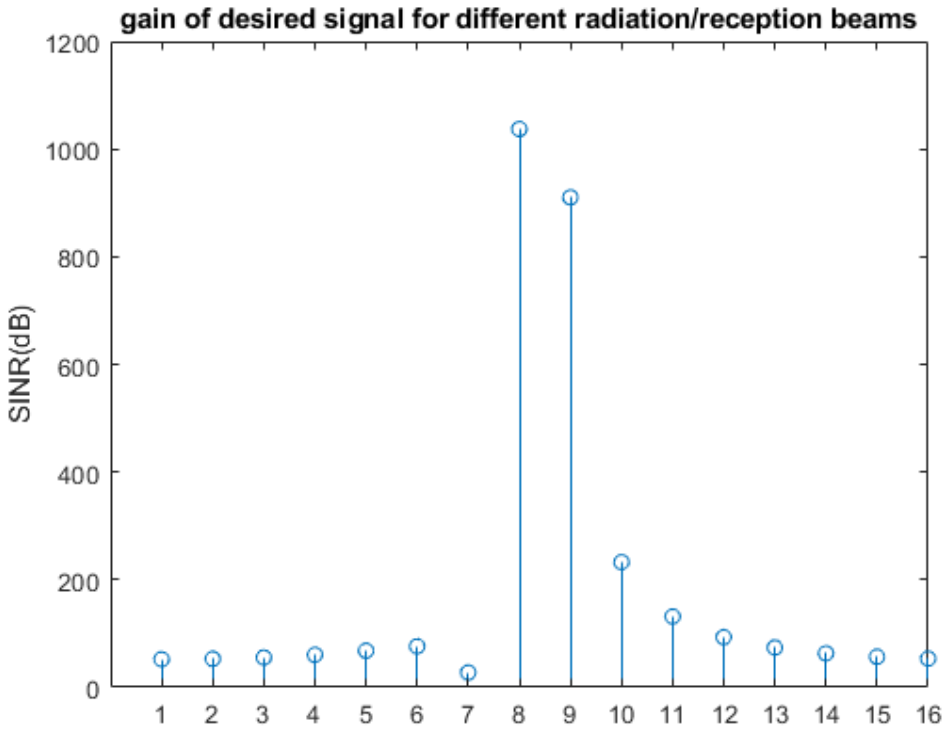




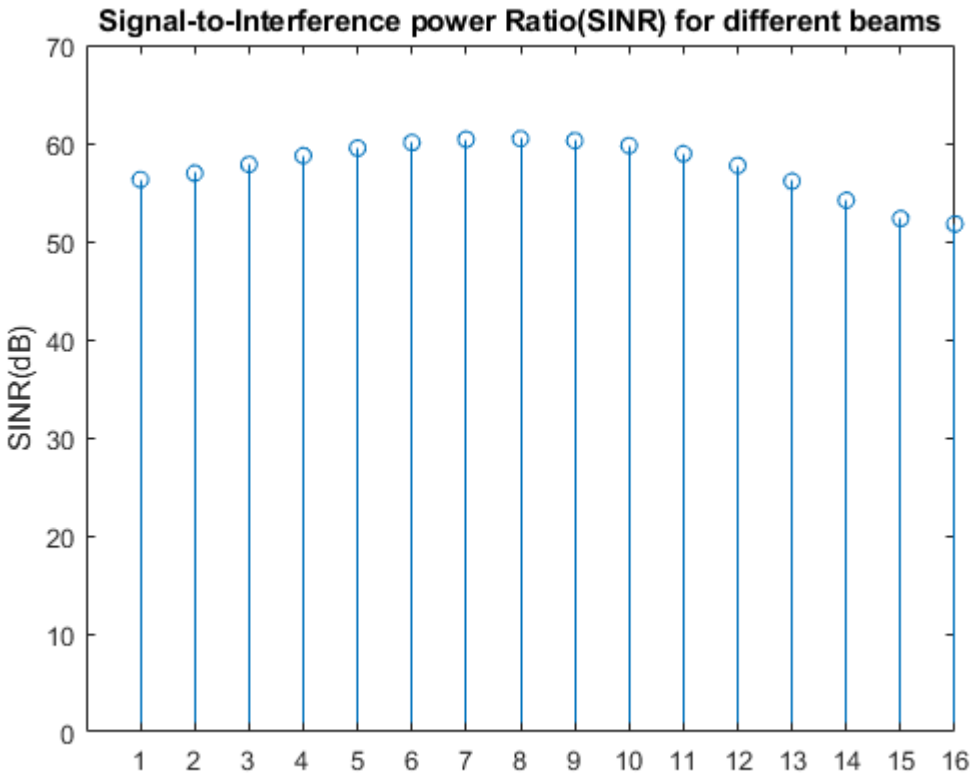




(4) The power gain of the desired signal for using different radiation beams



(5) The signal-to-interference power ratio (SIR) for using different beams



(6) The SIR of multiple input signals (multiple reception directions) with diversity combining (considering fading for the signals and interferences)

因為 MISO 的接收端只有一個天線，沒有辦法應用 combining technique，所以(6)的結果會跟(5)一樣。