通訊系統電腦模擬與量測

Simulations and Measurements of Communication Systems

國立臺灣海洋大學 通訊與導航工程學系

Oral Report_3

系級：通訊4A
學號：0086C035
姓名：余佳駿

Experiment # 9

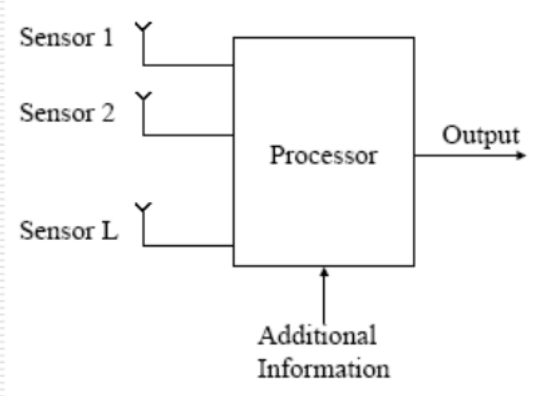
Smart Antenna and Beamforming (PhaseShift、MVDR)

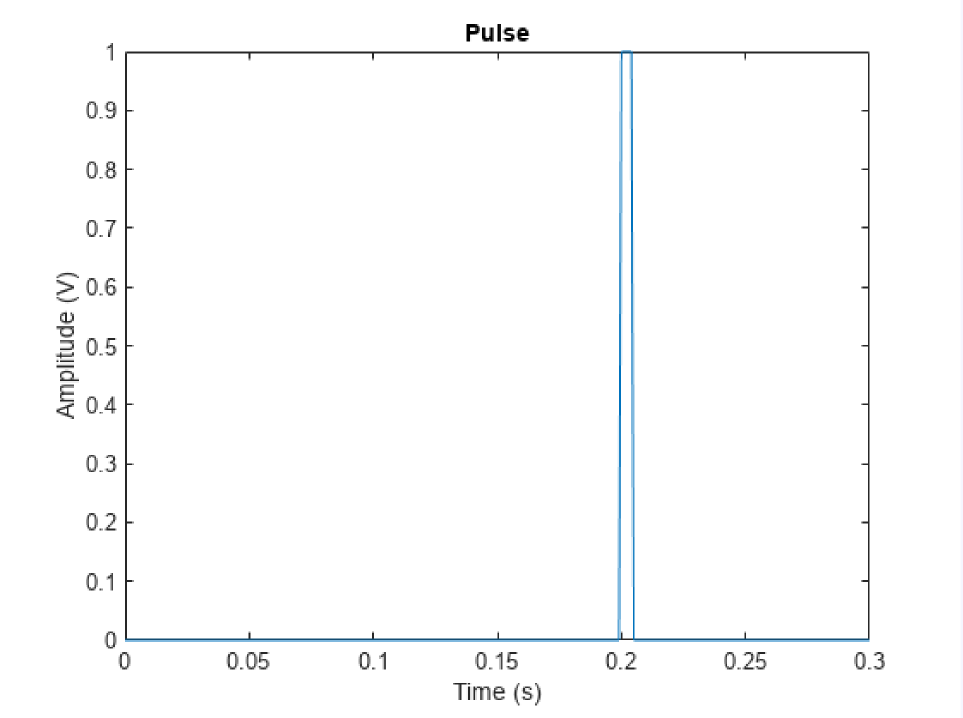
Conventional and Adaptive Beamformers

- 建立窄頻訊號

```
t = 0:0.001:0.3;                  % Time, sampling frequency : 1kHz
s = zeros(size(t));
s = s(:);
s(201:205) = s(201:205) + 1;      % Pulse signal
```

此實驗驗證如何將數位訊號之波束成形
應用於天線陣列接收的窄頻訊號。
並比較兩種波束成形方法
phase shift beamformer (PhaseShift),
the minimum variance distortionless response
(MVDR) beamformer

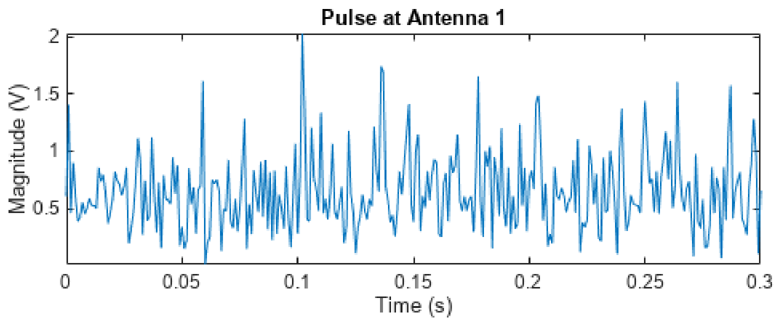




Conventional and Adaptive Beamformers

- 設定接收訊號角度 & 加入雜訊

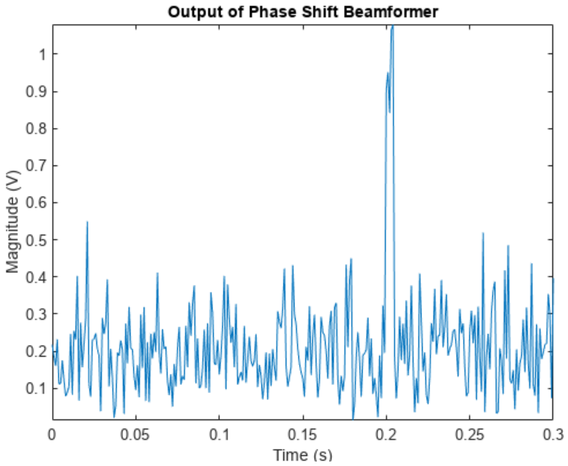
```
% setting arrive Angle
inputAngle = [45; 0];
x = collectPlaneWave(ula,s,inputAngle,carrierFreq);

% Create random number generator
rs = RandStream.create('mt19937ar','Seed',2008);

% Add noise
noisePwr = .5;   % noise power
noise = sqrt(noisePwr/2)*(randn(rs,size(x))+1i*randn(rs,size(x)));
rxSignal = x + noise;
```



Phase Shift Beamformer

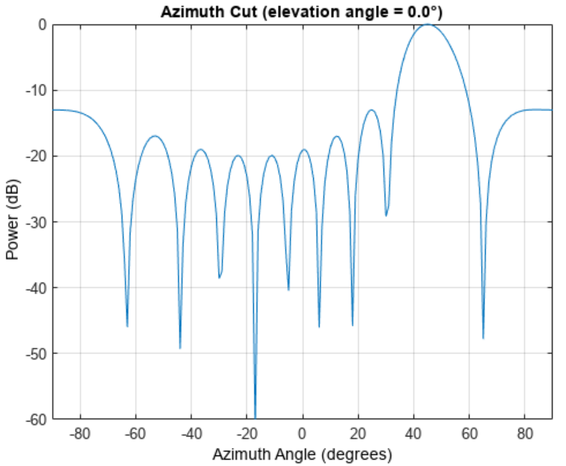
```matlab
%% Phase Shift Beamformer
psbeamformer = phased.PhaseShiftBeamformer('SensorArray',ula,...
    'OperatingFrequency',carrierFreq,'Direction',inputAngle,...
    'WeightsOutputPort', true);
%% We can now obtain the output signal and weighting coefficients
[yCbf,w] = psbeamformer(rxSignal);
```

```matlab
plot(t,abs(yCbf)); axis tight;
```



Phase Shift Beamformer延遲每個天線接收到的訊號，使訊號對齊，就好像它們同時到達所有天線一樣。在窄帶情況下，相當於每個天線接收到的訊號乘上一個相位因子

```matlab
%% Plot array response with weighting
pattern(ula,carrierFreq,-180:180,0,'Weights',w,'Type','powerdb',...
    'PropagationSpeed',physconst('LightSpeed'),'Normalize',false,...
    'CoordinateSystem','rectangular');
axis([-90 90 -60 0]);
```

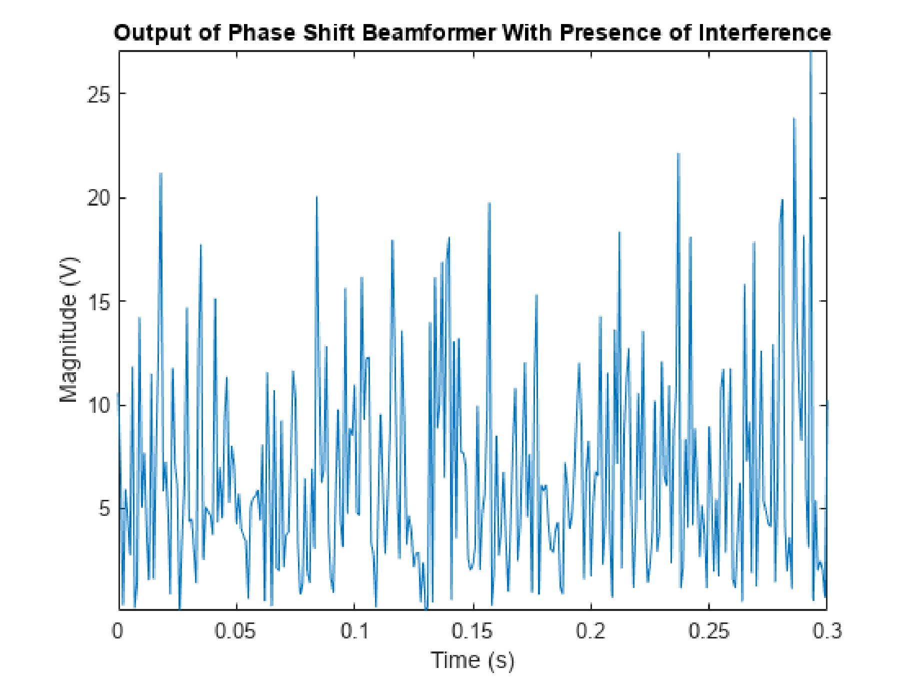


可以看到波束形成器的主波束正像預期的那樣指向所需的方向（45 度）

Modeling the Interference Signals

- 建立干擾訊號模型 (30 度和 50 度 方位角)

```
%% Modeling the Interference Signals
nSamp = length(t);
s1 = 10*randn(rs,nSamp,1);
s2 = 10*randn(rs,nSamp,1);
% interference at 30 degrees and 50 degrees
interference = collectPlaneWave(ula,[s1 s2],[30 50; 0 0],carrierFreq);

%% To illustrate the effect of interference,

noisePwr = 0.00001;                          % noise power, 50dB SNR
noise = sqrt(noisePwr/2)*(randn(rs,size(x))+1i*randn(rs,size(x)));

rxInt = interference + noise;                % total interference + noise
rxSignal = x + rxInt;                        % total received Signal

%% First, we'll try to apply the phase shift beamformer to retrieve the signal
yCbf = psbeamformer(rxSignal);
```



在強干擾的情況下，若使用相移波束器，
目標訊號可能被干擾訊號所掩蓋。

MVDR Beamformer

波束形成的基本構想，是希望對每根陣列天線收到的訊號，乘以不同的權重，使每跟訊號加總起來的訊號，可以有濾波的效果。所以我們假設經由空間濾波後的訊號，可以表示成 $y=W^H X$。MVDR 演算法的基本假設有兩個：第一個是將訊號源入射角度的訊號能量維持在 0dB，第二個是要讓收到訊號的能量降到最低。這兩個假設組合在一起，就達到了濾除雜訊的效果。收到訊號的能量，可以表示為

$$E\{|y|^2\}=E\{|W^H X|^2\}=W^H R_{xx} W$$

為了同時滿足兩個假設，使用了 Lagrange Multiplier

$$\begin{cases}\nabla_W[W^H R_{xx} W]-\lambda\nabla_W[W^H a(\theta_s)]=0\\ W^H a(\theta_s)=1\end{cases}$$

可解出

$$\lambda=W^H R_{xx} W=\frac{1}{a^H(\theta_s)R_{xx}^{-1}A(\theta_s)}$$

$$\Rightarrow\quad W=\frac{1}{a^H(\theta_s)R_{xx}^{-1}A(\theta_s)}R_{ss}^{-1}A(\theta_s)$$

而 W 即為每根天線的權重值，$y=W^H X$ 可濾出想要的訊號。

```matlab
%% MVDR Beamformer
% Define the MVDR beamformer
mvdrbeamformer = phased.MVDRBeamformer('SensorArray',ula,...
    'Direction',inputAngle,'OperatingFrequency',carrierFreq,...
    'WeightsOutputPort',true);

mvdrbeamformer.TrainingInputPort = true;

[yMVDR, wMVDR] = mvdrbeamformer(rxSignal,rxInt);
```

$$\nabla_W[W^H R_{xx} W]-\lambda\nabla_W[W^H a(\theta_s)]=0$$

約束目標方向增益不變

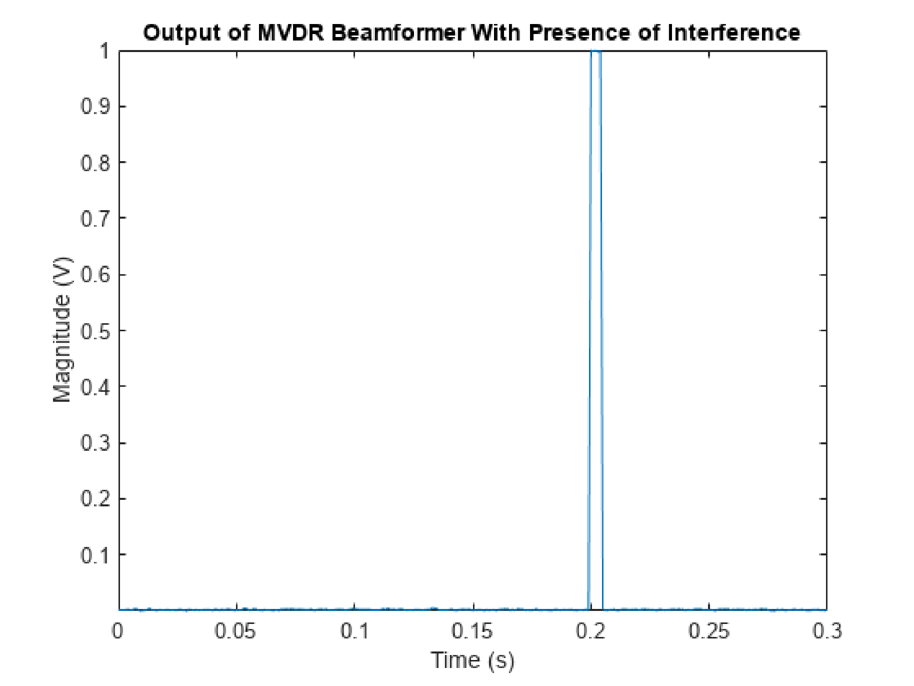
$$W^H a(\theta_s)=1$$

約束接收波束成形後在指定方向的能量

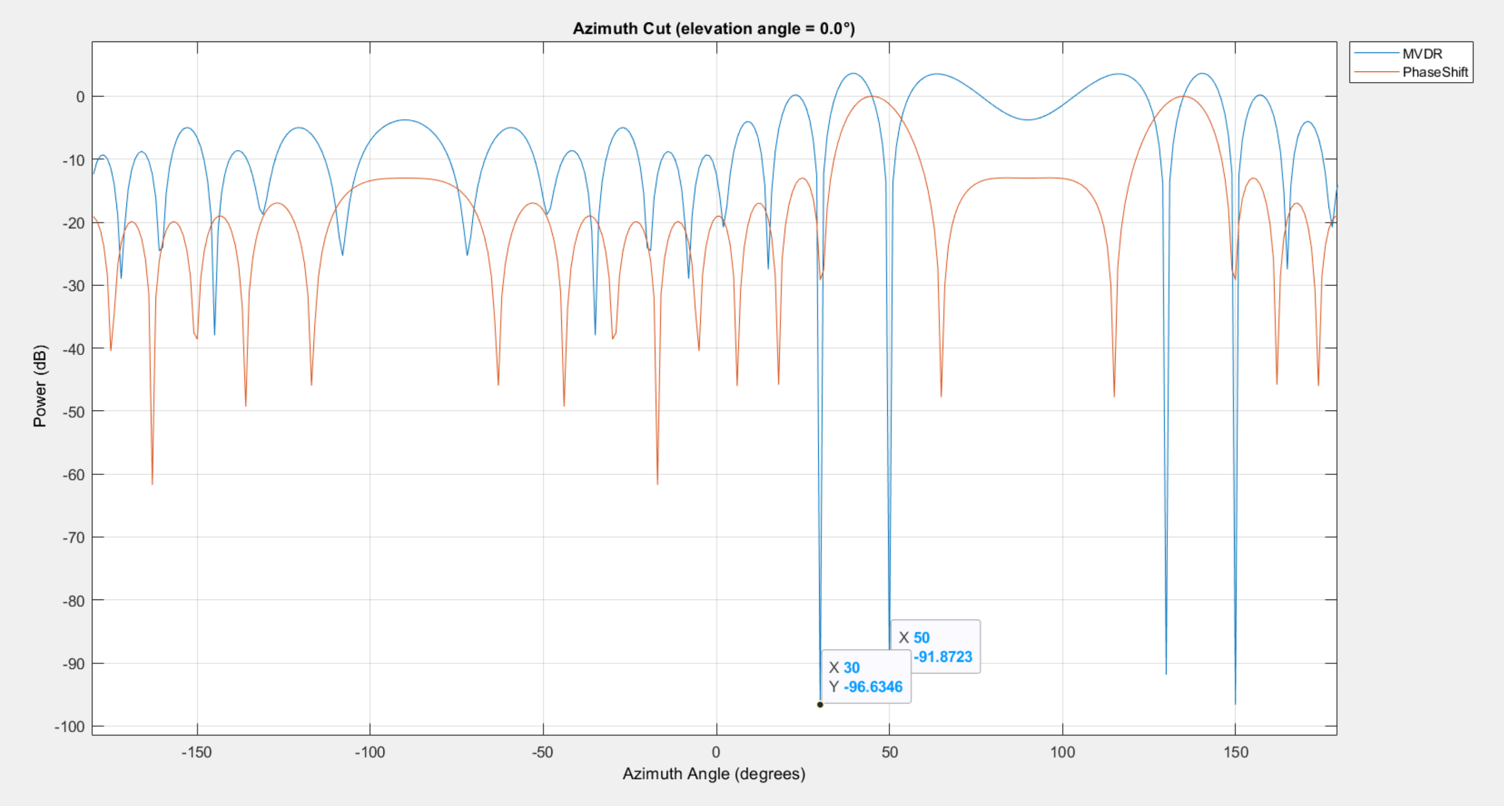
MVDR Beamformer

因此引入自適應波束形成器來解決這個問題。
這邊使用MVDR Beamformer

```
%% MVDR Beamformer
% Define the MVDR beamformer
mvdrbeamformer = phased.MVDRBeamformer('SensorArray',ula,...
    'Direction',inputAngle,'OperatingFrequency',carrierFreq,...
    'WeightsOutputPort',true);

mvdrbeamformer.TrainingInputPort = true;

[yMVDR, wMVDR] = mvdrbeamformer(rxSignal,rxInt);
```



OUTPUT



可以看到沿干擾方向（30 度和 50 度）有兩個深度零點。波束形成器沿 45 度的目標方向也具有約 0 dB 的增益。因此，MVDR 波束形成器保留了目標信號並抑制了干擾信號。

Experiment # 10

MIMO Transmission (STBC、MRC)

STBC Alamouti 2x1

空時分組編碼STBC（Space Time Block Coding）
STBC Alamouti的關鍵思想是利用空間多種性質，通過在不同的空間上發送相互正交的信號來增強通信系統的可靠性。

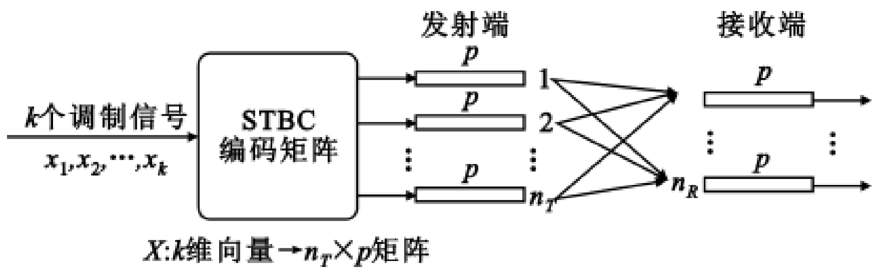
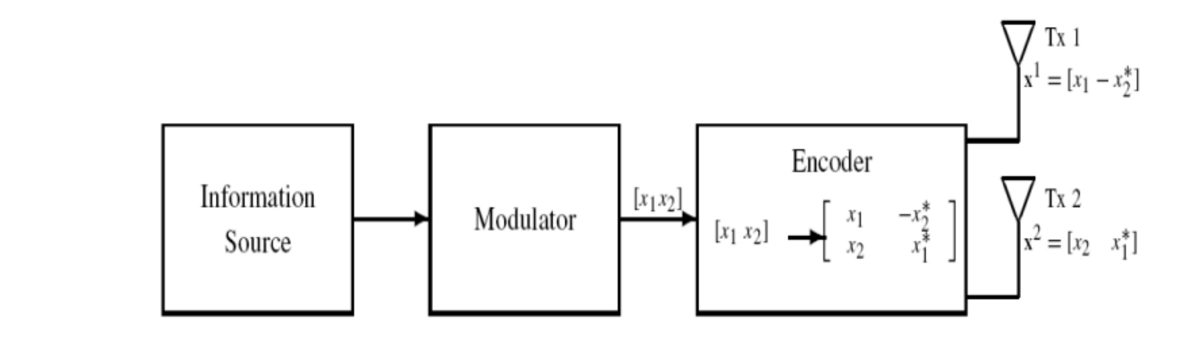


图 1　空时分组码系统结构框图

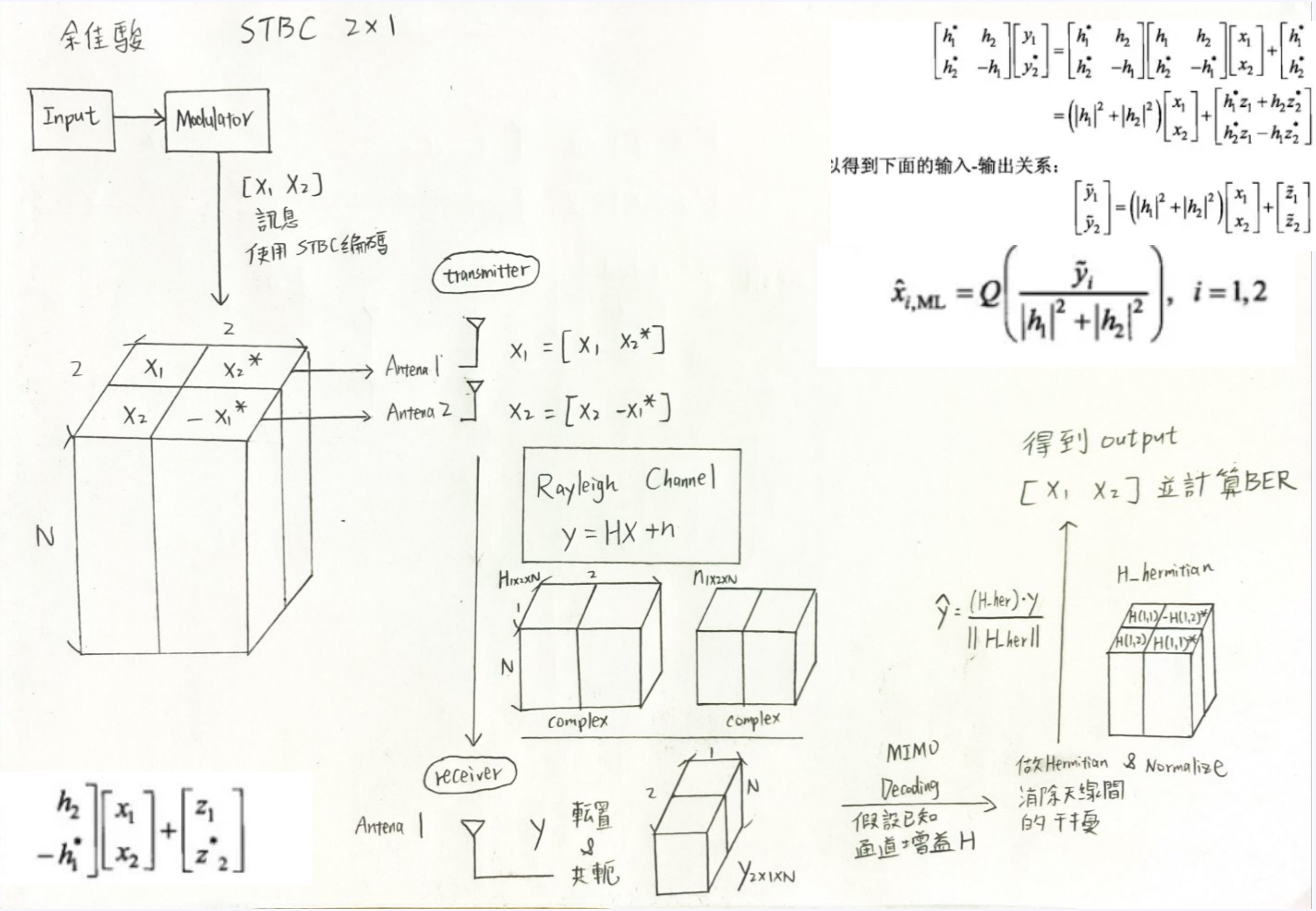
Fig.1 Block diagram of STBC

STBC Alamouti 2x1

```
    % bits to symbol mapping
    symbols = qammod(bits, M, "gray", "InputType", "bit", 'UnitAveragePower', true);
    symbols = reshape(symbols, 2, 1, []);
    X = zeros(2, 2, N);

    % STBC Alamouti
    % 1st interval，antena1:x1 ，antena2:x2
    X(:, 1, :) = symbols;

    % 2nd interval，antena1:x2* ，antena2:-x1*
    X(1, 2, :) = conj(symbols(2, 1, :));
    X(2, 2, :) = -conj(symbols(1, 1, :));

    % transmission over Rayleigh fading channel
    H = sqrt(N0/2) * (randn(1, 2, N)+1j*randn(1, 2, N));
    n = sqrt(N0/2) * (randn(1, 1, N)+1j*randn(1, 1, N));
    y = sqrt(Es/2)*pagemtimes(H, X)+n; % y=HX+n
```



STBC Alamouti 2x1



$$\begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix}\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix}\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix}\begin{bmatrix} z_1 \\ z_2^* \end{bmatrix}$$

$$= \left(|h_1|^2 + |h_2|^2\right)\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} h_1^* z_1 + h_2 z_2^* \\ h_2^* z_1 - h_1 z_2^* \end{bmatrix} \tag{10.49}$$

以得到下面的输入-输出关系：

$$\begin{bmatrix} \tilde{y}_1 \\ \tilde{y}_2 \end{bmatrix} = \left(|h_1|^2 + |h_2|^2\right)\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \tilde{z}_1 \\ \tilde{z}_2 \end{bmatrix} \tag{10.50}$$

$$\hat{x}_{i,\mathrm{ML}} = Q\left(\frac{\tilde{y}_i}{|h_1|^2 + |h_2|^2}\right), \quad i = 1, 2$$

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2^* \end{bmatrix}$$

MRC 1x2

最大比合併MRC（maximum ratio combining）
是一個分集接收技術，目的是改善接收端的信號質量。

MRC的原理是通過對多條接收天線上的信號進入行權組合，以最大化接收信號的訊雜比（SNR）。

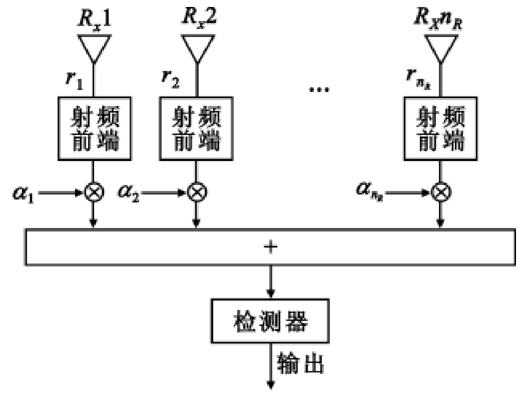
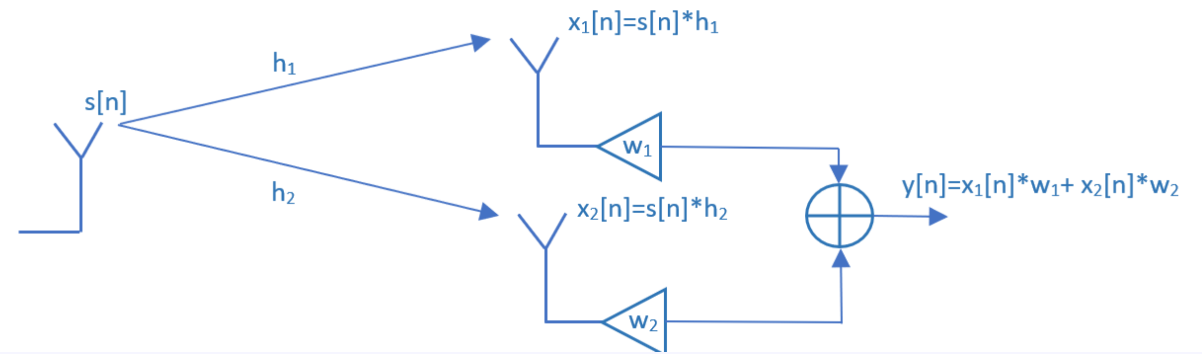


图 2 最大比合并原理框图
Fig.2 Block diagram of maximum ratio combination

MRC 1x2

```
% channel coding

% bits to symbol mapping
symbols = qammod(bits, M, "gray", "InputType", "bit", 'UnitAveragePower'
X = reshape(symbols, 1, 1, N);

% transmission over Rayleigh fading channel
H = sqrt(N0/2) * (randn(2, 1, N)+1j*randn(2, 1, N));
n = sqrt(N0/2) * (randn(2, 1, N)+1j*randn(2, 1, N));
y = sqrt(Es)*H.*X+n;
```



MRC 1x2

```
% transmission over Rayleigh fading channel
H = sqrt(N0/2) * (randn(2, 1, N)+1j*randn(2, 1, N));
n = sqrt(N0/2) * (randn(2, 1, N)+1j*randn(2, 1, N));
y = sqrt(Es)*H.*X+n;

norm_factor = squeeze(abs(H(1, 1, :)).^2+abs(H(2, 1, :)).^2);
y_hat = pagemtimes(pagectranspose(H), y);
y_hat = squeeze(y_hat)./norm_factor; % squeeze:刪除了長度為1 的維度
```

In summary, since the conjugate of a complex number inverts its phase but leaves the magnitude unchanged, the optimal w_j can be chosen as complex conjugates of h_j.

$$\boxed{w_j = h_j^* \qquad (7)}$$

$$z = \{h_1^* \cdot h_1 + h_2^* \cdot h_2\} \cdot s + \text{noise} = \left\{|h_1|^2 + |h_2|^2\right\} \cdot s + \text{noise}$$

$$\hat{s} = \frac{z}{|h_1|^2 + |h_2|^2}$$

Output

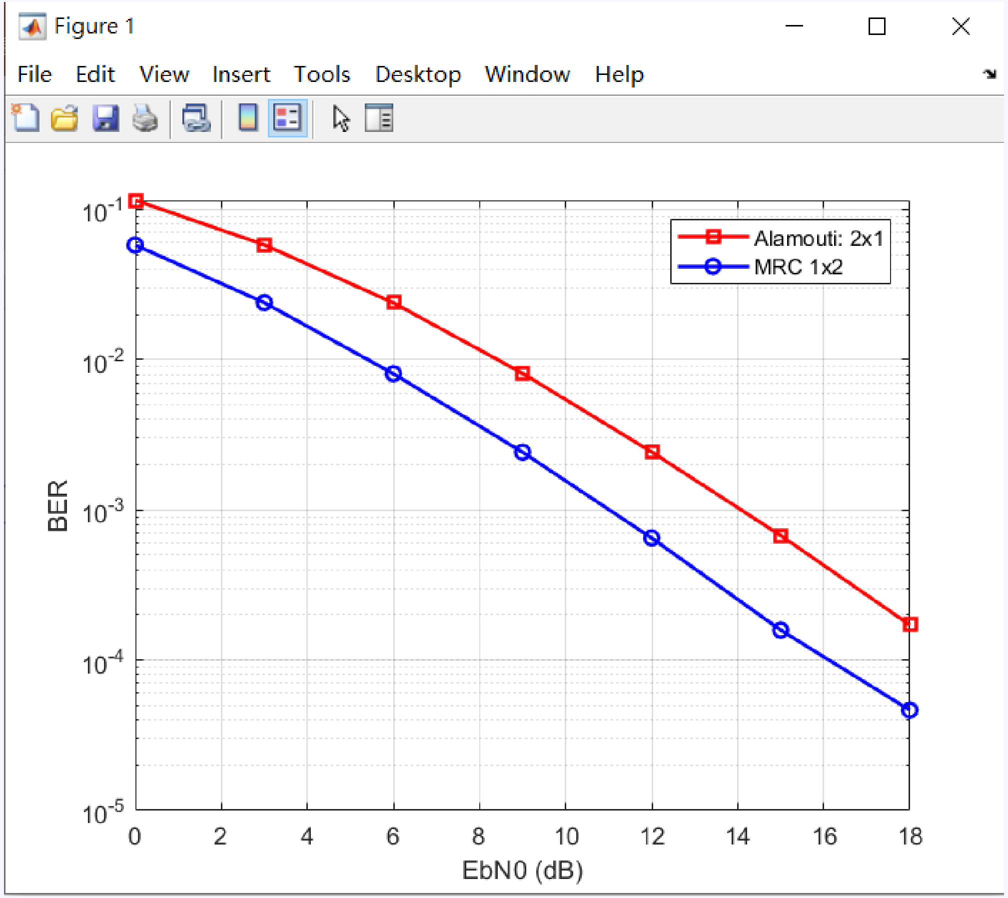


Figure 1
File Edit View Insert Tools Desktop Window Help
Alamouti: 2x1
MRC 1x2
BER
EbN0 (dB)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0 2 4 6 8 10 12 14 16 18

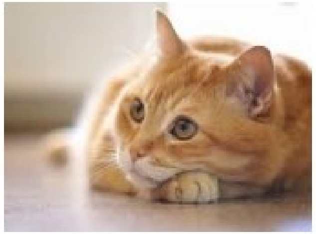
Experiment # 11 #12

OFDM System & SDR (using FPGA)

MIMO OFDM

四筆相異資料



MIMO OFDM

1.	2.	3.	4.	5.	6.	7.
RS	PSS		SSS		Data	RS

Slot定序:設定各訊號放置Symbol位置如上：

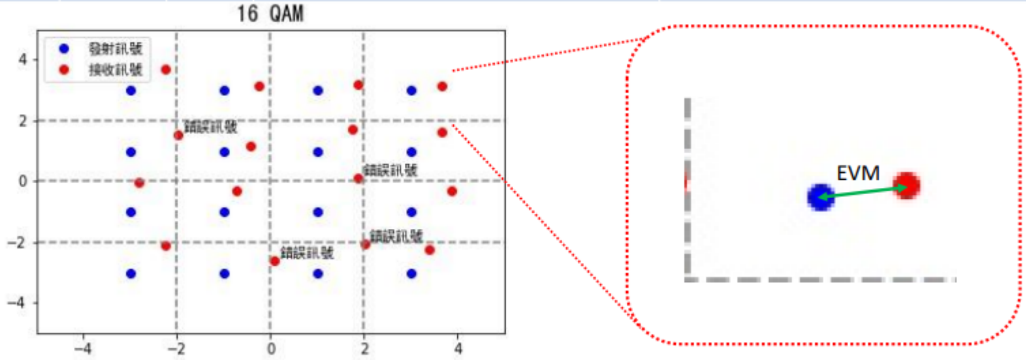
第1和7層為RS訊號、第2層為PSS、第4層為SSS、

第6層為Data，第3和5層則留空（null）。

EVM 誤差向量幅度

```
%% === EVM calculation ===
for m = 1:Num_Layer
    err(m, :) = rn_Equal_Data(m, :) - sn_Data(m, :);
    evm(m) = nansum(abs(err(m, :)).^2, 2) ./ nansum(abs(sn_Data(m, :)).^2, 2);
    EVM(m) = 10 * log10(evm(m));
end
```

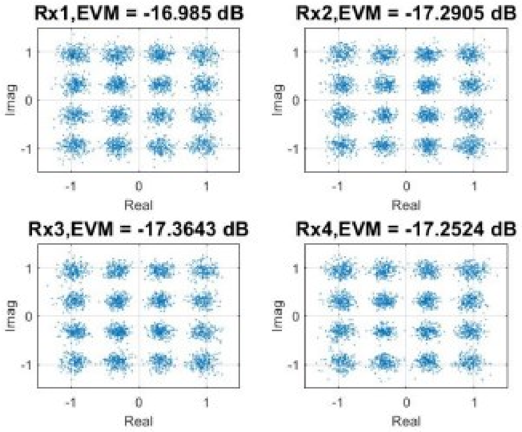
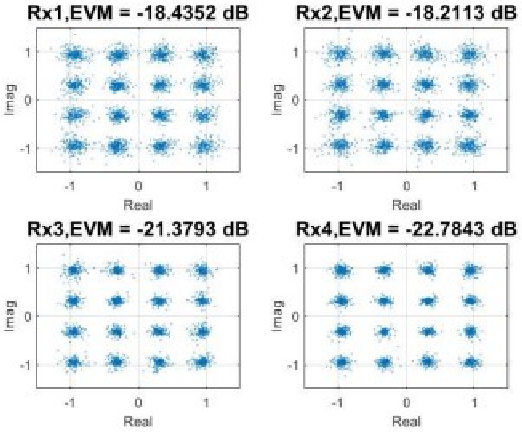
參數	範圍	單位	公式物理意義	天線物理意義
EVM	0~∞	%	信號星座圖中測量信號與理想無差錯點之間的差別	1. 評估收發機+天線效能 2. 值越小表示效能越好 3. 傳導儀器0.25%、SDR 1.2%



MIMO OFDM

7symbol , 1data (index 6)

1.	2.	3.	4.	5.	6.	7.
RS	PSS		SSS		Data	RS

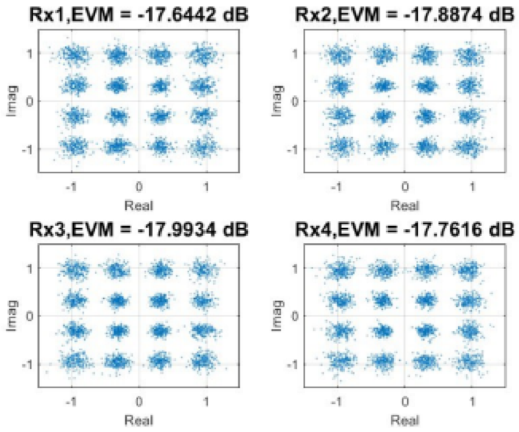
模擬結果(加入高斯白雜訊)	實驗結果
	

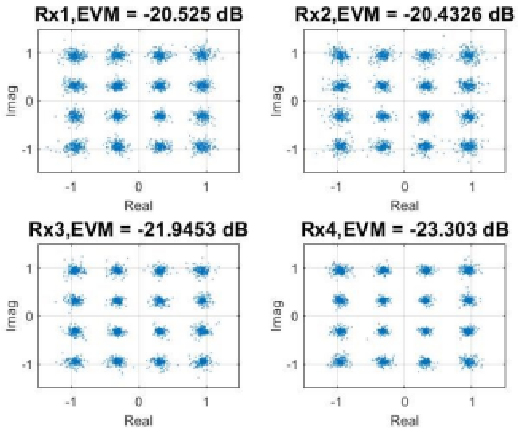
MIMO OFDM

7symbol , 2data (index 5,6)

1.	2.	3.	4.	5.	6.	7.
RS	PSS		SSS	Data	Data	RS

模擬結果(加入高斯白雜訊)	實驗結果

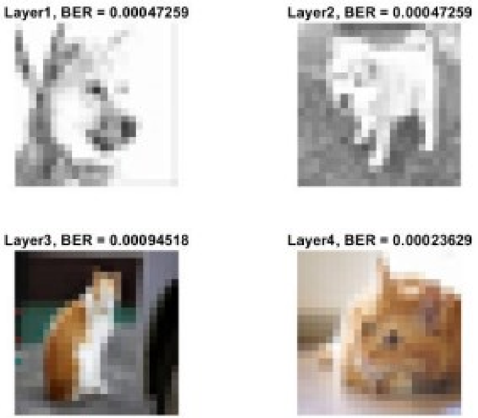
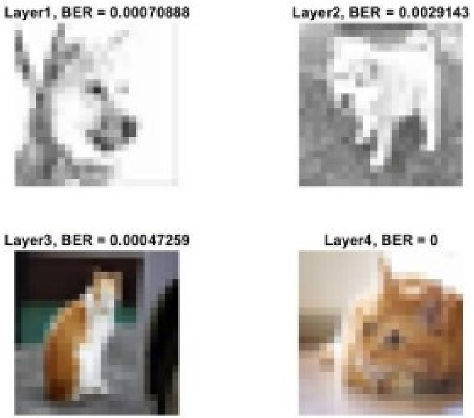




MIMO OFDM

7symbol , 1data (index 6)

1.	2.	3.	4.	5.	6.	7.
RS	PSS		SSS		Data	RS

模擬結果(加入高斯白雜訊)	實驗結果
	

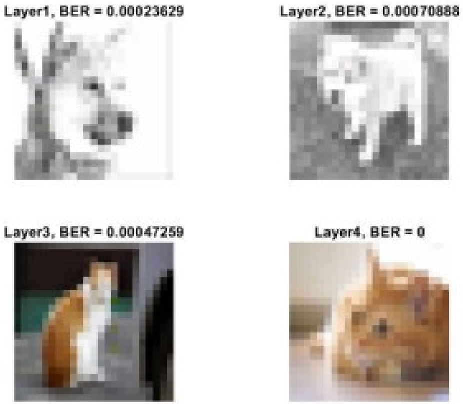
Average-BER	0.00082703	0.00094518

MIMO OFDM

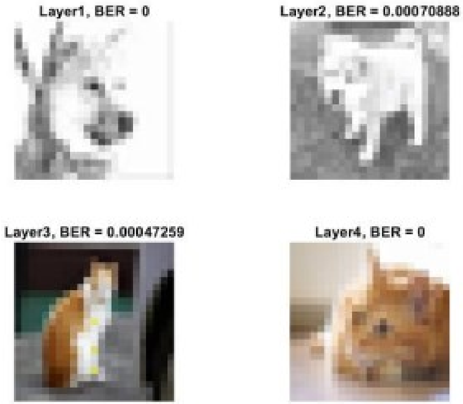
7symbol , 2data (index 5,6)

1.	2.	3.	4.	5.	6.	7.
RS	PSS		SSS	Data	Data	RS

模擬結果(加入高斯白雜訊)



實驗結果



Average-BER	0.00035444	0.00011815

結論

經由測試分析，我們得到當OFDM符元區間內具有兩個資料符元數，並在接收端等化處理後進行資料平均，相比於其他組合具有較優異的系統表現，得以在sub-6G環境下穩定送收，成功實現5G NR之MIMO通訊平台建置，根據此研究結果，可得到重複碼以及等化器處理對於系統穩定度之影響，因此可應用於進一步之系統效能之優化與改進。

Thanks