# Communication Lab
# Final Project Presentation
## Group 2

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# Selected Topic & Goal

**Topic:**

Apply the property of Yagi-Uda antenna and multipath effect on distance estimation.

**Basic goal:**

Study the property of Yagi-Uda antenna and mulipath effect.

**Advanced goal:**

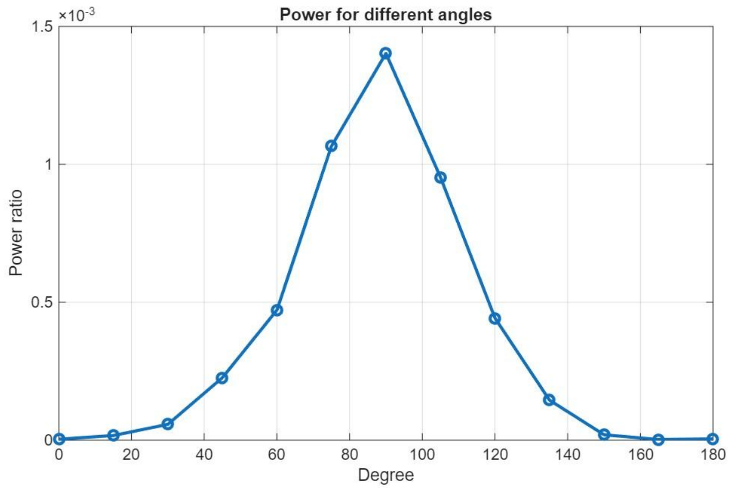
Distance estimation using multipath

**Others:**

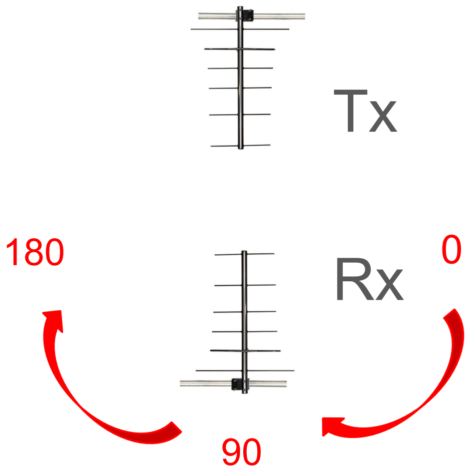
Some interesting topics about Yagi-Uda Antenna and reflection.

# How does Yagi-Uda antenna different with general antenna?

To demonstrate that the EM wave **direction** of a Yagi-Uda antenna **differs** from that of a regular one, we rotated the angle between the two antennas and recorded the energy changes. The result showed that the **directivity was obvious**, and the energy received in the environment was **symmetrical**.



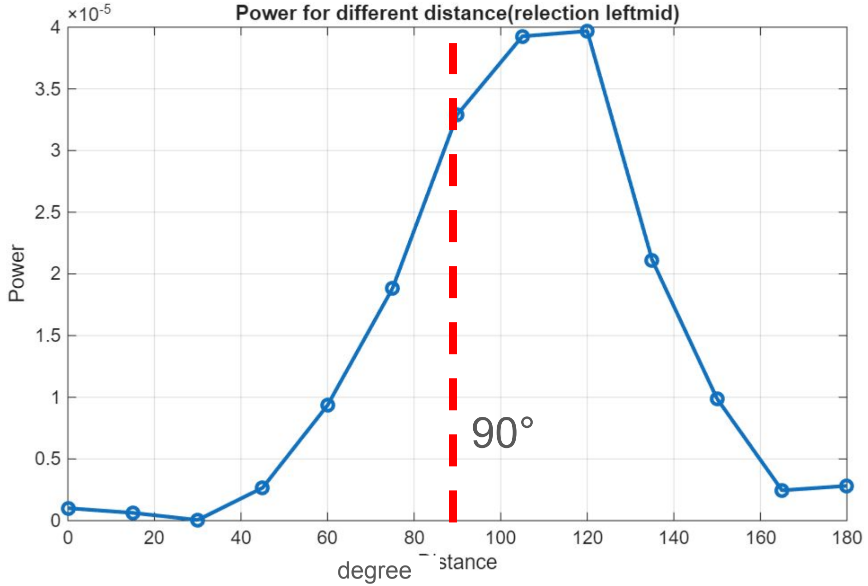

angle difference vs power



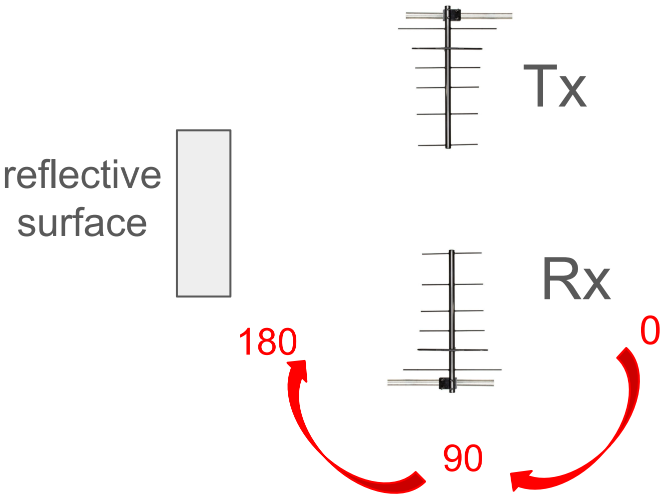

schematic diagram

# Is there any multipath effect ?

We added a reflective surface to the original environment, which allows us to see in the graph that the peak value **shifts towards the direction** of the reflection path, and the average power increases.



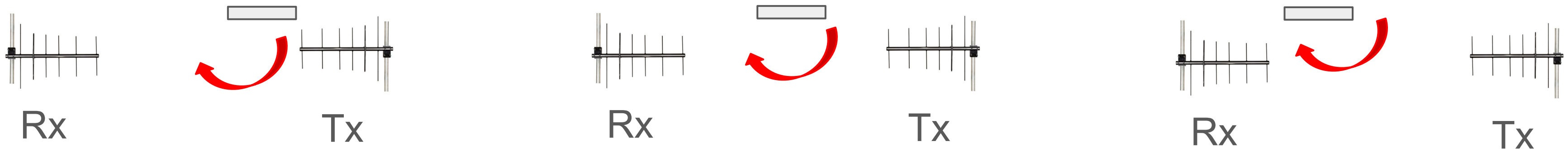

angle difference vs power



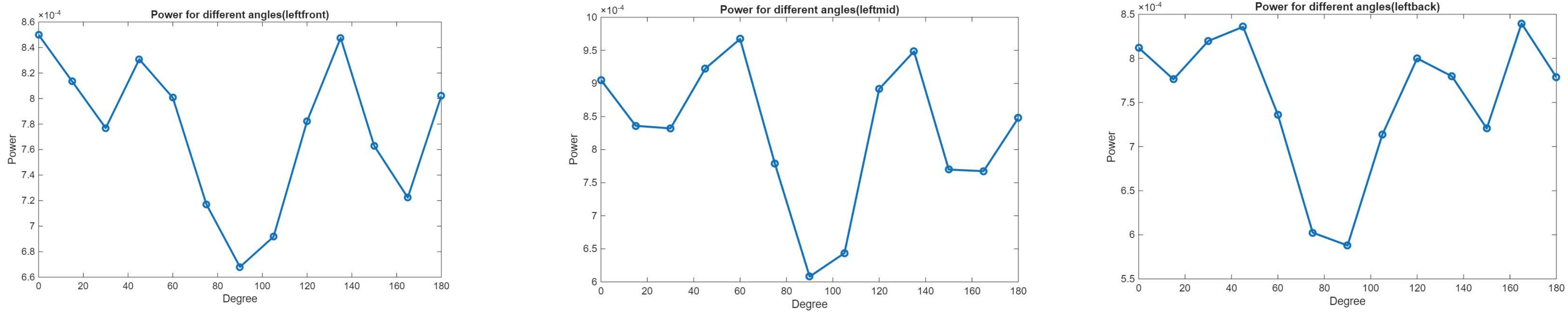

schematic diagram

# How does the multipath effect behave?

We put RS at three different horizontal positions and rotate 0~180 degrees at each position. The result showed that the power intensity across positions exhibits an **M-shaped pattern**, likely caused by **constructive and destructive interference.**



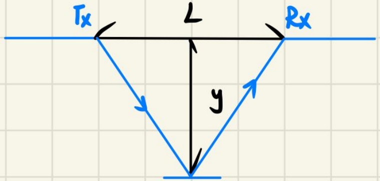

schematic diagram




angle difference vs power, accordiong to different RS placement.

# Can this be used for distance measurement?

We gradually **move the surface away** from the device, causing a change in the **reflection pathway**, thereby altering the effect of the path on the original energy(constructive or destructive interference).




$r_d = L$

$r_r(y) = 2\sqrt{\left(\frac{L}{2}\right)^2 + y^2}$

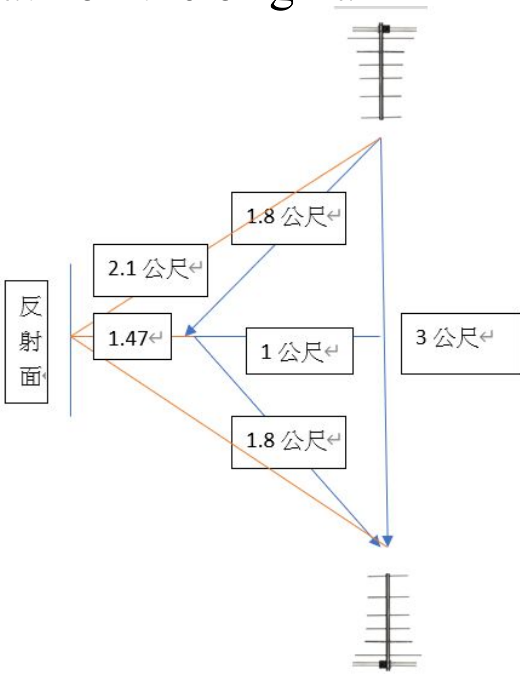
$\Delta y = r_r(y) - r_d = \sqrt{L^2 + 4y^2} - L$

$$\begin{cases} E_d = \frac{A}{r_d} e^{-jkr_d} \\ E_r = \Gamma \frac{A}{r_r(y)} e^{-jkr_r(y)} \end{cases}$$

$$P \propto |E_d + E_r|^2 \rightarrow P(y) = P_d + P_r(y) + 2\sqrt{P_d P_r(y)} \cos(k\Delta y + \phi_r)$$

$$\rightarrow P(y) = \underbrace{\frac{A^2}{L^2}}_{\text{No reflect}} + \underbrace{\frac{A^2|\Gamma|^2}{r_r(y)^2}}_{\text{multipath}} + \underbrace{\frac{A^2|\Gamma|}{L\, r_r(y)} \cos(k\Delta y + \phi)}_{\text{constructive/destructive}}$$

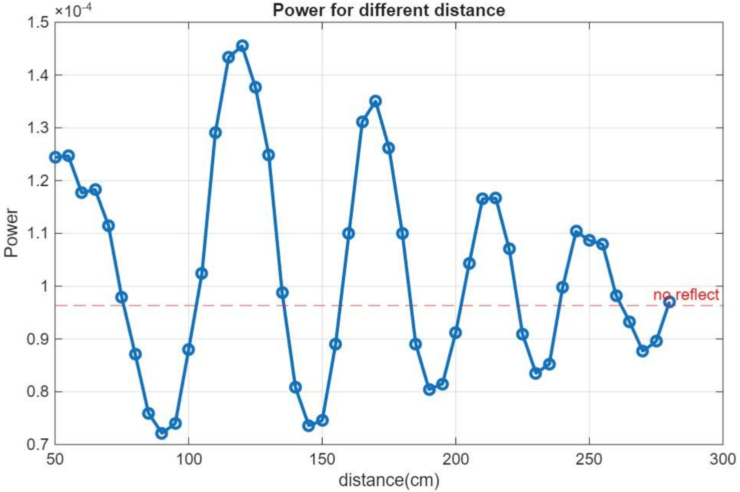
math model for received power vs distance



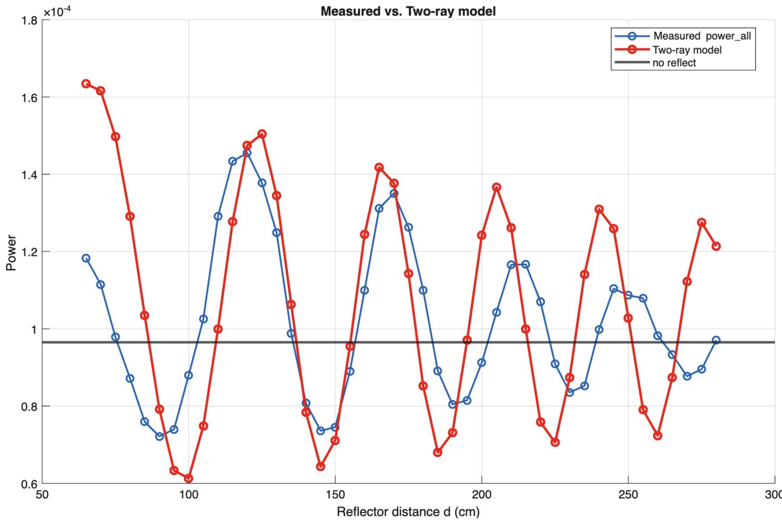

schematic diagram

# Discussion of the experiment result

1. The period of change of power gets shorter
2. The amplitude (power) gets smaller, and the long distance behavior converges to the power with no reflection surface.
3. Compare to the mathematical model, they share the same charateristic though the Γ of the RS is unknown.




RS distance vs power



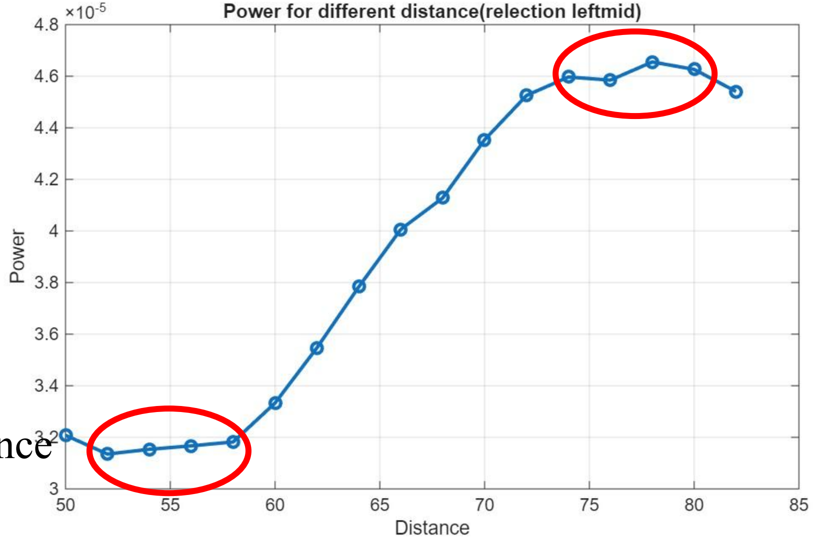

compare with mathematical model (assume Γ =0.3, no phase shift)

# Application: distance estimation

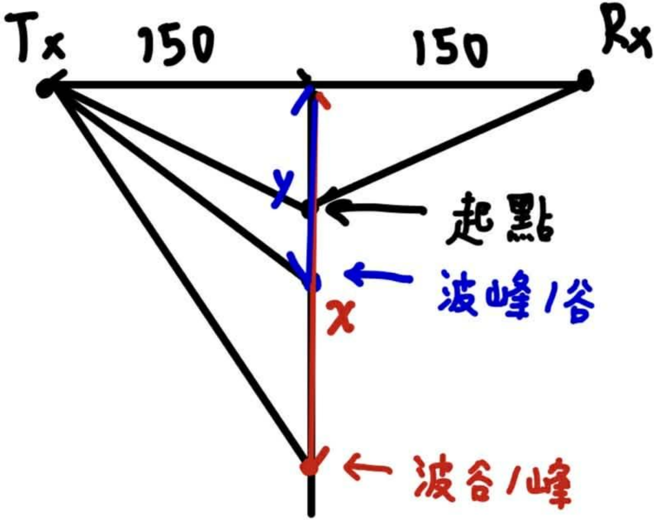
By the previous result, the power changes with distance periodically due to the interference. In addition, the period reduces with distance. Hence, it is possible to roughly estimate the distance by using reflection surface.

## -Method

1. Start from an unknown point.
2. Each time go forward for a fixed distance (e.g. 2cm, 5cm)
3. Terminate until there is a peak & trough
4. Take the average index of extreme value
5. Plug in the equation to obtain the estimated distance




This method can approach around an **±10cm error** compared with ground truth.



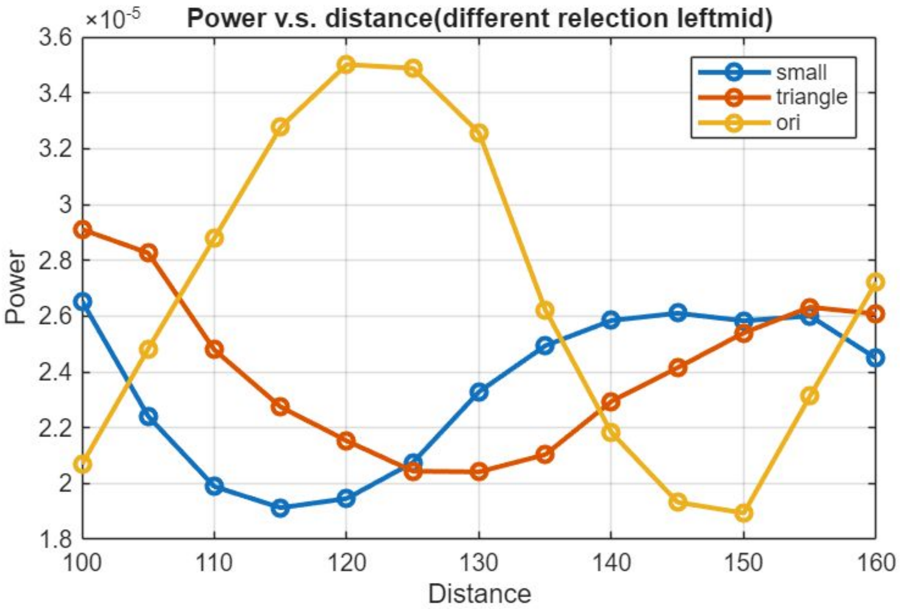

$$\Rightarrow \begin{cases} 2\left(\sqrt{150^2+x^2}-\sqrt{150^2+y^2}\right)=\frac{\lambda}{2} \\ x-y = d(峰,谷) \end{cases}$$

# What if we change the reflection surface?

We replace the reflection surface into (1) **a smaller surface** (2) **a corner reflector** to observe Power v.s distance.

## Result

1. The original reflector exhibits a larger amplitude due to its larger effective area.
2. The equivalent reflection phase differs among different reflecting surfaces.

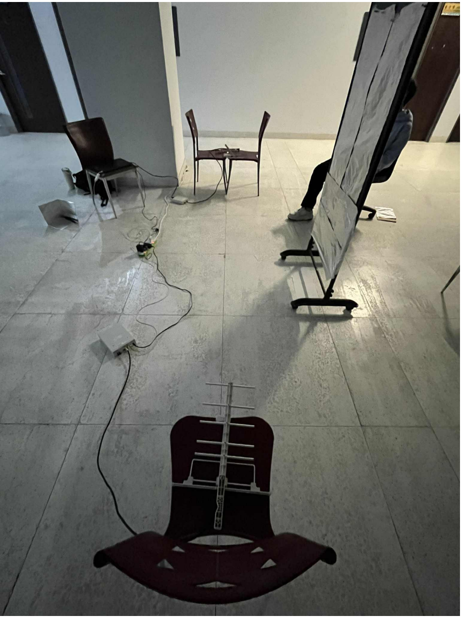


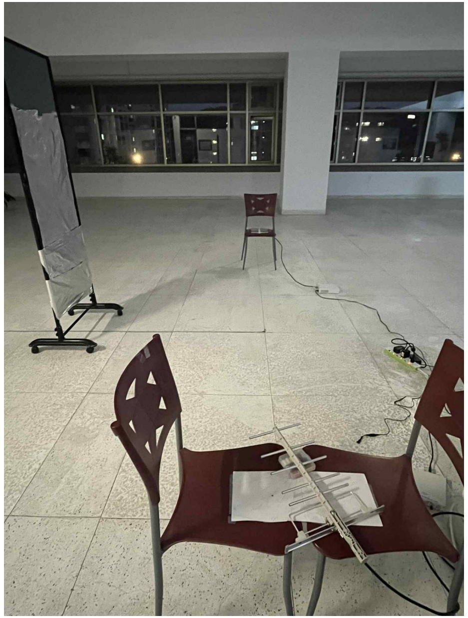
# Summary

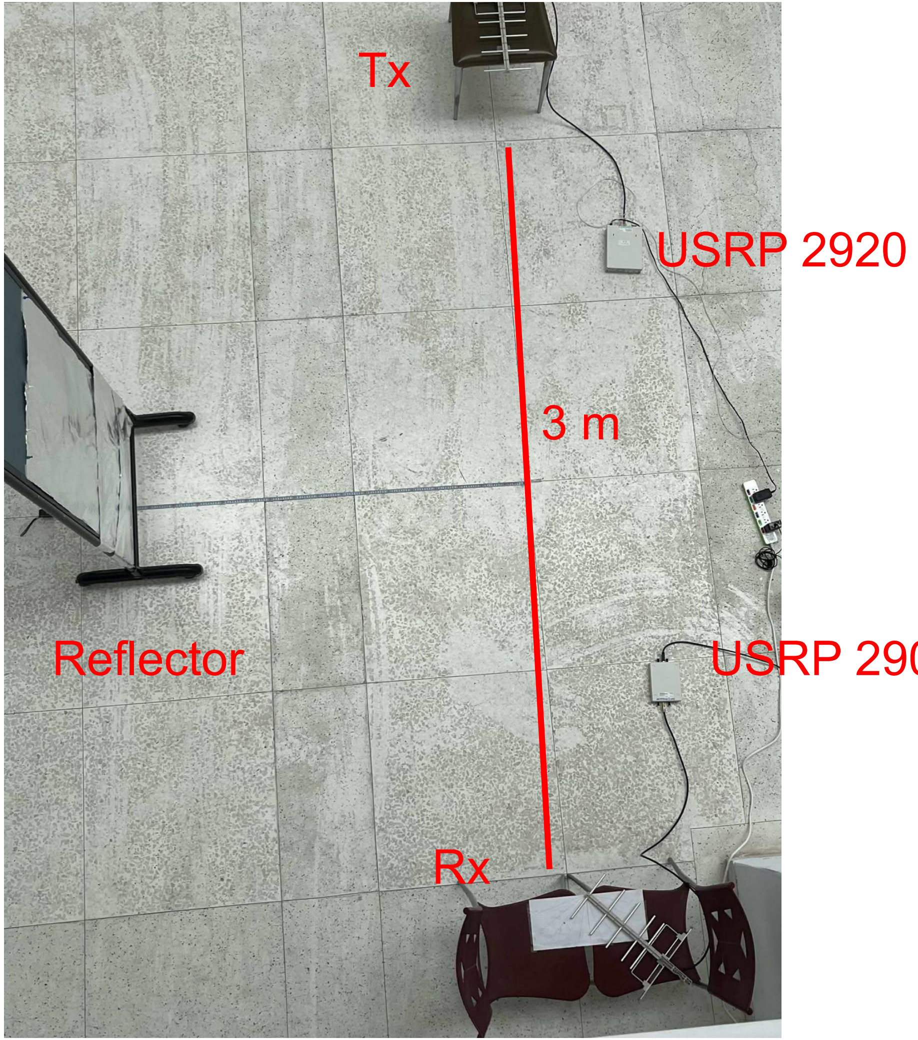
1. The Yagi–Uda antenna has **strong directivity.**
2. A reflecting surface **introduces multipath interference**, which can be clearly demonstrated through vertical displacement.
3. The observed interference pattern **agrees well with the theoretical model**.
4. Distance estimation is achieved **using peak–trough features**, with an **error of about ±10 cm**.
5. Different reflectors exhibit different reflection amplitudes and phase shifts.

# Communication Lab
# Final Project Demo
# Group 2

# Experiment Setting





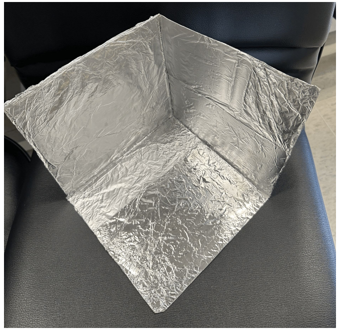


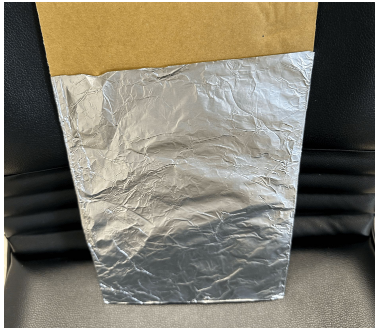
# Experiment Equipments

Tx: Yagi-Uda antenna + USRP 2920

Rx: Yagi-Uda antenna + USRP 2901

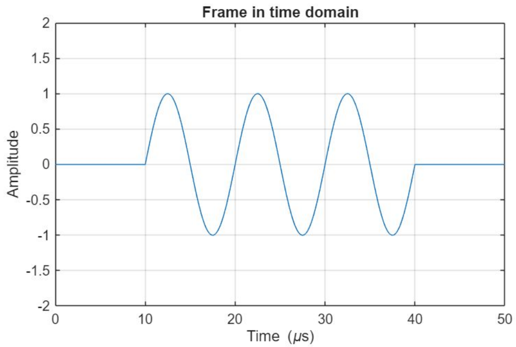
Reflectors





# Measurement of received power

Signal




```
% function
function [Signal_power, f, start_tone] = DegreevsEnergy(tx_frame)

N_fft = 64;
Fs = 10e6;
rx_length = length(tx_frame) + 5*N_fft; % Set receive buffer size to match transmitted frame
[radio_Tx, radio_Rx] = USRP_init(rx_length);

N_frames = 200;
rx_buffer = zeros(N_frames+30,rx_length) ;
rx_buffer_all = [];
for k = 1:N_frames
    tunderrun = radio_Tx(tx_frame(:));        % send k-th signal
    [rx_frame, ~, ~] = step(radio_Rx); % receive signal
    rx_buffer(k,:) = rx_frame.'; % save the signal to buffer
    rx_buffer_all = [rx_buffer_all, rx_buffer(k,:)];
end

release(radio_Tx);
release(radio_Rx);
```

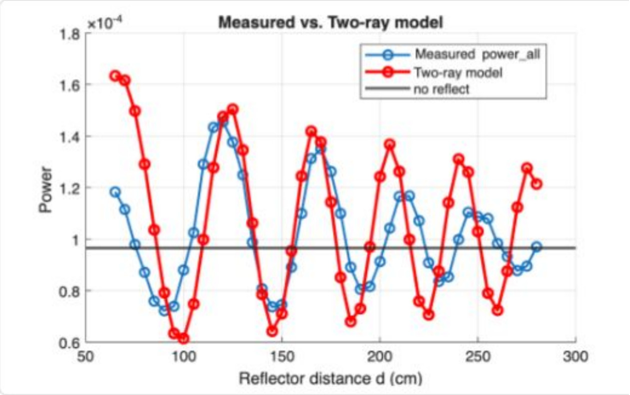
```
max_a = 0;
for i = 120:200
    f = rx_buffer(i,:);
    % === 找 tone 起點
    p  = abs(f).^2;
    ps = movmean(p, 64);
    cp = findchangepts(ps, 'Statistic','mean', 'MaxNumChanges', 4);
    start_tone = cp(1);
    start_tone = max(1, start_tone - 64);
    if abs(f(start_tone))<1e-3
        break;
    end
end

Ntone = 500;
stop_tone = min(length(f), start_tone + Ntone - 1);
seg = f(start_tone:stop_tone);

Signal_power = mean(abs(seg).^2);
end
```

# Mathematical model

```
d_cm = 50+5*((4:47)-1); d_m = d_cm/100;
lambda = 0.6;
h = 1.5;
R0 = 3;
eta = 0.3;
k = 2*pi/lambda;
Pavg = 9.65e-5;
A0 = range(P(4:47))*mean(d_m);
phi0 =-0*pi;
fig = figure('Name','Two-ray overlay','Color','w');
ax = axes('Parent',fig);
hold(ax,'on');
grid(ax,'on');
hMeas = plot(ax, d_cm, P(4:47), 'o-', 'LineWidth',1.5, 'Di
model_fun = @(A,phi) Pavg + eta.^2*Pavg*R0.^2./(2*(d_m.^2 
p_model0 = model_fun(A0, phi0);
hModel = plot(ax, d_cm, p_model0, 'ro-', 'LineWidth',2.0,
xlabel(ax,'Reflector distance d (cm)');
ylabel(ax,'Power ');
yline(Pavg, '-', 'LineWidth',2.0, 'DisplayName','no reflec
title(ax,'Measured vs. Two-ray model');
legend(ax,'Location','best');
```



# Distance estimation

```
peak index = 14.5, valley index = 3.5, Delta_d = 22 cm
```

```
h = 150;
lambda = 60;
rhs = lambda/4;

% 解：sqrt(h^2+x^2) - sqrt(h^2+y^2) = rhs,  x - y = Delta_d
% 令 x = y + Delta_d，解 g(y)=0
g = @(yy) sqrt(h^2 + (yy + Delta_d).^2) - sqrt(h^2 + yy.^2) - rhs;

y_sol = fzero(g, [80, 200]);
x_sol = y_sol + Delta_d;

fprintf('Solved x = %.6f cm, y = %.6f cm\n', x_sol, y_sol);
```

```
Solved x = 151.009221 cm, y = 129.009221 cm
```

```
start_est = y_sol - 2*(min(idx_peak, idx_val) - 1);

fprintf('Estimated start distance ≈ %.6f cm\n', start_est);
```

```
Estimated start distance ≈ 124.009221 cm
```