# Improving Detection Accuracy using Subspace Method in LCX Based Positioning System of Radio Terminals


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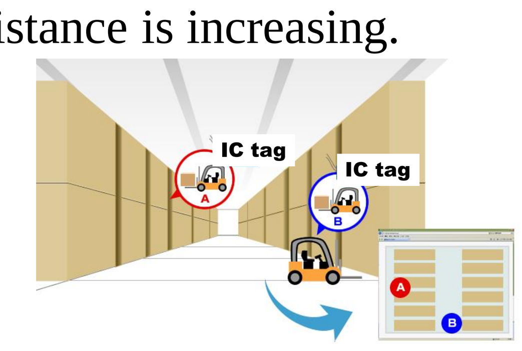
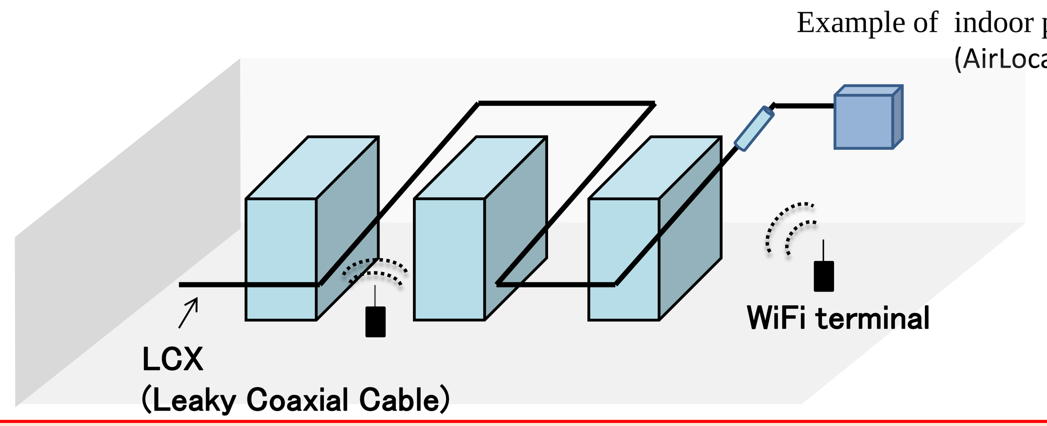
## Background

- **The spread of smart phone**
  The service using position information is provided. ➡ The demand for position detection using personal assistance is increasing.
- **Existing positioning system**
  **GPS** is not effective indoors.
  The system using **ZigBee** or **RFID** needs many readers.




Example of indoor positioning system using RFID (AirLocation:Hitach corp.)

- **Proposal**



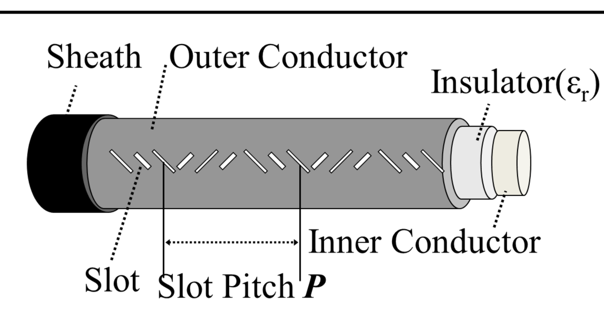

We use OFDM (Orthogonal Frequency Division Multiplexing) signals and Leaky Coaxial Cable(LCX). By using them,
- we can decrease the number of base stations and develop radio area in the wide range.
- we can provide wireless communication service and positioning service simultaneously.

## Channel Response

- **Directivity of LCX**

$$\theta_m = \sin^{-1}\left(\sqrt{\varepsilon_r} + \frac{m\lambda_{RF}}{P}\right), \quad (m = -1, -2, \cdots)$$

LCX has two directivity by removing a terminator




- **Channel estimation using OFDM subcarriers**
  Channel response changes corresponding to a terminal position.
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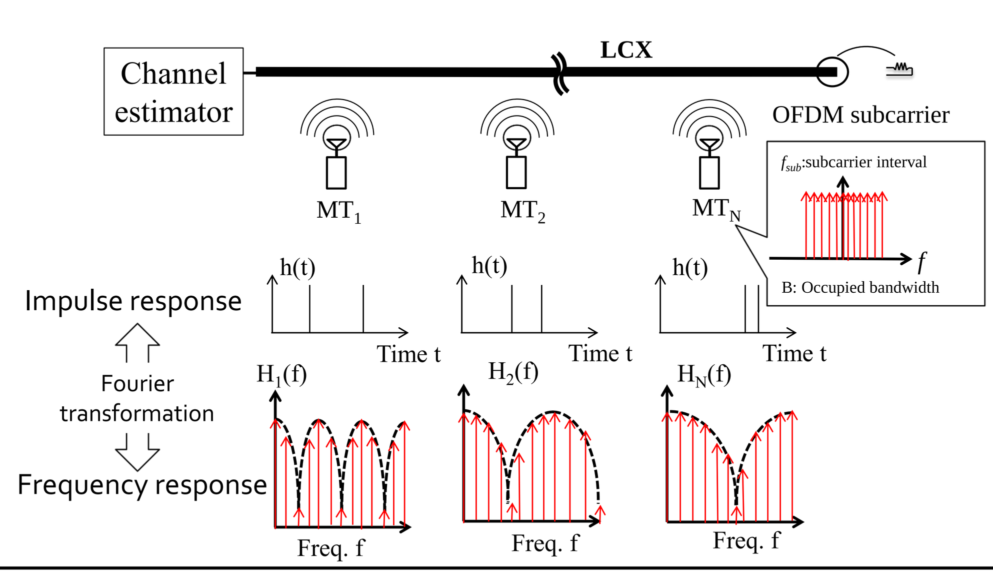
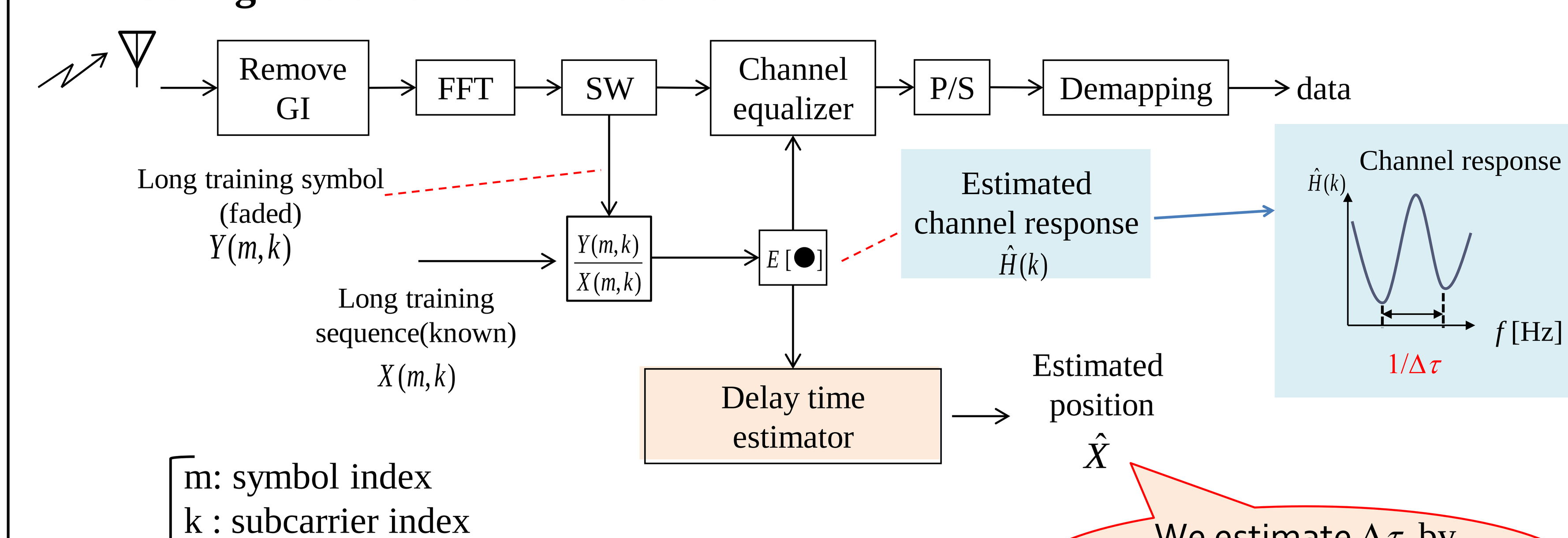
  Channel Response is multiplied by each OFDM subcarriers.




## Delay Time Estimation in Propagation Path

- **Configuration of OFDM receiver**




- **Application of subspace method in time domain under the condition that the input signal series consist of complex sine wave and a complex white noise**

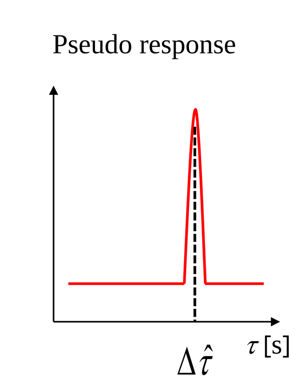
$$R = \sum_{i=1}^{M} \lambda_i \mathbf{v}_i \mathbf{v}_i^H = \sum_{i=1}^{p} (\zeta_i + \sigma_v^2) \mathbf{v}_i \mathbf{v}_i^H + \sum_{i=p+1}^{M} \sigma_v^2 \mathbf{v}_i \mathbf{v}_i^H$$

Autocorrelation matrix — Signal subspace — Noise subspace

$\mathbf{v}_i$ : eigenvector of $R$
$\zeta_i$ : eigenvalue of $R$ only from a sine wave signal
$\sigma_v^2$ : variance of white noise

➡ We decompose an autocorrelation matrix of channel response into signal subspace and Noise subspace.

$$g(\tau) = \frac{1}{\sum_{k=p+1}^{M} \left|\mathbf{e}^H \hat{\mathbf{v}}_k\right|^2} \quad : \text{Pseudo response}$$




IFFT vector

$$e = \left[1, \exp(j2\pi\tau), \exp(j2\pi 2\tau), \cdots, \exp(j2\pi(M-1)\tau)\right]^H$$

We estimate terminal position using $\Delta\hat{\tau}$ which shows a peak in pseudo response.

## Principle of Detecting a Position

- **Channel response in propagation path**

$$H(f) = \sum_{i=1}^{2} r_i \exp\{(j\phi_i - 2\pi f \tau_i)\} \quad \begin{pmatrix} \rho = a_1/a_2 \\ \Delta\tau = \tau_2 - \tau_1 \end{pmatrix}$$

$$|H(f)| \equiv \sqrt{1 + \rho^2 + 2\rho\cos\{2\pi f\Delta\tau - (\varphi_2 - \varphi_1)\}}$$

$|H(f)|$ is periodic function and its period is $f = (\Delta f) = \frac{1}{\Delta\tau} = \frac{1}{\tau_2 - \tau_1}$

- **Derivation of estimated position using Δτ**

$$\Delta\tau = \frac{2(L - X)\sqrt{\varepsilon_r}}{c} \iff \hat{X} = L - \frac{c\Delta\tau}{2\sqrt{\varepsilon_r}}$$

Δτ can be derived geometrically.
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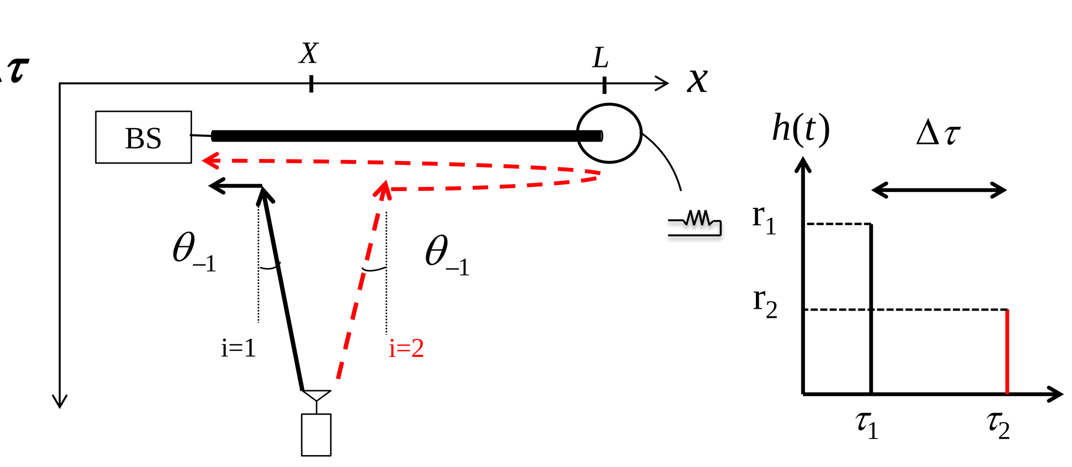
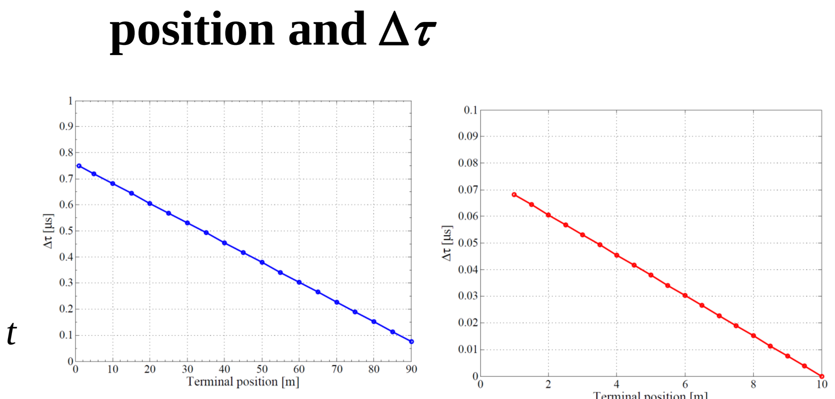
Target position can be estimated if Δτ is known

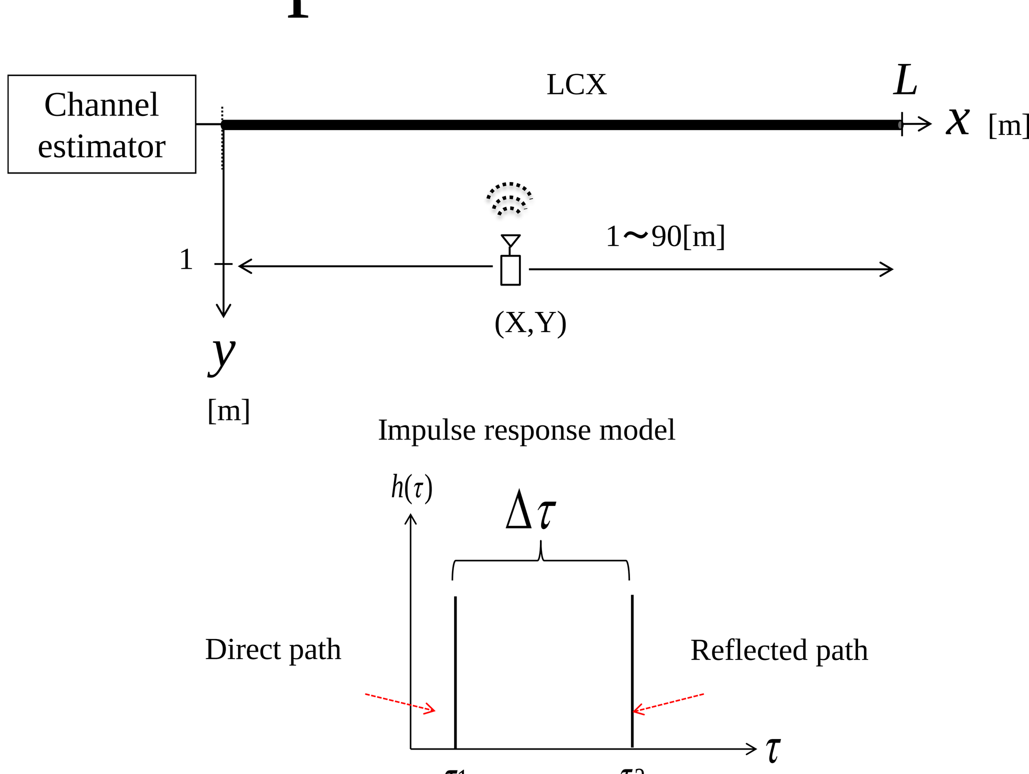



- **Relationship between a terminal position and Δτ**



(a) L=100m (b) L=10m

## Computer Simulation

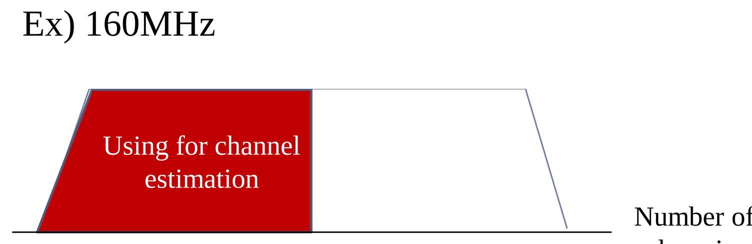



| Simulation parameters | |
|---|---|
| Radio standard | IEEE802.11g/a(OFDM) |
| Modulation | BPSK |
| FFT size | 64 |
| Subcarrier frequency spacing [kHz] | 312.5 |
| Effective symbol duration [μs] | 3.2 |
| Guard interval [μs] | 0.8 |
| Symbol interval [μs] | 4.0 |
| Occupied bandwidth [MHz] | 16.6 |
| Number of received frame | 1 |
| Length of LCX [m] | 100 |
| Peak directivity [deg] | -25 |
| AWGN | N/A |
| Fading | N/A |

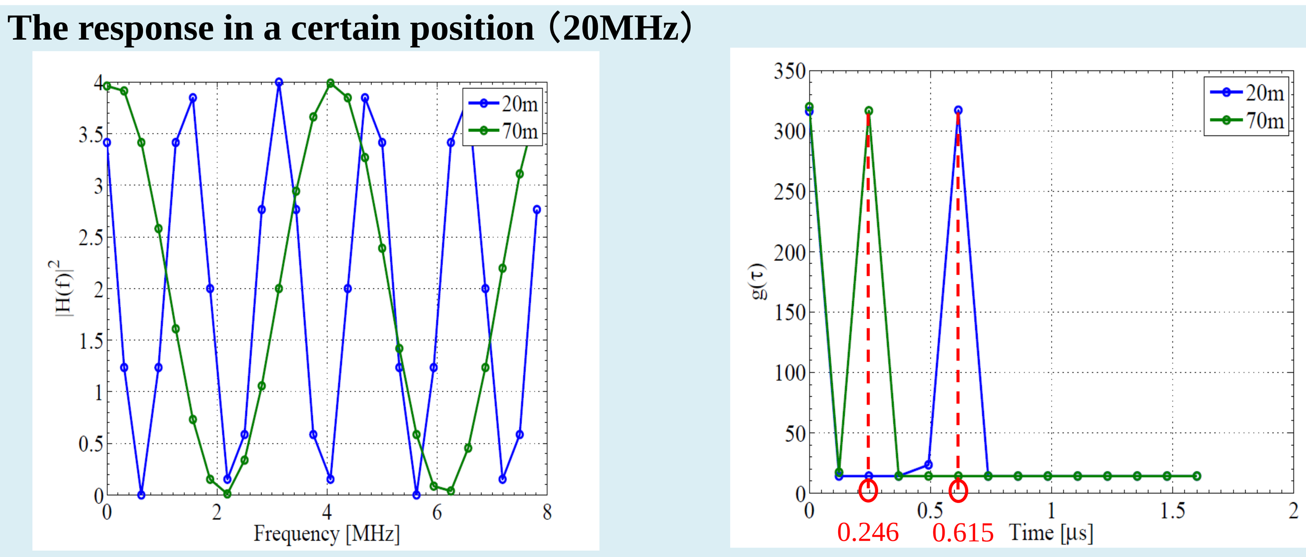
Broad band WiFi system parameters

| System [MHz] | Occupied bandwidth [MHz] | FFT size | Number of subcarrier |
|---|---|---|---|
| 20 | 16.6 | 64 | 52 |
| 40 | 33.2 | 128 | 104 |
| 80 | 66.4 | 256 | 208 |
| 160 | 132.8 | 512 | 416 |

Ex) 160MHz




- **The response in a certain position (20MHz)**




(a) Raw frequency response (b) Pseudo response

Delay time

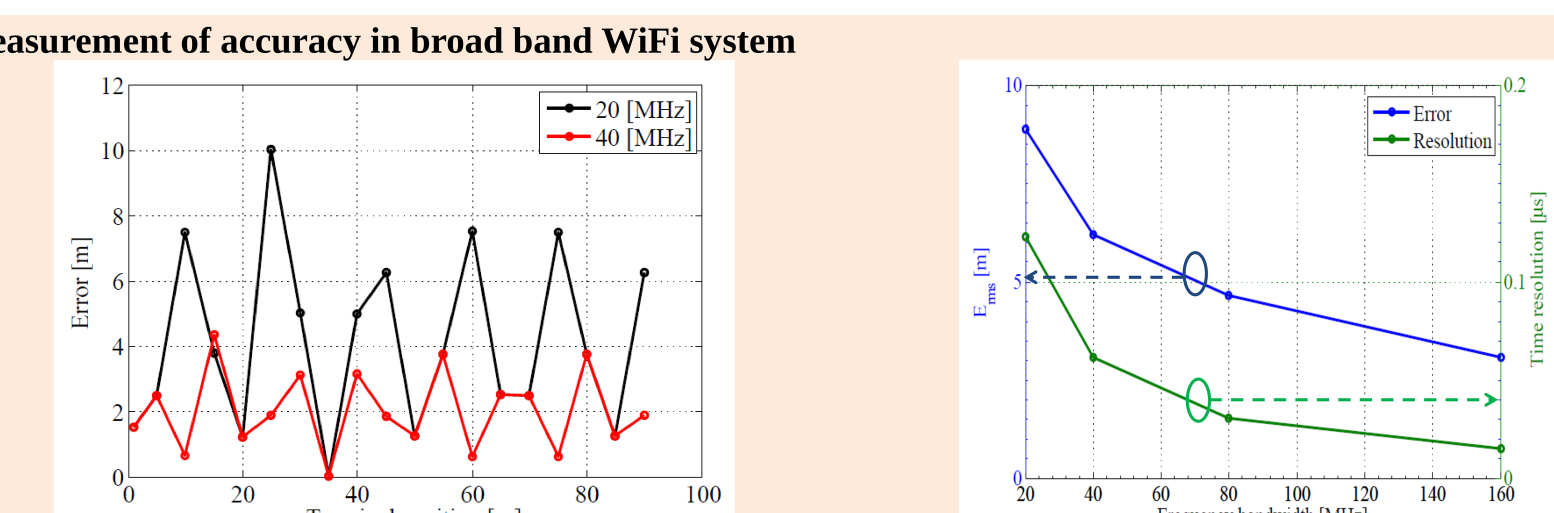
| Δτ [μs] | $\Delta\hat{\tau}$ [μs] |
|---|---|
| 0.606 | 0.615 |
| 0.227 | 0.246 |

⬇

Target position

| X [m] | $\hat{X}$ [m] |
|---|---|
| 20 | 18.8 |
| 70 | 67.5 |

- **Measurement of accuracy in broad band WiFi system**




(a) Relationship between target position and error (b) Error and time resolution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