FDM based MIMO Spatio-Temporal Channel Sounder

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Motivation

The performance of MIMO communication system depends on the directional as well as temporal behaviour of channel.

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The field measurement data of MIMO channel are strongly required to develop and evaluate the MIMO communication systems.

An important difference between MIMO and SIMO channel sounding

→ the MIMO channel sounder needs some kind of multiplexing to distinguish between transmitting antennas.

MIMO Channel Parameter Estimation

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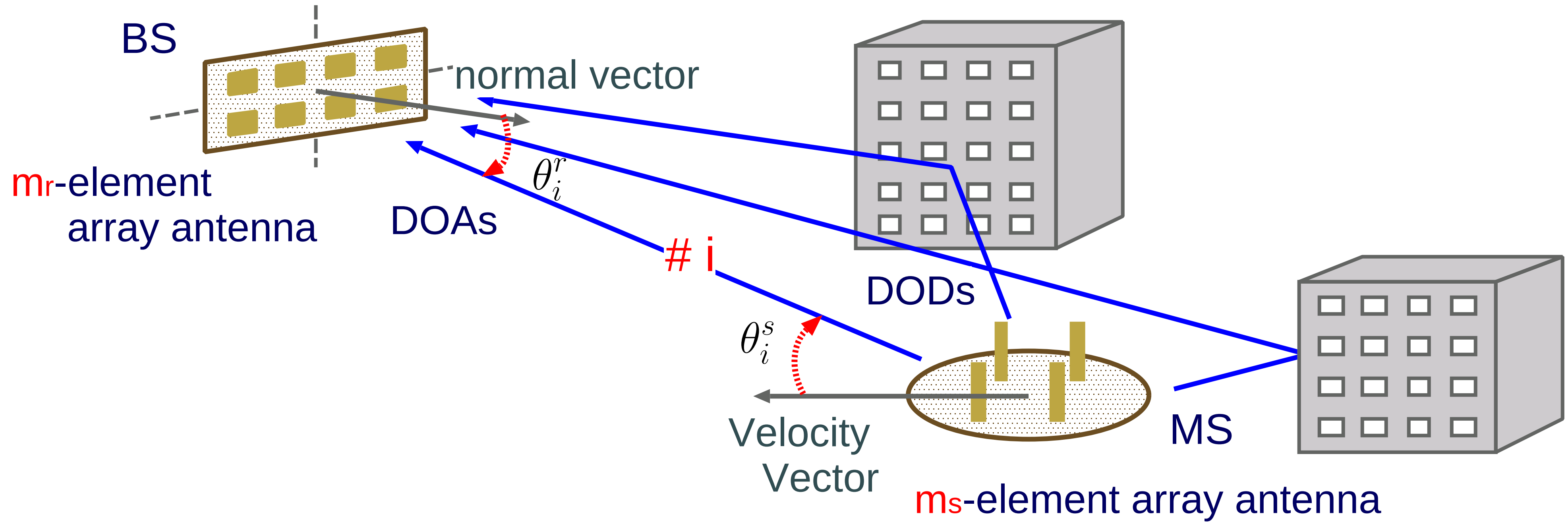


A $m_r \times m_s$ channel matrix $\mathbf{H}$ at the center frequency of f_c can be expressed as

$$\mathbf{H} = \sum_{\mathbf{i}} \gamma_{\mathbf{i}}(\mathbf{t}) \mathbf{e}^{-\mathbf{j}2\pi \mathbf{f_c} \tau_{\mathbf{i}}} \mathbf{a}(\theta_{\mathbf{i}}^{\mathbf{r}}) (\mathbf{a_s}(\theta_{\mathbf{i}}^{\mathbf{s}}))^{\mathbf{T}}$$

Frequency response vector is introduced for the wideband measurement.

The $m_r \times m_s \times m_f$ channel matrix $\mathbf{H}$ can be reformulated to an $m_r \cdot m_s \cdot m_f$ dimensional vector $\mathbf{h}$.

$$\mathbf{h} = \sum_{\mathbf{i}} \gamma_{\mathbf{i}} \mathbf{a}(\theta_{\mathbf{i}}^{\mathbf{r}}) \otimes \mathbf{a_s}(\theta_{\mathbf{i}}^{\mathbf{S}}) \otimes \mathbf{a_f}(\tau_{\mathbf{i}})$$

$\otimes$: Kronecker product

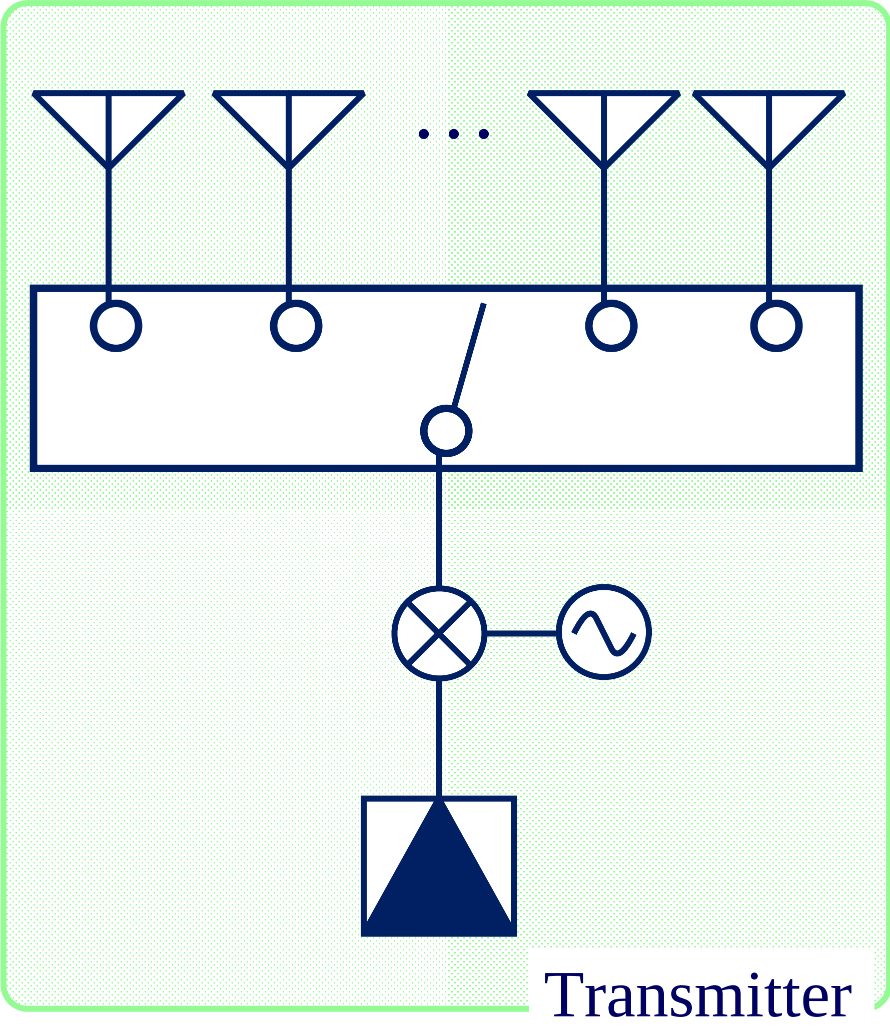
Approach to Multiplexing

By using an analogy with multi-user communication scenarios, we considered three types of multiplexing techniques for sounding purpose in terms of realtime measurement, hardware cost effectiveness, and major drawbacks.

The three types of multiplexing :

- TDM (Time Division Multiplexing)
- CDM (Code Division Multiplexing)
- FDM (Frequency Division Multiplexing)

TDM based Technique



- Realtime measurement ➡ poor

  Measurement which has m_s times baseband signal period and furthermore guard interval and switching are needed.

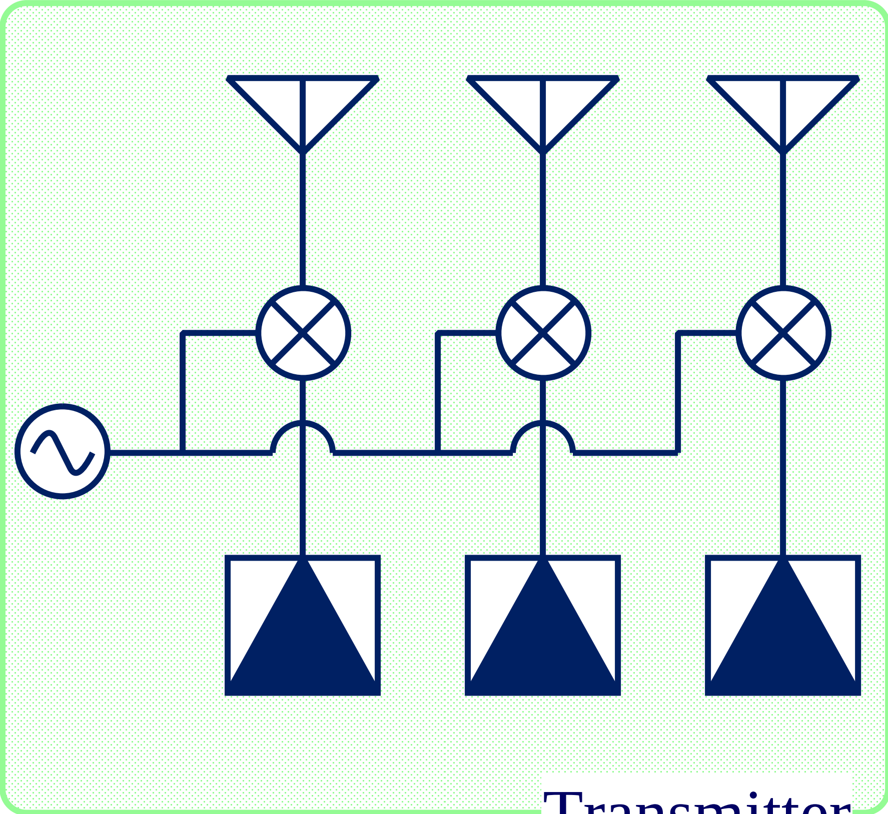
- Hardware cost ➡ excellent

  It is realizable only by changing one transmitter to the other antennas with a switch.

- Major drawback

  Absolute time synchronization between transmitter and receiver is required.

CDM based Technique



Transmitter

- Realtime measurement ➡ excellent

  Measurement period doesn't depend on m_s.

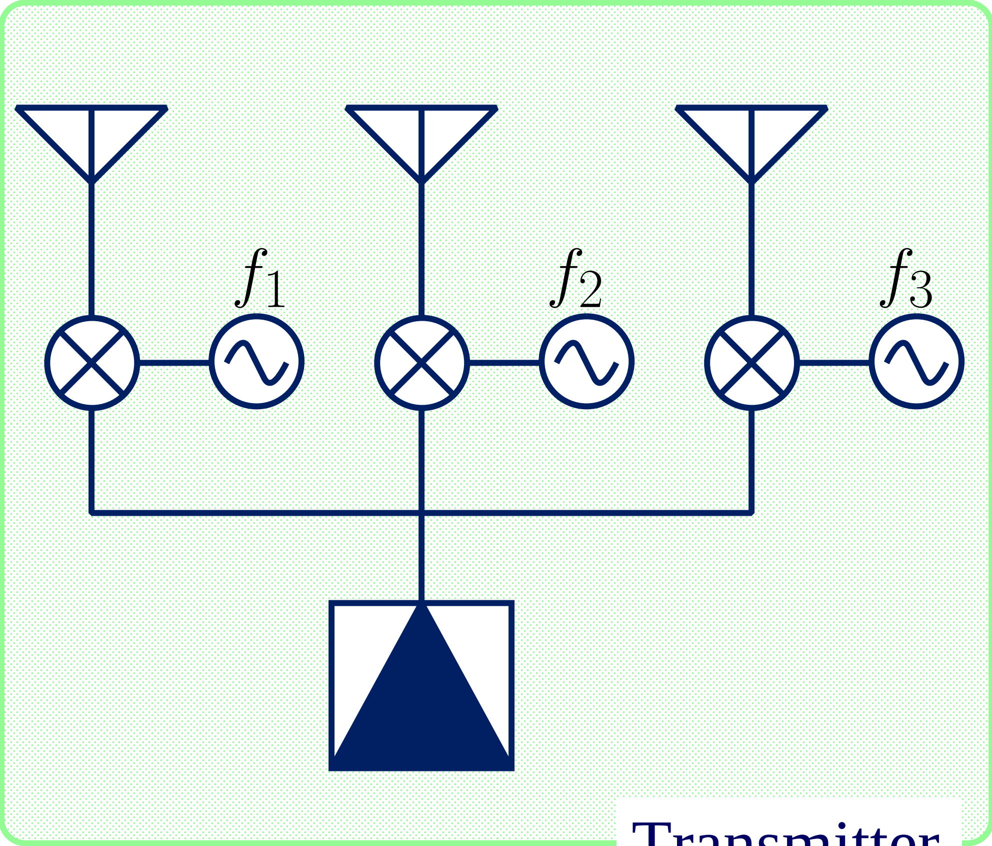
- Hardware cost ➡ poor

  It needs m_s transmitter channels.

- Major drawback

  Dynamic range of the system is limited by m_s due to cross-correlation between different codes.

FDM based Technique



Transmitter

- Realtime measurement ➡ good

  Measurement period is m_s times baseband signal period.

- Hardware cost ➡ good

  It requires m_s local oscillators, but one signal generator.

- Major drawback

  Some modification is needed for the data model, since the frequency sample points in each transmitting antenna are different.

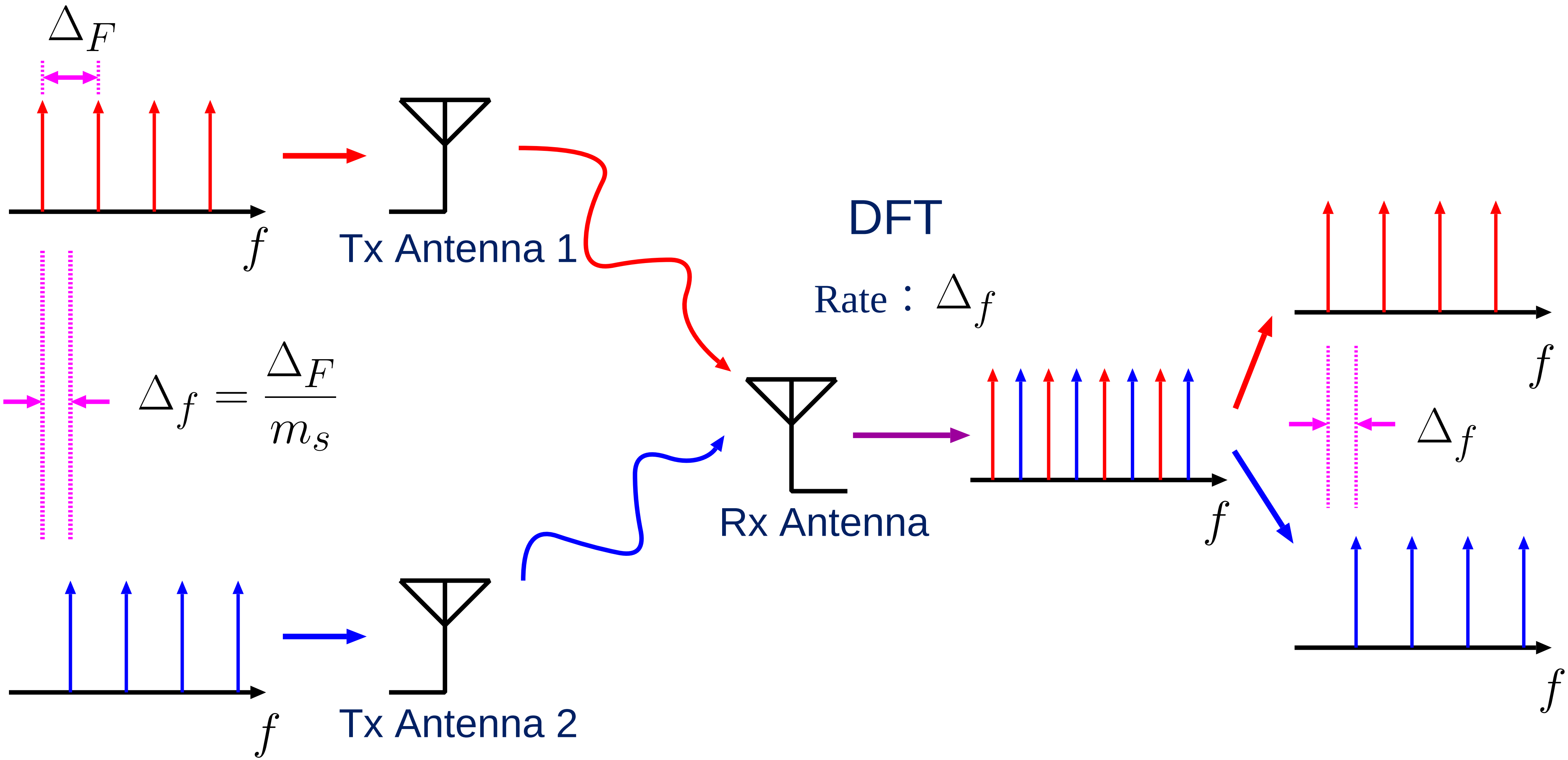
Comparison of Multiplexing

	Realtime Measurement	Hardware Cost	Major Drawback
TDM	poor	excellent	Synchronization between Tx and Rx
CDM	excellent	poor	Cross-correlation between codes
FDM	good	good	Frequency shift in Tx signals.

FDM achieve both realtime measurement and hardware cost effectiveness.

Therefore, we chose the FDM based technique.

Multi-tone FDM



Multi-tone Signal

Channel Impulse Response

A FDM response vector is defined as

$$\mathbf{a}_{\text{FDM}}(\tau_i) \triangleq [1, e^{-2\pi\Delta_f\tau_i}, \cdots, e^{-j2\pi(m_s-1)\Delta_f\tau_i}]^T$$

By using this vector, the transmitting array response vector is rewritten as

$$\mathbf{a}'(\psi_\mathbf{i}^\mathbf{s}) = \mathbf{a}(\theta_\mathbf{i}^\mathbf{s}) \odot \mathbf{a}_{\text{FDM}}(\tau_\mathbf{i})$$

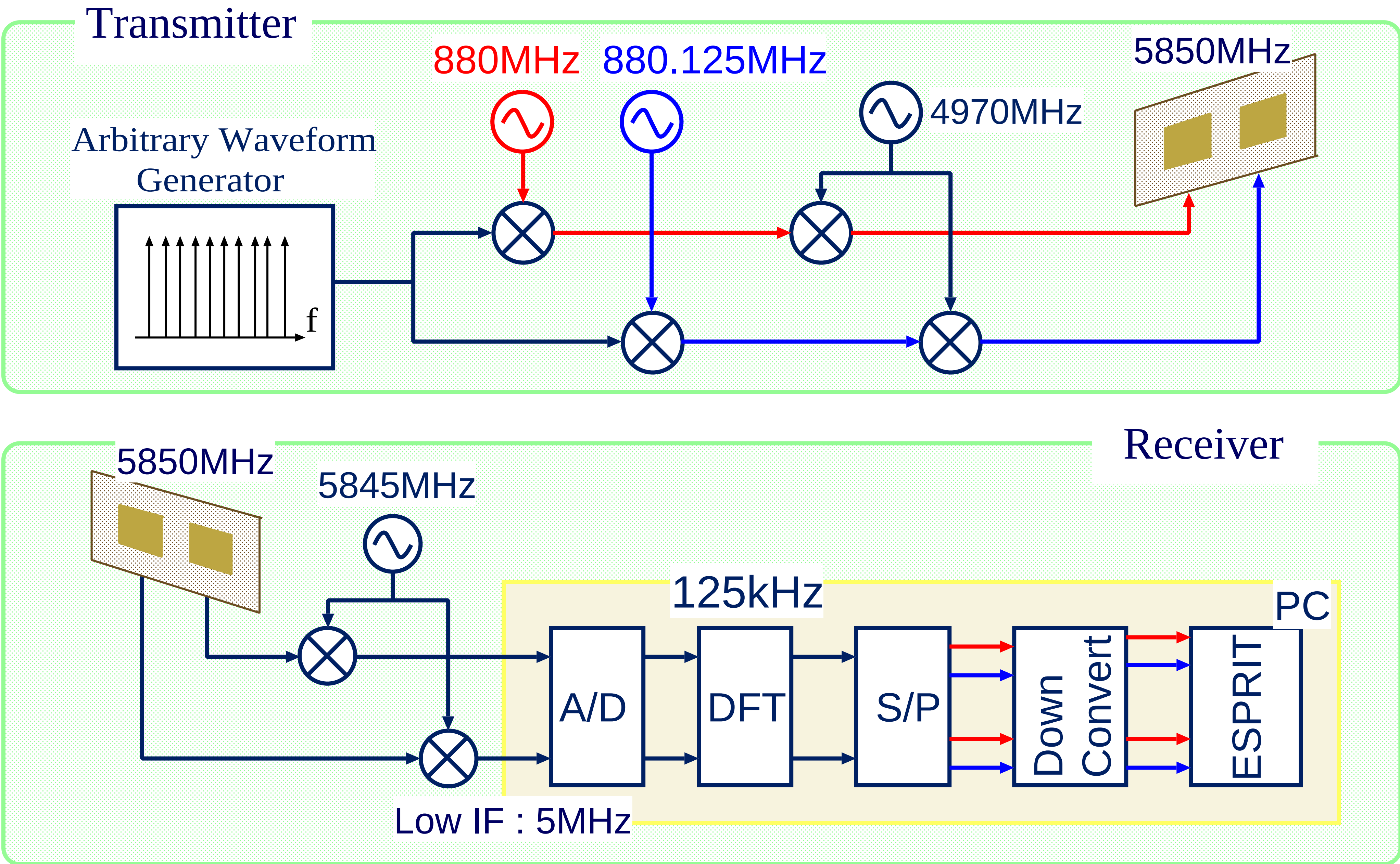
$\odot$: Hadamard product

Therefore, the channel response vector for FDM based MIMO system is written as

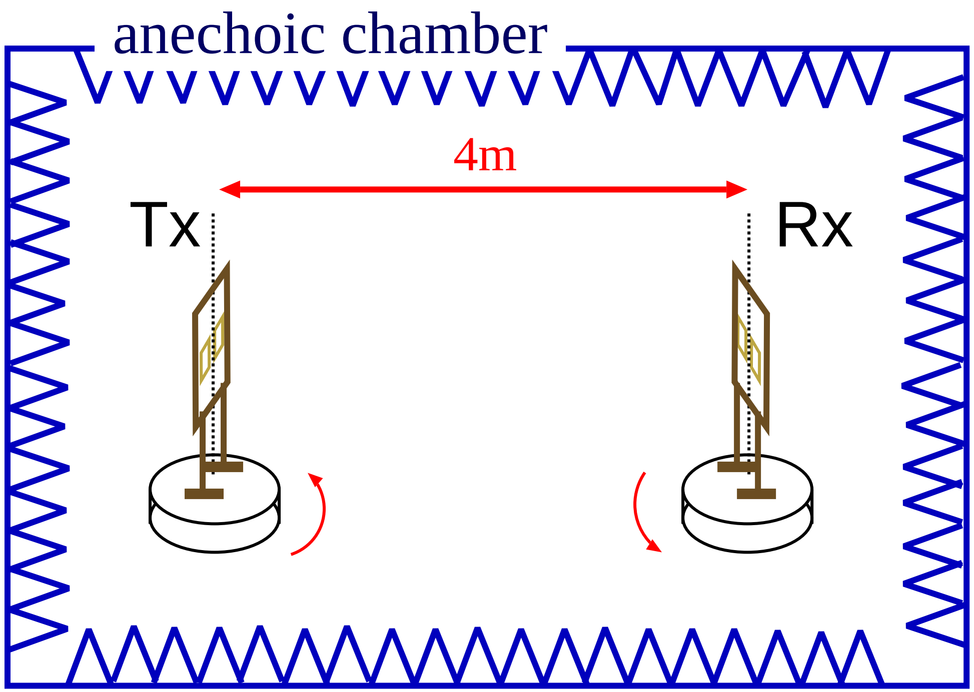
$$\mathbf{h}' = \sum_\mathbf{i} \gamma_\mathbf{i}(\mathbf{t})\mathbf{a}_\mathbf{r}(\theta_\mathbf{i}^\mathbf{r}) \otimes \mathbf{a}'_\mathbf{s}(\psi_\mathbf{i}^\mathbf{s}) \otimes \mathbf{a}_\mathbf{f}(\tau_\mathbf{i})$$

By using this, the parameter sets $\{\theta_i^r, \theta_i^s, \tau_i\}$ can be simultaneously estimated.

Hardware Implementation

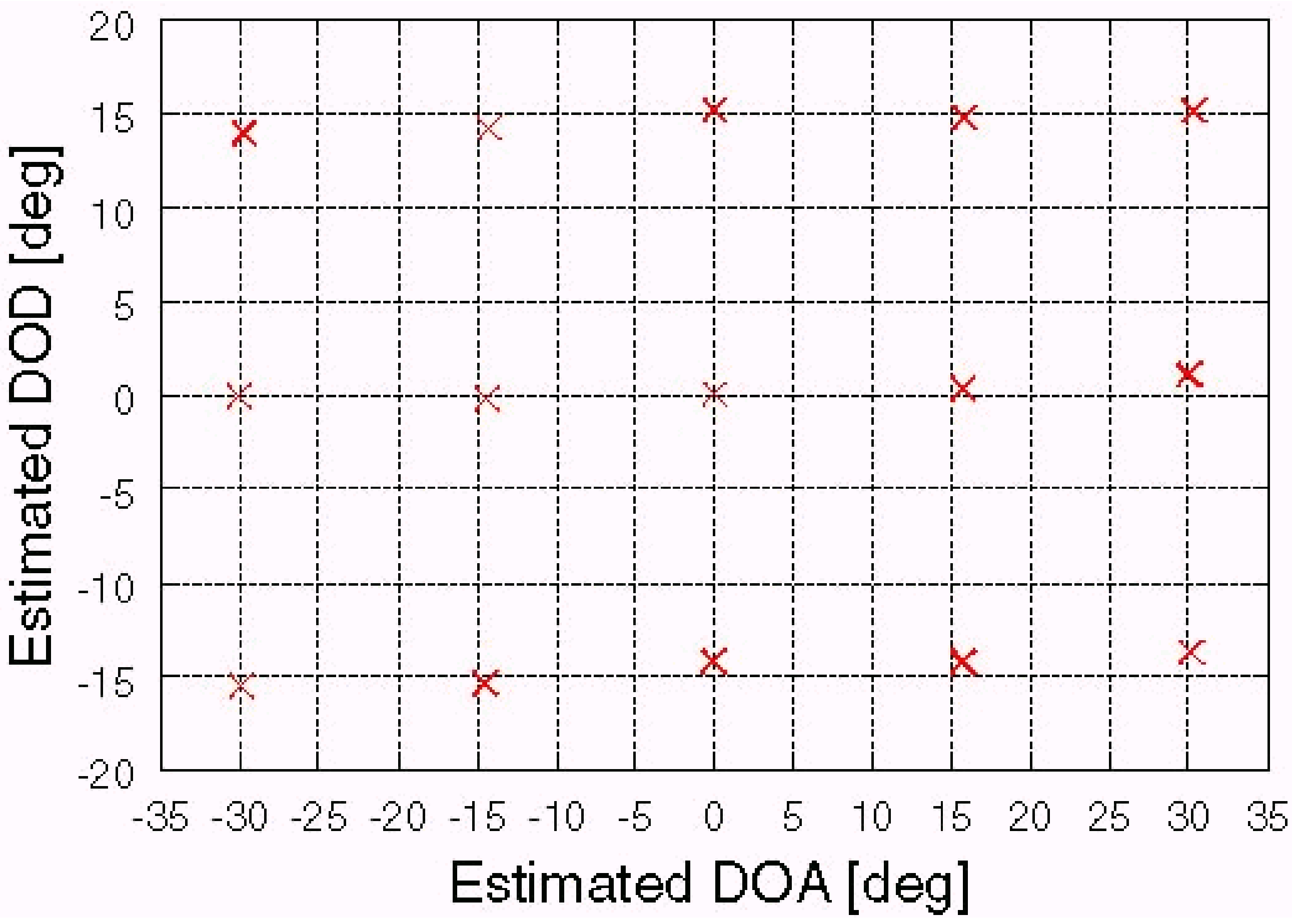


Measurement Environment



Tx antenna	2-element ULA
Rx antenna	2-element ULA
Bandwidth	9.5MHz
ΔF	500kHz
Δf	125kHz
Snapshot	30 times
SNR	about 30dB
Estimation algorithm	3-D Unitary ESPRIT

Measurement Results



Setting Value :
the every 15[deg] grid

The factor of the main error:

- Setup error
- Calibration error

Conclusion

- After considerable discussions about multiplexing techniques to distinguish between the transmitting antennas, the FDM based architecture was chosen to achieve cost effectiveness and realtime measurement.

- In the frame work of FDM, we proposed a new transmitting signal configuration and a new algorithm to estimate the MIMO channel parameters.

- We implemented the FDM based MIMO channel Sounder.

- We confirmed the validity of the FDM based architecture through measurements in anechoic chamber.