ISI and ICI Suppression for Mobile OFDM System by Using a Hybrid 2-Layer Diversity Receiver

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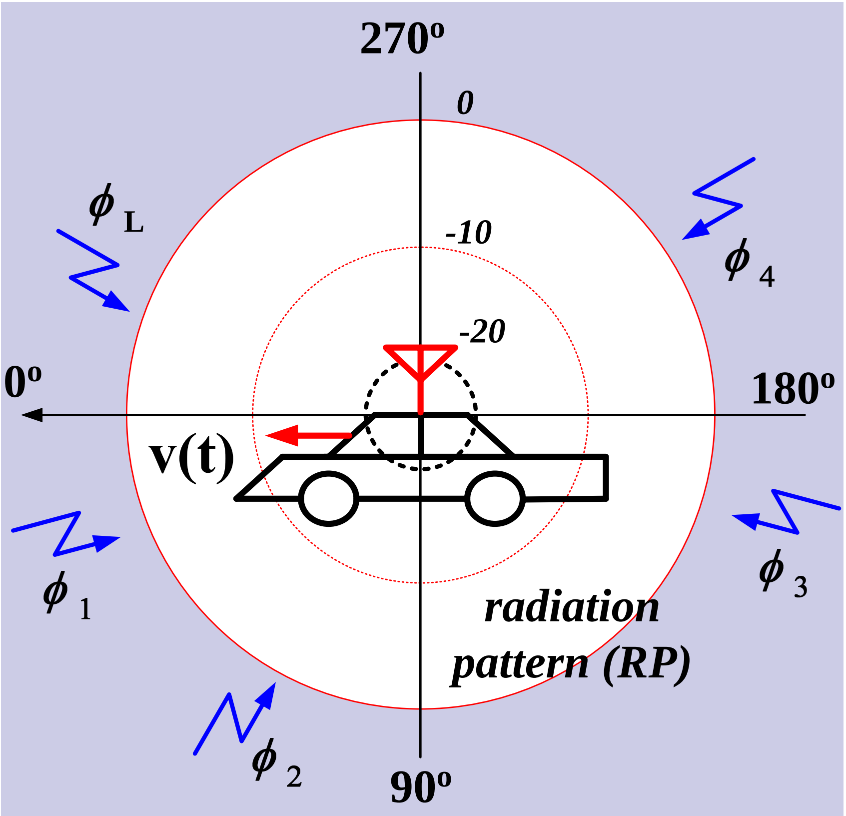
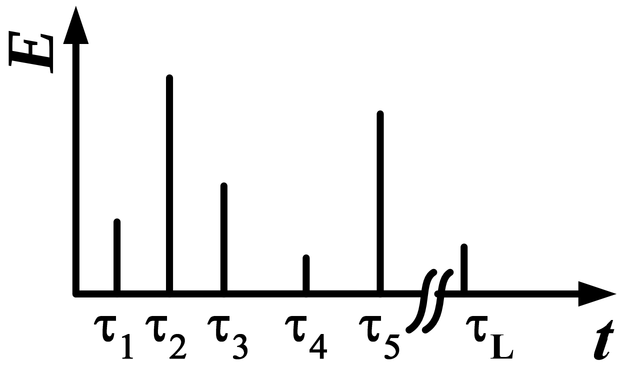
Research purpose:

- This research is focused on a high-performance and low-complexity OFDM receiver by taking account of inter symbol interference (ISI) and inter carrier interference (ICI) suppression.

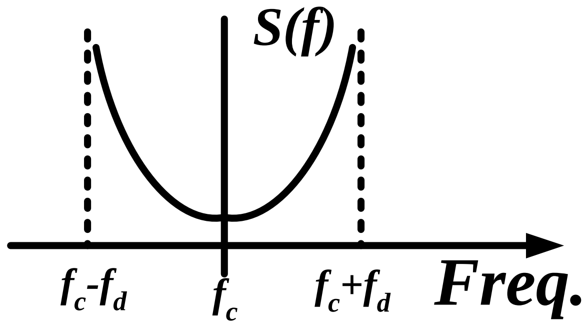
Background-1: Multi-path Fading Channel



delay profile:



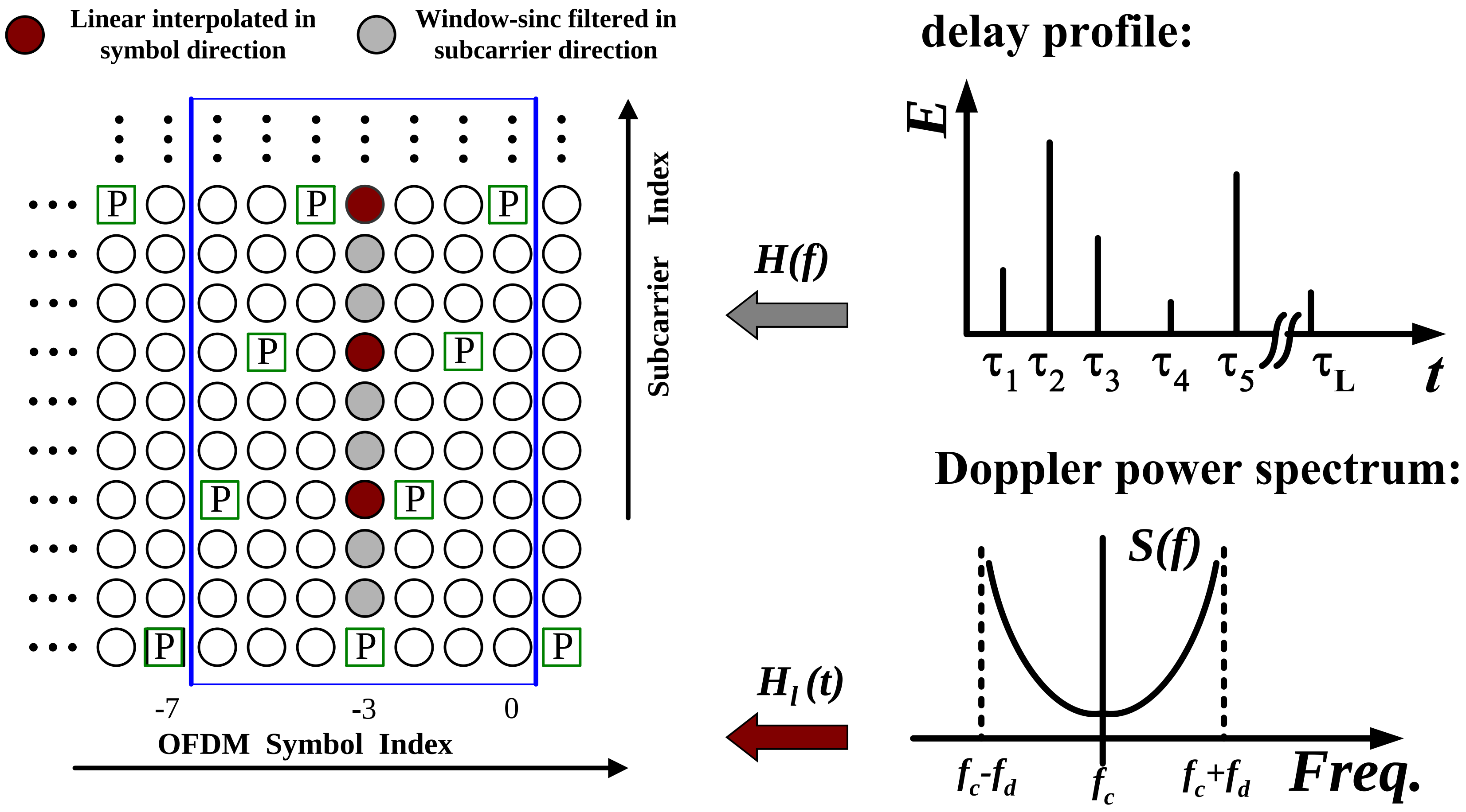
Doppler power spectrum:



ISI, delay-ICI and Doppler-ICI

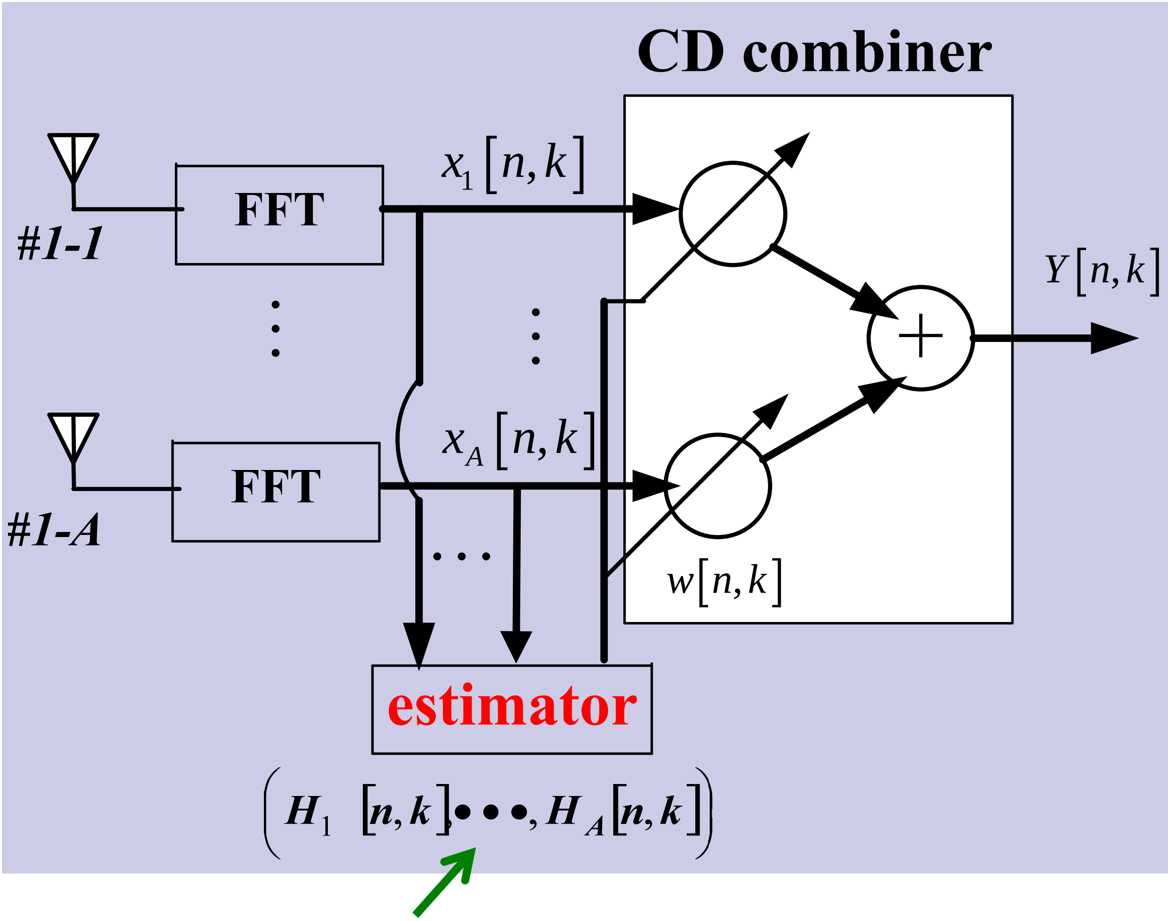
background-1:

the Channel Transfer Function (CTF) Estimating



***H (f, t) will be effected by* ISI, delay-ICI *and* Doppler-ICI**

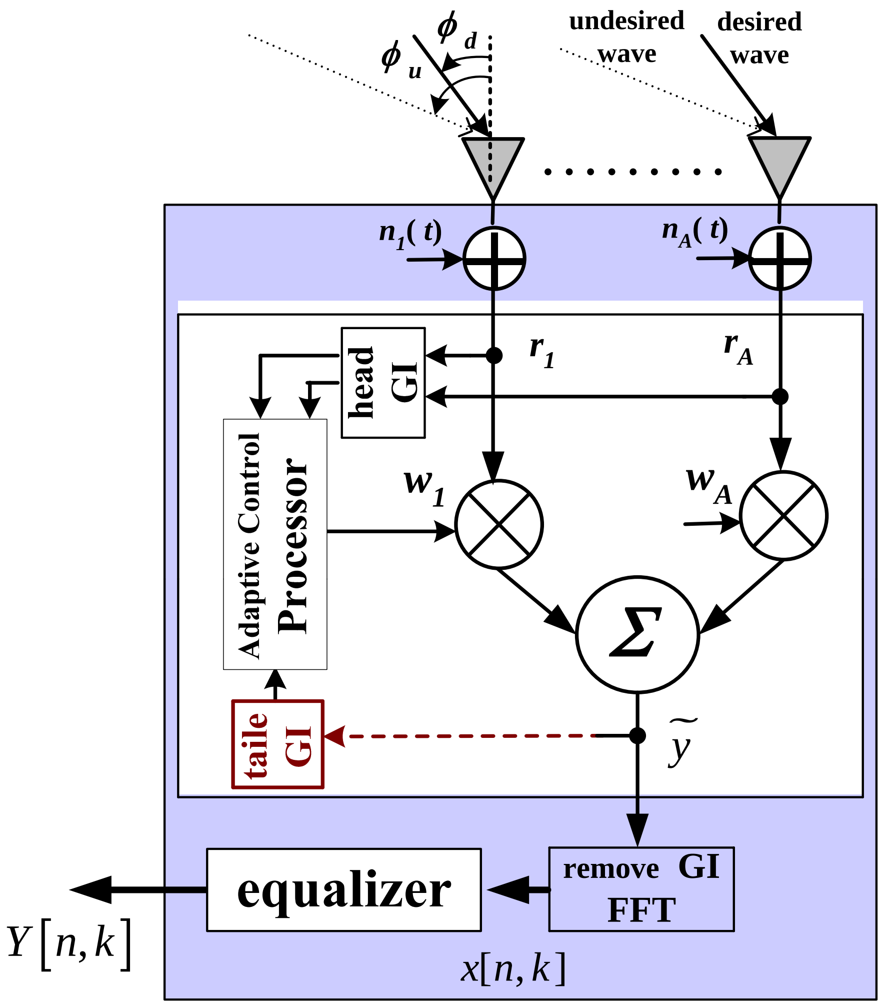
Background-2: Conventional post-FFT Carrier Diversity (CD) Combining Receiver



Channel Transfer Function (CTF)

- signal processing on sub-carrier basis
- high-complexity
- the challenge of accurate estimating of CTF

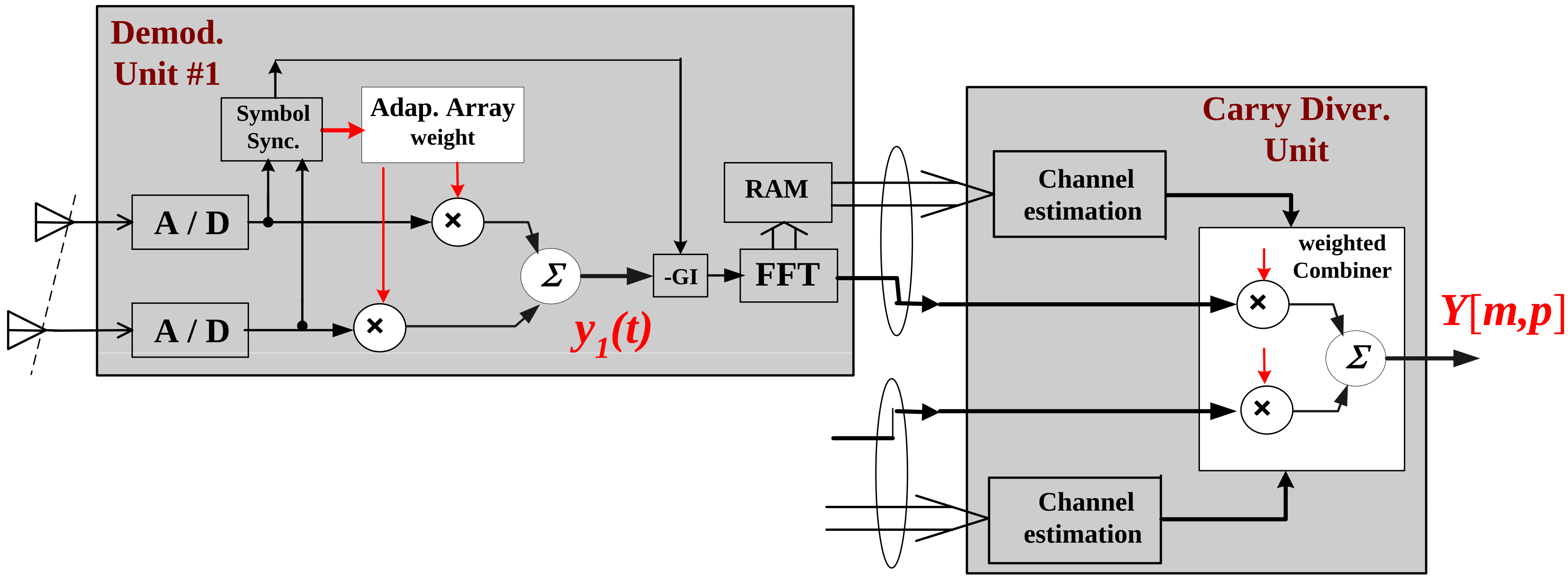
background 3: pre-FFT adaptive array (AA) receiver



- **low-complexity:**
  1. ***decreasing the number of FFT processors***
  2. ***Only 1-set of AA-weigh is required in one OFDM symbol duration***

- **undesired signals depressing:**
  1. ***ISI-suppression***
  2. ***more accurate estimating***

Hybrid AA/CD two-layer Receiver



1st layer:

1. **Depressed maxi-excess delay profile.**
2. **Modified SINR**

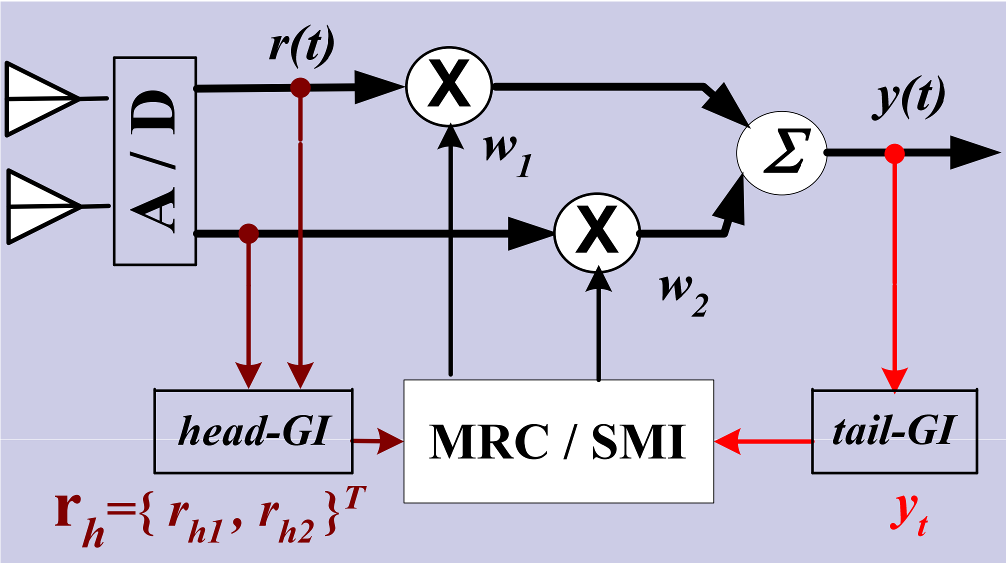
   (by using MMSE criteria)

2nd layer:

1. **High quality of CTF estimation**
2. **High performance Carrier**

   Diversity (CD)

1^{st} *layer:* **pre-FFT Adaptive Array (AA) Using Guard Interval (GI) of OFDM Symbol** ***(based on 2-element)***

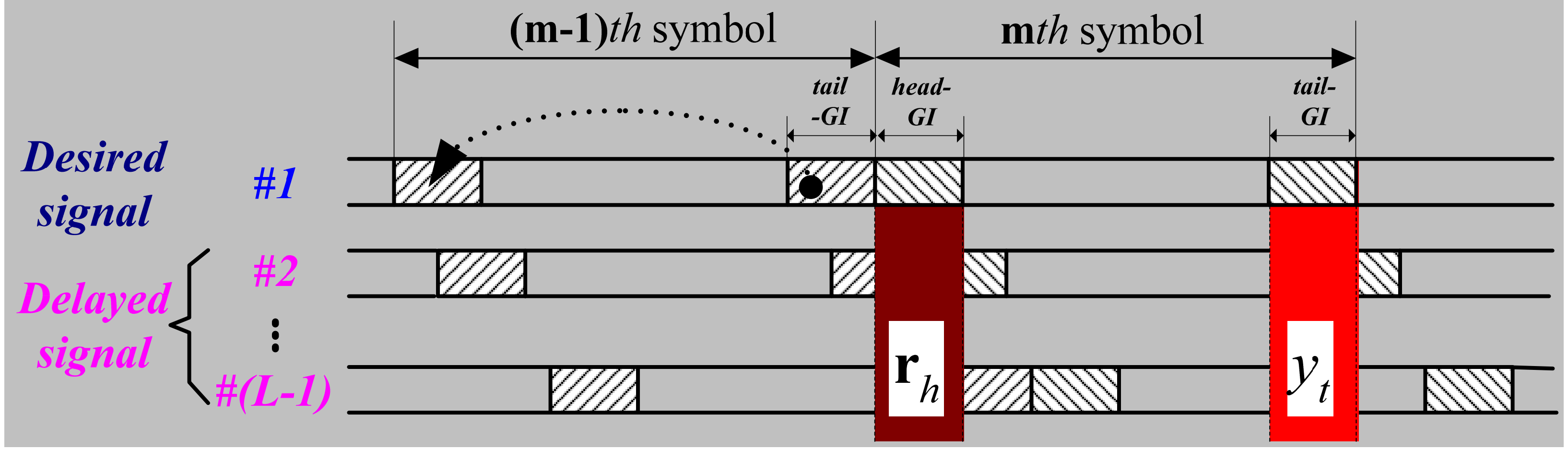


$$\mathbf{w}_{MRC} = E\left[\mathbf{r}_h(i)\, y_t^*(i)\right]$$

$$\mathbf{w}_{SMI} = \mathbf{R}_{rr}^{-1} E\left[\mathbf{r}_h(i)\, y_t^*(i)\right]$$

$$\mathbf{R}_{rr} = E\left[\mathbf{r}_h \mathbf{r}_h^H\right]$$

* **GI is the copying in front of a symbol from its own end.**



1st layer: **pre-FFT**

SMI and MRC Adaptive Array (AA) Schemes

Maxi-ratio Combining (MRC):

(using the cross-correlation vector)

$$\mathbf{w}_{MRC} = E\left[\mathbf{r}_h(i)\, y_t^*(i)\right]$$

Sample Matrix Inversion (SMI):

(MMSE criteria)

$$\mathbf{R}_{rr} = E\left[\mathbf{r}_h \mathbf{r}_h^H\right]$$

$$\mathbf{w}_{SMI} = \mathbf{R}_{rr}^{-1} E\left[\mathbf{r}_h(i)\, y_t^*(i)\right]$$

2[nd] layer: **post-FFT**

MRC And EGC Carrier Diversity (CD) Scheme

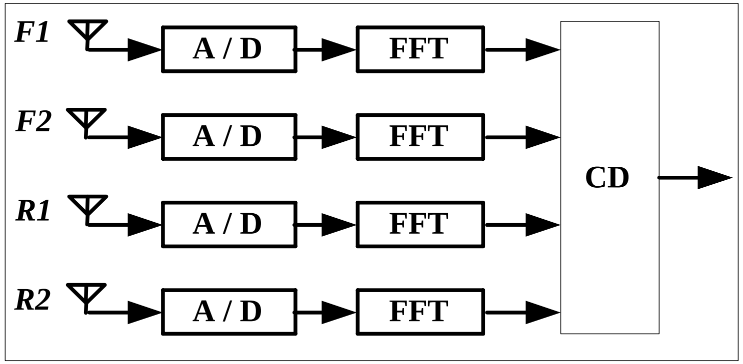
Maxi-ratio Combining (MRC): $$w_l(m,p) = \frac{H_l^*(m,p)}{\sum_{l=1}^{L} \left| H_l(m,p) \right|^2}$$

Equal Gain Combining (EGC): $$w_l(m,p) = \frac{H_l^*(m,p)}{\left| H_l(m,p) \right| \sum_{l=1}^{L} \left| H_l(m,p) \right|}$$

⇓

$$w_l(m,p) = \frac{H_l^*(m,p)}{\alpha_l}, \quad \text{where } \alpha_1 \text{ is a real factor.}$$

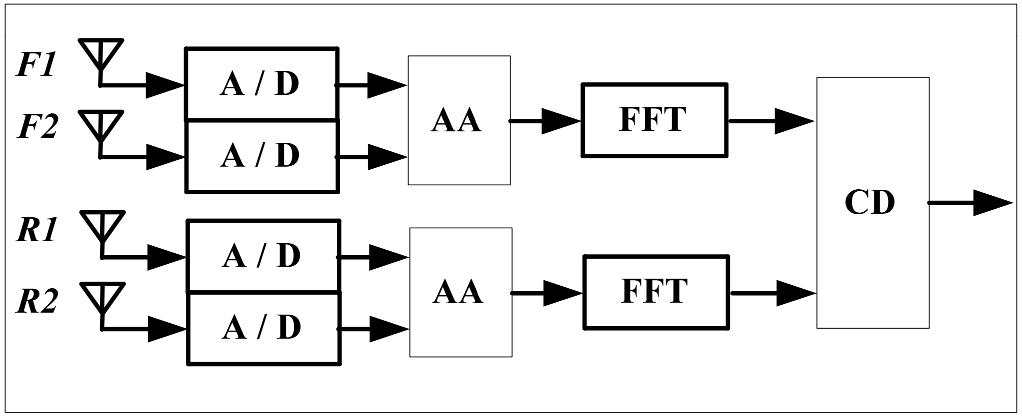
Simulation: 5 Kinds of the Receiver Models



Conventional CD Receiver

convention:

"cd-MRC"



Hybrid AA / CD Receiver

hybrid:

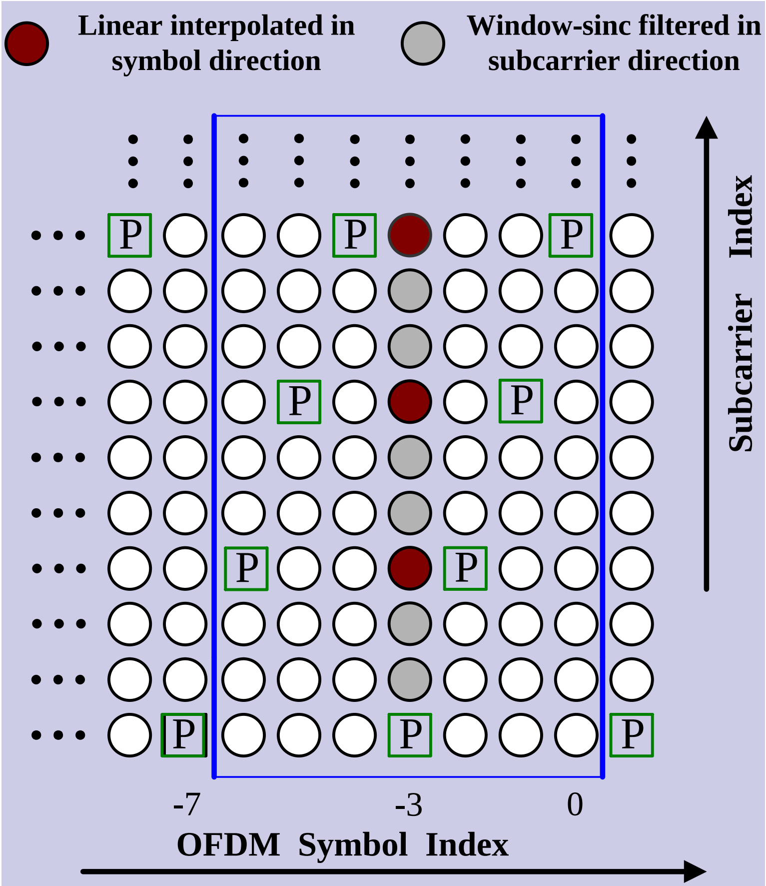
"aa-MRC / cd-MRC"

"aa-MRC / cd-EGC"

"aa-SMI / cd-MRC"

"aa-SMI / cd-EGC"

ICI-1: the CTF Estimation in Doppler Channel



$H_l(t)$

$$H_l(m,p) = \frac{x_l(m,p)}{d(m,p)}$$

CTF estimation in symbol direction at each pilot position

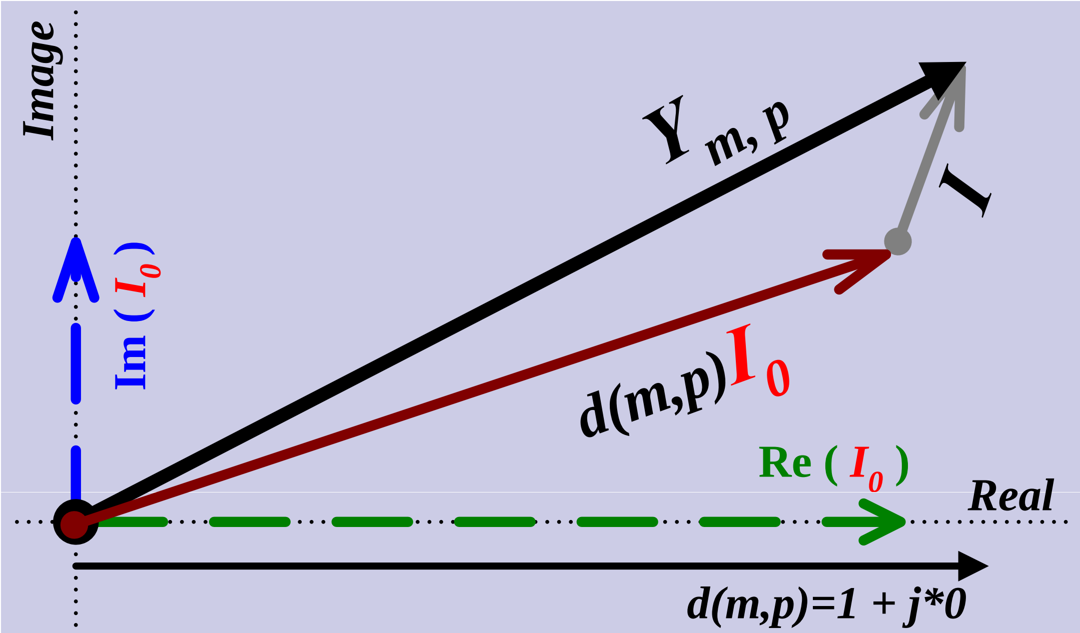
Doppler-modulated *l*th branch signal

$$x_l(m,p) = d(m,p)\frac{\sin \pi f_{Dl} T}{N \sin(\pi f_{Dl} T / N)} e^{j\pi f_{Dl} T \frac{N-1}{N}} + \sum_{k=0, k\neq p}^{N-1} d(m,k) I_{k-p}^{l}$$

$$= d(m,p) I_{0l} + I_l(m,p)$$

(Attenuation and phase-rotate + ICI)

ICI-2: **post-FFT CD Combining Over Doppler Branches**



$$I_0 = \sum_l \frac{1}{\alpha_l}\left(\left|I_{0l}\right|^2 + \frac{I_l^*(m,p)\, I_{0l}}{d^*(m,p)}\right)$$

$$I = \sum_l \frac{1}{\alpha_l}\left(\frac{\left|I_l(m,p)\right|^2}{d^*(m,p)} + I_{0l}^* I_l(m,p)\right)$$

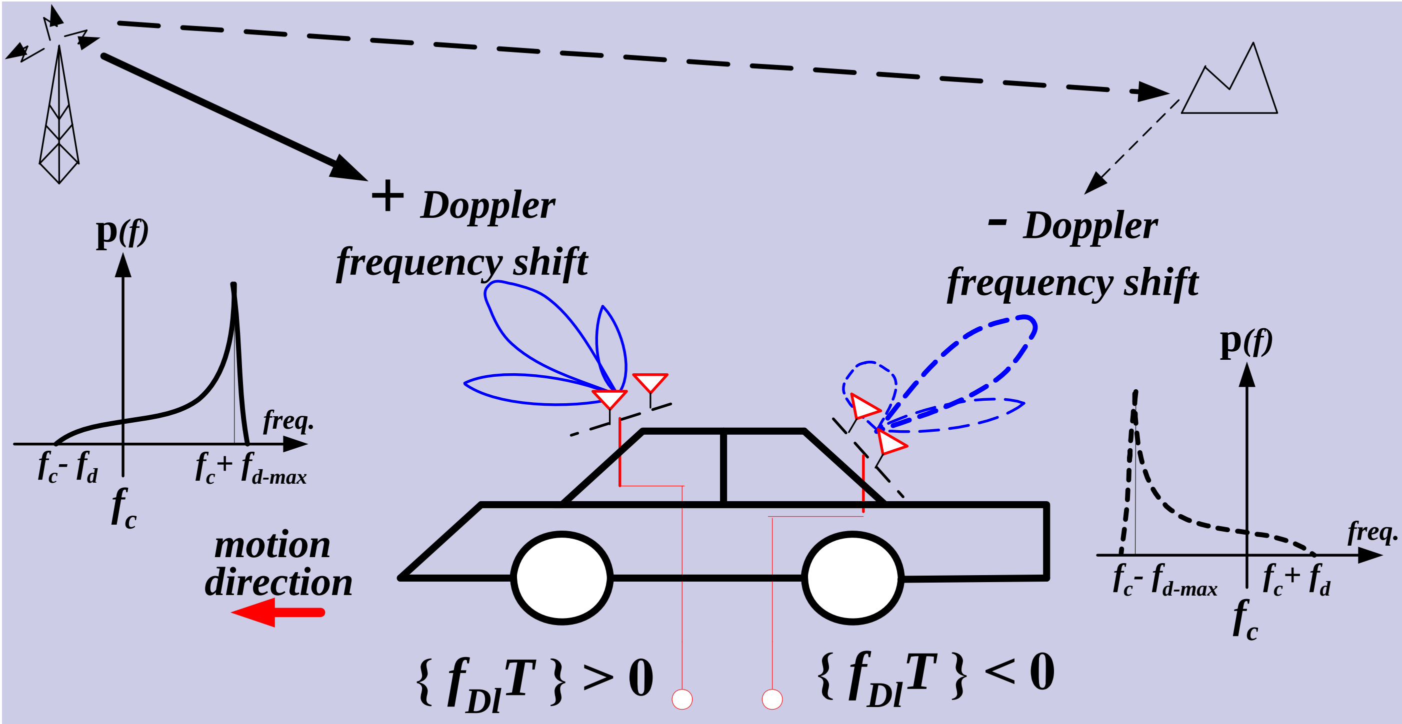
$$Y_{m,p} = \sum_l \frac{1}{\alpha_l} H_l^*(m,p)\, x_l(m,p)$$ **(CD combining output)**

$$= d(m,p)\, I_0 + I$$ (**useful component** + **ICI-noise**)

$$= d(m,p)\left\{\mathrm{Re}(I_0) + j * \mathrm{Im}(I_0)\right\} + I$$

data — **desired signal** — **extra-noise** — **ICI-noise**

ICI-3: post-FFT CD Combining Over Doppler Branches



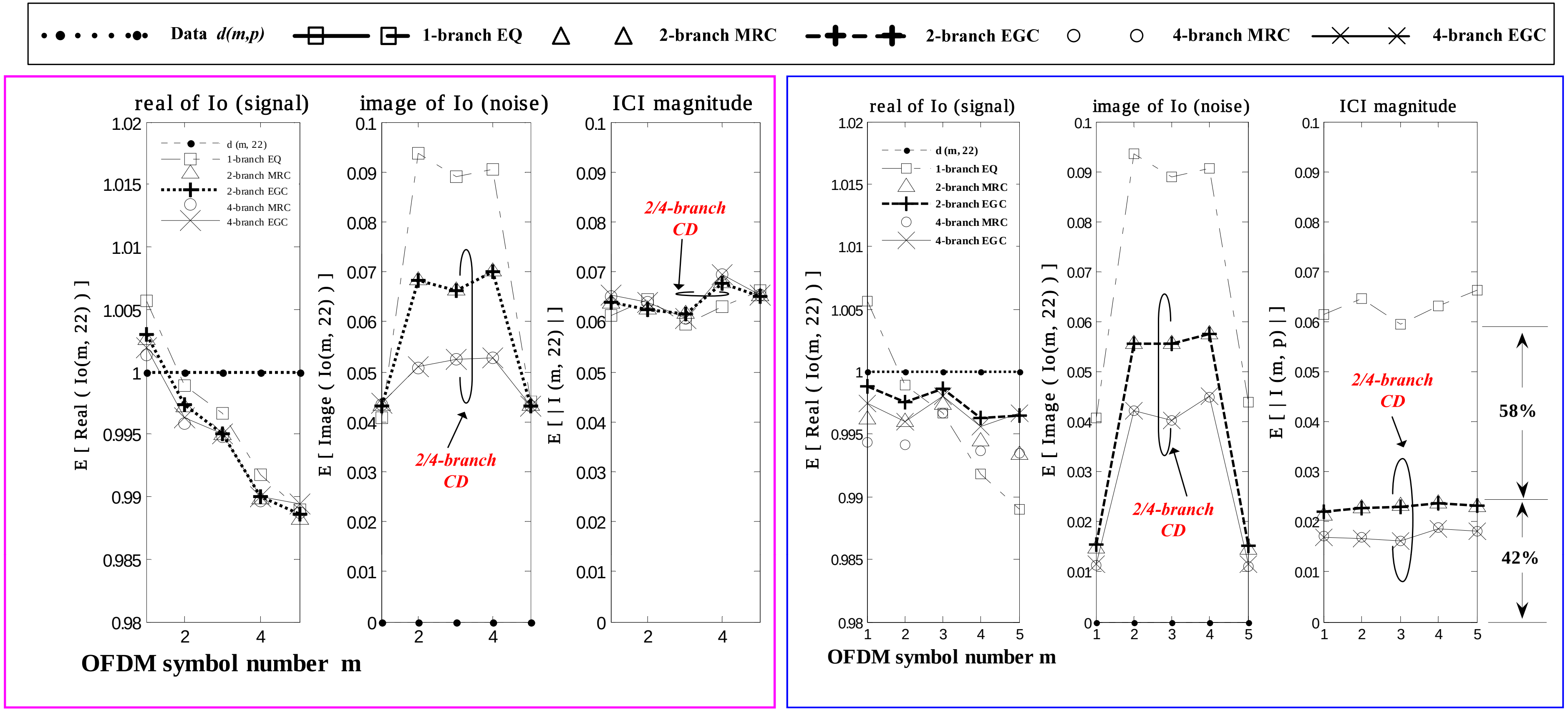
Case-1: *all the CD branch signal arrived from only the **Forward / or Rear** directions.*

CD over $\{+ f_{Dl}T\}$ *or* $\{- f_{Dl}T\}$

Case-2: *all the CD branch signal arrived from the **Forward-Rear** directions.*

CD over $\{\pm f_{Dl}T\}$.

ICI-4 : Using CD for ICI and Extra-noise Suppression



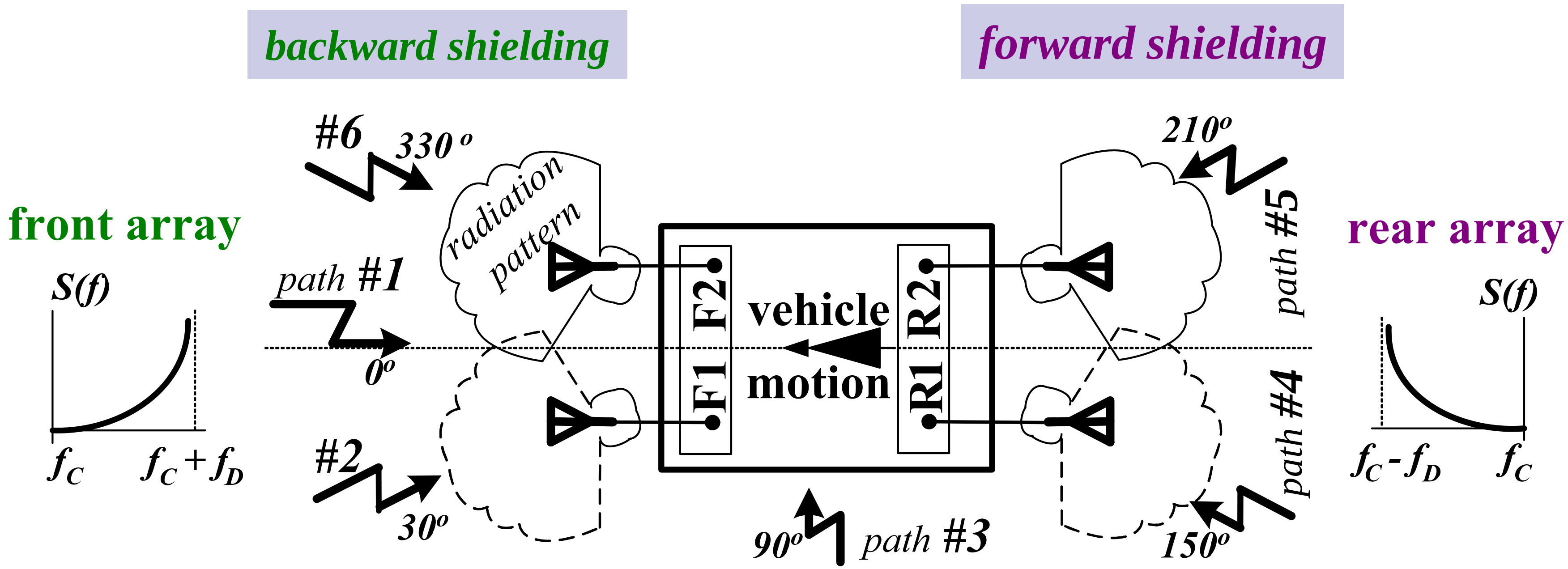
$0 < \{ f_{D1}T, f_{D2}T, f_{D3}T, f_{D4}T \} < 0.1$

$-0.1 < \{ f_{D1}T, f_{D2}T, f_{D3}T, f_{D4}T \} < 0.1$

- **the CD over both CASE-1 *(see left)* and CASE-2 *(see right)* can depress the extra noise by comparing with 1-branch EQ. In CASE-2 is more effective.**
- **the CD over $\{ \pm f_{Dl}T \}$ branches (*right* CASE-2) can suppress the ICI-noise significantly (58%).**

Mobile application-1:

Configuration of Antennas Mounted on Car

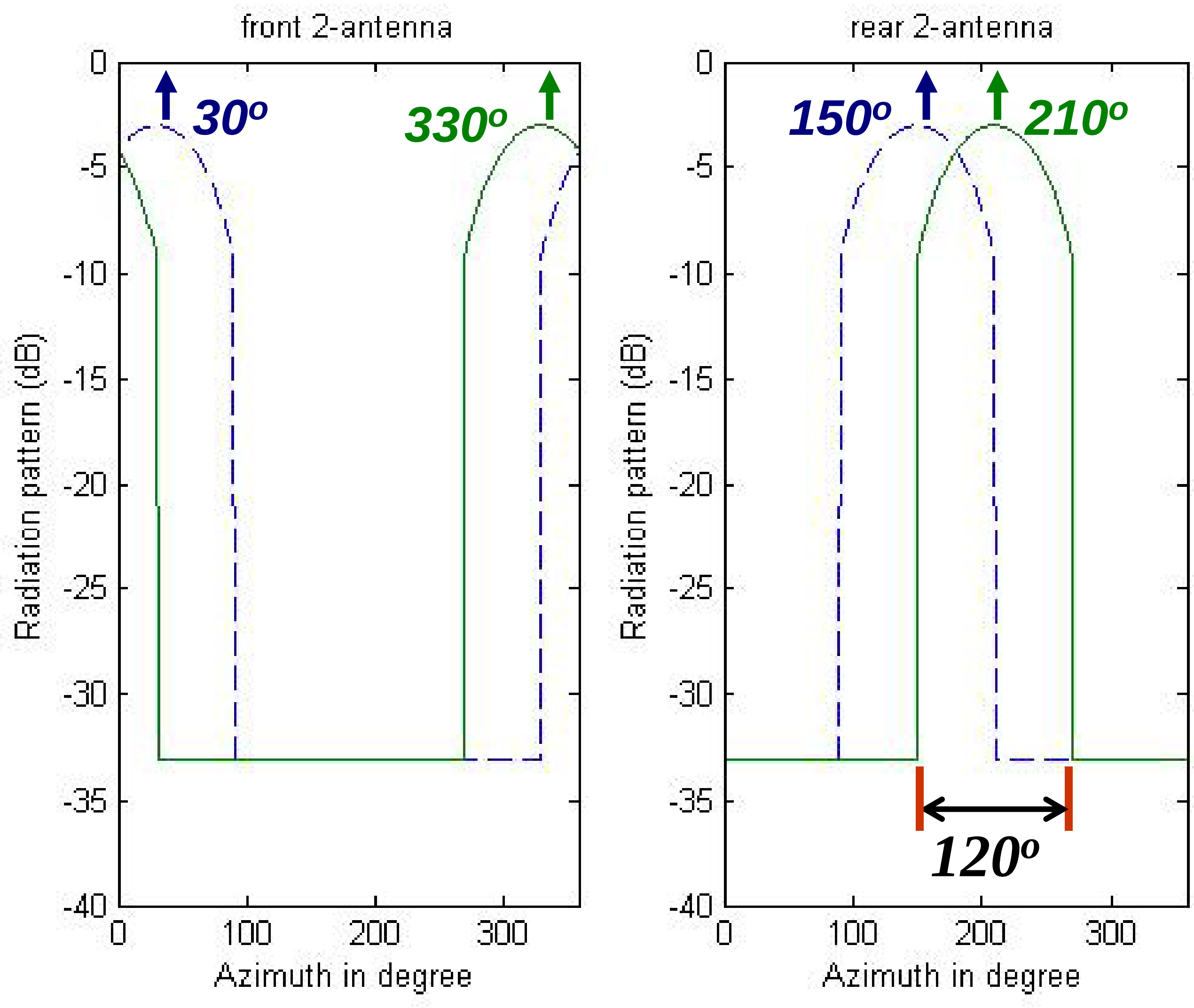


1. **High correlation for high Adaptive Array (AA) performance.**

2. **Front AA: (*F1+F2*)**

3. **Rear AA : (*R1+R2*)**

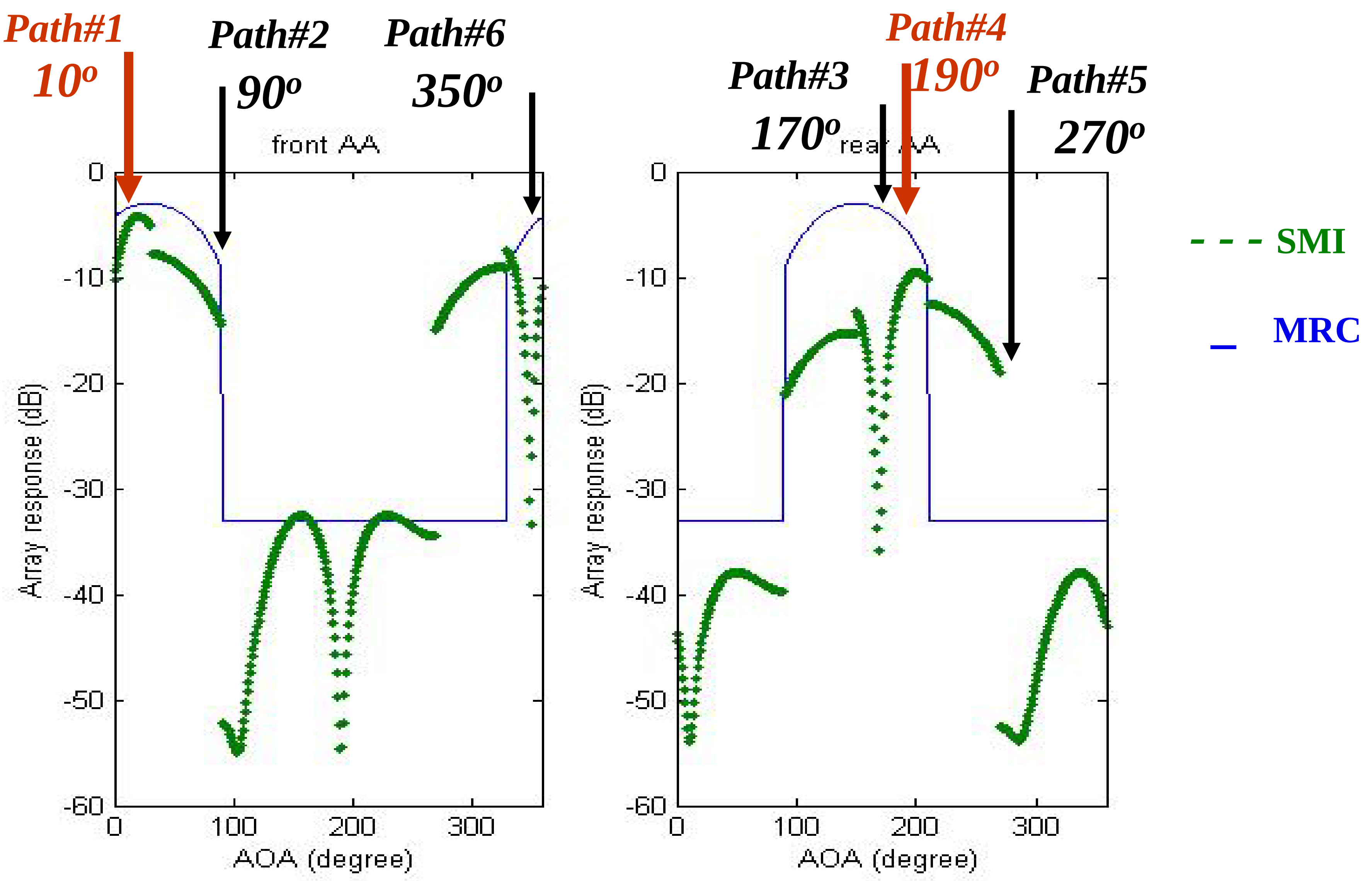
Mobile application-2: the Radiation Character of the Used Four Array Elements (*half power* BW=120^o)



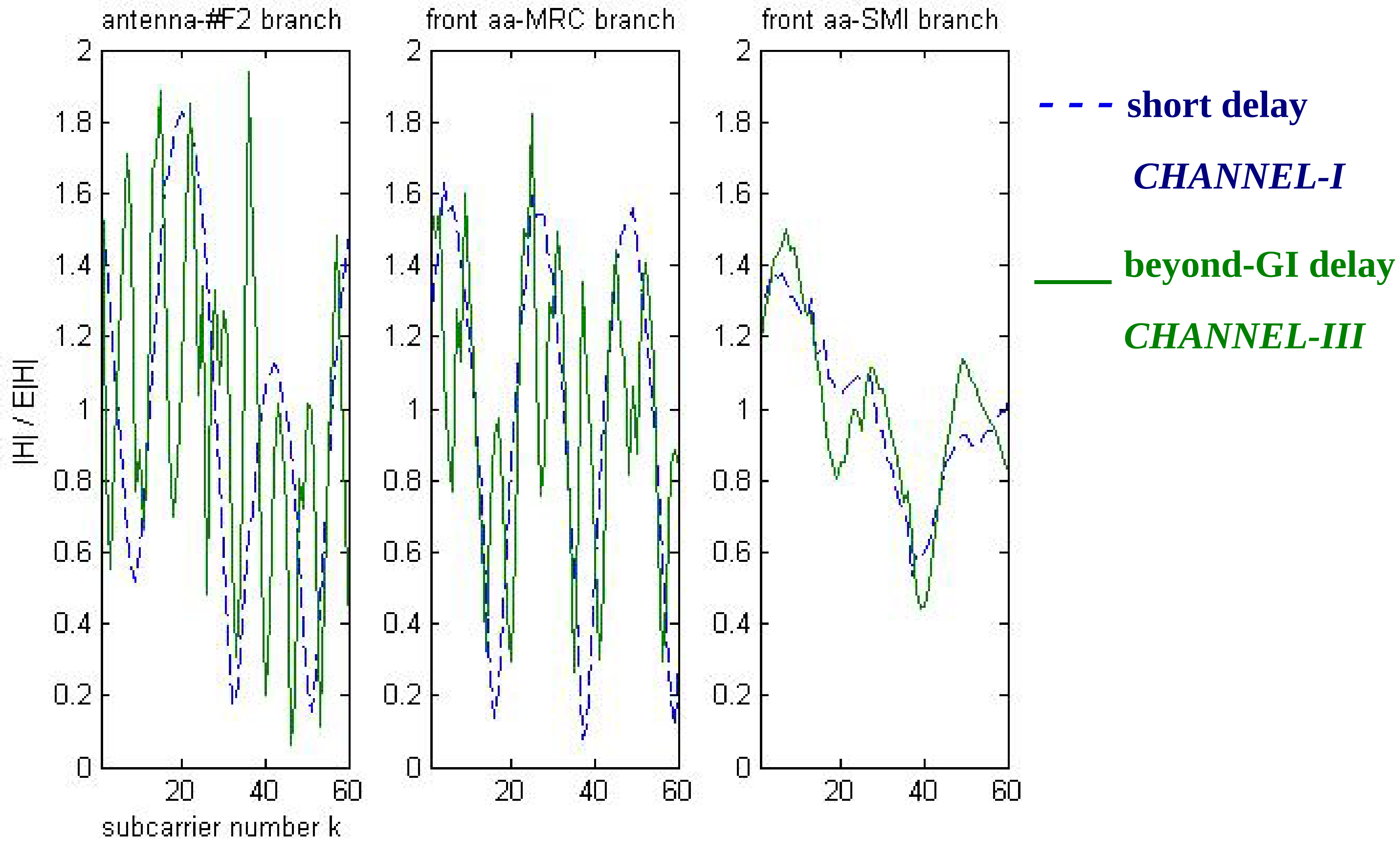
Simulated three Channel Models

Path	D/U *(dB)*	AOA *(deg.)*	Delay time		
			Channel-I	Channel-II	Channel-III
#1	0	10	0.01*(Tg/8)		
#2	3	90	3.0*(Tg/8)		
#3	5	170	6.0*(Tg/8)		
#4	1.5	190	0.5*(Tg/8)		
#5	2	270	1.0*(Tg/8)		
#6	4	350	3.0*(Tg/8)	5.5*(Tg/8)	9.0*(Tg/8)

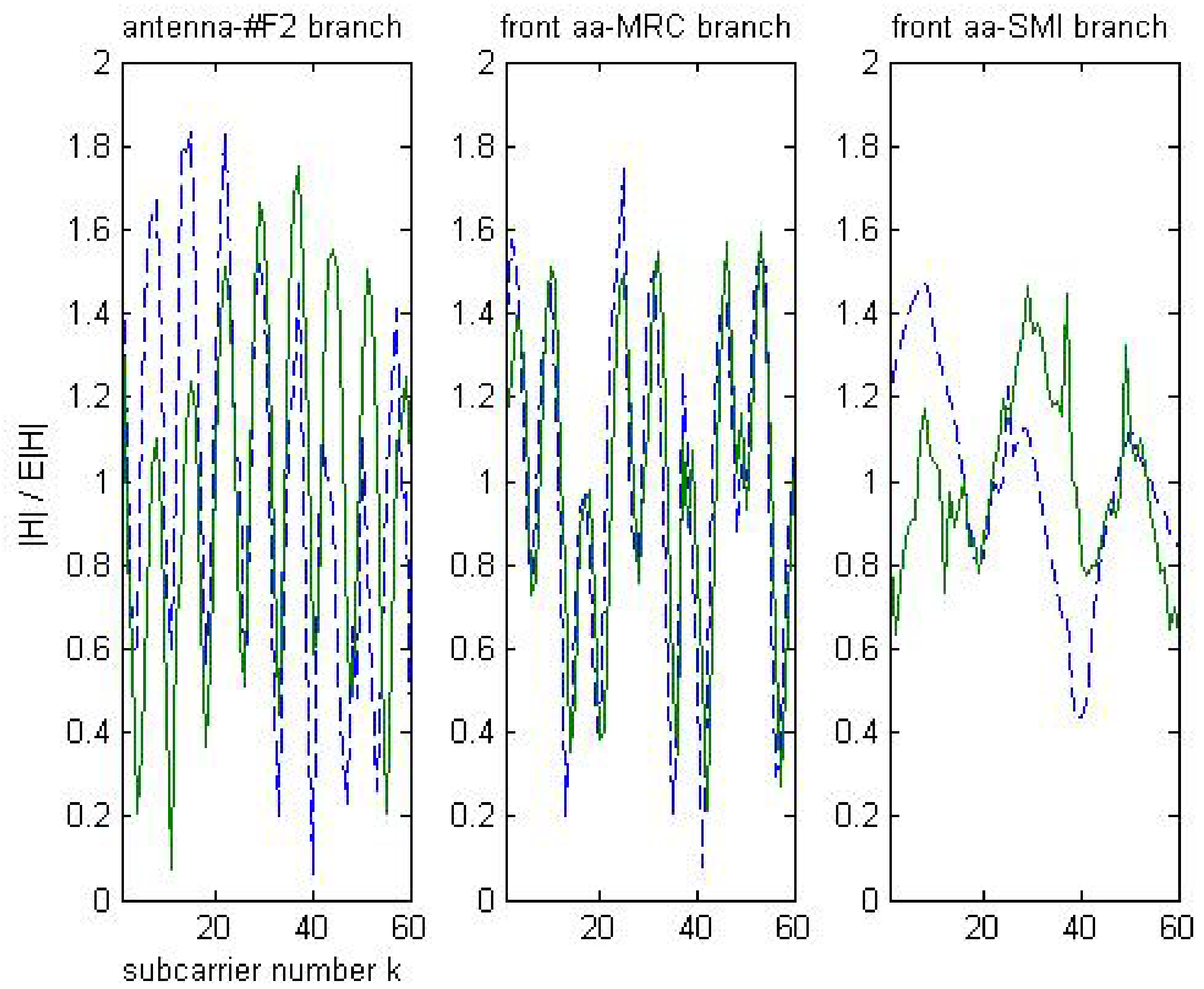
Adaptive Array-1: **Beam-pattern of AA Schemes** *(SNR=35dB)*



Adaptive Array-2: Normalized CTF Varying With Subcarrier Index *(with SNR=35dB, no Doppler shift)*



Adaptive Array-3: **Normalized CTF Varying With Subcarrier Index** *(in beyond-GI delayed CHANNEL-III)*



- - - ***no Doppler***

—— ***f_D= 30 Hz***

($f_D T$=0.03)

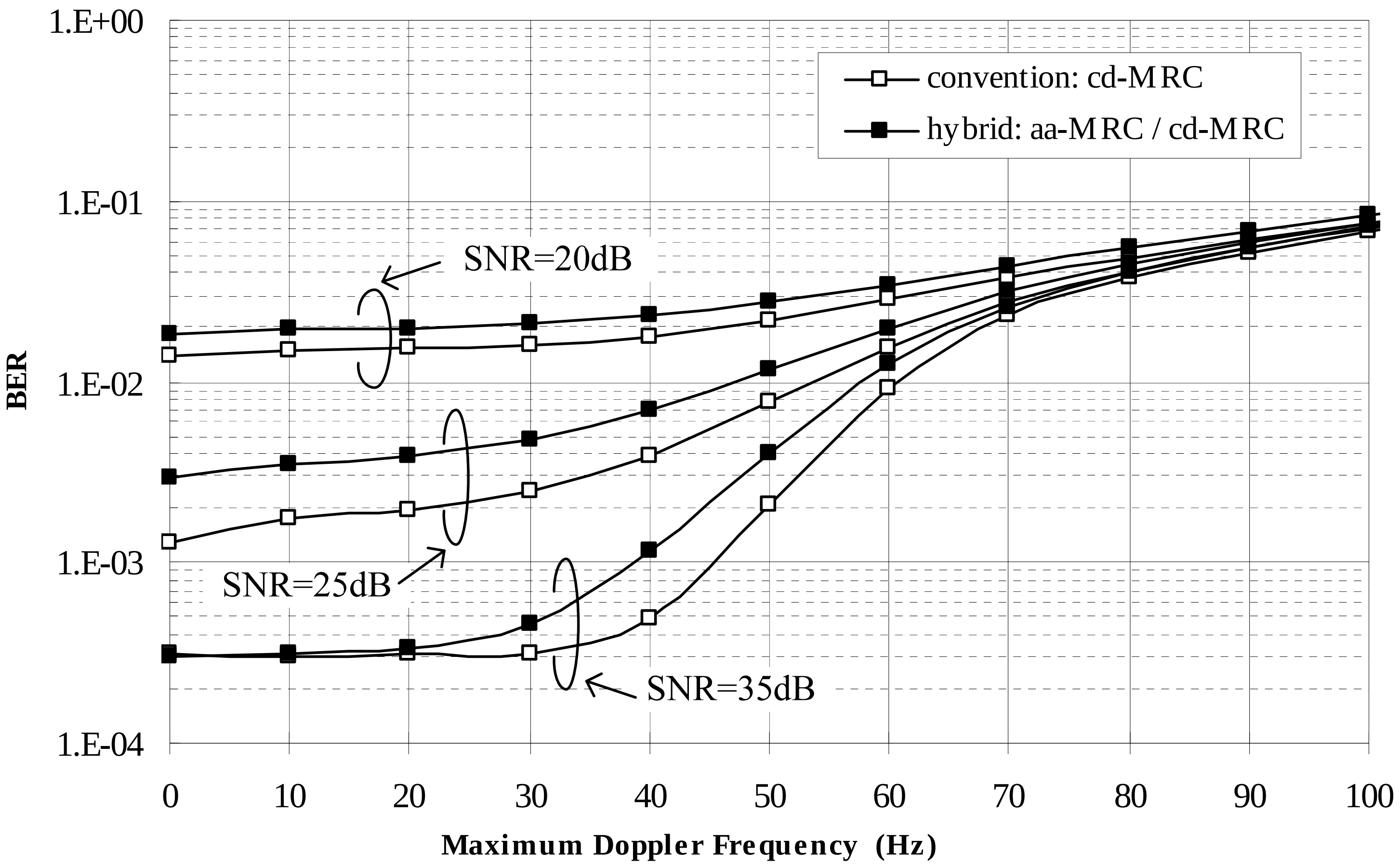
Simulation System Parameter

(ISDB-T Digital TV Standard of Japan and Brazil)

Carrier frequency	f_c	563.143 MHz *(UHF-28ch)*
Subcarrier spacing	f_0	0.992 kHz
Number of carriers	N	8192
Number of effective carriers	N_e	5617
Effective symbol duration	T_e	1008*us*
Guard interval duration	T_g	$(1/8)T_e$
Digital modulation		64QAM

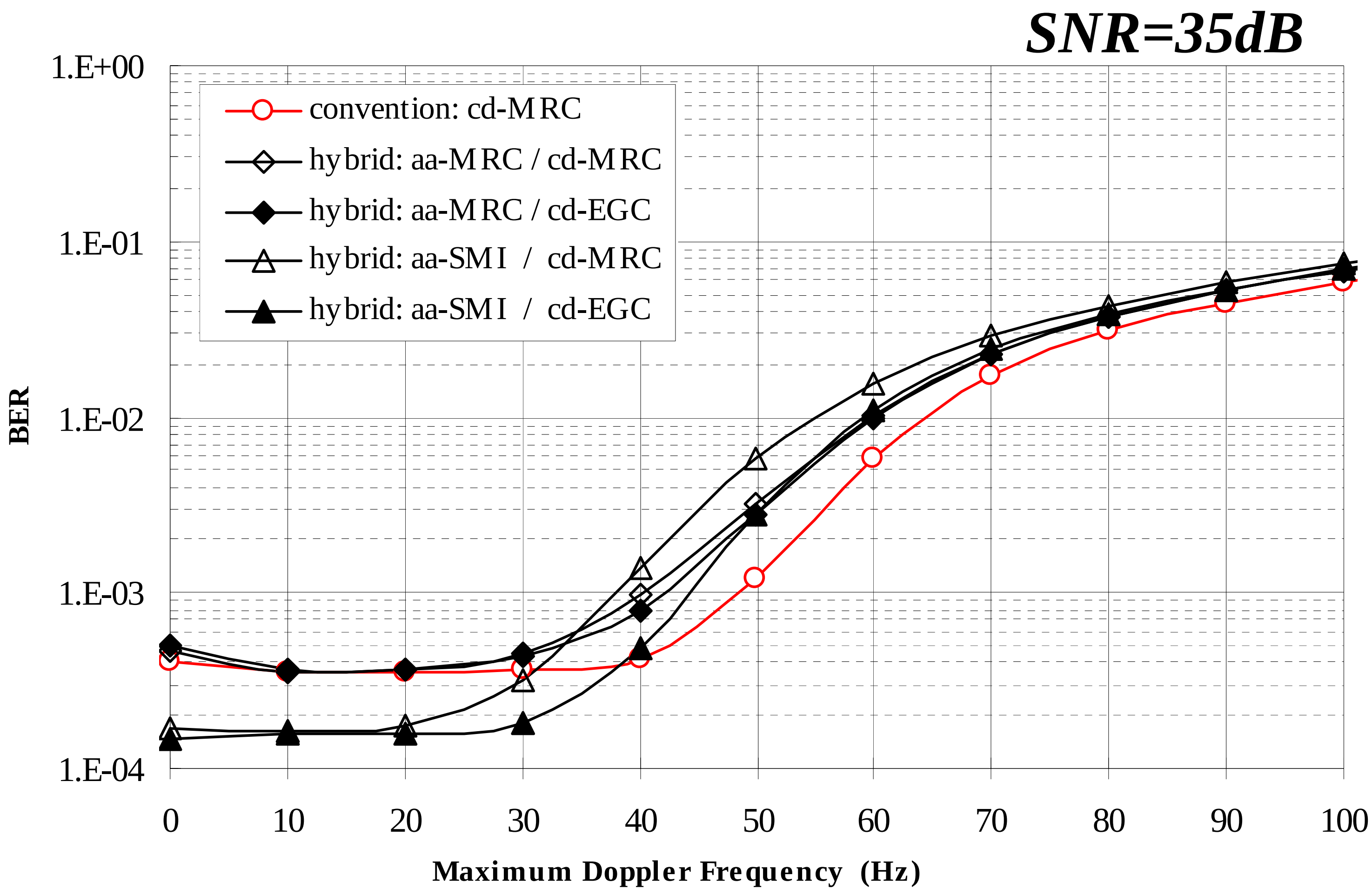
Simulation result-1:

BER Performance in Channel-1 *(short-delay)*



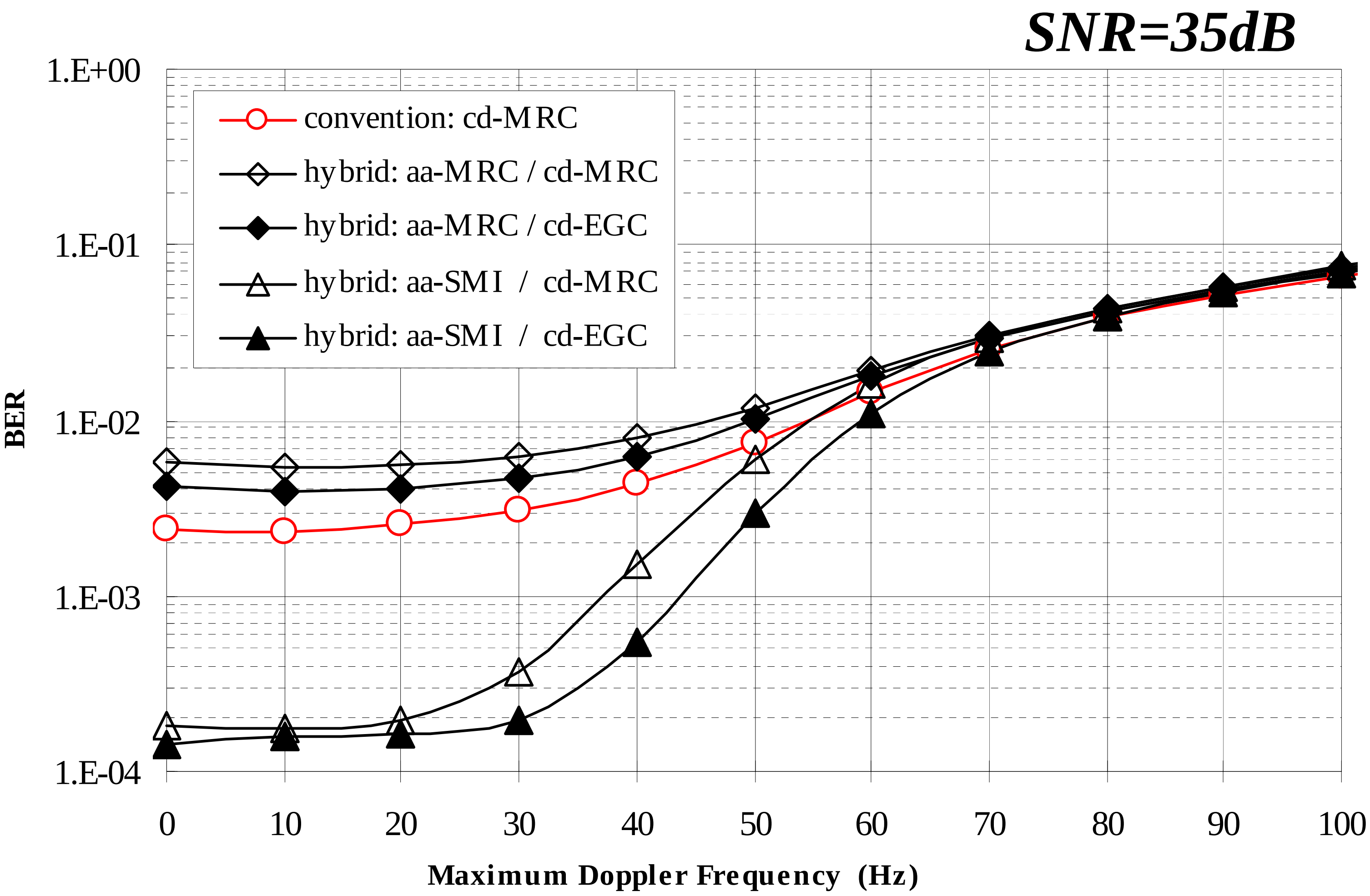
Simulation result-2:

BER Performance in Channel-2 *(short delay)*



Simulation result-3:

BER Performance in Channel-3 *(long delay)*



conclusion

1. **Proposed hybrid AA/CD two layers receiver is analyzed.**

2. **The Hybrid receiver is a low-complexity method, it can halve CD branches in comparison with the conventional CD receiver.**

3. **The hybrid receiver is a high-performance approach. Especially, when the received signal suffers from large delayed or beyond GI delayed path conditions, by using the SMI AA in 1st layer, the proposed hybrid AA/CD 2-layer receiver show good performance while that of the conventional post-FFT CD receiver is degraded significantly.**