HDTV Performance Improvement with Multiple Antennas

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Contents

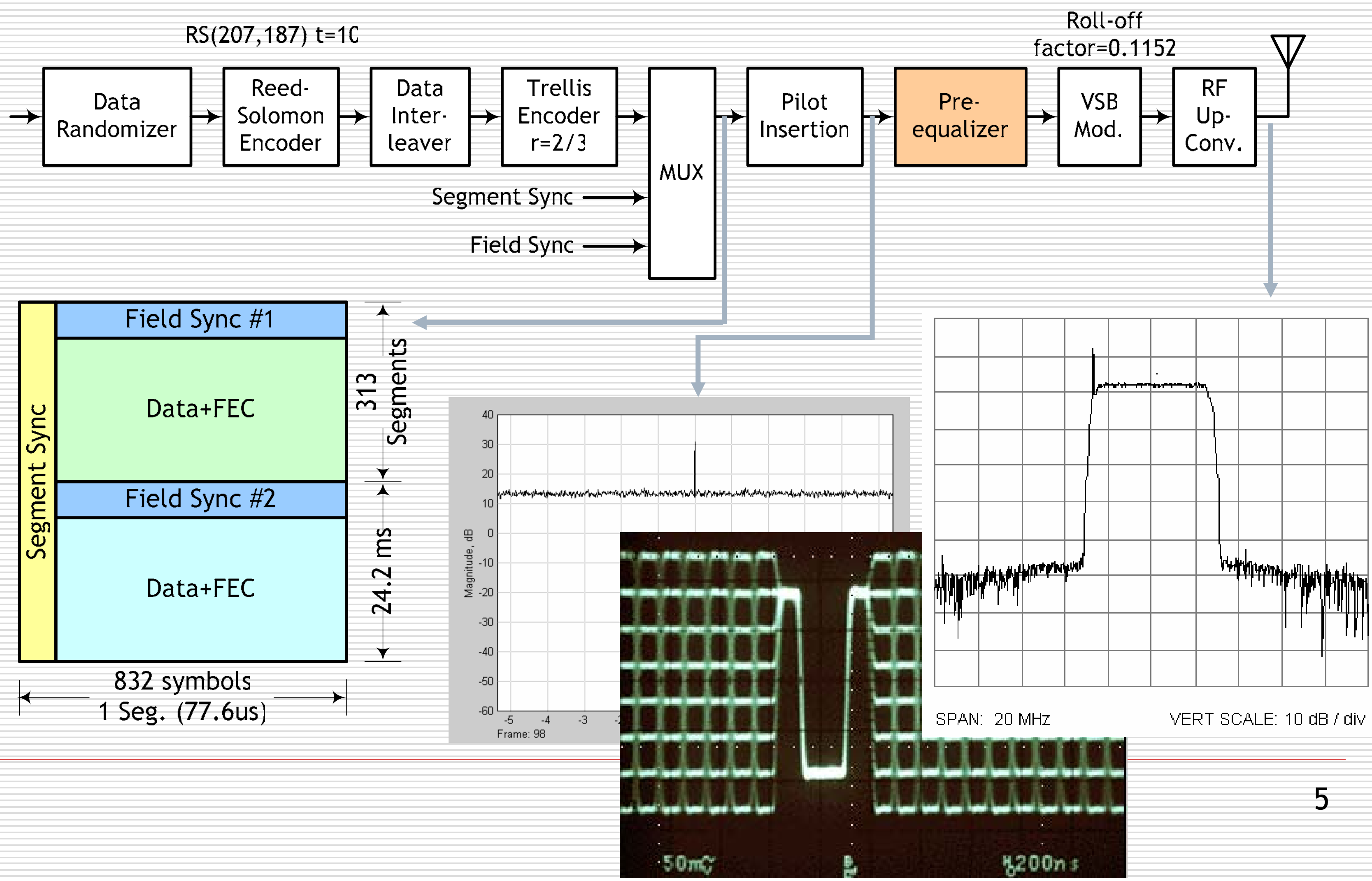
DTV Standards

DTV Standards

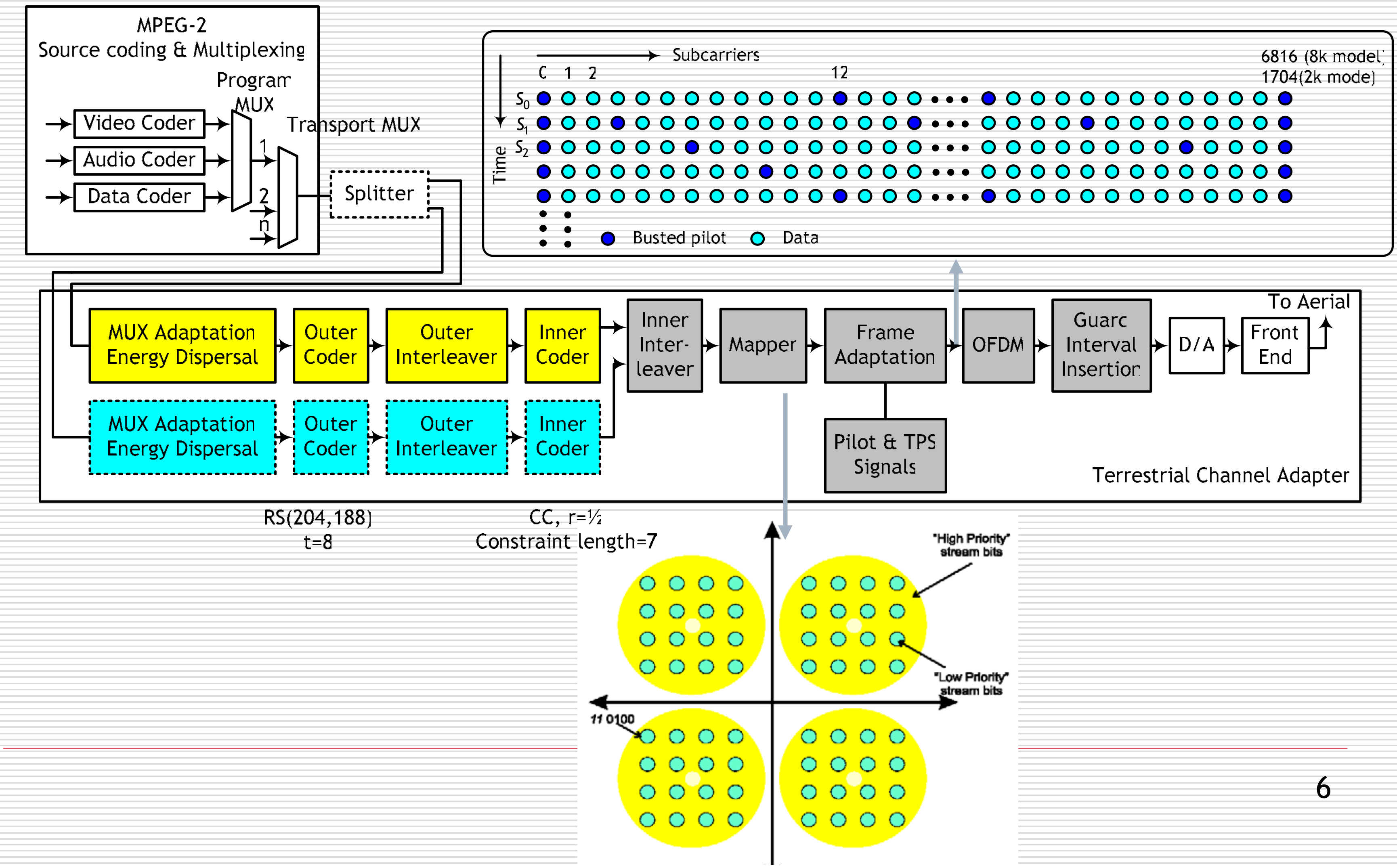
	ATSC	DVB-T	ISDB-T
Video	MPEG-2	MPEG-2	MPEG-2
Audio	Dolby AC-3	MPEG-2	MPEG-2
Multiplexing	MPEG-2	MPEG-2	MPEG-2
Modulation	8-VSB	COFDM	Band segmented COFDM
Bandwidth	6MHz	6,7,8MHz	6MHz
Service	SDTV / HDTV	SDTV	SDTV / HDTV

- **HDTV vs. Mobility ?**

ATSC 8-VSB


RS(207,187) t=10
Roll-off
factor=0.1152
Data
Randomizer
Reed-
Solomon
Encoder
Data
Inter-
leaver
Trellis
Encoder
r=2/3
MUX
Pilot
Insertion
Pre-
equalizer
VSB
Mod.
RF
Up-
Conv.
Segment Sync
Field Sync
Segment Sync
Field Sync #1
Data+FEC
Field Sync #2
Data+FEC
313
Segments
24.2 ms
832 symbols
1 Seg. (77.6us)
Magnitude, dB
Frame: 98
SPAN: 20 MHz
VERT SCALE: 10 dB / div

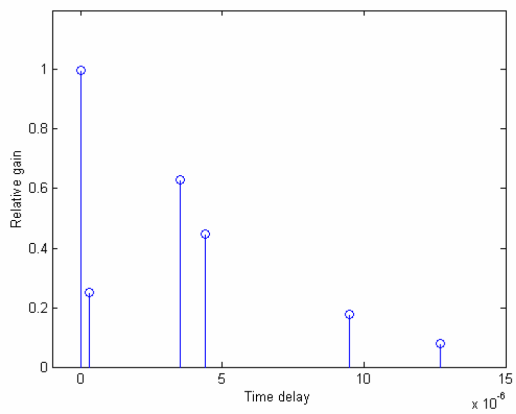
DVB-T COFDM

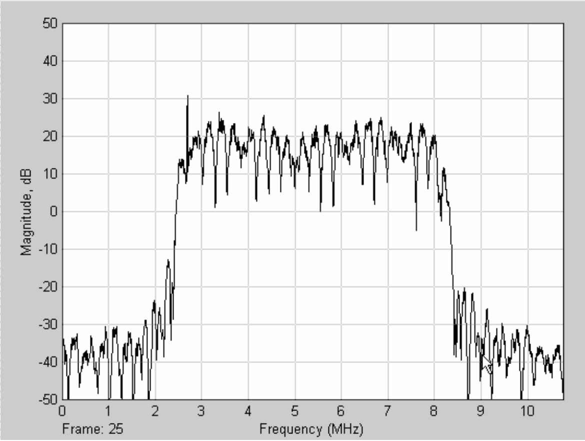

MPEG-2
Source coding & Multiplexing
Program MUX
Video Coder
Audio Coder
Data Coder
Transport MUX
1
2
n
Splitter
Subcarriers
C 1 2
12
6816 (8k mode)
1704(2k mode)
S_0
S_1
S_2
Time
Busted pilot
Data
MUX Adaptation Energy Dispersal
Outer Coder
Outer Interleaver
Inner Coder
MUX Adaptation Energy Dispersal
Outer Coder
Outer Interleaver
Inner Coder
Inner Inter-leaver
Mapper
Frame Adaptation
OFDM
Guard Interval Insertion
D/A
Front End
To Aerial
Pilot & TPS Signals
Terrestrial Channel Adapter
RS(204,188)
t=8
CC, r=½
Constraint length=7
"High Priority" stream bits
"Low Priority" stream bits
11 0100

DTV Channel

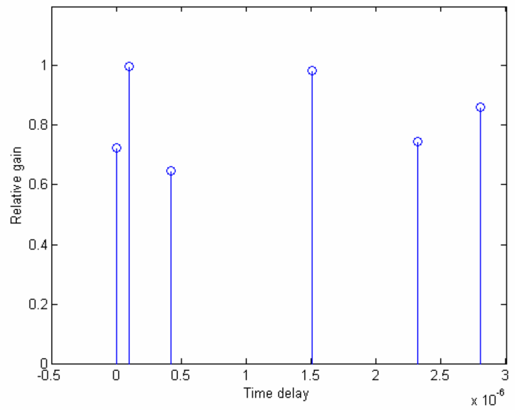
DTV Channel

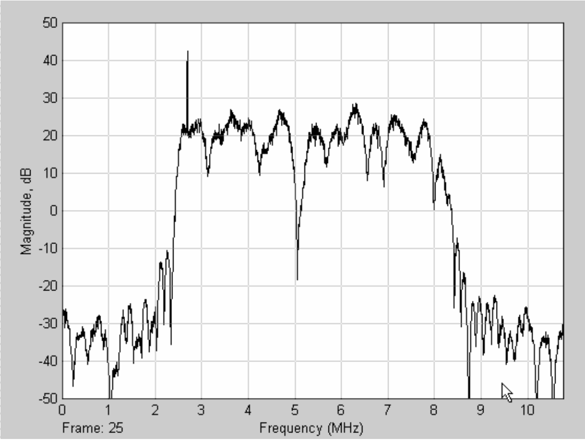
- Brazilian ch. B





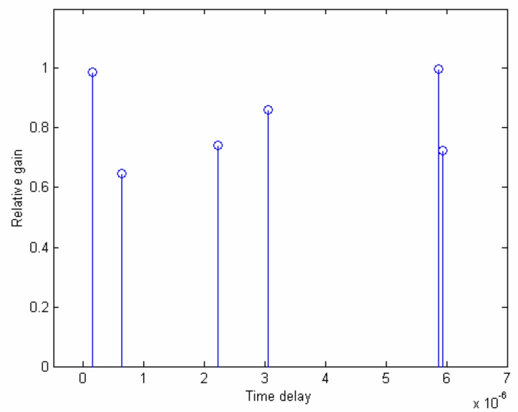
- Brazilian ch. C

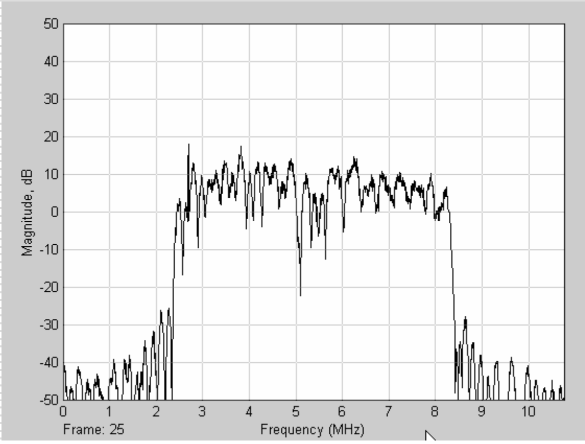




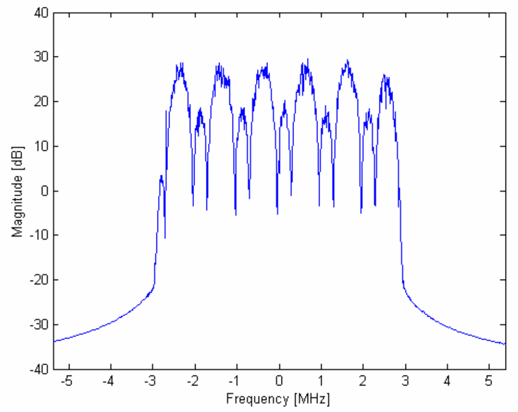
DTV Channel

- Brazilian ch. D





- Brazilian ch. E



DTV Channel

- ***Dermot Nolan*****,** a director of Telecommunications and Broadcast Services, a well-known digital terrestrial consultancy
  - ***DTV RF channels are time varying***, even in the case of directional outdoor antennas. This indicates that the most appropriate channel model for DTV system designers is ***Rayleighian with time-varying multipath***.

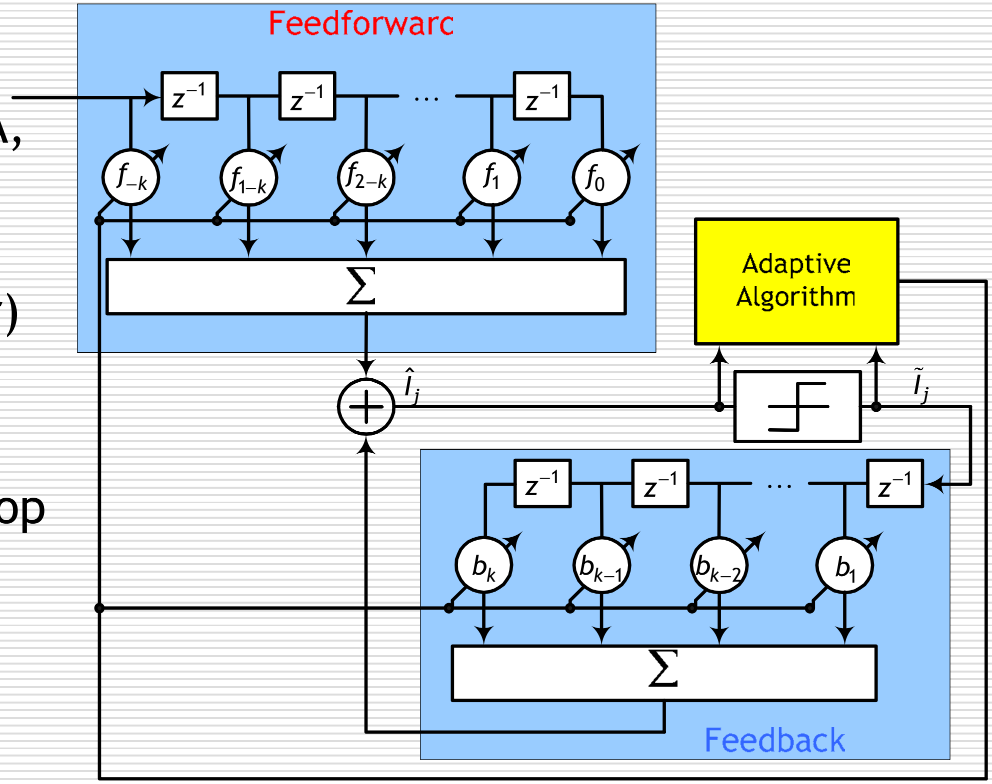
Conventional Equalization

Conventional Equalizer

- Decision Feedback Equalizer
  - FFF(feed-forward filter)

    Filter length: 15 (Brazil A, B, D, E chs),50 (Brazil C CH)
  - FBF(feed-backward filter)

    Filter length: 150
  - Algorithm: LMS with training sequence and Stop & Go blind equalizer



Conventional Equalizer

- SNR 20dB

Channel type	Before equalization		After equalization	
	Output SINR	SER	Output SINR	SER
Brazil A	7.6018	0.5314	19.4310	0.0362
Brazil B	1.4956	0.7052	9.3584	0.4919
Brazil C	-5.0707	0.7914	9.1450	0.5059
Brazil D	-5.2609	0.7931	2.3923	0.7645
Brazil E	-3.0279	0.7641	5.7354	0.6574

TOV(threshold of visibility): BER 20%

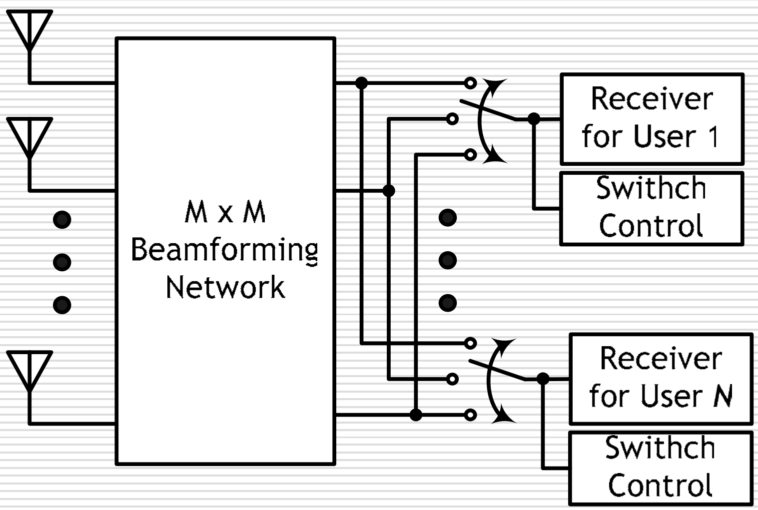
- **How we can improve the reception performance in indoor and mobile environments ?**

  Sophisticated antenna, Equalizer, …

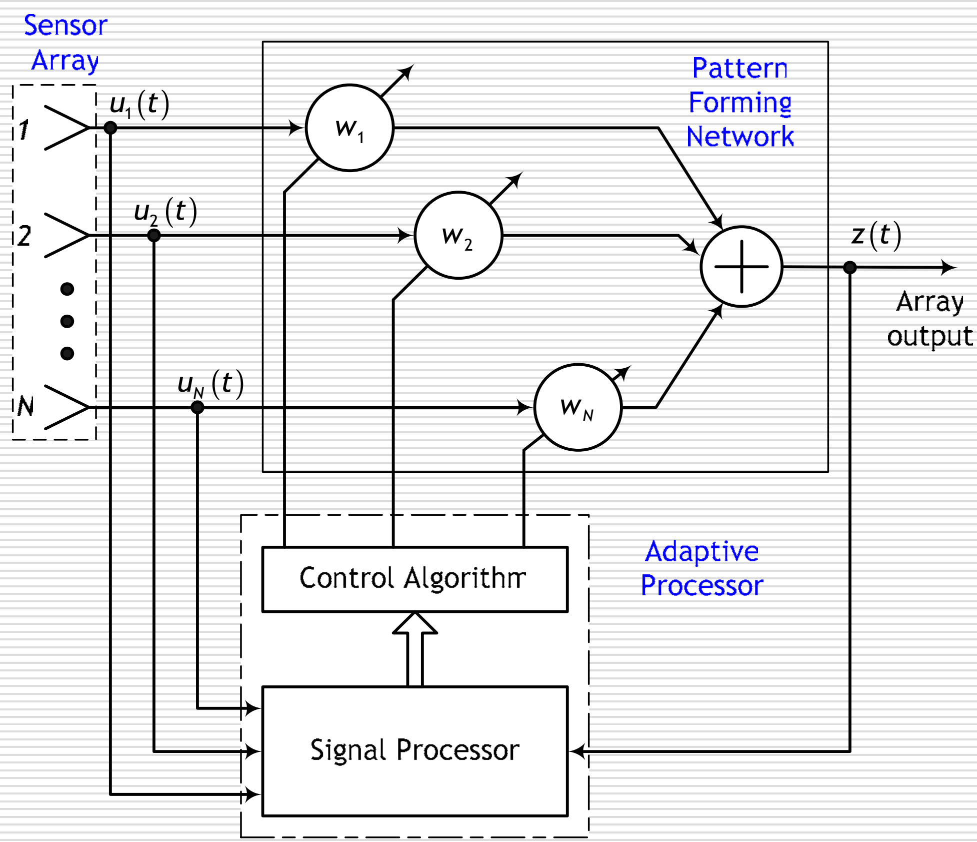
Beamforming Techniques

Beamformer Structures

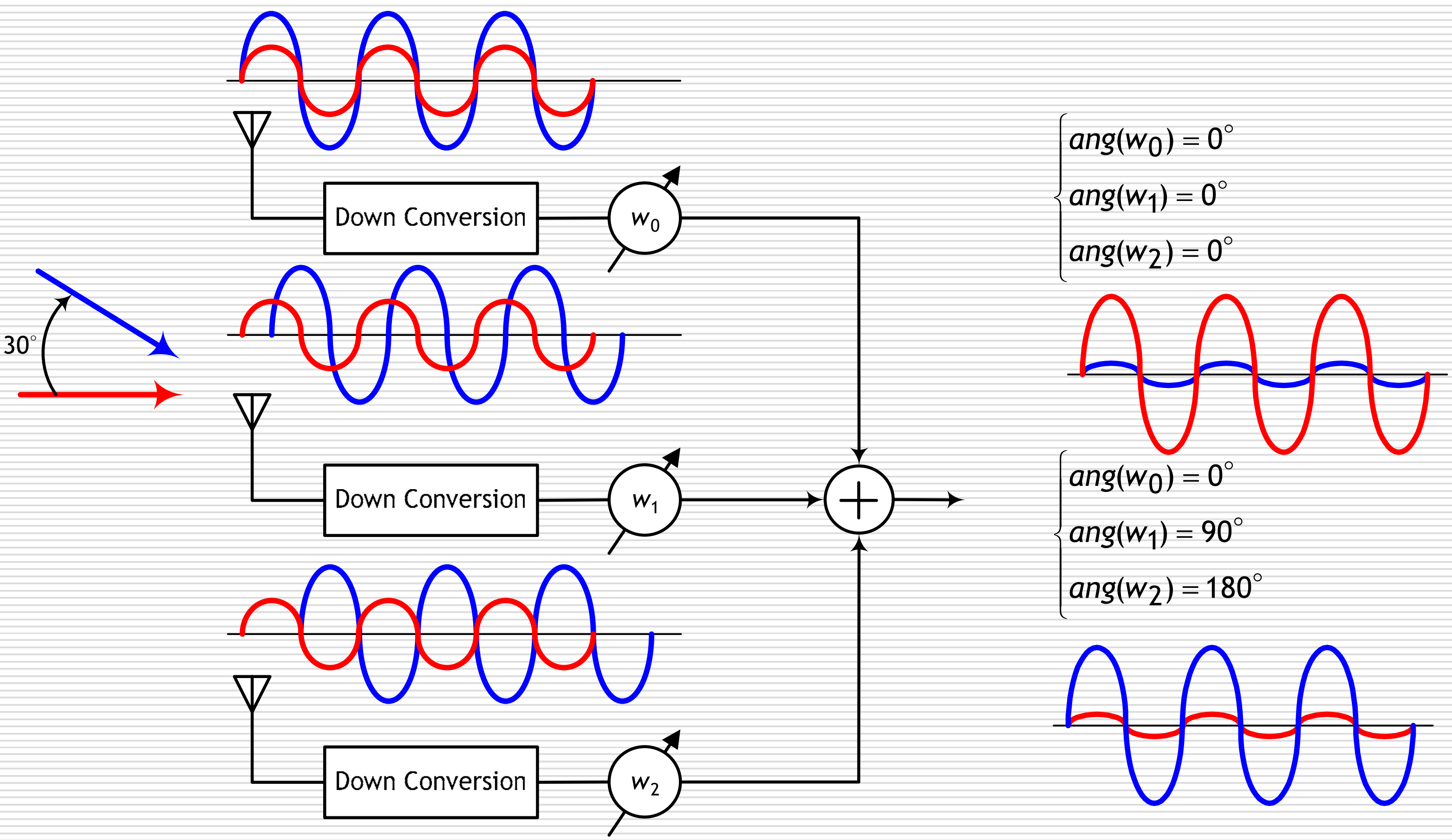
- Switched beam system



- Adaptive array

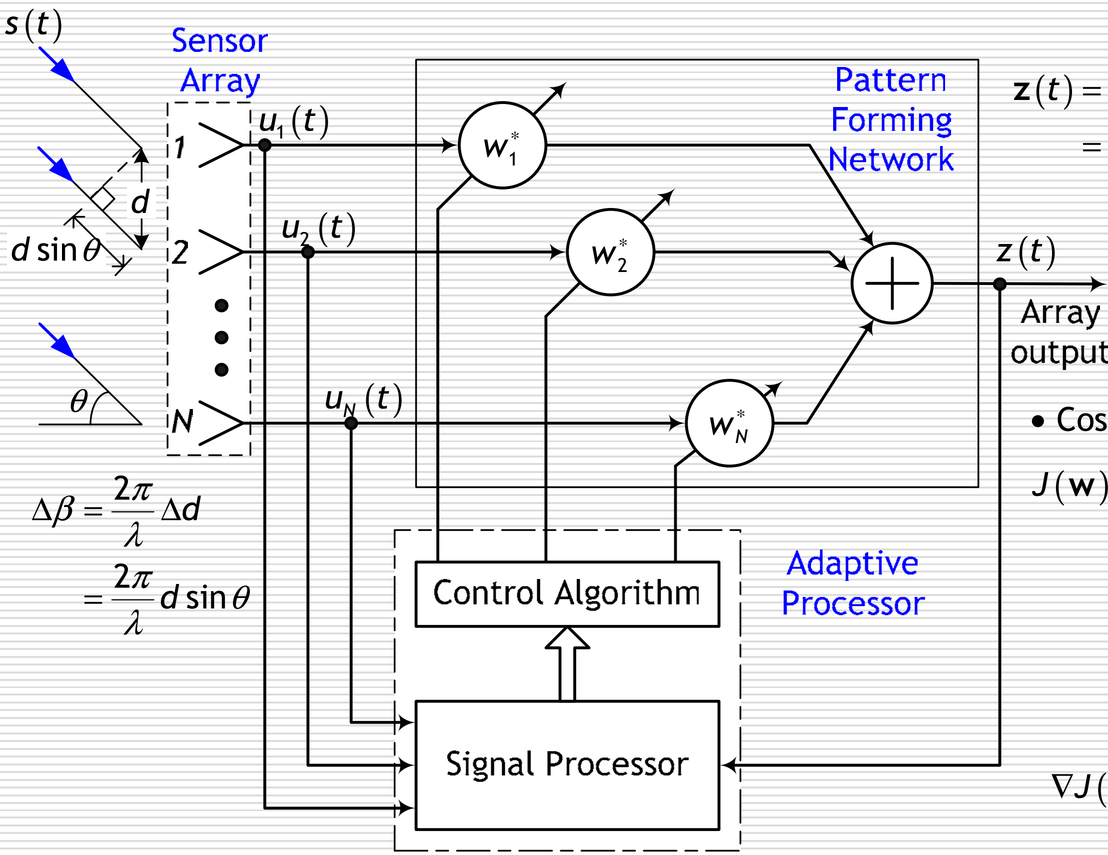


Principle



30°
Down Conversion
Down Conversion
Down Conversion
w_0
w_1
w_2
$ang(w_0) = 0°$
$ang(w_1) = 0°$
$ang(w_2) = 0°$
$ang(w_0) = 0°$
$ang(w_1) = 90°$
$ang(w_2) = 180°$

Adaptive Beamformer



$$\Delta\beta = \frac{2\pi}{\lambda}\Delta d = \frac{2\pi}{\lambda} d\sin\theta$$

$$\mathbf{z}(t) = \mathbf{w}^H\mathbf{u}(t) = \mathbf{w}^H\left[s(t)\mathbf{a}(\theta,\phi) + \mathbf{n}(t)\right]$$

- Cost function

$$J(\mathbf{w}) = E\left\{\left|\mathbf{w}^H\mathbf{u}(t) - s(t)\right|^2\right\}$$
$$= \mathbf{w}^H E\left\{\mathbf{u}(t)\mathbf{u}^H(t)\right\}\mathbf{w} - \mathbf{w}^H E\left\{\mathbf{u}(t)s^*(t)\right\}$$
$$- E\left\{s(t)\mathbf{u}^H(t)\right\}\mathbf{w} + E\left\{\left|s(t)\right|^2\right\}$$
$$= \mathbf{w}^H\mathbf{R}\mathbf{w} - \mathbf{w}^H\mathbf{p} - \mathbf{p}^H\mathbf{w} + E\left\{\left|s(t)\right|^2\right\}$$

$$\nabla J(\mathbf{w}) = 2\mathbf{R}\mathbf{w} - 2\mathbf{p} = 0$$

$\mathbf{w}_{opt} = \mathbf{R}^{-1}\mathbf{p}$: Normal equation   Power gain=N

Adaptive Array

- Adaptive array based on received data
  - LMS (least mean square): requires reference signal
  - MV (minimum variance): uses directional constraint
  - CMA (constant modulus algorithm): restores the array output to a constant envelope signal on average

- DOA based array
  - SLC (sidelobe canceller)
  - Frost array
  - GSC (generalized sidelobe canceller)

Signal Processing Algorithms

- DOA estimation-based algorithm
  - Estimate DOA with signal covariance matrix
  - Beam-steering to the estimated DOA
  - MUSIC, Pisarenko, ESPRIT, ML
- Training sequence-based algorithm
  - Pilot channel in wireless systems
  - SMI, LMS, RLS
- Blind algorithms
  - CMA, Cyclo-stationary, Higher order statistic

DOA Estimation

- Delay and sum

$$\max_{\mathbf{w}} \left\{ \mathbf{w}^H \mathbf{a}(\theta) \mathbf{a}^H(\theta) \mathbf{w} \right\} = \max_{\mathbf{w}} \left| \mathbf{w}^H \mathbf{a}(\theta) \right|^2, \text{ subject to } \mathbf{w}^H \mathbf{w} = 1$$

$$V_{BF}(\theta) = \frac{\mathbf{a}^H(\theta) \mathbf{R} \mathbf{a}(\theta)}{\mathbf{a}^H(\theta) \mathbf{a}(\theta)} \Rightarrow \mathbf{w}_{BF} = \frac{\mathbf{a}(\theta_{\max})}{\sqrt{\mathbf{a}^H(\theta_{\max}) \mathbf{a}(\theta_{\max})}}$$

  - Advantage: the most simple
  - Disadvantage

    Spatial resolution: highly depending on the number of antenna elements and SNR

    Estimation error: due to signals from other directions

DOA Estimation

- Capon's minimum variance method

$$\min_{\mathbf{w}} \mathbf{w}^H \mathbf{R} \mathbf{w} \quad \text{subject to} \quad \mathbf{w}^H \mathbf{a}(\theta) = 1$$

$$V_{CAP}(\theta) = \frac{1}{\mathbf{a}^H(\theta)\mathbf{R}^{-1}\mathbf{a}(\theta)} \quad \Rightarrow \quad \mathbf{w}_{CAP} = \frac{\mathbf{R}^{-1}\mathbf{a}(\theta_{\max})}{\mathbf{a}^H(\theta_{\max})\mathbf{R}^{-1}\mathbf{a}(\theta_{\max})}$$

  - Advantage

    Removing signals from other directions

    Relatively simple

  - Disadvantage

    Spatial resolution: highly depending on the number of antenna elements and SNR

DOA Estimation

- MUSIC (MUltiple SIgnal Classification)
  - Define the signal and noise subspaces from the eigen decomposition

$$R = [U_s \quad U_n] \operatorname{diag}\{\lambda_1, \cdots, \lambda_M\} [U_s \quad U_n]^H$$

  - From the orthogonality of the signal and noise subspaces, finding the peaks in the estimator function

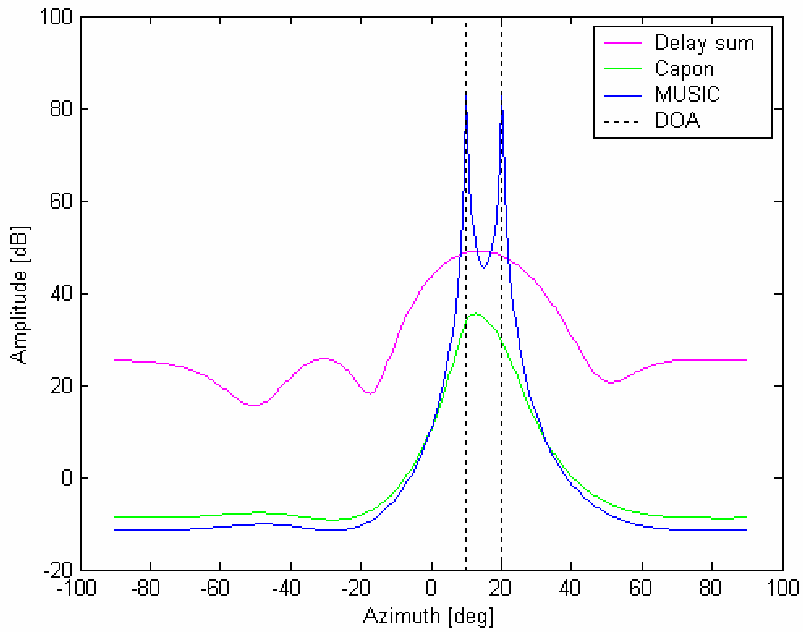
$$\mathbf{a}^H(\theta_i)\mathbf{U}_n\mathbf{U}_n^H\mathbf{a}(\theta_i) = 0 \qquad V_M(\theta) = \frac{1}{\mathbf{a}^H(\theta)\mathbf{U}_n\mathbf{U}_n^H\mathbf{a}(\theta)}$$

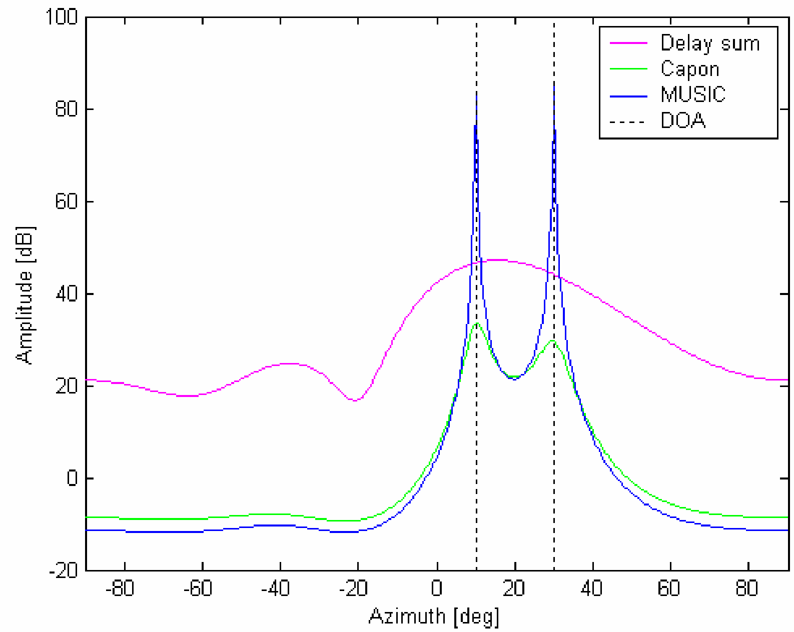
  - Advantage: High spatial resolution
  - Disadvantage
    - The number of antenna elements > the number of incoming signals
    - Complexity

DOA Estimation (Spatial Spectrum)

- Incoming signals
  - DOA: 10°, 20°
  - Amplitude: 1, 0.8

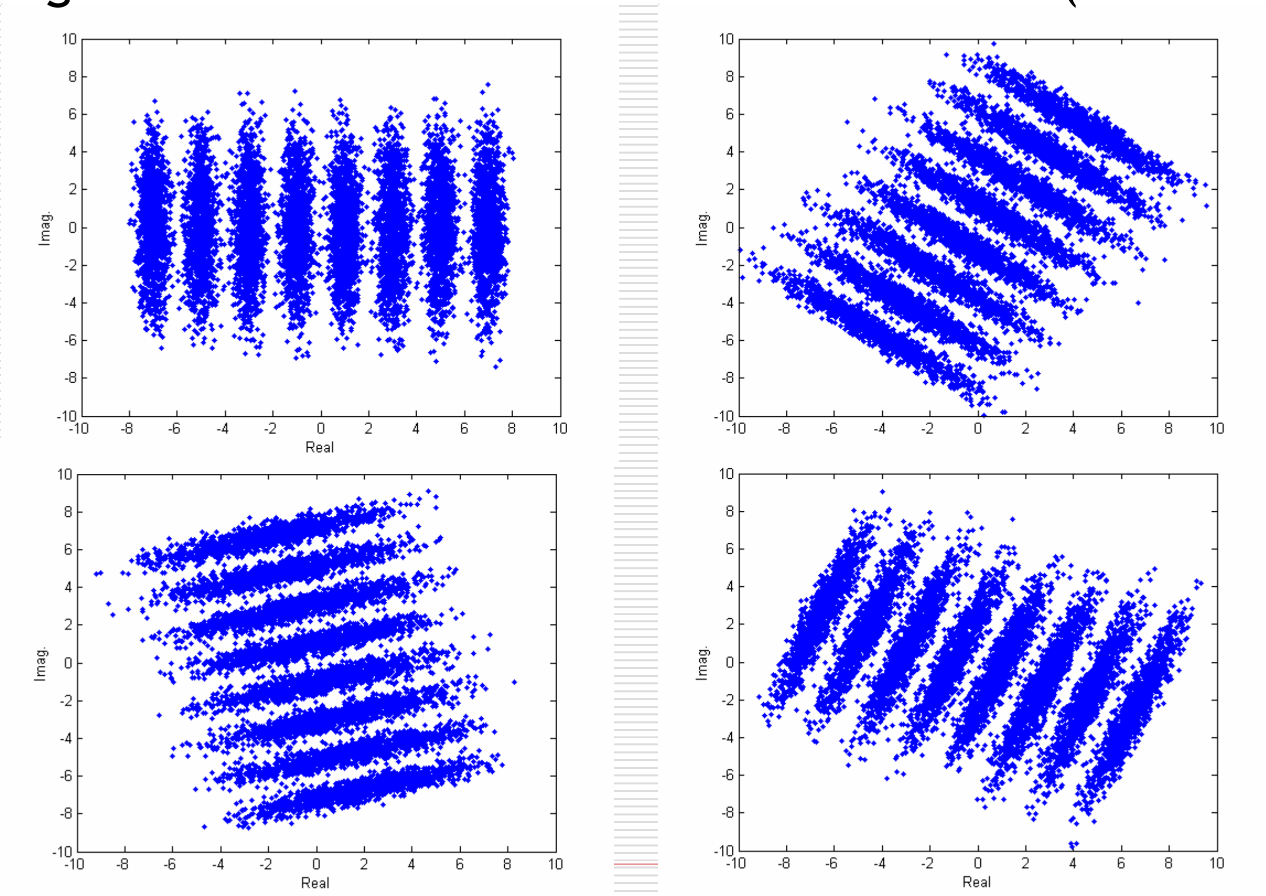
- Incoming signals
  - DOA: 10°, 30°
  - Amplitude: 1, 0.8





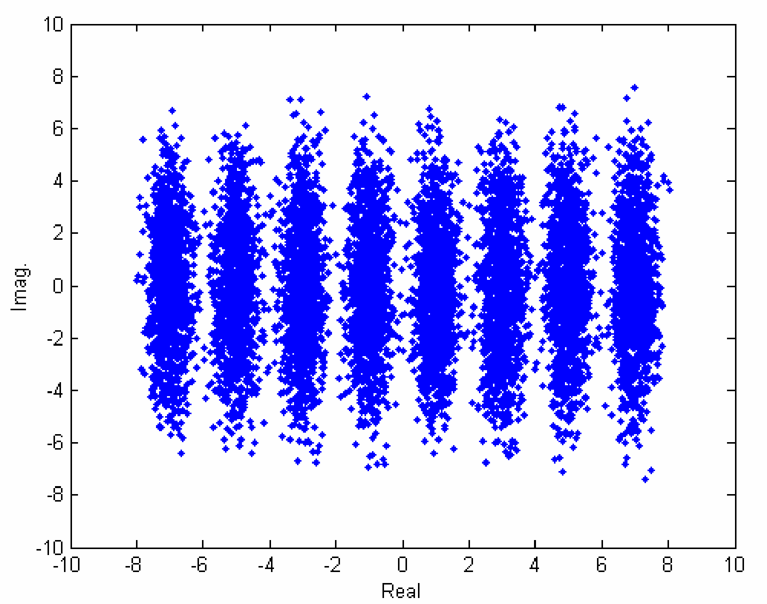
SNR Improvement in AWGN for 8-VSB

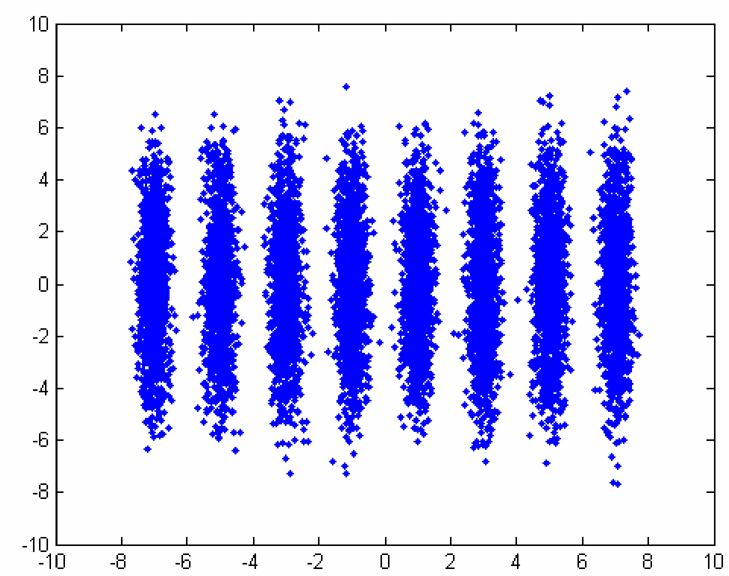
- Signal constellations at 4 antenna elements (SNR: 20dB)



SNR Improvement in AWGN for 8-VSB

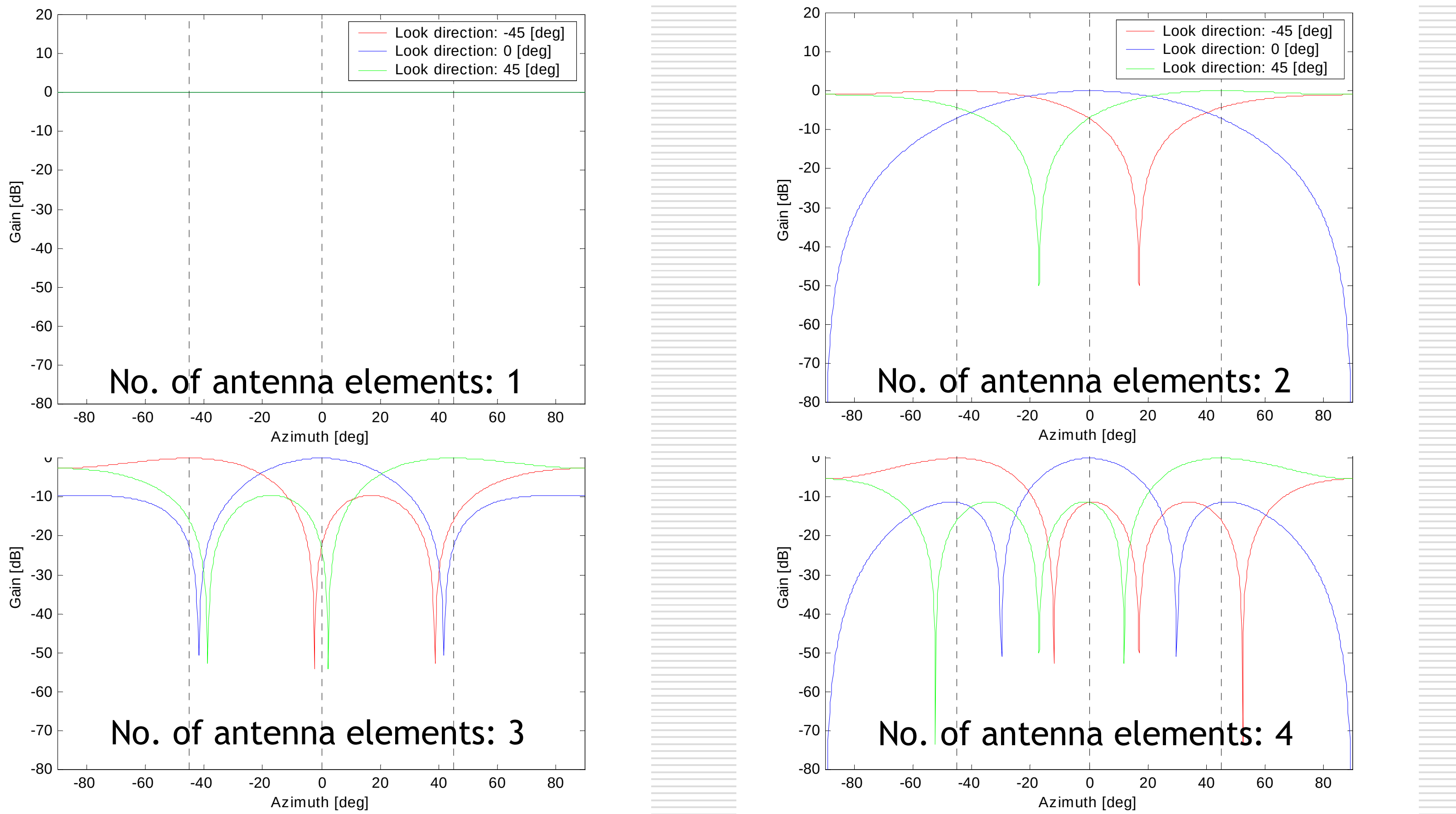
- Without beamforming
  - SNR=20dB
- After beamforming
  - SNR=26dB (6dB ⇑)



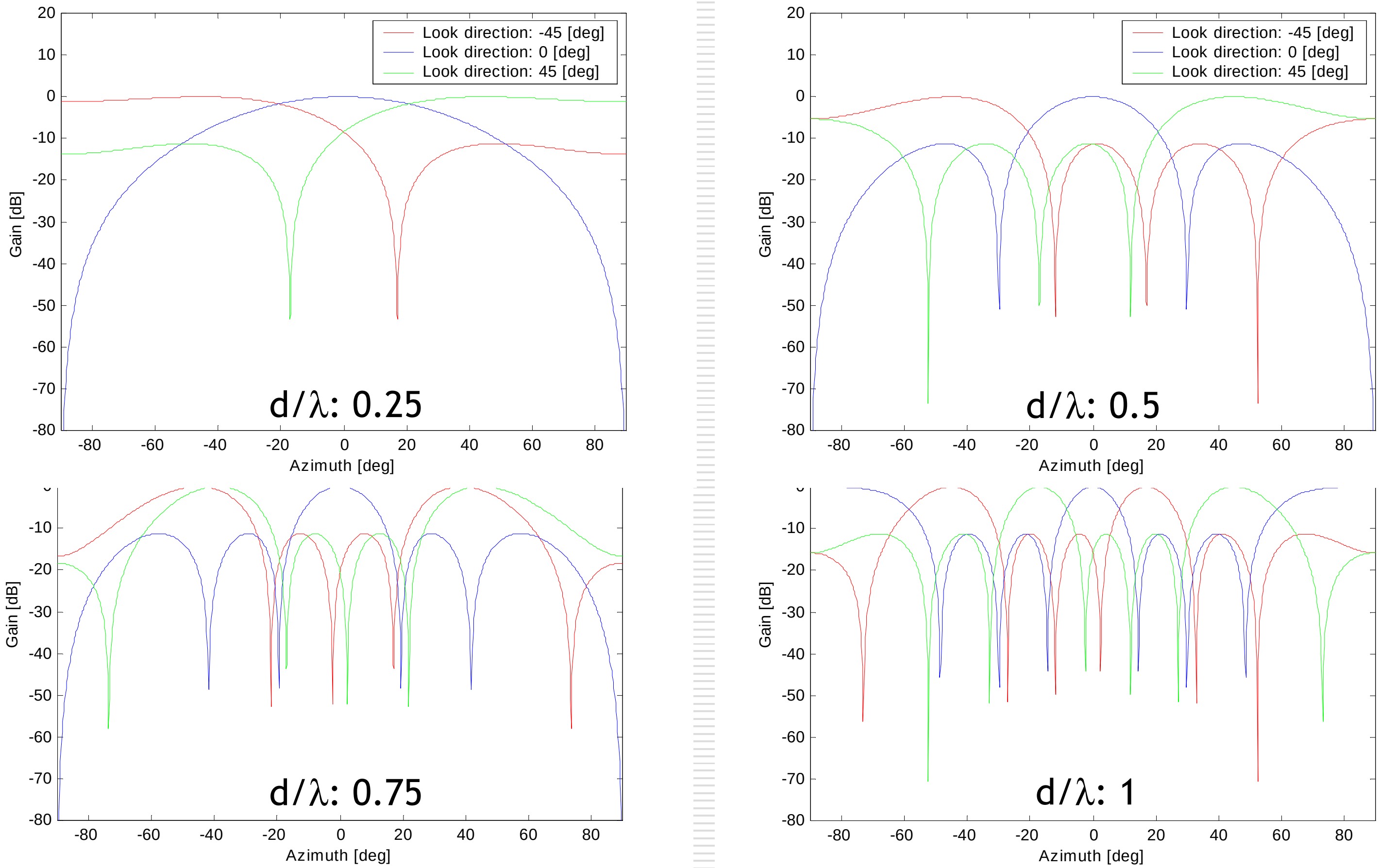


Beampattern for Broadcasting Frequencies

Beampattern in terms of Number of Antenna Elements



Beampattern in terms of Antenna Distance



Beampattern for ATSC D-TV

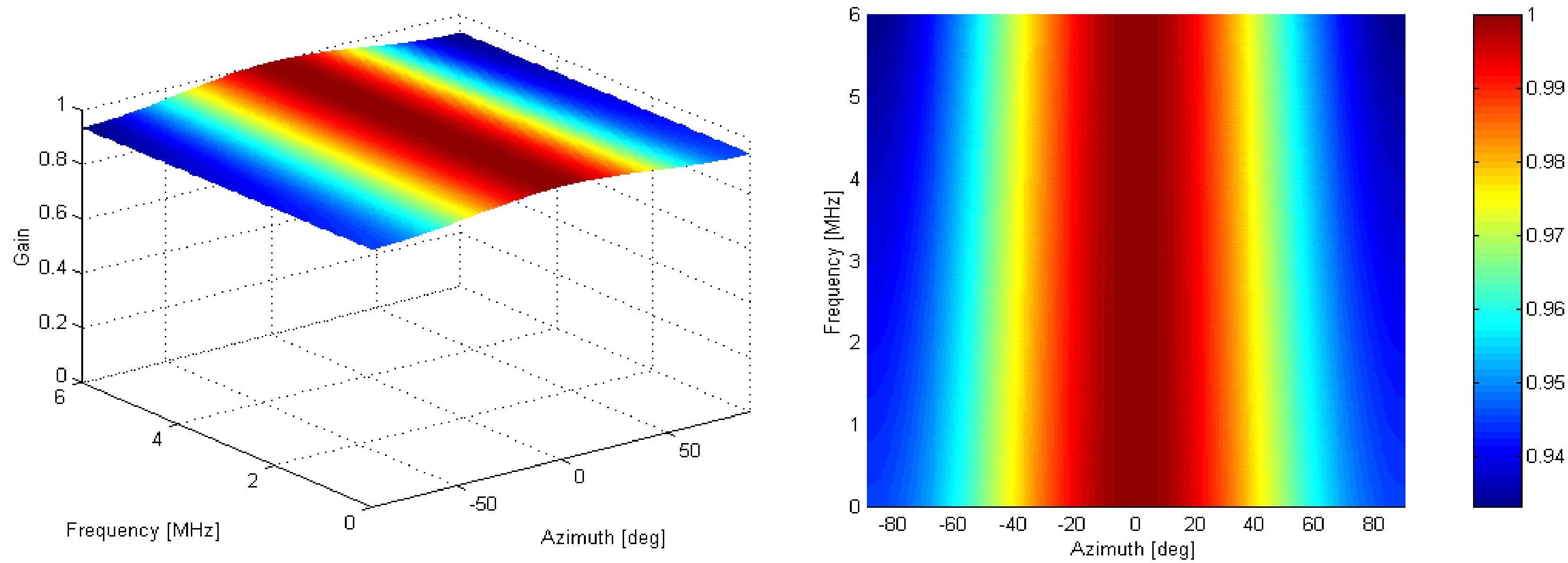
- Frequency bands for terrestrial broadcasting

Band	Channel	Frequency
VHF Low	Ch. 2 ~ Ch. 6	52~72MHz, 76~88MHz
VHF High	Ch. 7 ~ Ch. 13	174~216MHz
UHF	Ch. 14 ~ Ch. 83	470~890MHz

- Linear array structure
  - No. of antenna elements: 4
  - Reference frequency: 600 MHz
  - Distance between adjacent antenna elements: 0.25 m

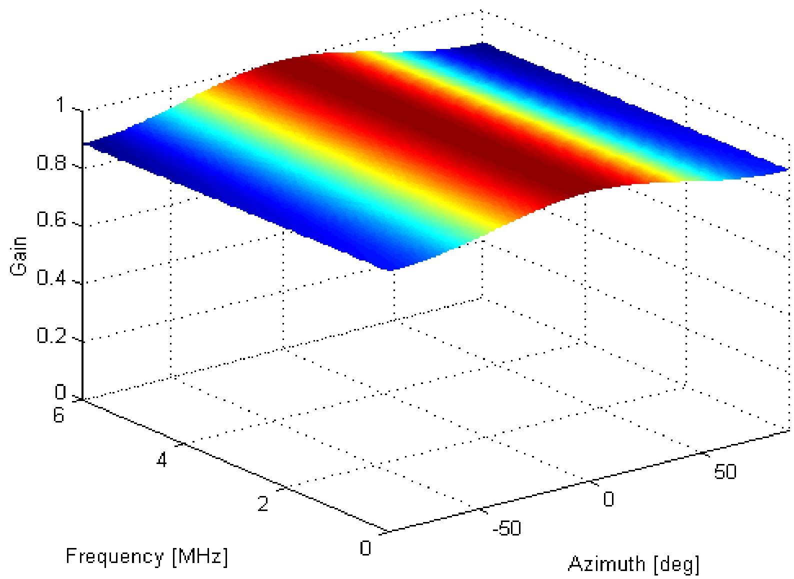
Beampattern for ATSC D-TV

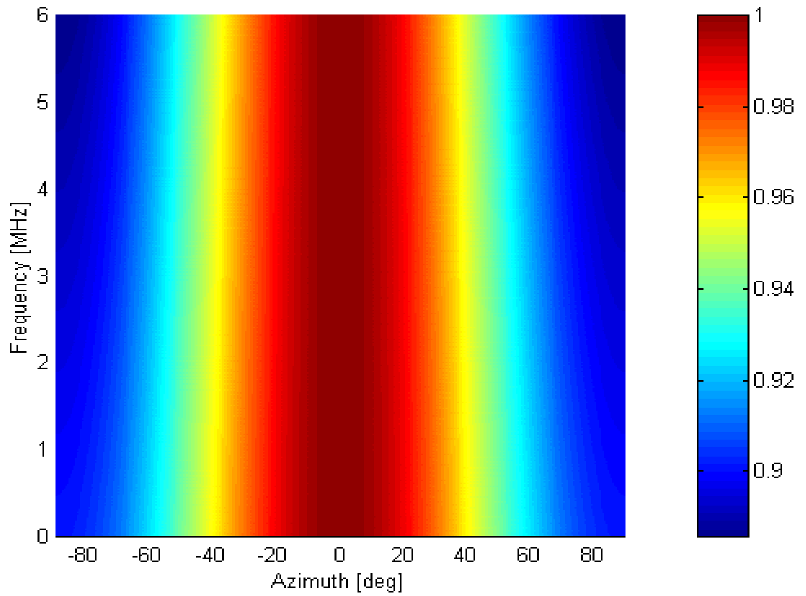
- 60MHz (half wavelength: 2.5m)



Beampattern for ATSC D-TV

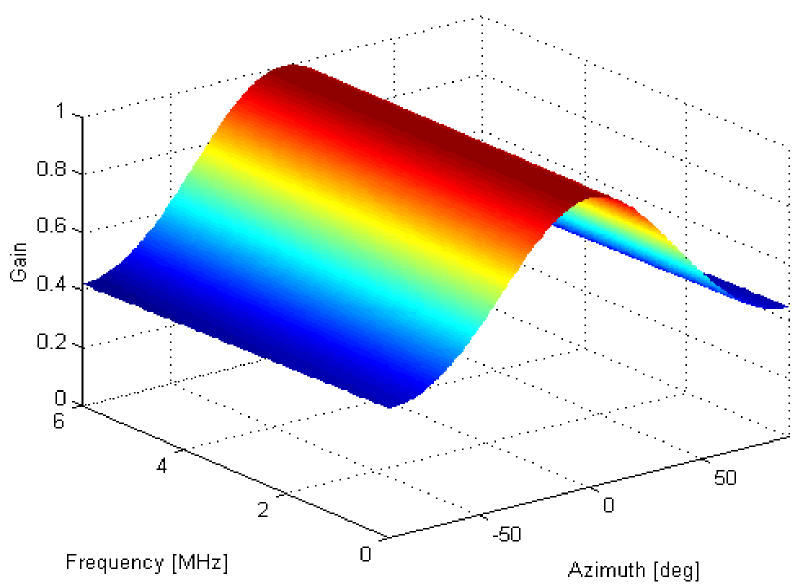
- 80MHz (half wavelength: 1.875m)

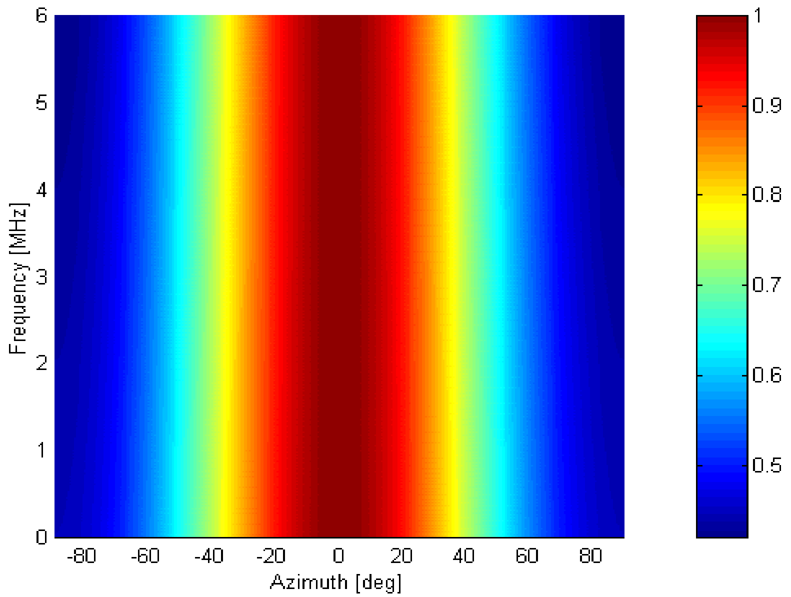




Beampattern for ATSC D-TV

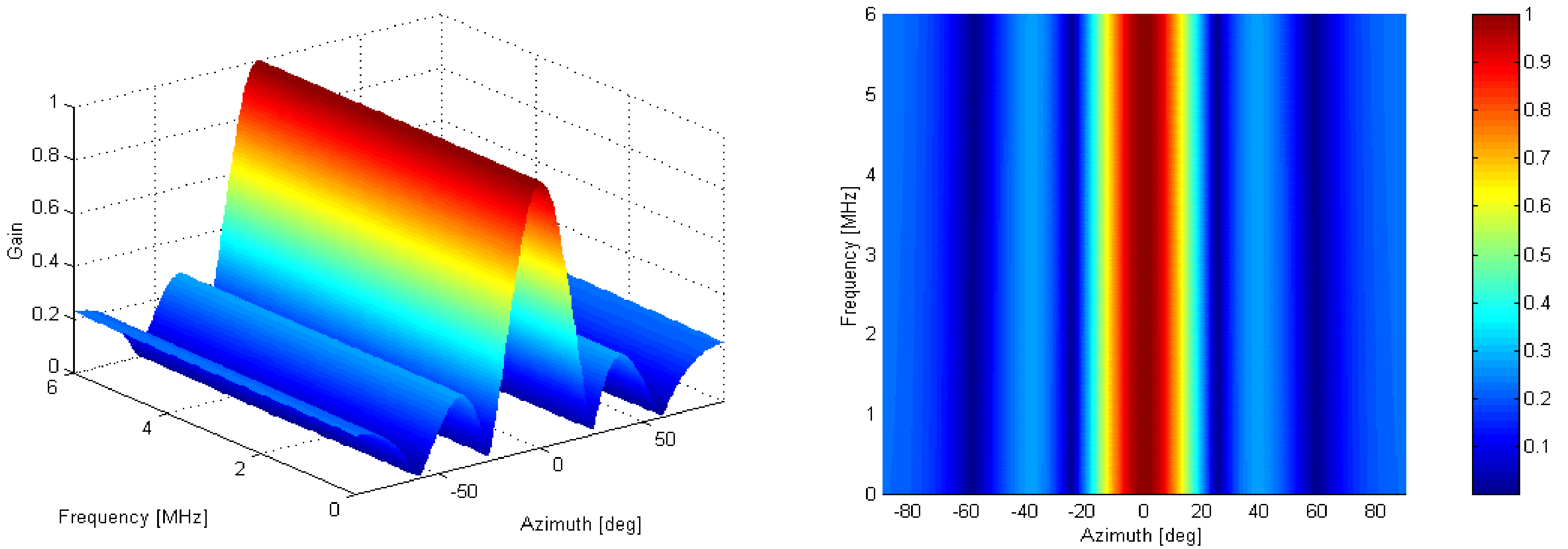
- 200MHz (half wavelength: 0.75 m)





Beampattern for ATSC D-TV

- 700MHz (half wavelength: 0.2143 m)



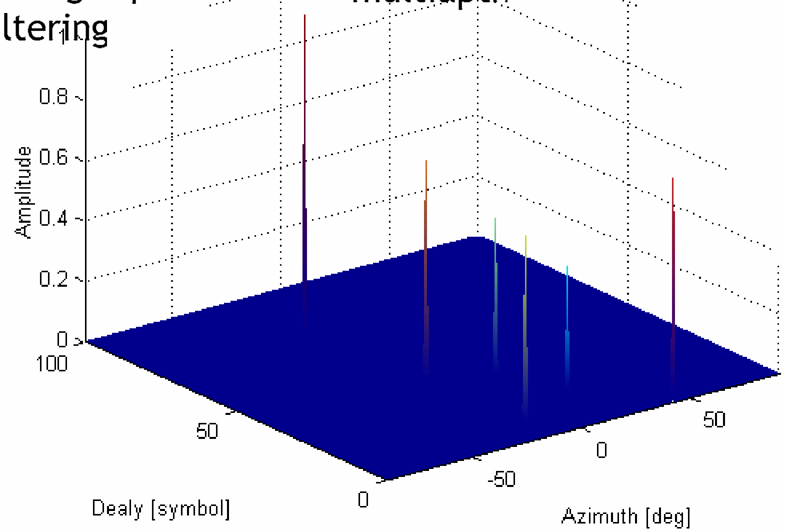
Performance of DOA Estimation-based DTV Receiver

DOA Estimation-based DTV Receiver

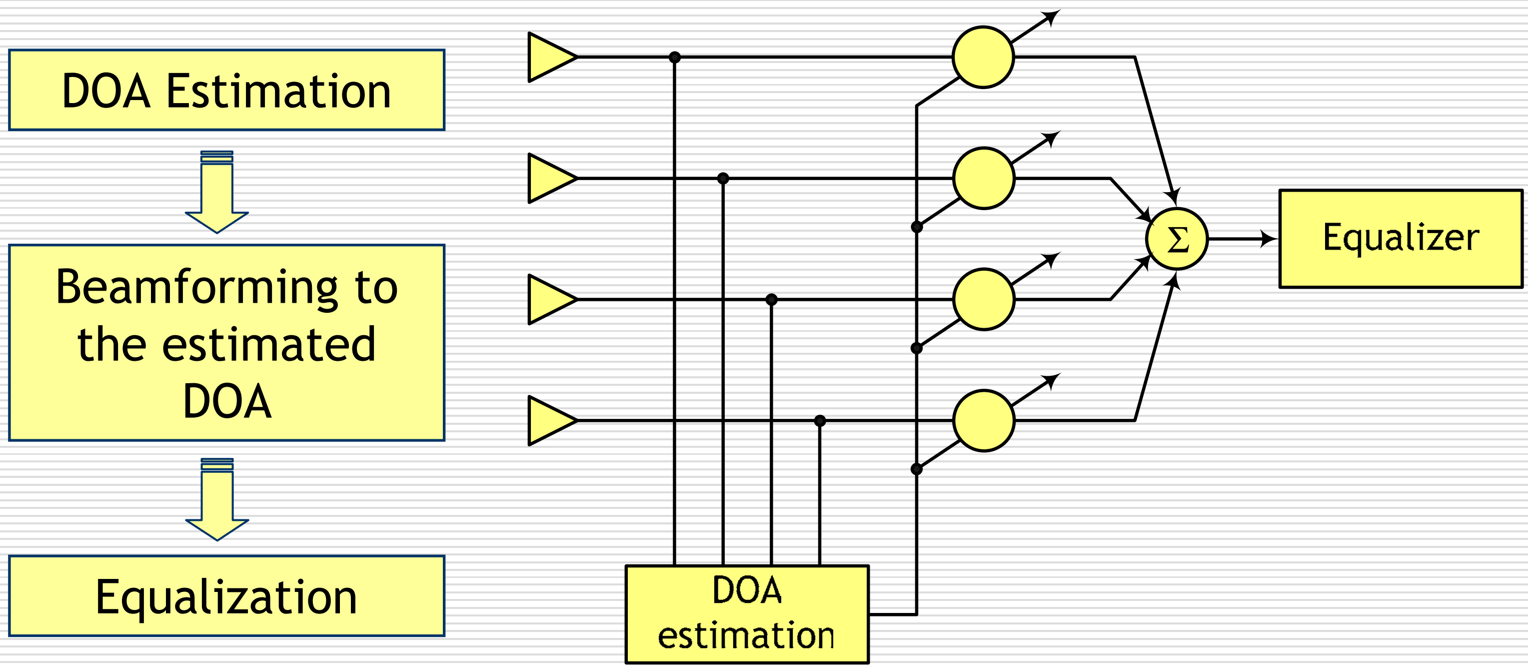
- Scheme

DOA estimation → Beamforming → Equalization → Analysis the performance → Switching Algorithm

- DOA estimation
  - Capon beamforming
  - Spatial spectrum
- Beamforming
  - Remove multipath through spatial filtering
- Equalization
  - Remove remained multiapth
- Analysis the performance
  - Can we see DTV?
- Switching Algorithm
  - Estimate other DOA



DOA Estimation-based DTV Receiver

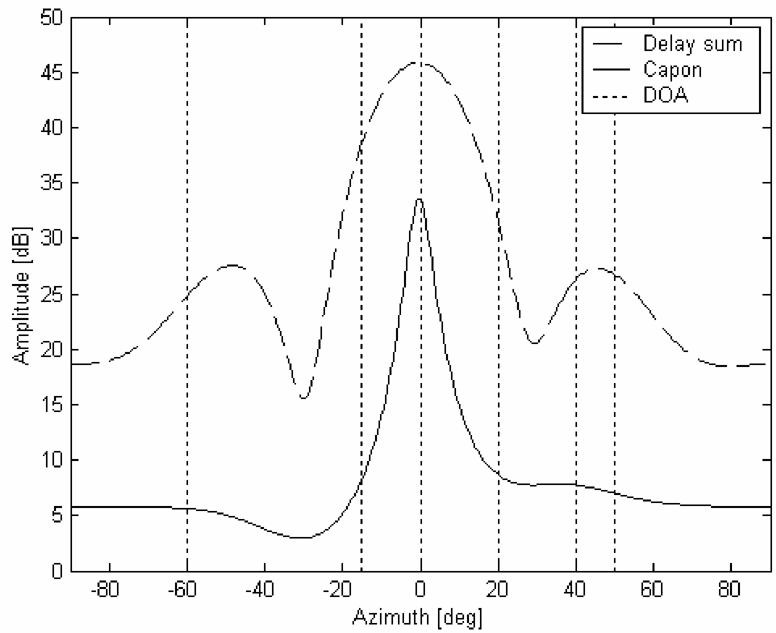


Simulation Condition

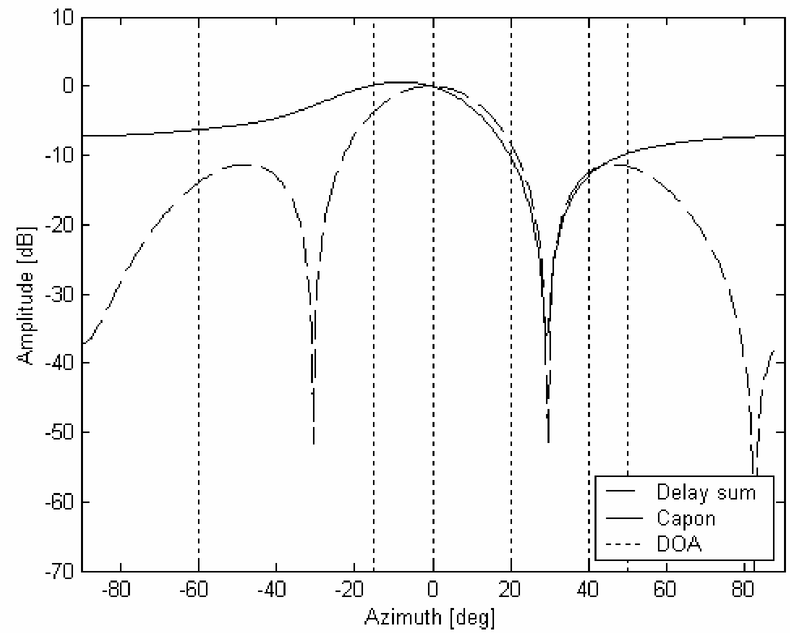
- 4 linear antennas
- SNR: 20 dB
- DOA estimation
  - Capon method with 1 field sync signals
- DFE(decision feedback equalizer)
  - FFF (feed-forward filter)
    - Filter length: 50
  - FBF (feed-backward filter)
    - Filter length: 150
  - SAG (stop and go) algorithm

Brazilian Channel A

- Estimated DOA
  - Capon: -0.5°, Delay sum: -0.5°

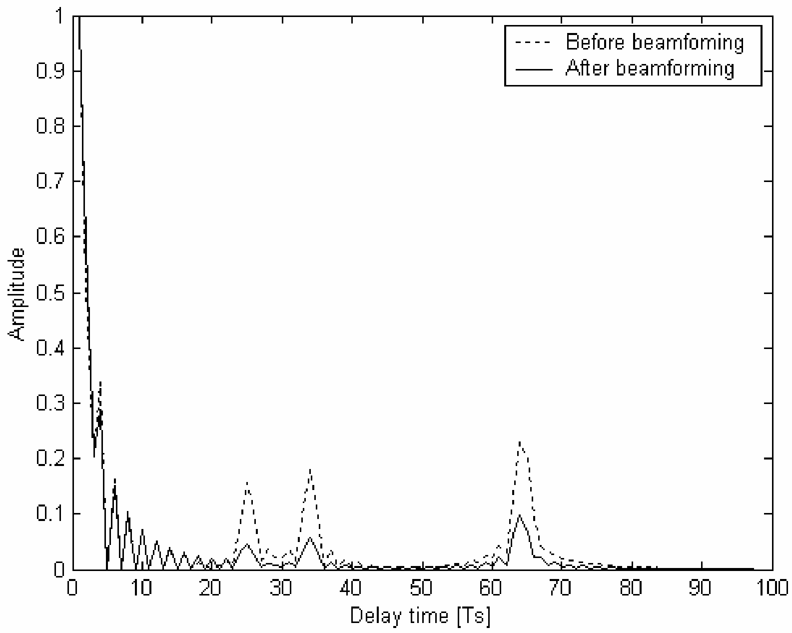


Spatial Spectrum

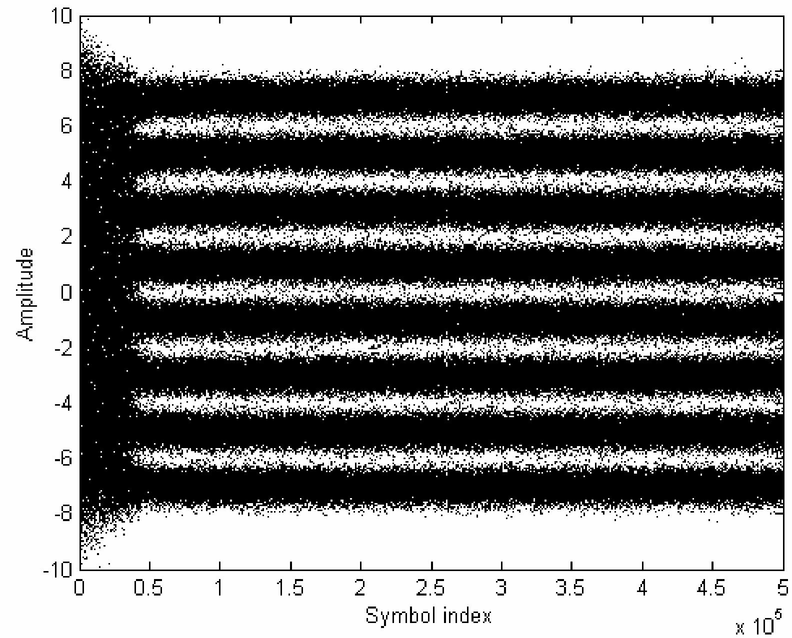


Beampattern

Brazilian Channel A



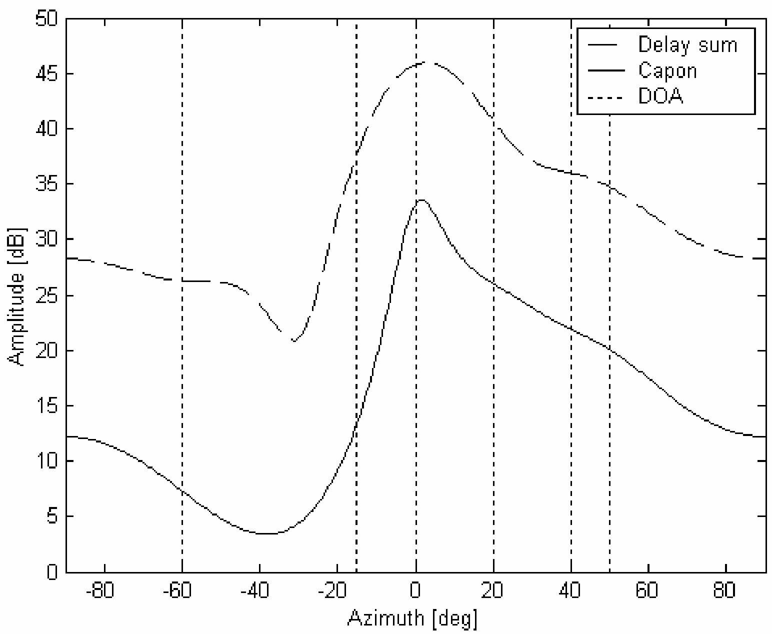
Delay profile



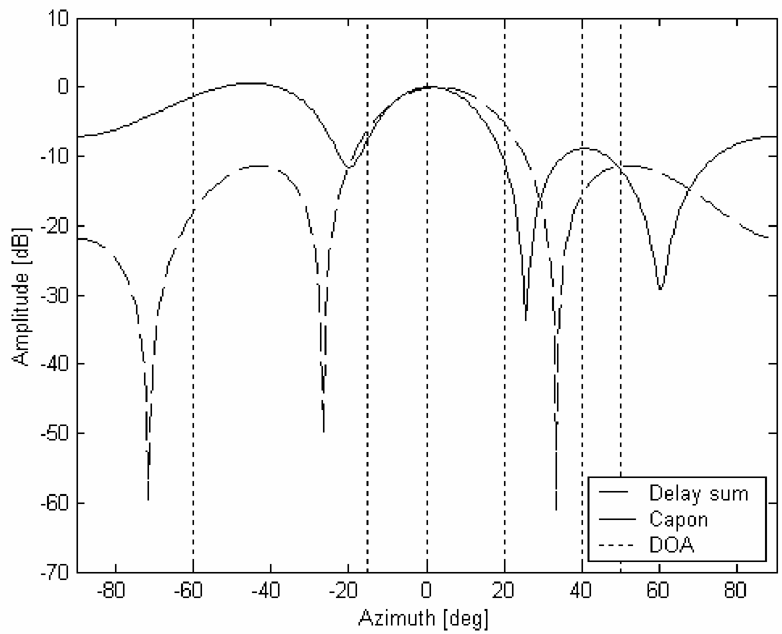
Constellation

Brazilian Channel B

- Estimated DOA
  - Capon: 1.5°, Delay sum: 3°

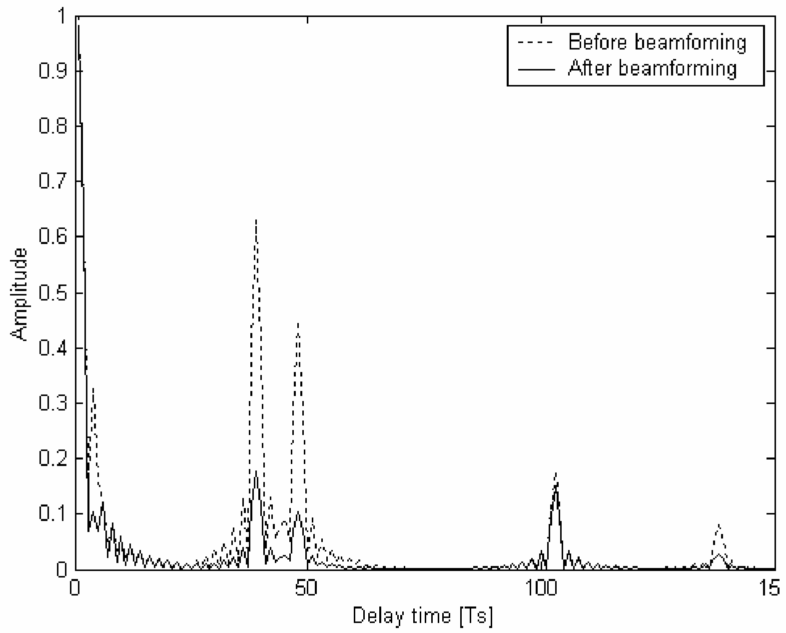


Spatial Spectrum

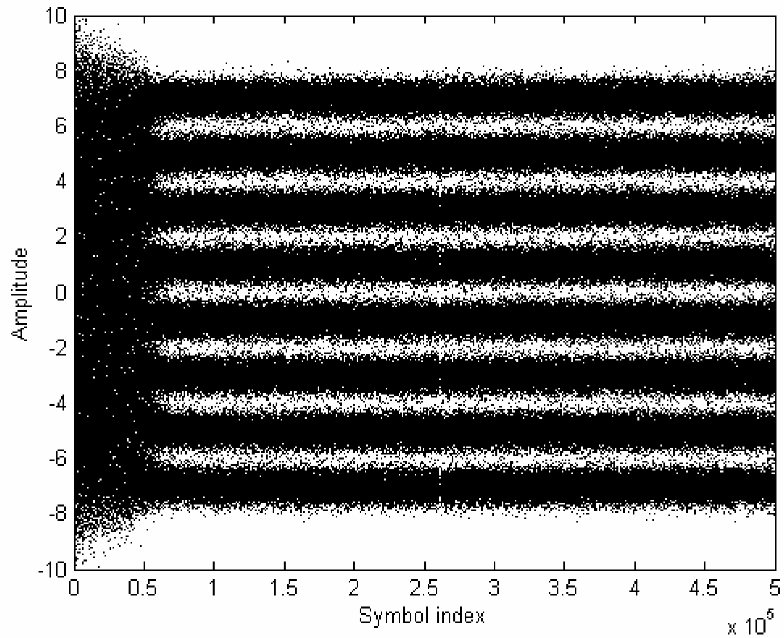


Beampattern

Brazilian Channel B



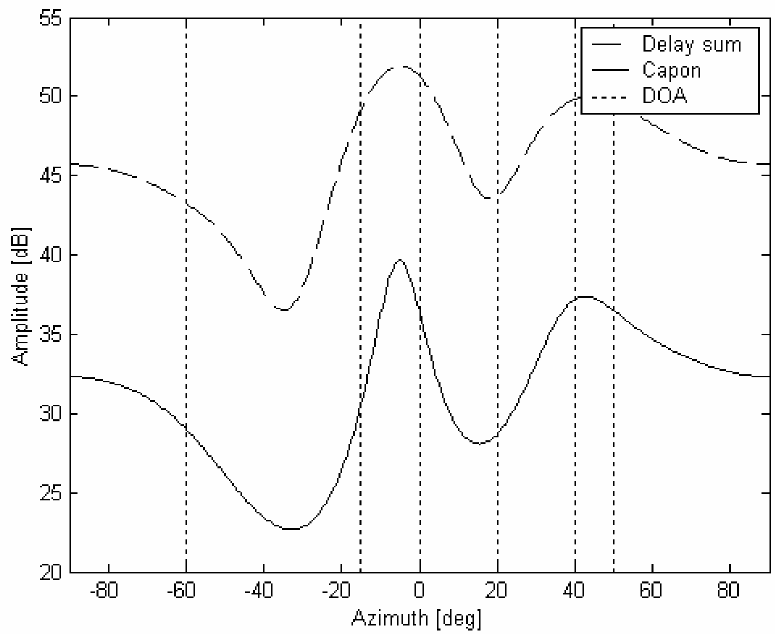
Delay profile



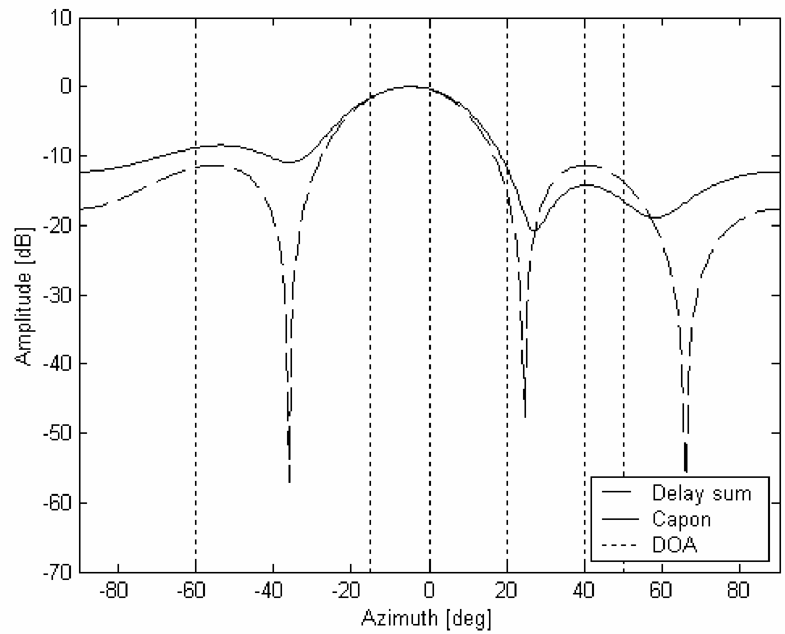
Constellation

Brazilian Channel C

- Estimated DOA
  - Capon: -5°, Delay sum: -5°

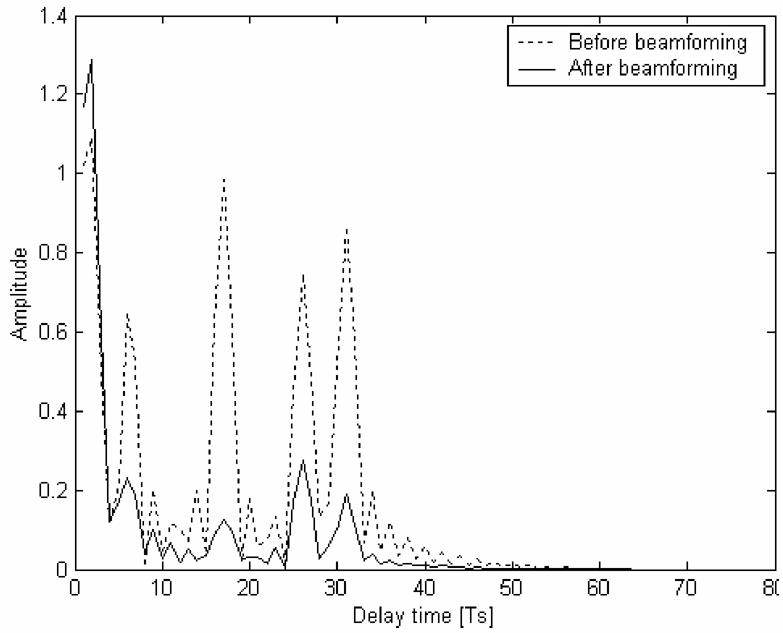


Spatial Spectrum

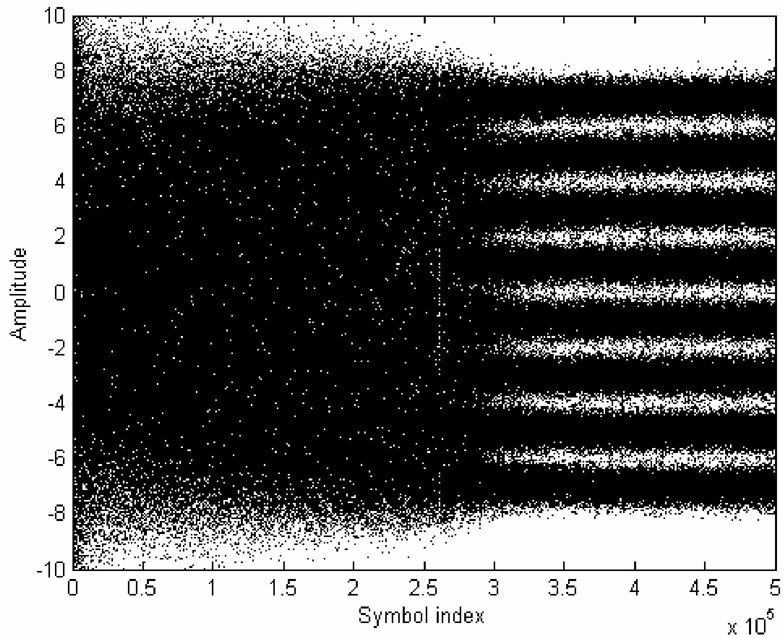


Beampattern

Brazilian Channel C



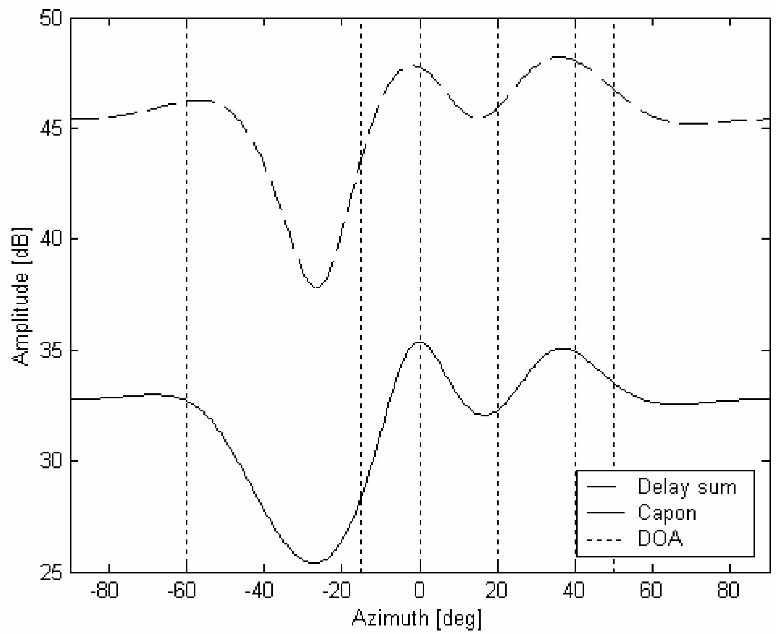
Delay profile



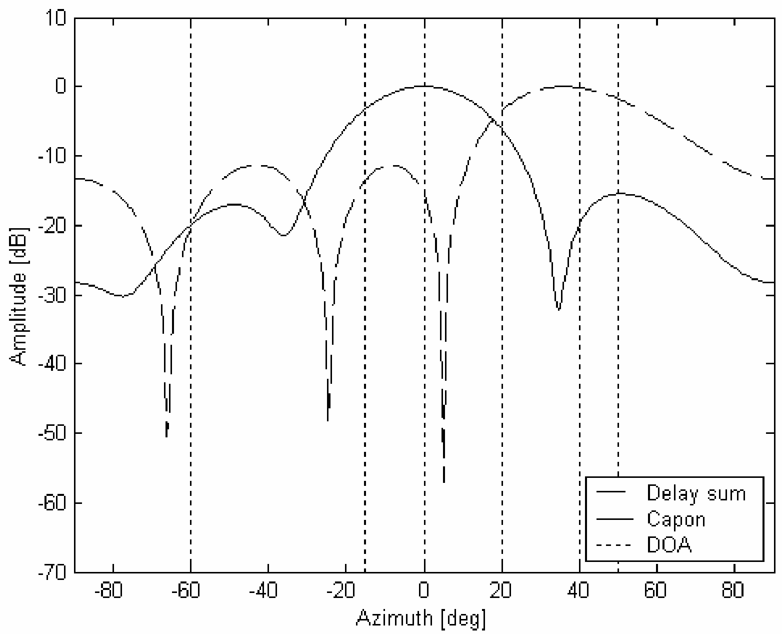
Constellation

Brazilian Channel D

- Estimated DOA
  - Capon: 0°, Delay sum: 36°

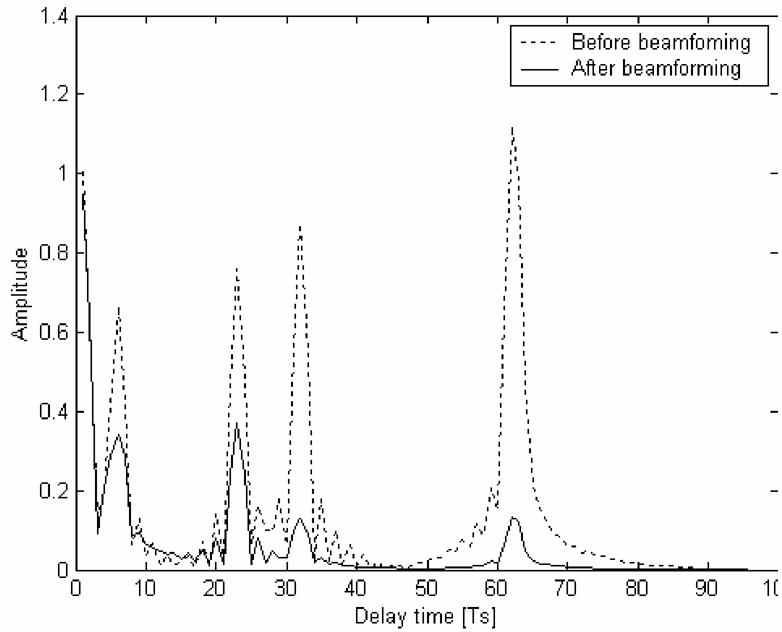


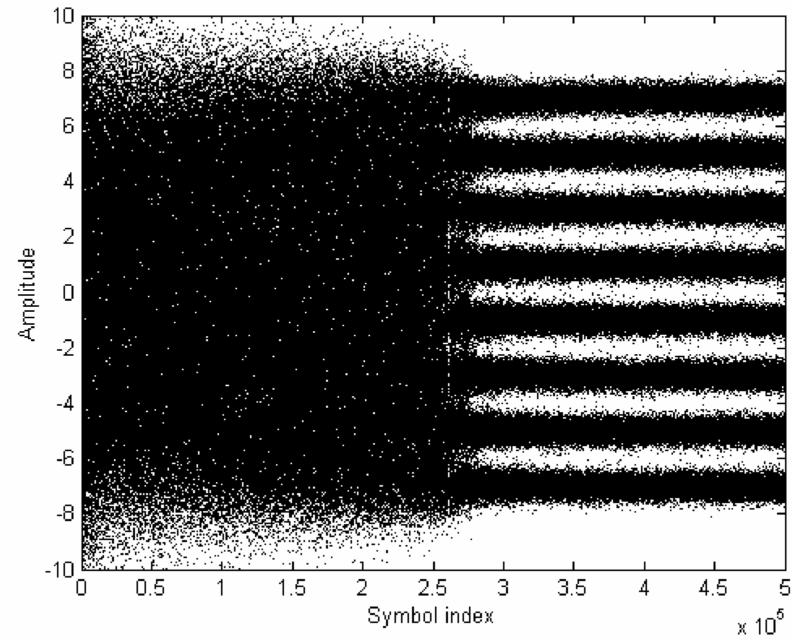
Spatial Spectrum



Beampattern

Brazilian Channel D



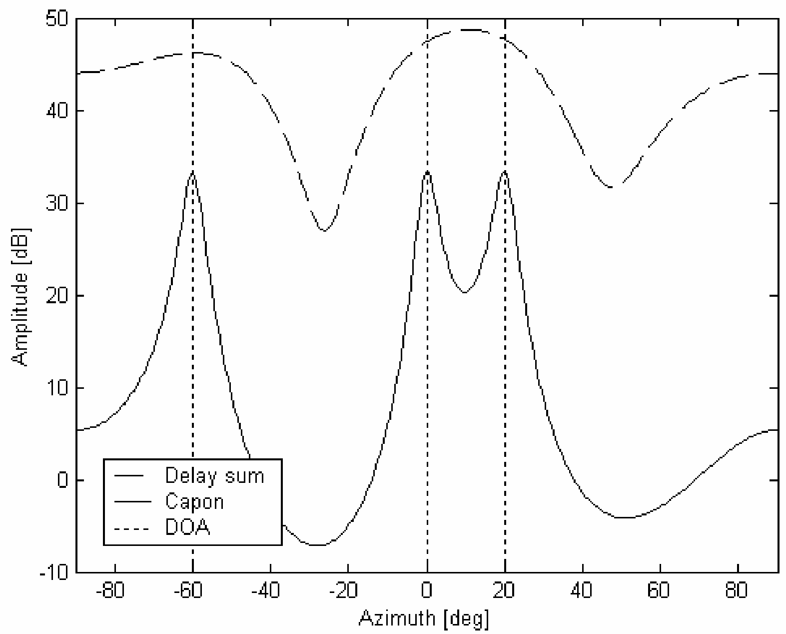


Delay profile

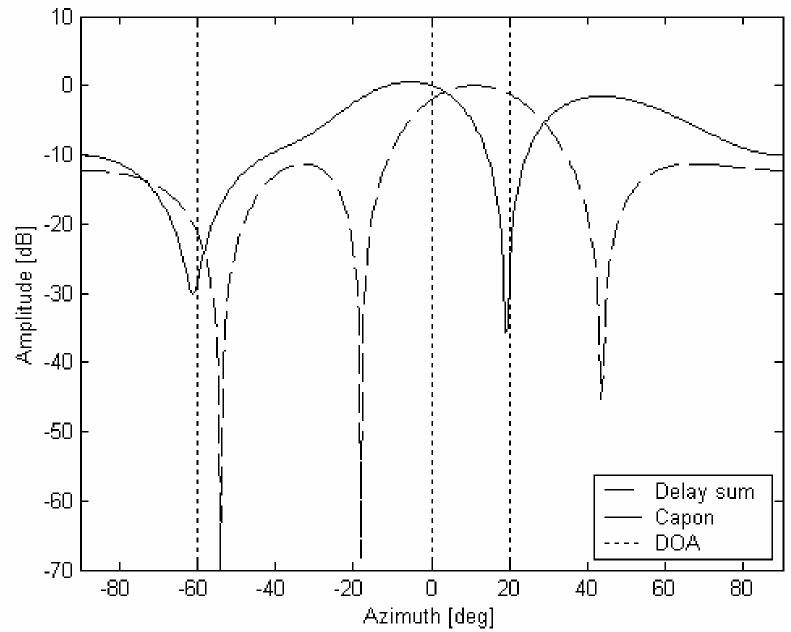
Constellation

Brazilian Channel E

- Estimated DOA
  - Capon: 0°, Delay sum: 11°

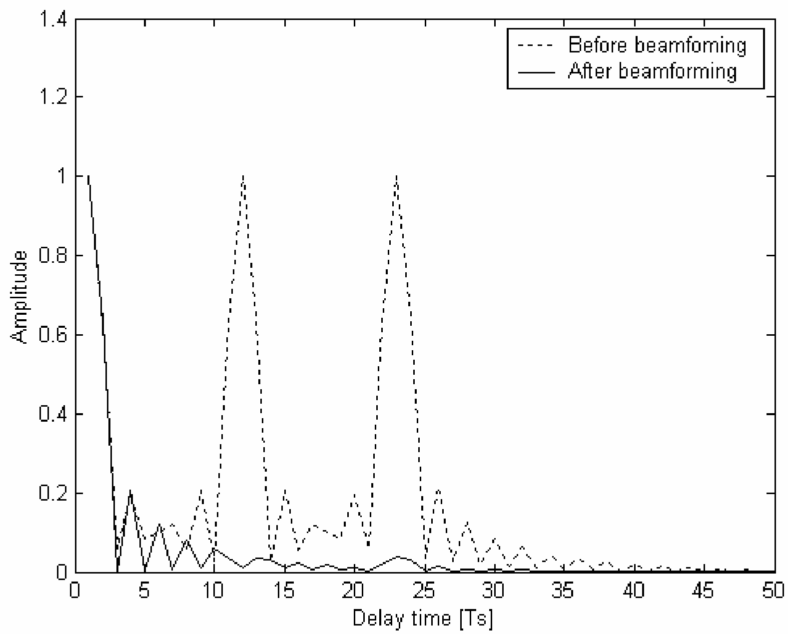


Spatial Spectrum

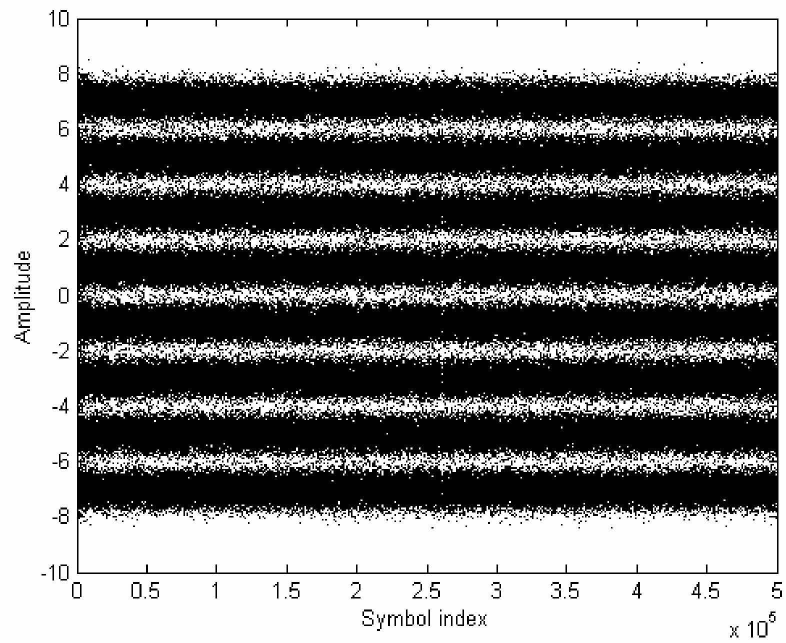


Beampattern

Brazilian Channel E



Delay profile



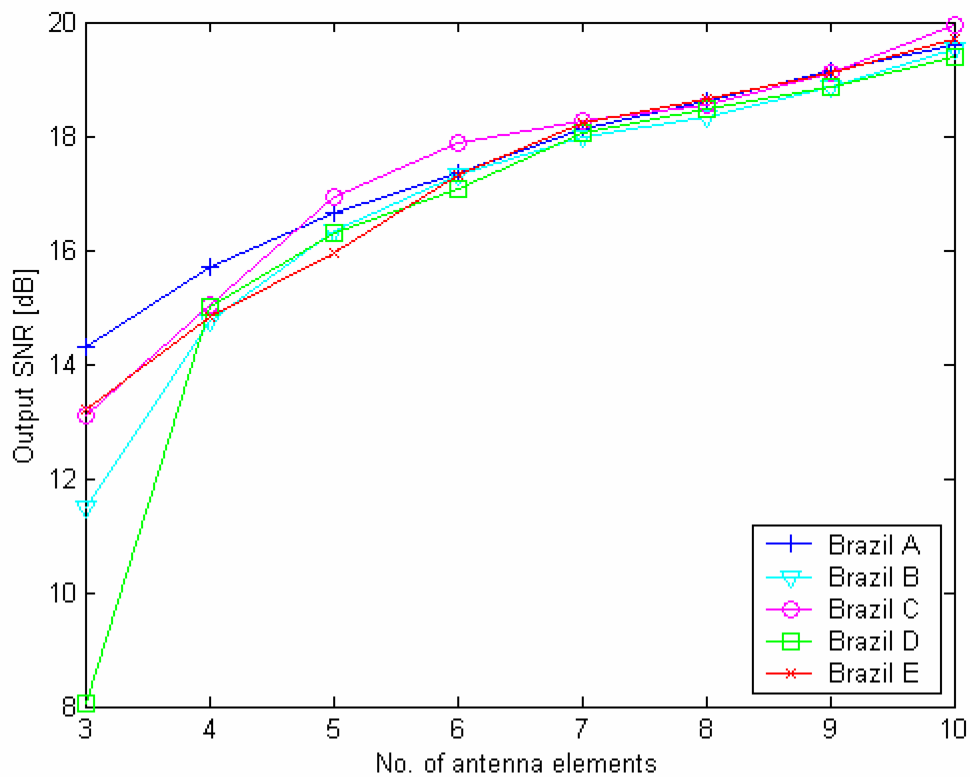
Constellation

Summary

SNR	Channel	Beamformer			Equalizer	
		Input SINR	Output SINR	SER	SINR	SER
SNR=15 dB	Brazil A	7.1032	11.8262	0.3544	18.8045	0.0508
	Brazil B	1.3582	9.8316	0.4488	18.5231	0.0576
	Brazil C	-5.0924	1.0190	0.7001	19.6816	0.0299
	Brazil D	-5.2659	4.2071	0.6436	18.1856	0.0688
	Brazil E	-3.0608	17.7802	0.0797	18.7236	0.0531
SNR=10 dB	Brazil A	5.8000	11.2354	0.3768	14.6339	0.2190
	Brazil B	0.9738	8.0259	0.5240	13.7249	0.2658
	Brazil C	-5.1768	0.9418	0.6997	15.6890	0.1671
	Brazil D	-5.3521	4.0054	0.6484	12.4024	0.3383
	Brazil E	-3.2019	11.8097	0.3448	12.2021	0.3495

SNR Performance in terms of No. of Antenna Elements

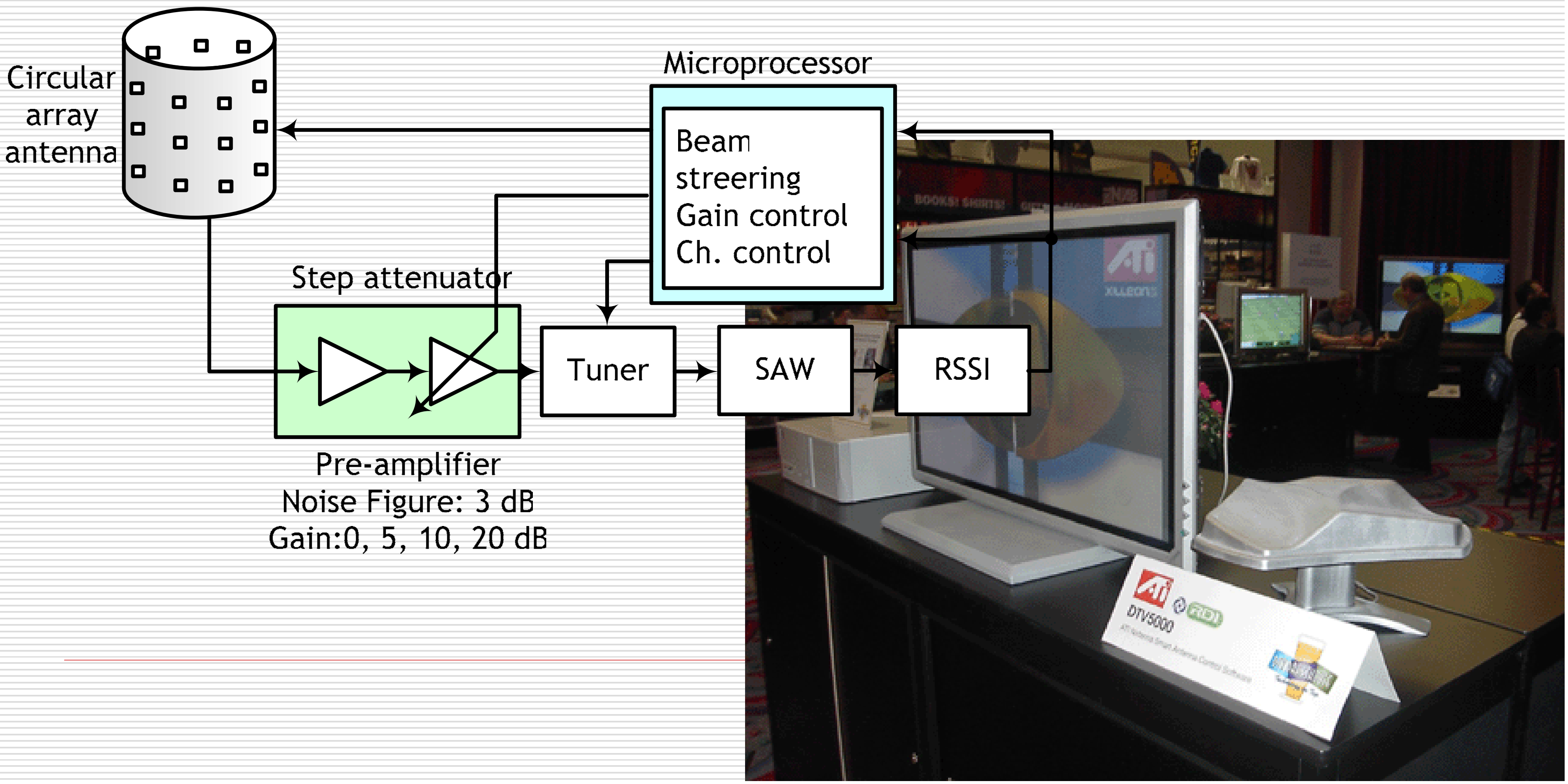
- Linear array
- DOA: [20°, -10°, 0°, 45°, -50°, 60°]
- No. of antenna elements: 3~10
- Input SNR: 10 dB
- Beamformer
  - Beamforming with LMS during training sequences
  - Equalizer: LMS and Blind



Implementation

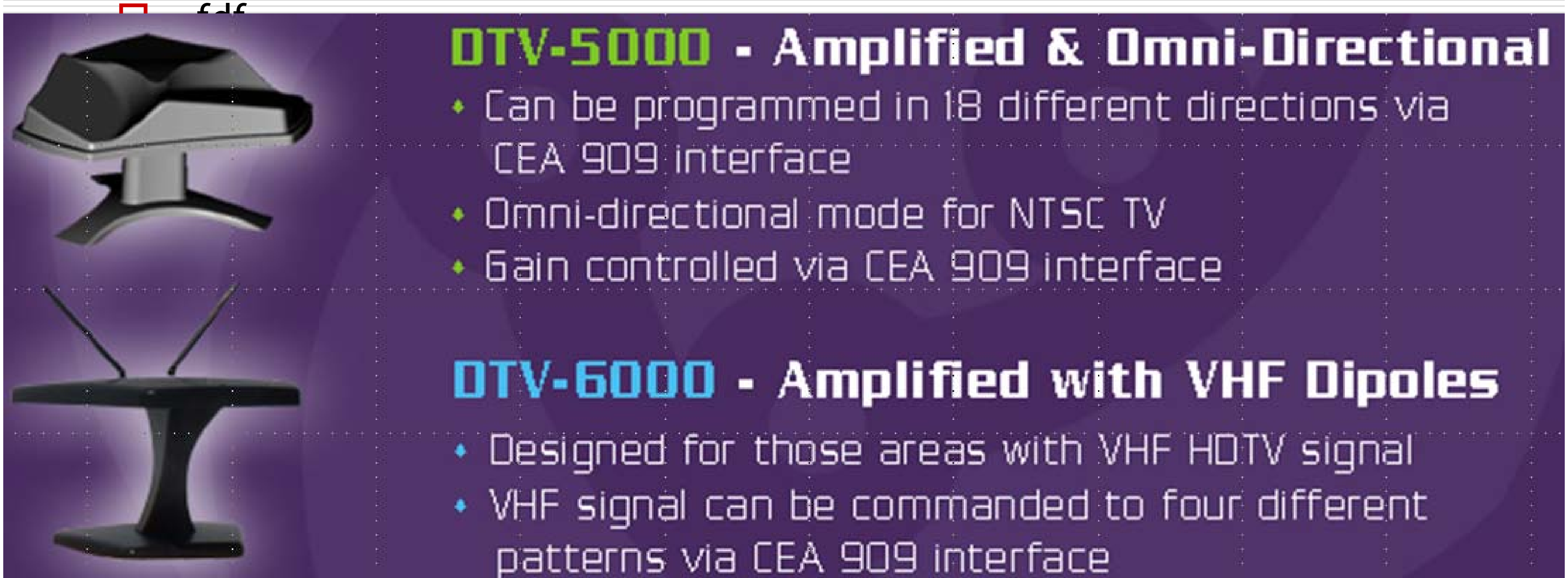
Beam Selection

- Electrically steered fixed beamformer
- Seek out the direction of the highest signal strength automatically



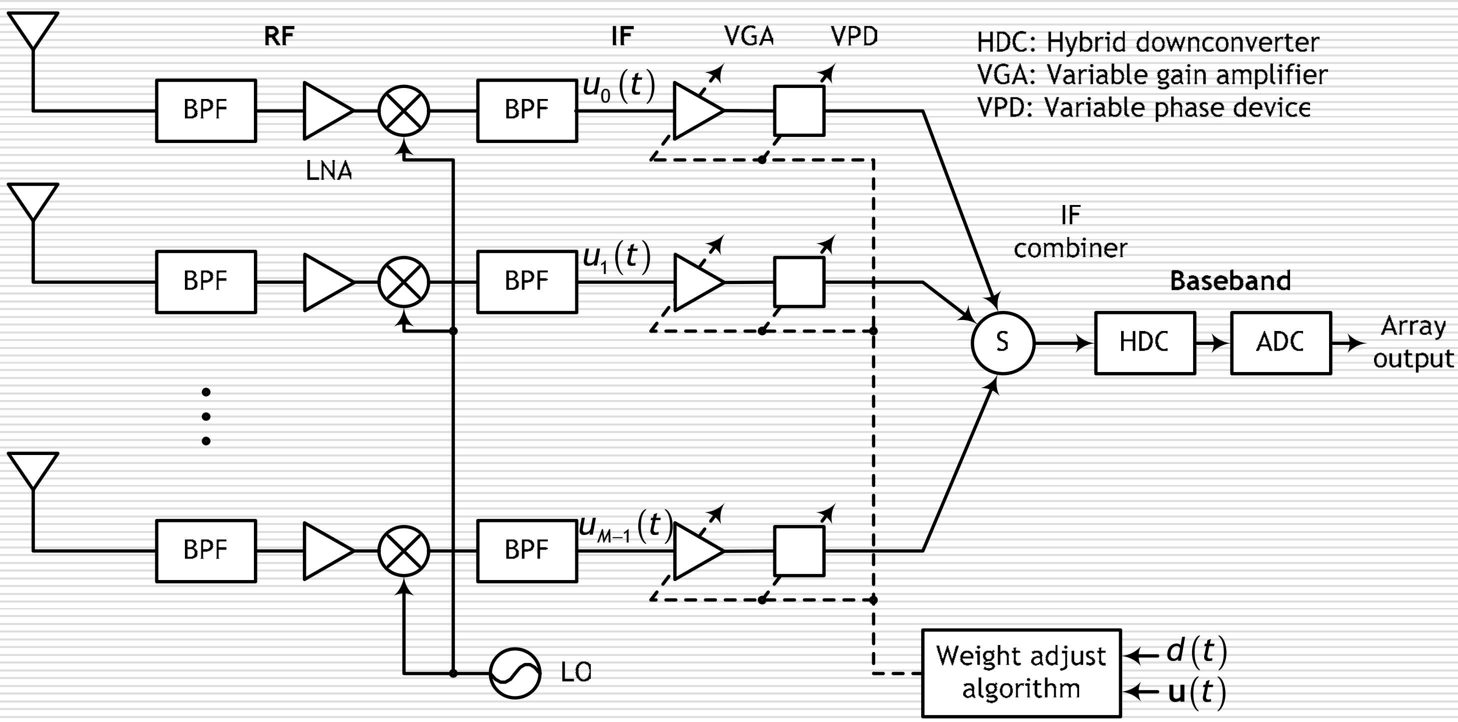
Beam Selection

- fdf



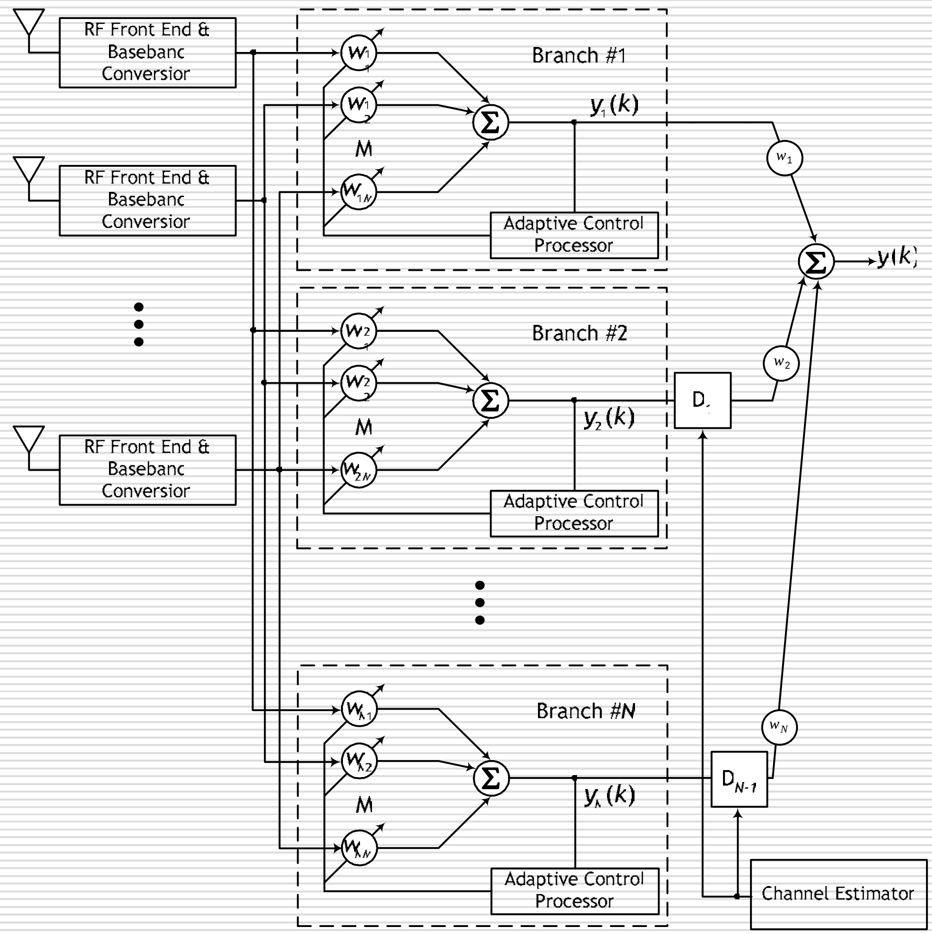
Analog Beamformer

- Analog IF weighting and combining
  - Easy for timing & carrier recovery

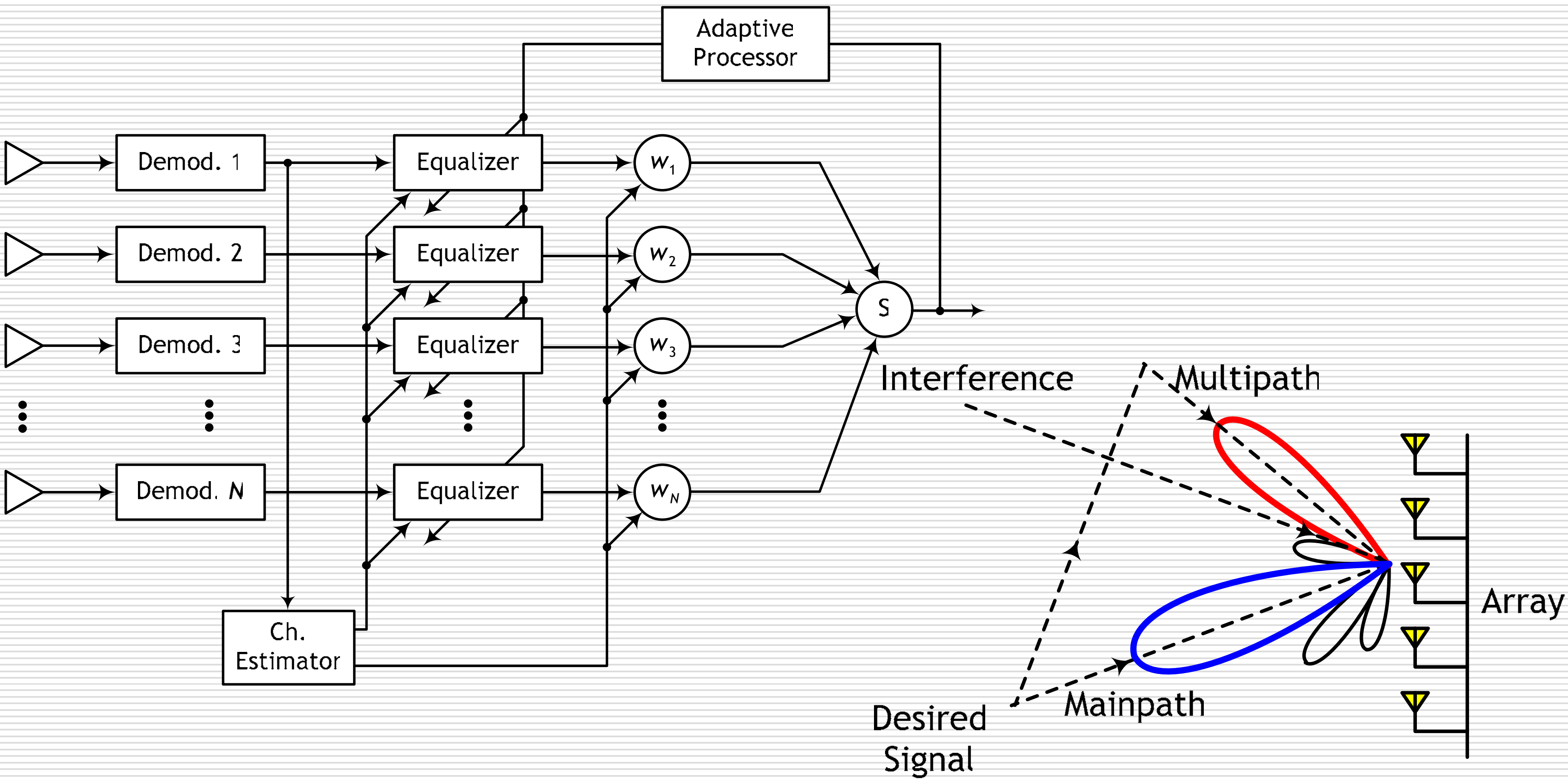


Spatial Diversity and Combining I

- Channel estimation with field sync signal
  - Select main and dominant multipath signals
  - Combining each signal with EQC or MRC
  - Advantage
    - Increase of SNR with multipath combining



Spatial Diversity and Combining II



Conclusions

- Beamforming can be one of ways to improve DTV reception performance
- Beamforming is efficient for UHF bands
- DOA estimation based receiver with Capon method is reasonable for implementation
- Further study
  - Optimization of array structure
  - Synchronization schemes for array systems
  - Joint optimization of DOA and training sequence based algorithms
  - How to calibrate?