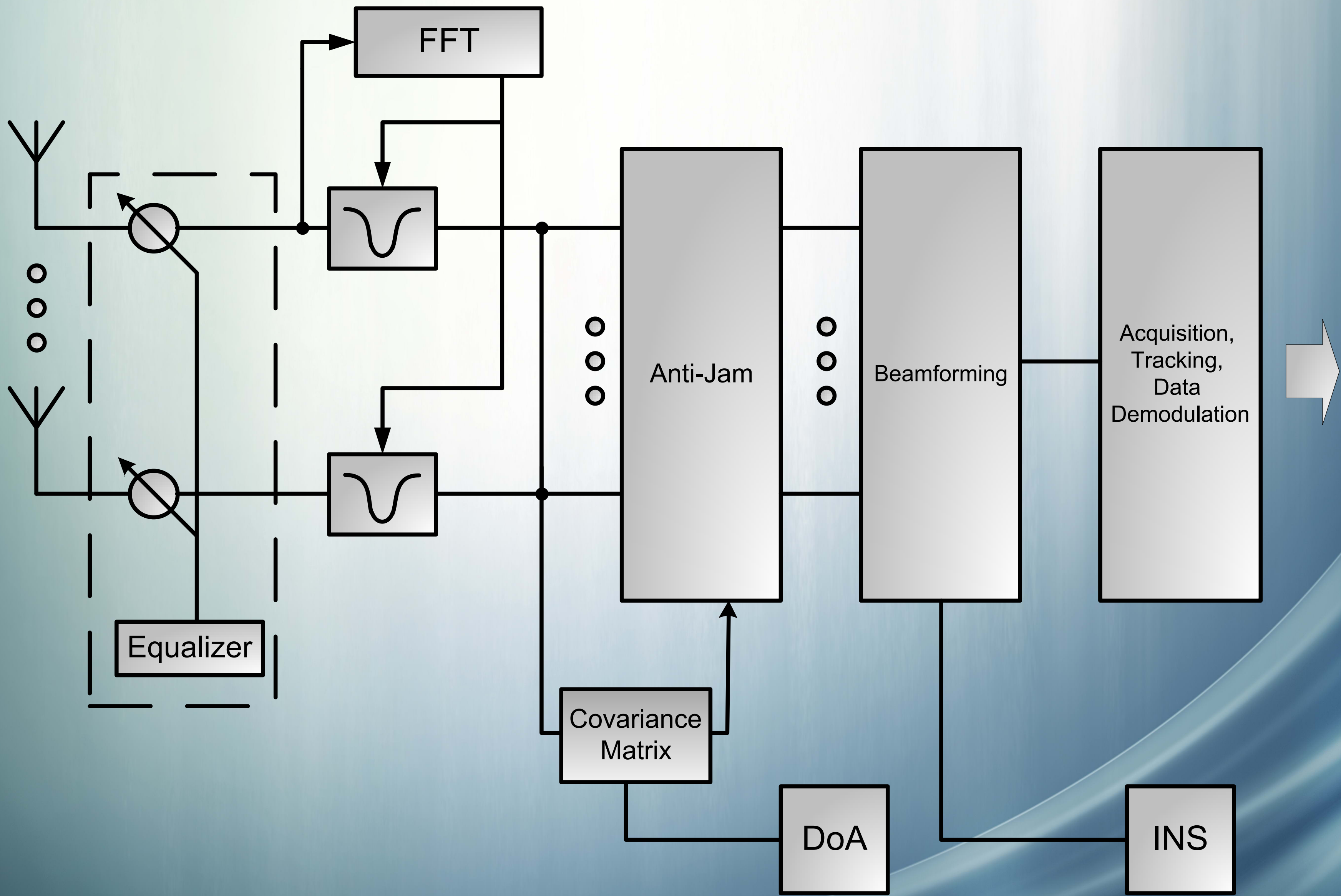
Moscow design bureau "Compas" JSC

Methods of improving efficiency of interference suppression GNSS anti-jam receivers.

ICG-9 WG-B, Prague, Czech Republic, 2014

Sokolov I.M., Kalmykov P.V.

Block diagram of the multi-antenna GNSS receiver



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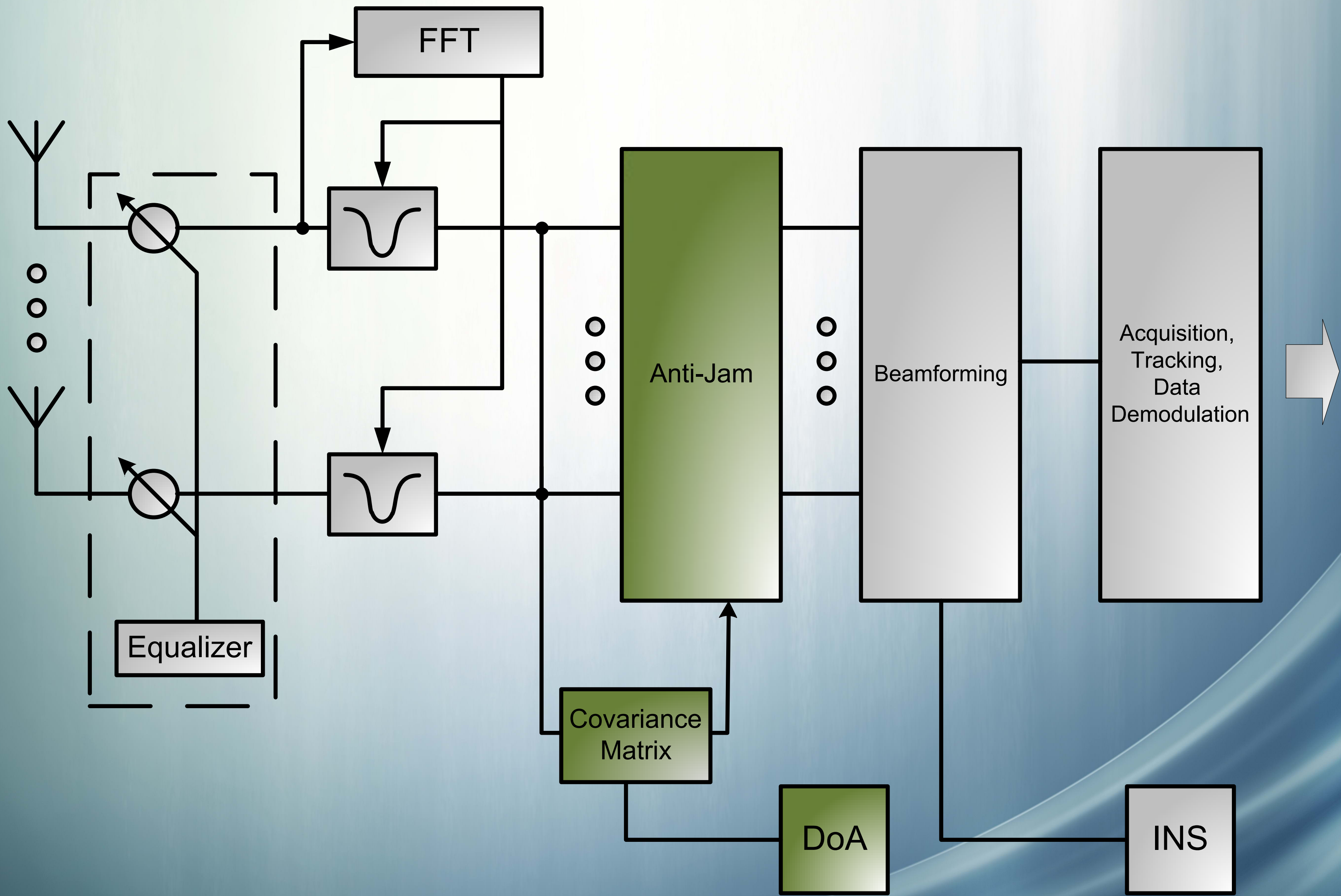
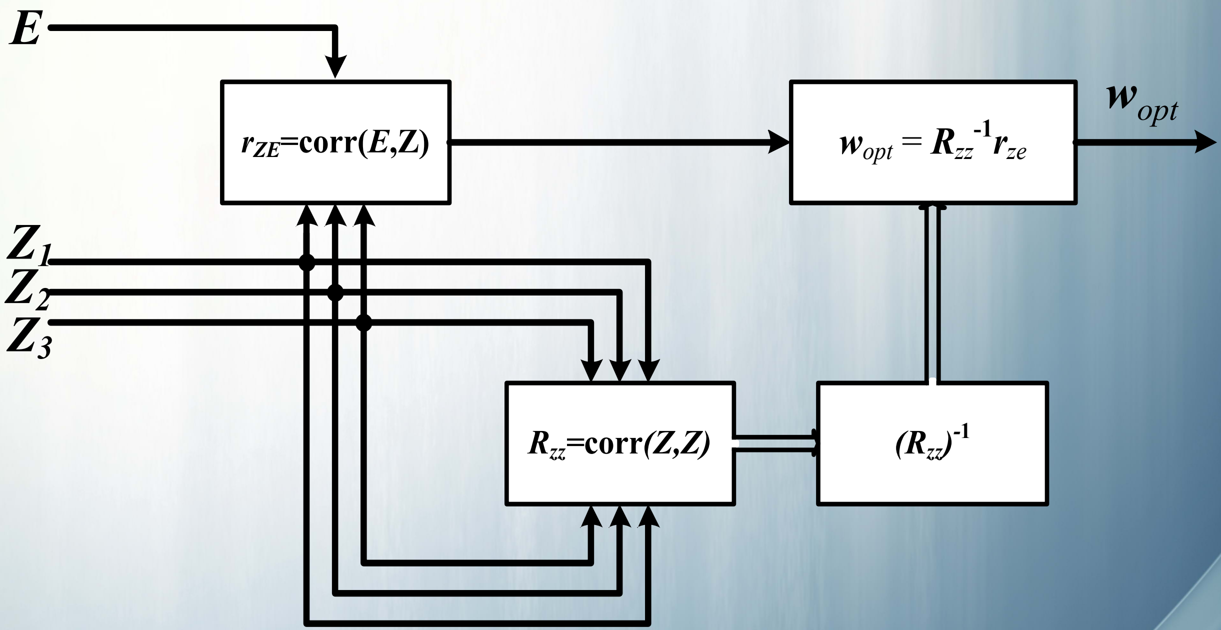


Nullformer

$$\boldsymbol{w}_{opt} = \boldsymbol{R}_{ZZ}^{-1}\boldsymbol{r}_{ZE}$$

$$\boldsymbol{R}_{ZZ} = \left\langle \boldsymbol{Z}^{\mathrm{H}}\boldsymbol{Z} \right\rangle$$

$$\boldsymbol{r}_{ZE} = \left\langle \boldsymbol{Z}^{\mathrm{H}}\boldsymbol{E} \right\rangle$$



Output signal:

$$\boldsymbol{Y} = \boldsymbol{E} - \boldsymbol{Z}\boldsymbol{w}_{opt}$$

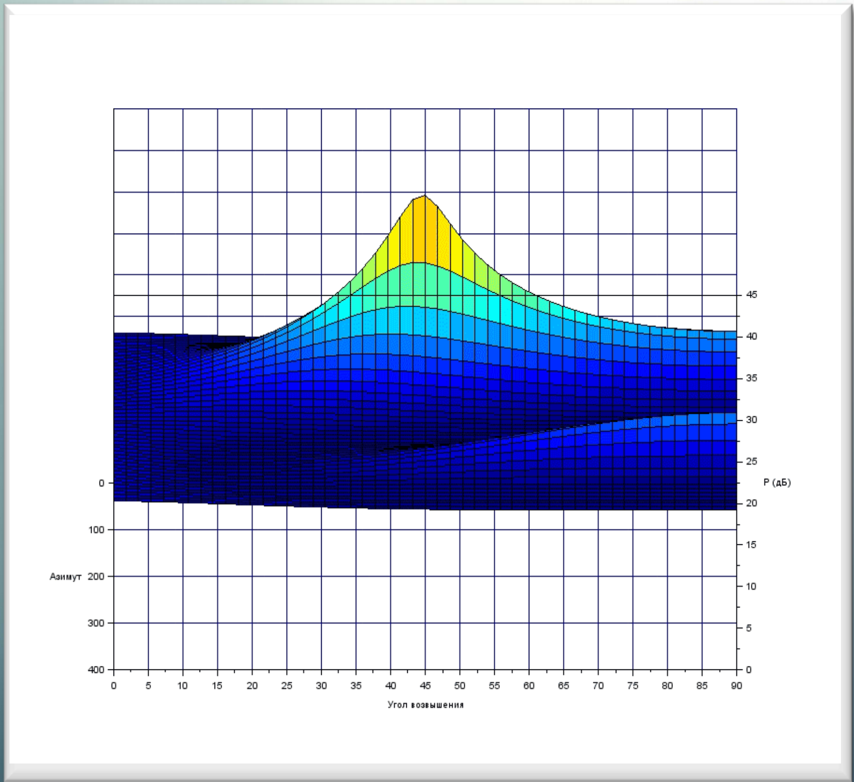
$$\boldsymbol{Z} = (\boldsymbol{Z}_1, \boldsymbol{Z}_2, \ldots, \boldsymbol{Z}_N)$$

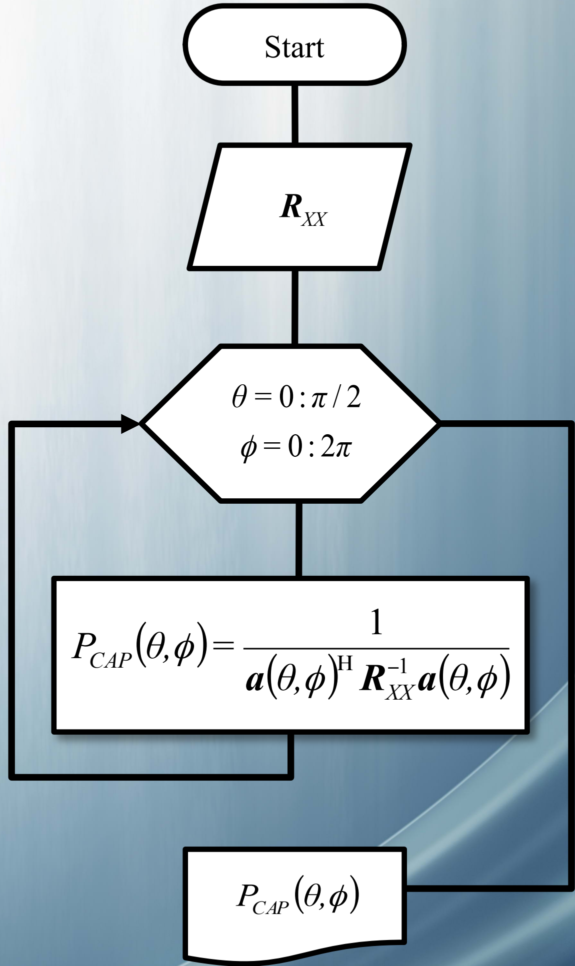
$\boldsymbol{E}$ – reference channel signal
$\boldsymbol{Z}_i$ – i-th adjusting channel

DoA Estimation by Capon method

$$\boldsymbol{R}_{XX} = \left\langle \boldsymbol{X}^{\mathrm{H}} \boldsymbol{X} \right\rangle \quad \boldsymbol{X} = \left(\boldsymbol{E}, \boldsymbol{Z}\right)$$

$$P_{CAP}(\theta,\phi) = \frac{1}{\boldsymbol{a}(\theta,\phi)^{\mathrm{H}} \boldsymbol{R}_{XX}^{-1} \boldsymbol{a}(\theta,\phi)}$$





EVD interference remover

$$\boldsymbol{R}_{XX} = \boldsymbol{U}\boldsymbol{\Lambda}\boldsymbol{U}^{\mathrm{H}}$$

$$\boldsymbol{U} = (\dot{\boldsymbol{U}}, \ddot{\boldsymbol{U}})$$

$$\boldsymbol{Y} = \boldsymbol{X} \cdot (\dot{\boldsymbol{U}}, \ddot{\boldsymbol{U}}) = (\dot{\boldsymbol{Y}}, \ddot{\boldsymbol{Y}})$$

$$(\dot{\boldsymbol{Y}}, \ddot{\boldsymbol{Y}}) \cdot \begin{pmatrix} \dot{\boldsymbol{U}}^{\mathrm{H}} \\ \ddot{\boldsymbol{U}}^{\mathrm{H}} \end{pmatrix} = \dot{\boldsymbol{X}} + \ddot{\boldsymbol{X}}$$

$$\boldsymbol{\Lambda} = \mathrm{diag}(\lambda_1, \lambda_2, \ldots, \lambda_N) \qquad \lambda_1 \le \lambda_2 \le \ldots \le \lambda_N$$

Interference-free subspace:

$$\dot{\boldsymbol{U}} = (\boldsymbol{u}_1, \ldots, \boldsymbol{u}_{N-J})$$

Interference subspace:

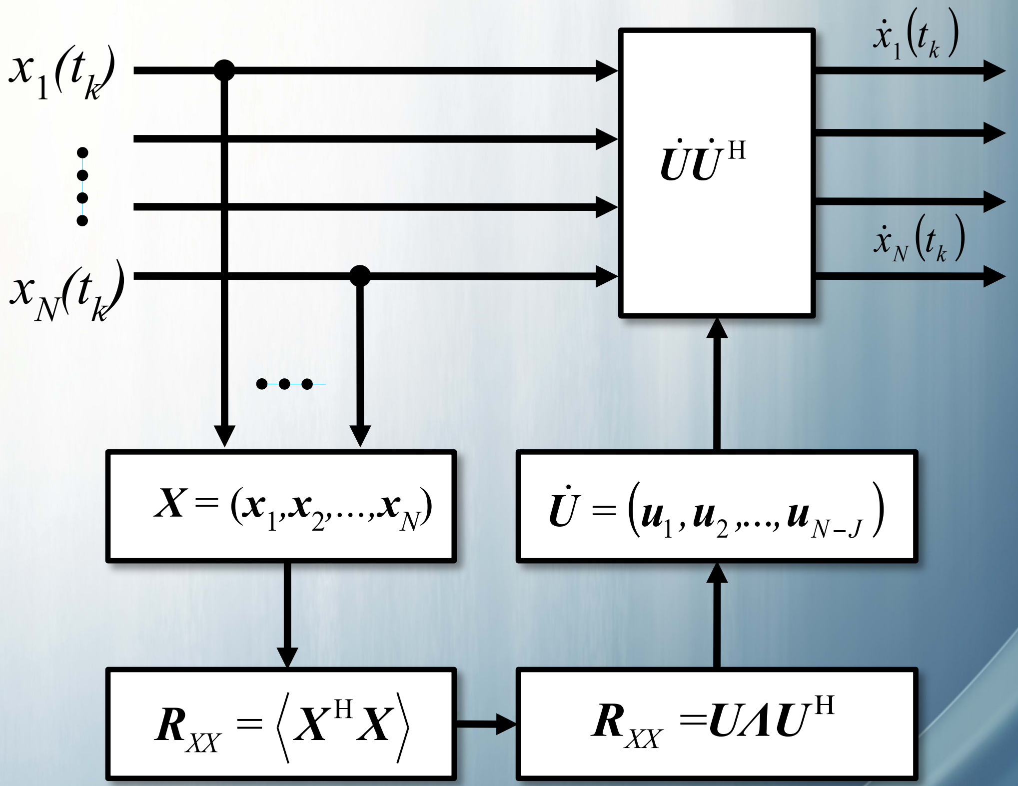
$$\ddot{\boldsymbol{U}} = (\boldsymbol{u}_{N-J+1}, \ldots, \boldsymbol{u}_N)$$

$\dot{\boldsymbol{X}}$ - interference-free signal

$\ddot{\boldsymbol{X}}$ – interference signal

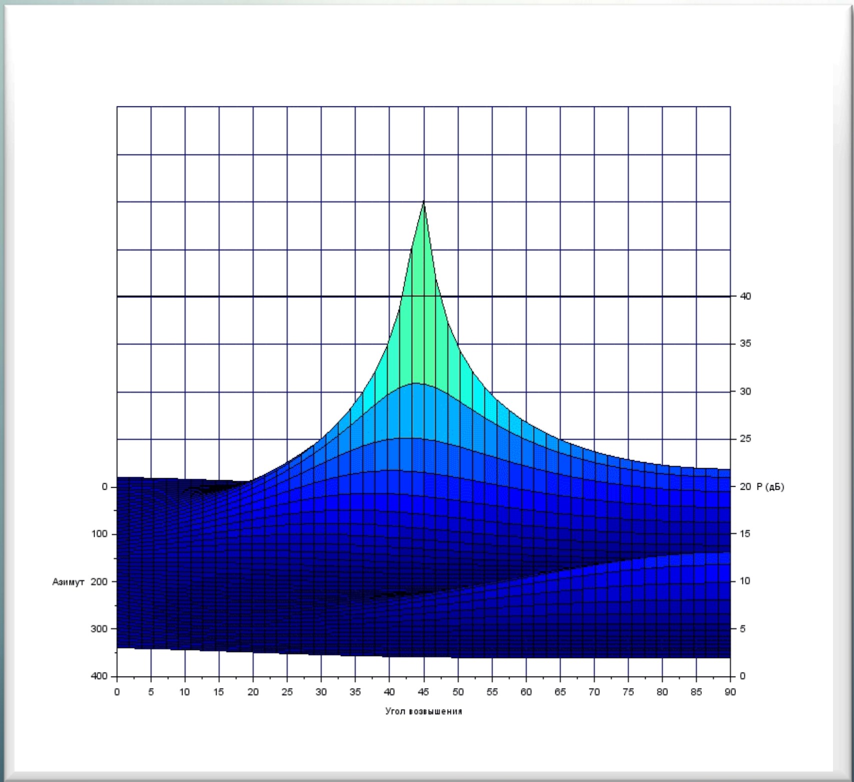
$$\lambda_{th} = v_0 + P_s$$

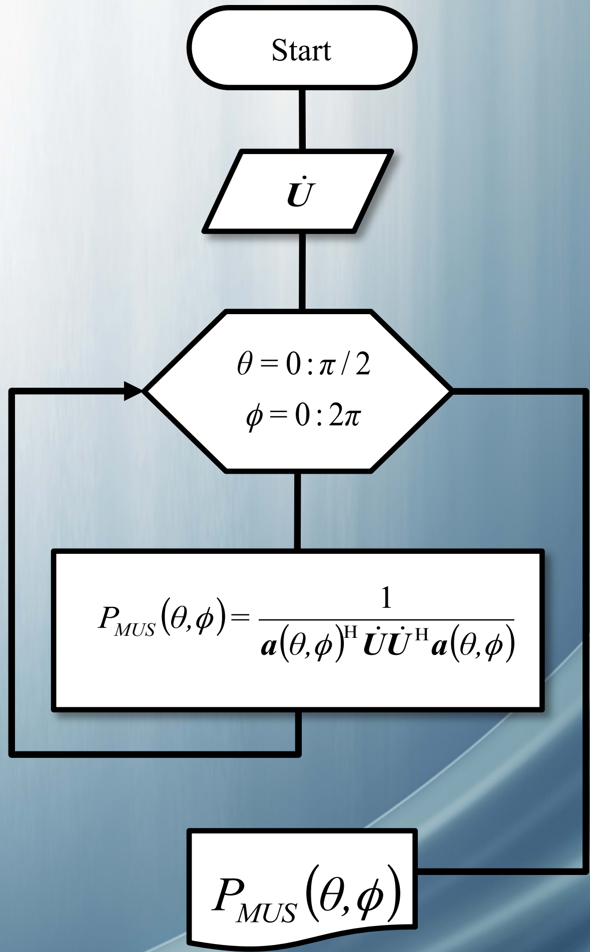
P_s – maximum power of GNSS signals



DoA Estimation by MUSIC

$$P_{MUS}(\theta,\phi)=\frac{1}{\boldsymbol{a}(\theta,\phi)^{\mathrm{H}}\dot{\boldsymbol{U}}\dot{\boldsymbol{U}}^{\mathrm{H}}\boldsymbol{a}(\theta,\phi)}$$





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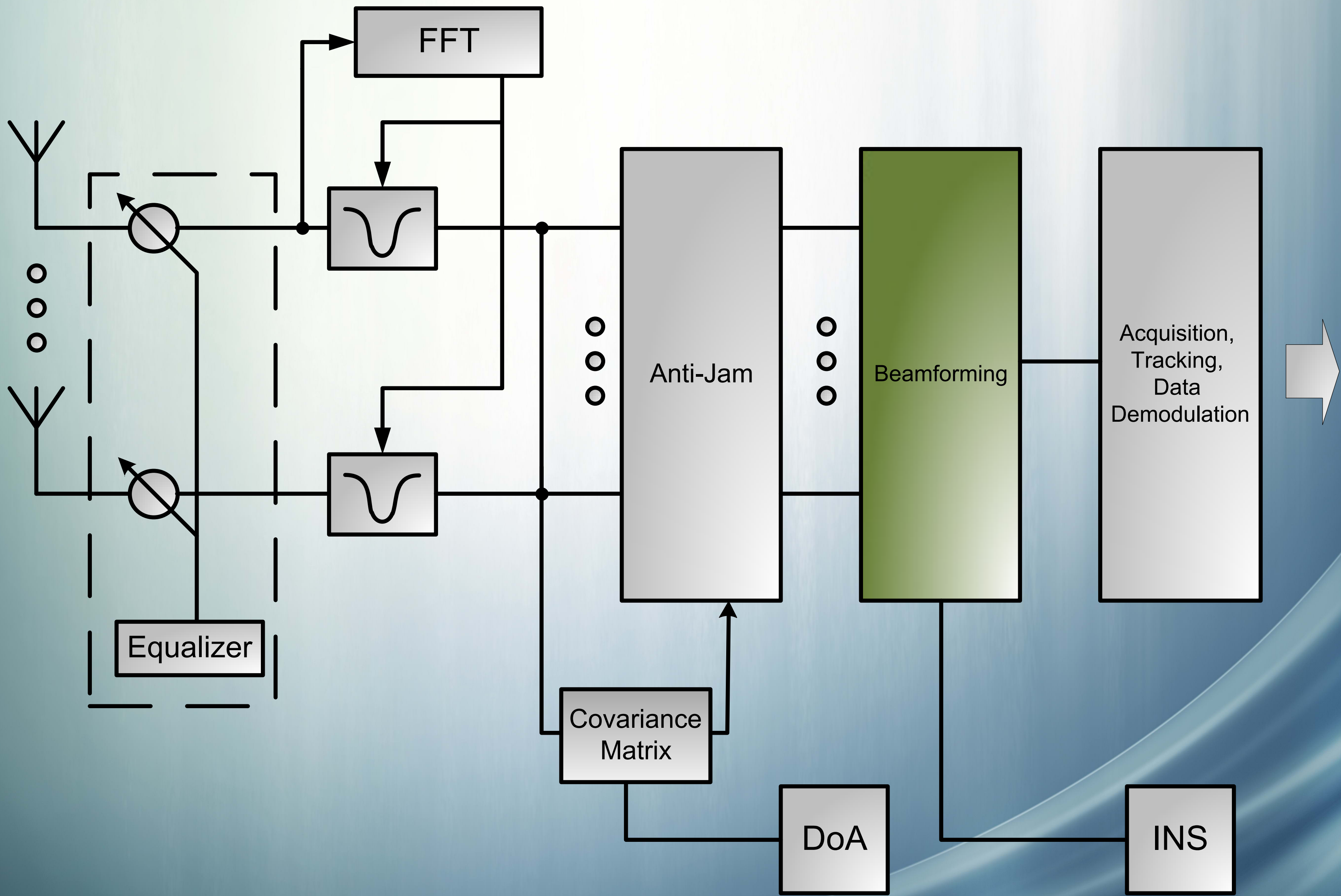
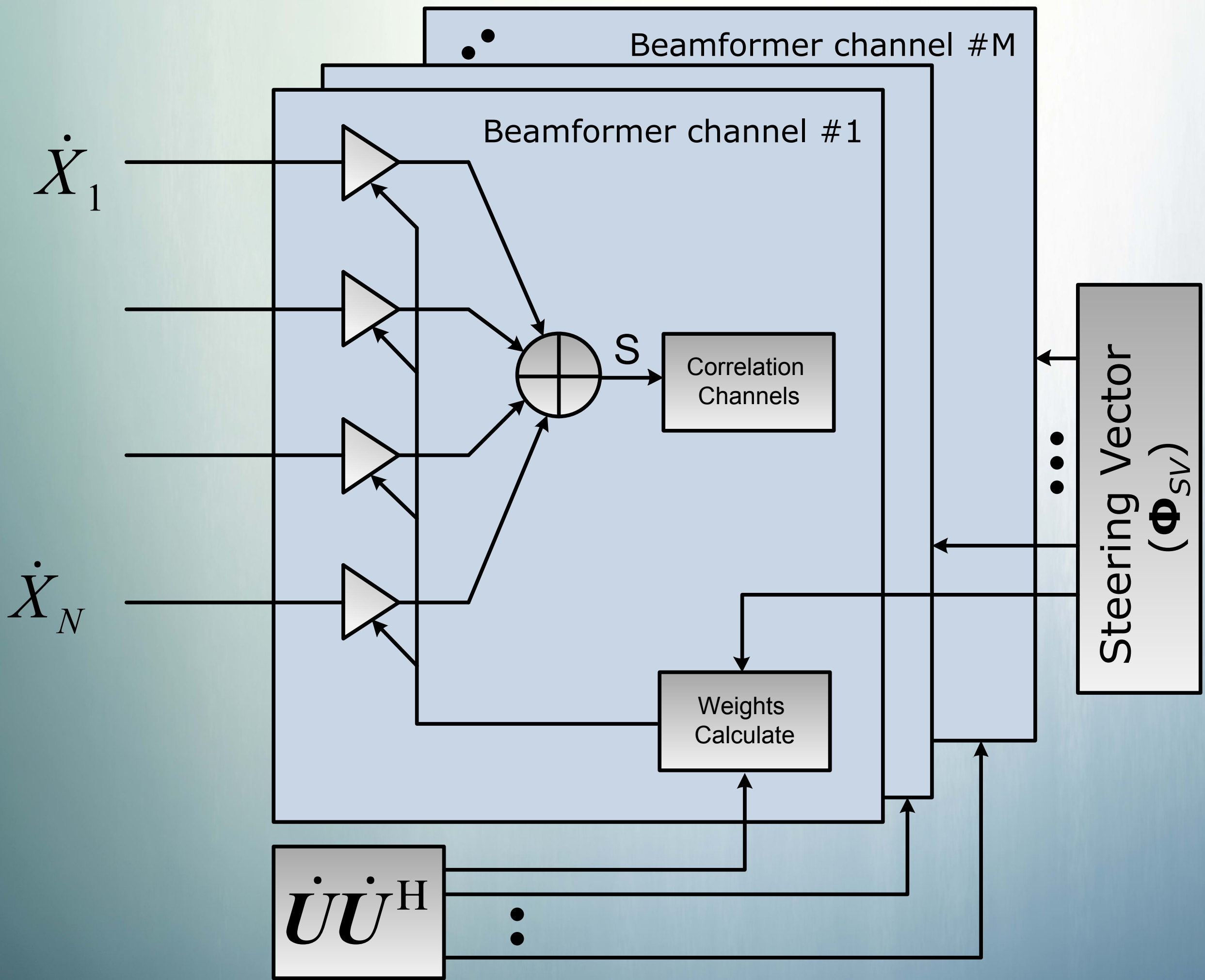


Beamforming



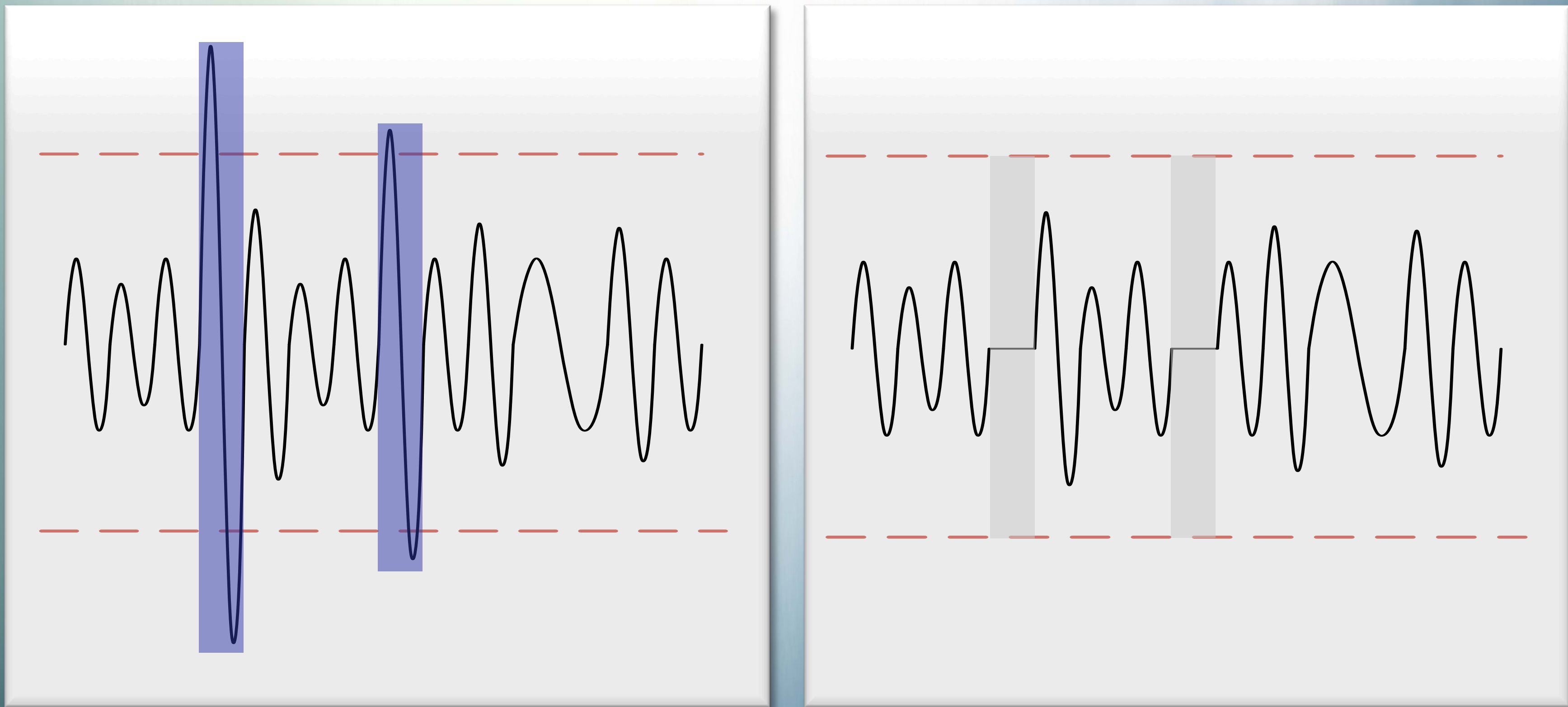
$$\boldsymbol{S} = \boldsymbol{X}\,\boldsymbol{\Phi}_{SV}^{*}\,\boldsymbol{U}\,\boldsymbol{U}^{H}$$

Factors affecting the efficiency of anti-jam devices base on spatial selection signals

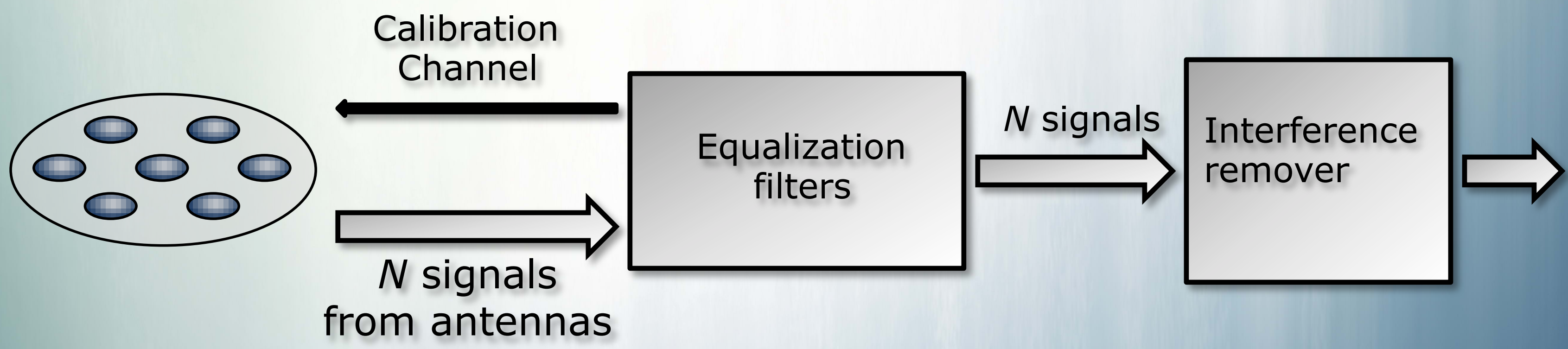
- Dynamic range ADC
- Channel non-identity
- Multipath interference

Dynamic range (cutoff)

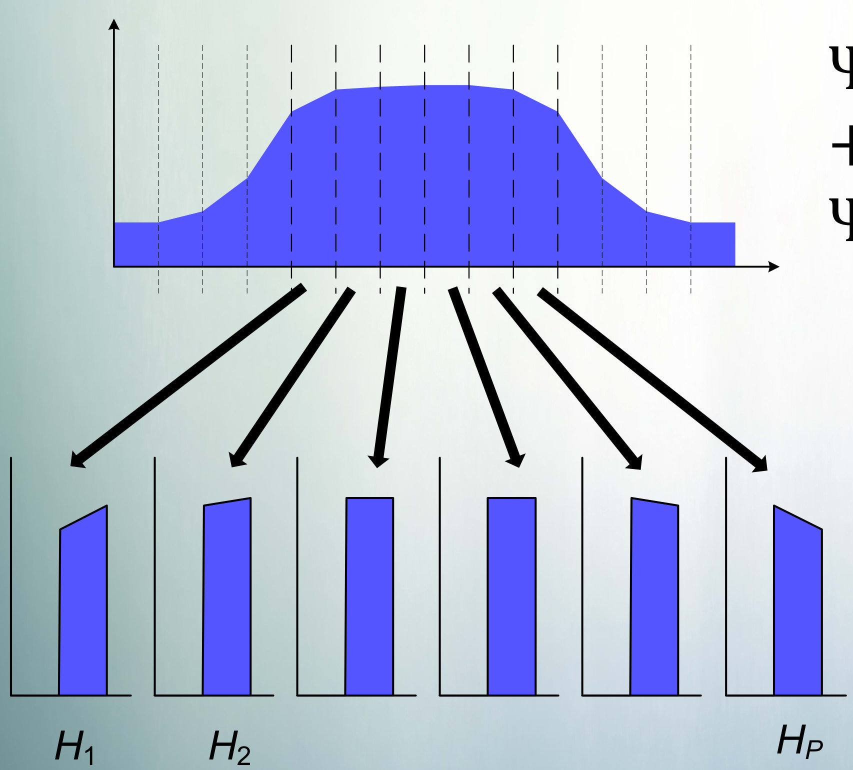
Interference is Gaussian noise: $C_{max} = 20 \log_{10} (2^D / 3)$



Channel identity (calibration)



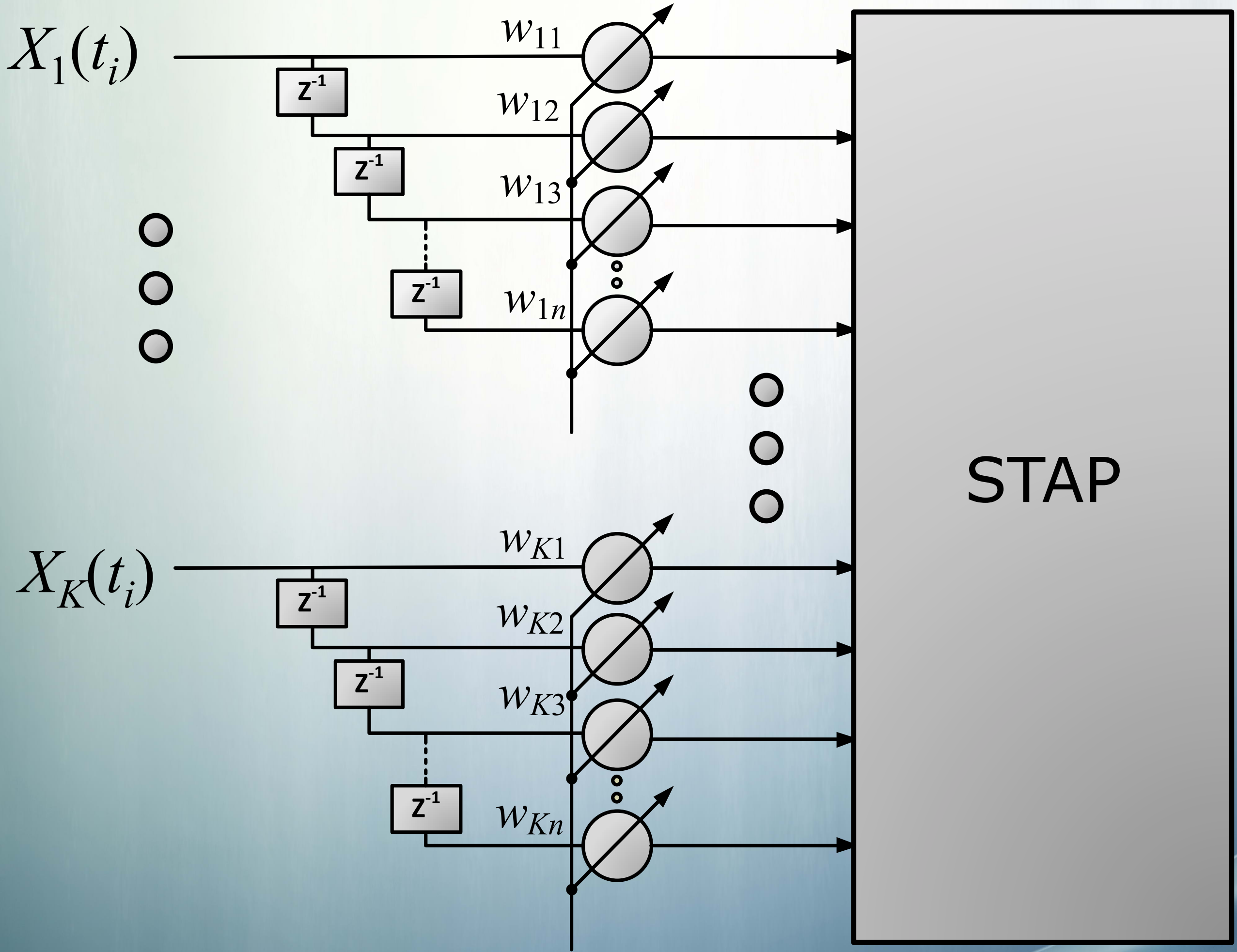
Channel identity (narrowband processing for broadband signals)



$$\Psi(\tau)*H_1+\Psi(\tau)*H_2+\ldots+\Psi(\tau)*H_P=\Psi(\tau)*\sum_{p=1}^{P} H_p \Rightarrow$$

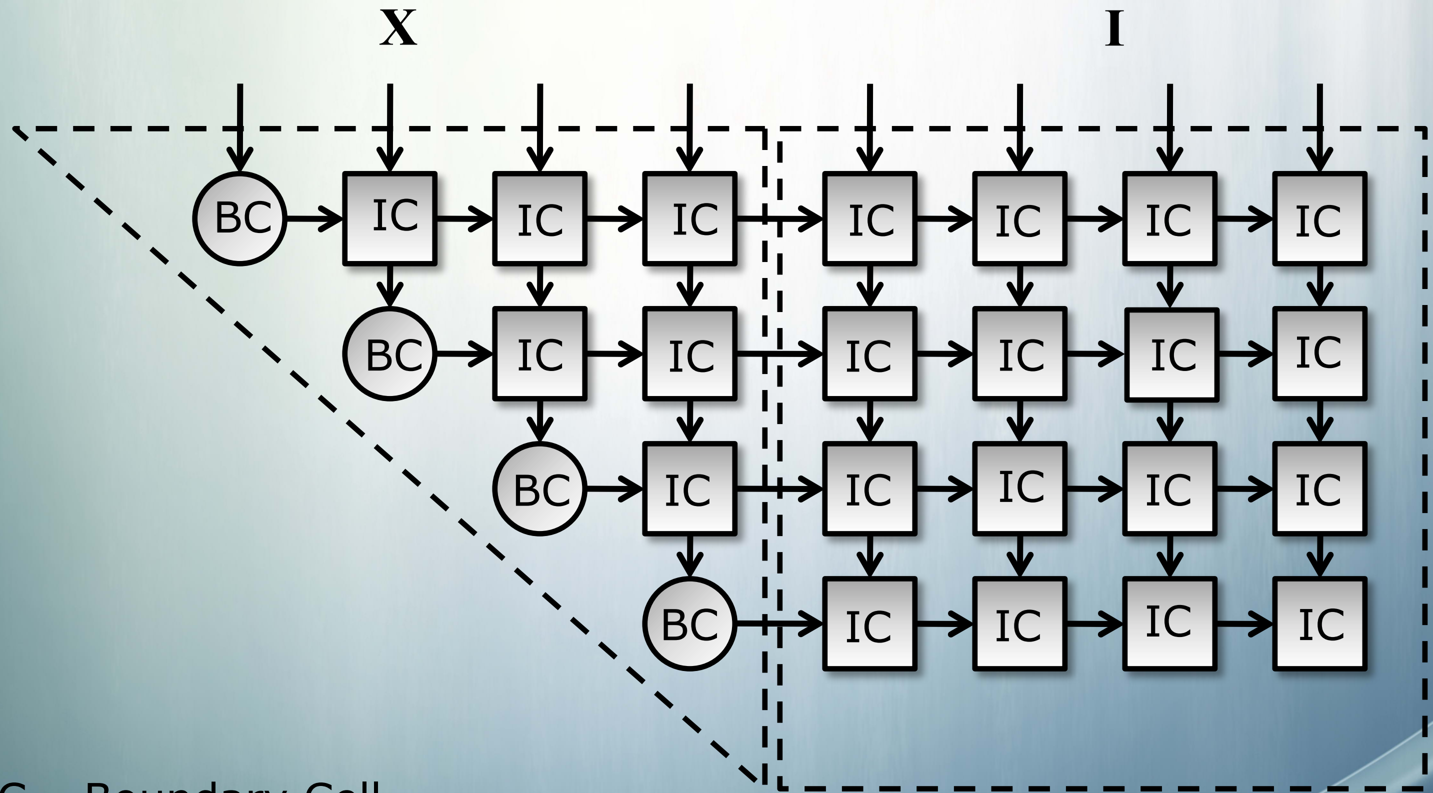
$$\sum_{p=1}^{P} H_p=\delta$$

Multipath interference (STAP)



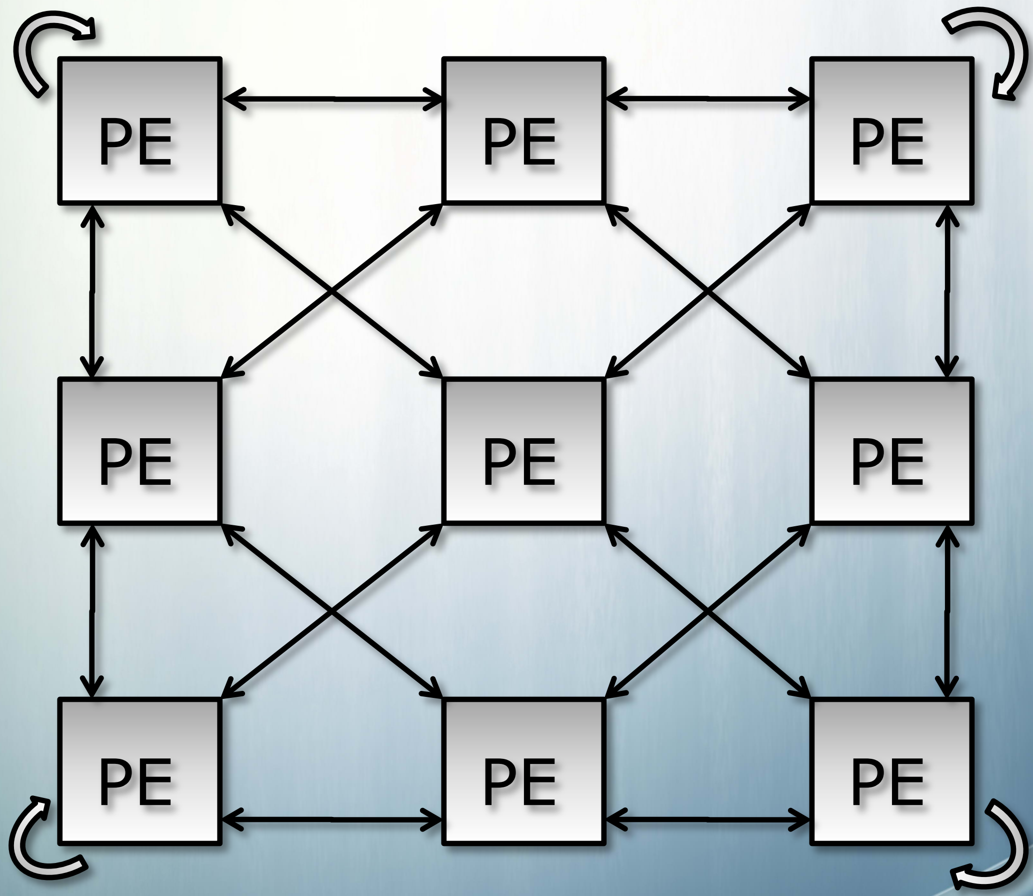
Increase of computational affinity of matrix inversion by systolic array

$$R_{XX} = QR$$



BC – Boundary Cell
IC – Internal Cell

Increase of computational affinity of EVD



PE- Processor Element

Anti-jam receiver

GNSS Systems	Glonass/GPS
Antenna	4-element CRPA
Tracking and navigation channels	48
Position accuracy (1σ)	V: 3 m H: 5 m
Velocity (1σ)	0,05 m/s
Temperature range	from -60 to +85°C
Size/Volume	115x115x50 mm
Power	14 W
Weight	1,3 kg

Conclusions:

- Describes the basic methods of building GNSS anti-jam receiver;
- Basic factors affecting anti-jam technology are considered, such as:
  - dynamic range
  - channel non-identity
  - Multipath interference
- Basic ways of suppression of these factors are reviewed;
- Ability to use systolic arrays for improving computational efficiency, including for the purposes:
  - QR-decomposition
  - EVD-decomposition
- All reviewed solutions are implemented in serial GNSS anti-jam receivers of MDB «Compas».

Thank for your attention

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