Adaptive Beamforming Algorithm in Real Numbers Arithmetic

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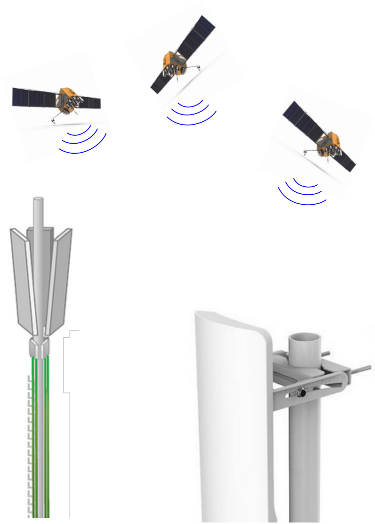


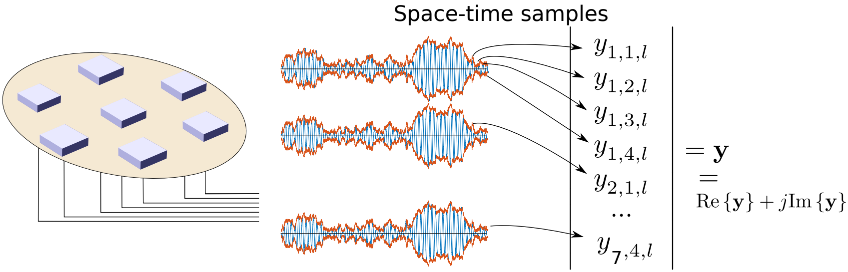
- Infrastructure relies on GNSS
- Signals are very weak
- Interferences can suppress the signals

The interferences are:

- unintentional spurs
- intentional blocking interferences
- intentional spoofing

The solution is controlled radiation pattern antennas (CRPA, serpers)

Typical complex number CRPA



$$\mathbf{y} = \mathbf{S} + \mathbf{J} + \mathbf{n}$$

Signal, Interference, Noise

Simple ML algorithm ⟹

$$\xi = \mathbf{H}^T(\alpha) \cdot \mathbf{R}^{-1} \cdot \mathbf{y}$$

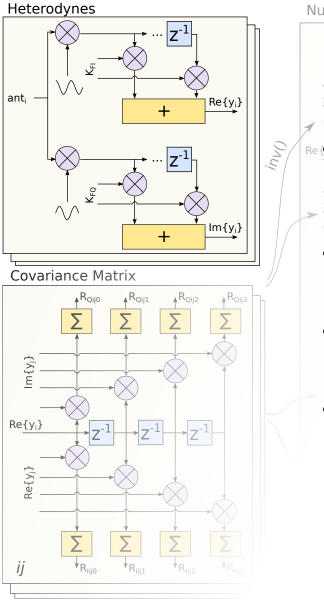
Clear and focused

Beamforming in α direction

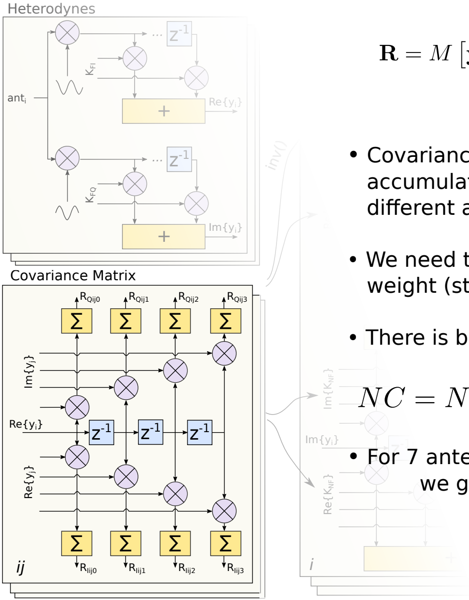
Nullforming

$\mathbf{R} = M\left[\mathbf{y} \cdot \mathbf{y}^T\right]$ - covariance matrix

$\mathbf{H}$ - steering vector



- Typical high-linear frontends don't have Q-channel, so we need to use heterodynes to get complex representation
- High-linear frontends utileze high-resolution analog-to-digit converters (12, 14, 16 bits)
- We need special DSP blocks to implement multiplications of such values
- Heterodynes consume about 10 DSPs per ant, we need about **70 DSPs** for the implementation



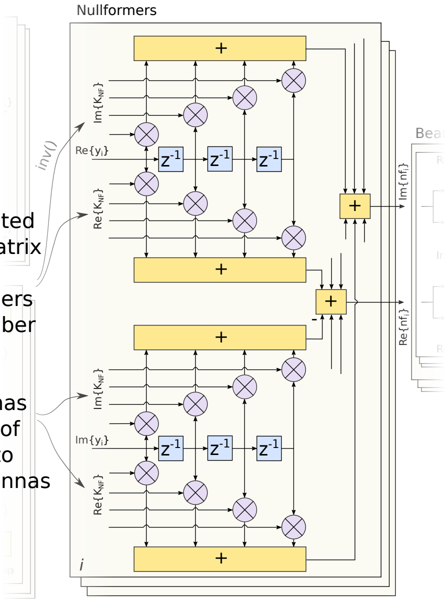
$\mathbf{R} = M\left[\mathbf{y} \cdot \mathbf{y}^T\right]$ - covariance matrix

- Covariance Matrix estimation block accumulates mutual multiplications for different antennas and time samples
- We need the matrix for the nullformer weight (steering) vector computation
- There is big number of combinations:

$$NC = NA^2 \cdot (NT - 1) + \frac{NA^2 + NA}{2}$$

- For 7 antennas and 4 time samples we get **350 DSPs**

- Nullformers reject interferences in space-time domian
- Weights are calculated from covariance matrix
- Number of nullformers is equal to the number of antennas
- Each beamformer has filters, the number of the filters is equal to the number of antennas



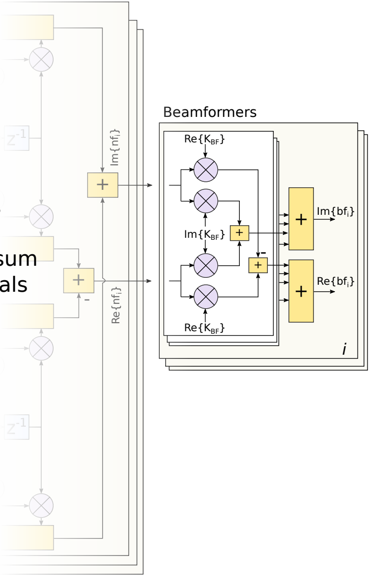
Nullforming:
$\mathbf{R}^{-1} \cdot \mathbf{y}$

7 nullformers
x
7 filters
x
4 time smpls
x
4 multipliers
=
784 DSPs

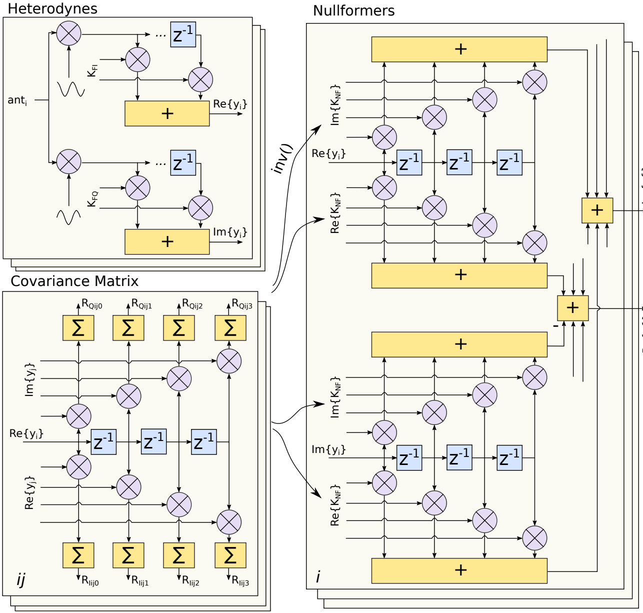
Beamforming:

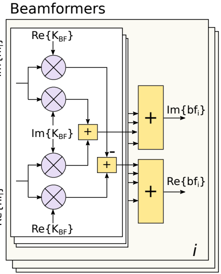
$$\xi = \mathbf{H}^T(\alpha) \cdot \mathbf{R}^{-1} \cdot \mathbf{y}$$

- 12 beamformers for 12 virtual RP with beams to 12 satellites
- Each beamformer calculates weighted sum for nullformers output signals
- 12 BF x 7 NF x 4 mult = **336 DSPs**



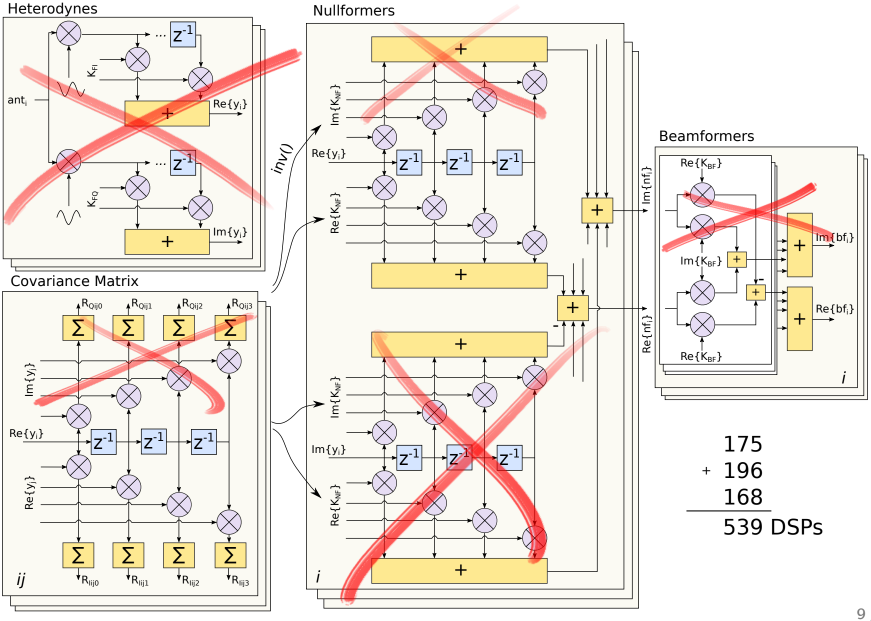
Complex algorithm



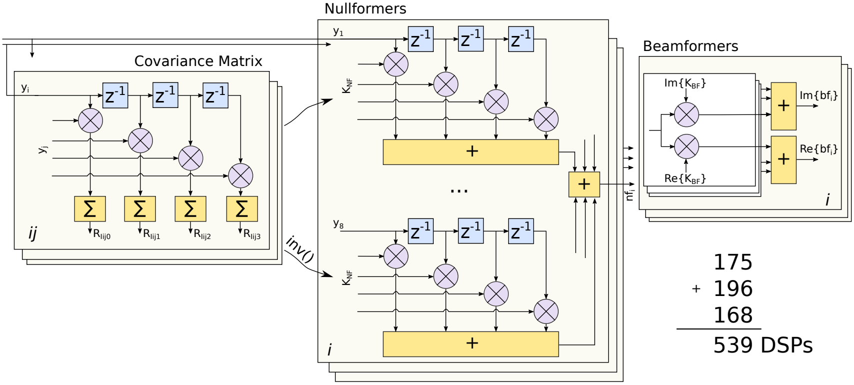


$$\begin{array}{r} 70 \\ 350 \\ + \quad 784 \\ 336 \\ \hline 1540 \text{ DSPs} \end{array}$$

$2000 Xilinx Zynq has only 900



  175
+ 196
  168
539 DSPs



  175
+ 196
  168

539 DSPs

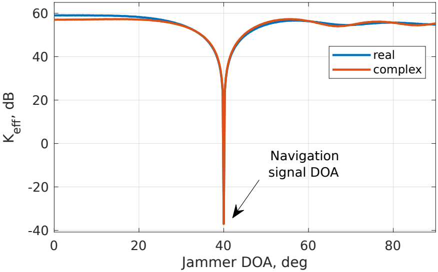
Clear and focused — Real-number samples

$$\xi = \mathbf{H}^T(\alpha) \cdot \mathbf{R}^{-1} \cdot \mathbf{y}$$

Complex steering for real inputs — Real-number nullforming

What is the price?

$$K_{eff} = \frac{P_{s,out}}{P_{n,out} + P_{j,out}} \Big/ \frac{P_{s,in}}{P_{n,in} + P_{j,in}}$$



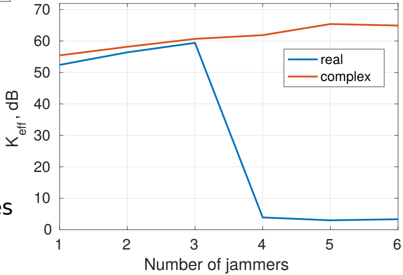
~55 dB

Interference supression is still great...

... but only in the case of a few number of jammers

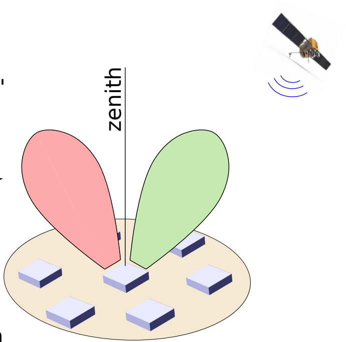
Complex number CRPA can suppress NA - 1 interferences,

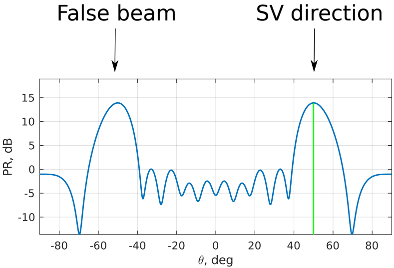
real number CRPA can reject only (NA - 1)/2 ones



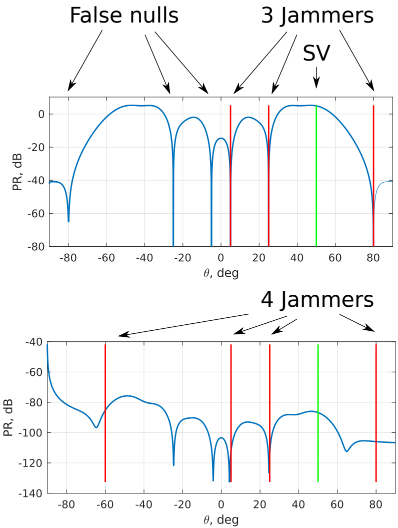
Radiation pattern symmetry

Real number algorithm
due to trigonometric limitations
doesn't distinguish "left" from "right"





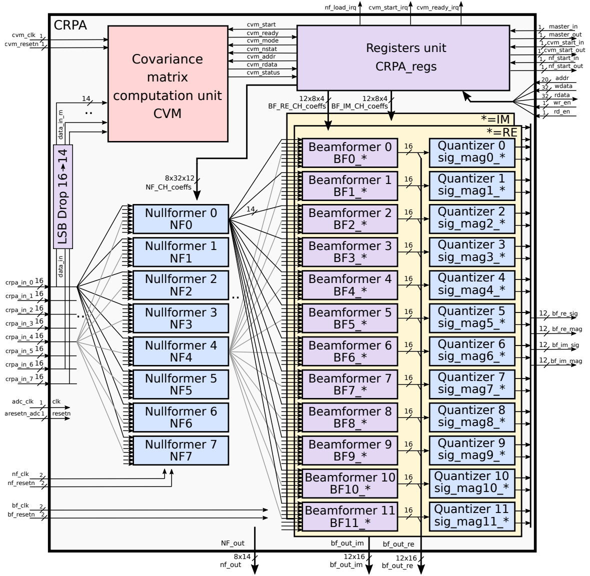
It forms a symmetrical diagram
about the Zenith (vertical plane)



The algorithm spends a half the degrees of freedom on the false nulls

7 element array rejects 3 independent interferences...

...but 4 jammers suppress the receiver



Implemented:

- as SystemVerilog FPGA module for Xilinx Zynq 7045
- as 8x8 mm ASIC

- GNSS STAP algorithm can be implemented in real number arithmetic
- Real number implementation consumes three times less resources
- Interference suppression efficiency is the same
- The number of suppressed interference is half in comparision with the complex number algorithm implementation
- It's a good choice for rather big arrays (7 and more elements)

Thank you for your attention!

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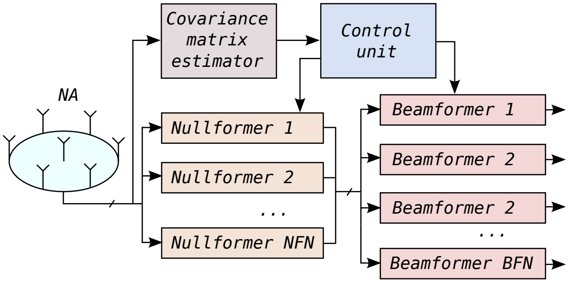
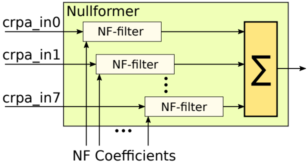
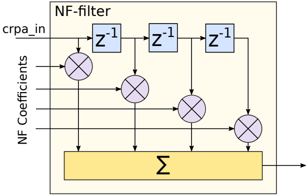

NA
Covariance matrix estimator
Control unit
Nullformer 1
Nullformer 2
...
Nullformer NFN
Beamformer 1
Beamformer 2
Beamformer 2
...
Beamformer BFN


Nullformer
crpa_in0
crpa_in1
crpa_in7
NF-filter
NF-filter
NF-filter
Σ
...
NF Coefficients


NF-filter
crpa_in
z-1
z-1
z-1
NF Coefficients
Σ