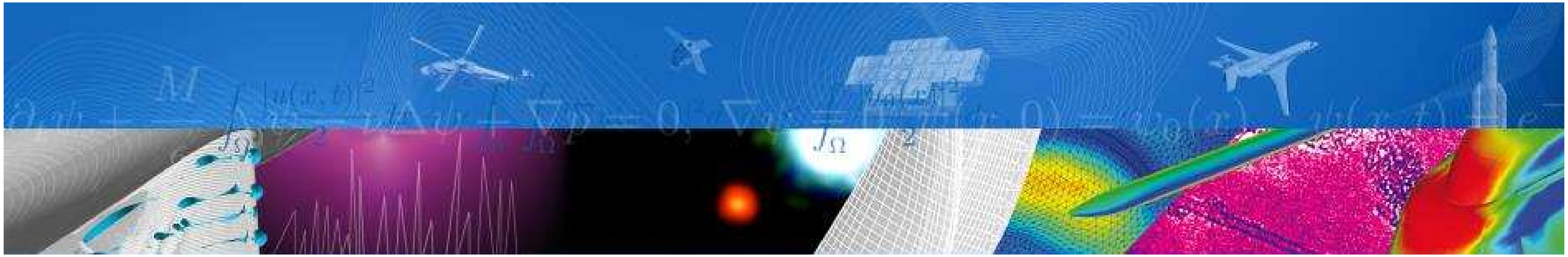


ONERA

THE FRENCH AEROSPACE LAB

MIMO, which applications in radar ?

Marc Lesturgie

3 September 2020

www.onera.fr

MIMO Radar

Content

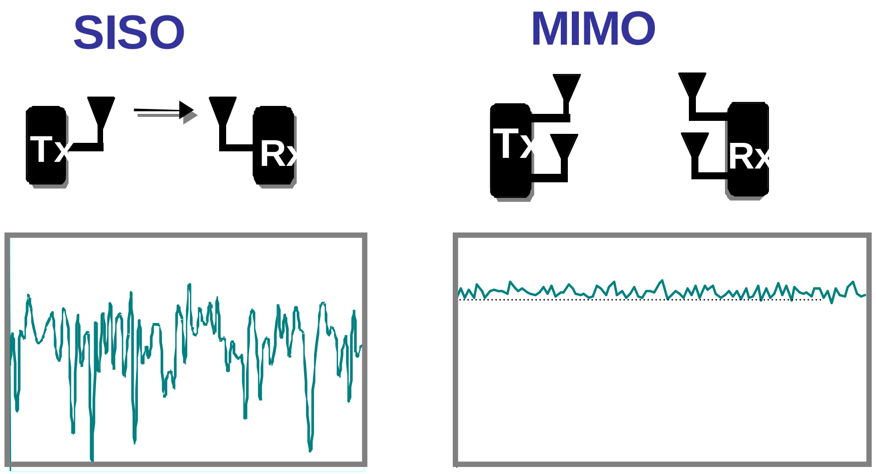
?

MIMO in Communication & Navigation..

MIMO=Multiple Input Multiple Output

MIMO in communication domain ….

In strong multipaths environments :
- Improvement of quality factor
- Reduction of fading probability
- Reduction co-channel interference
- Improvement of data-rate

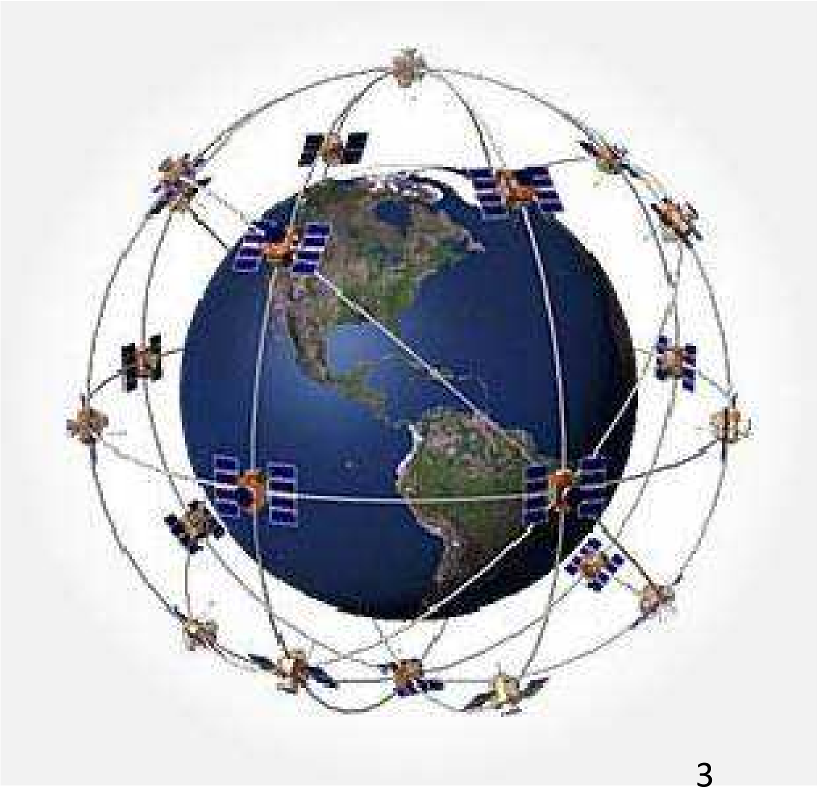


Space diversity

Navidation domain

GPS

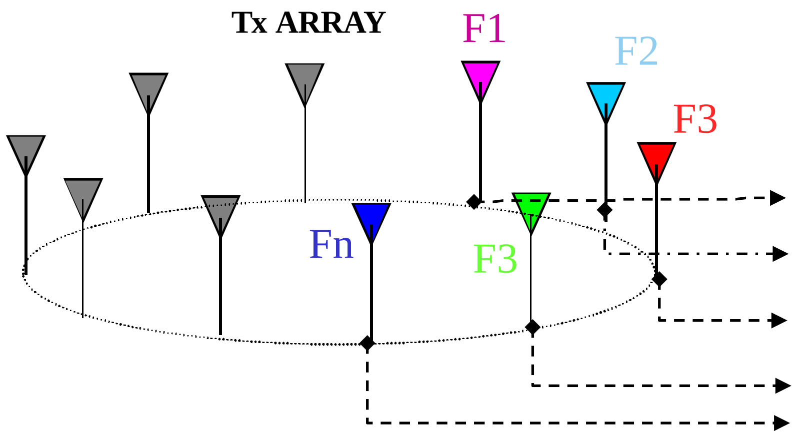
GNSS

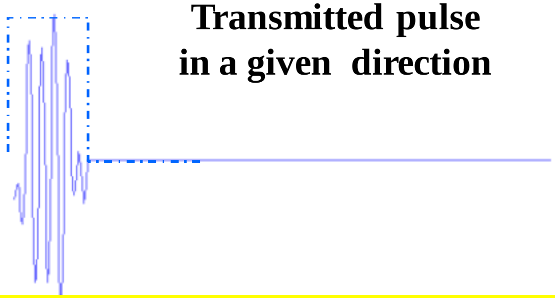


MIMO in Radar (not really new !)

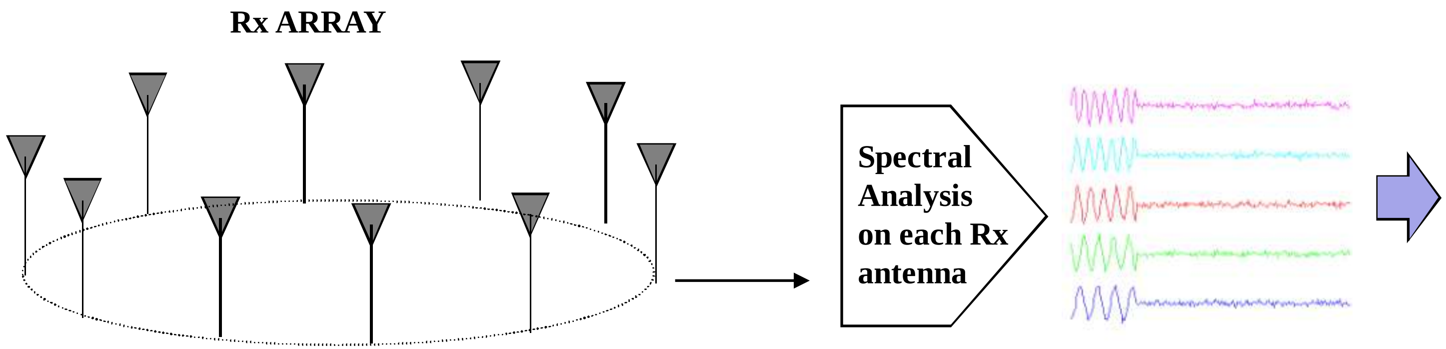
RIAS* / SIAR by Jacques Dorey (1986)** – « Space Frequency » orthogonal coding

The 1st VHF air surveillance radar to defeat stealth and cover from low to high altitudes





1. Un-focused but fully coherent and coded beams



2. Dual Digital beamforming capability

Received signals on one antenna

*RIAS : Radar à Impulsion et Antenne Synthétiques ** SIAR : Synthetic Impulse and Antenna Radar

The French RIAS/SIAR

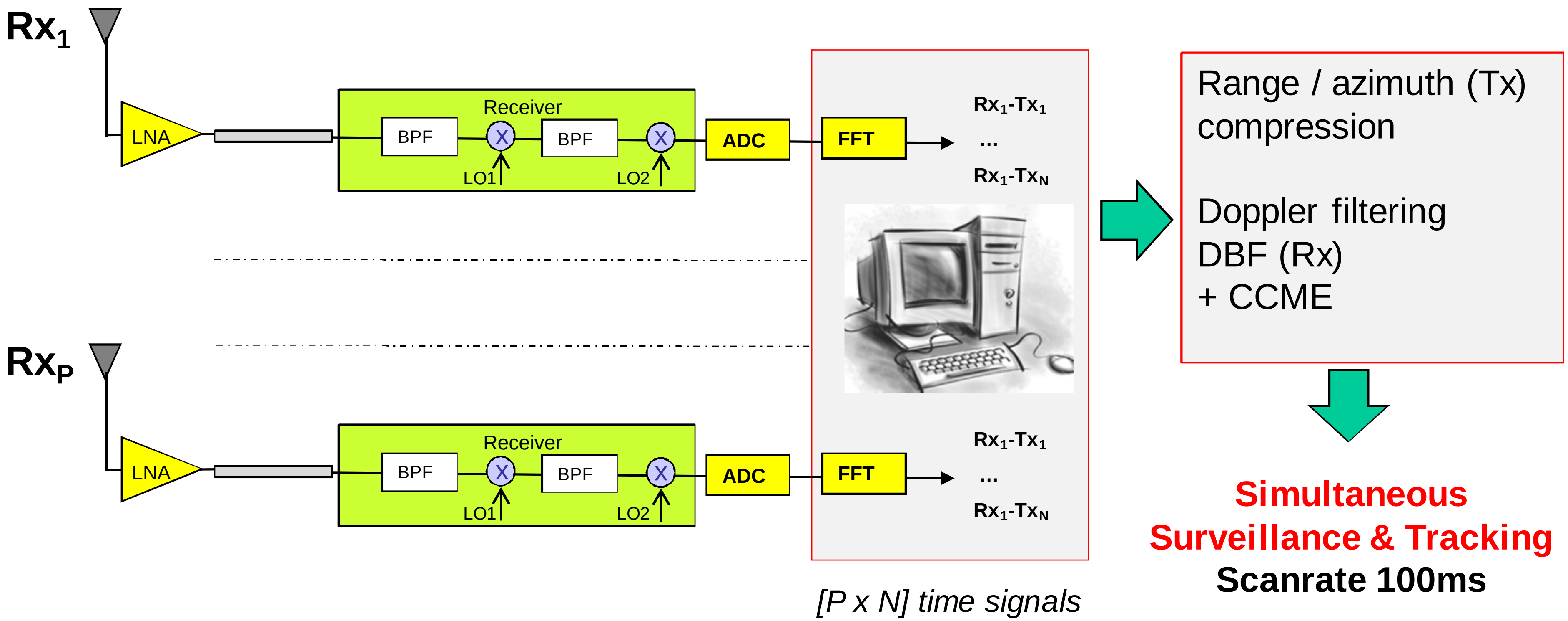
RIAS – Realisations…1987…1990…!

ONERA mock up (1987)

Thales demonstrator (1990)

- VHF band
- 2 imbricated arrays, Vertical polarization
- Application to air surveillance

RIAS Processing



J. Dorey, Y. Blanchard, and F. Christophe, "The RIAS project, a new approach to air surveillance radar," in *Colloque International sur le Radar*, ser. TP, no. 1984-20. Versailles, France: ONERA, 21-24 May 1984, in French.

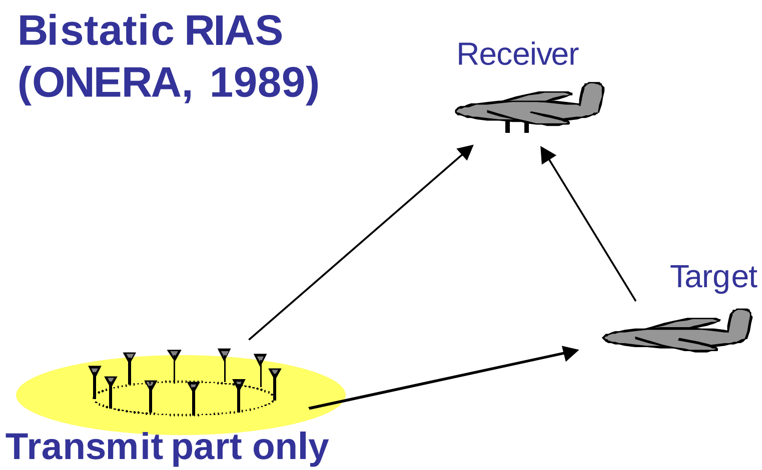
J. Dorey and G. Garnier, "The RIAS pulsed synthetic-antenna radar," *L'Onde Electrique*, vol. 69, pp. 36–44, Nov-Dec 1989, in French.

A.-S. Luce, H. Molina, D. Muller, and V. Thirard, "Experimental results on RIAS digital beamforming radar," in *Radar 92. International Conference*, Brighton, UK, Oct. 1992, pp. 74–77.

ONERA THE FRENCH AEROSPACE LAB

RIAS , a VOR (or GPS) - inspired radar?

VOR : VHF Omnidirectional Range



In the bistatic configuration, the receiver can detect and localise the target after decoding the signals received from the RIAS emitter, provided :

(i) Transmitted code sequence is known
(ii) Time and frequency syncrhonisation are performed

Finally, as a first observation

the common denominator of GPS, VOR, RIAS is

A coherent coding of the position or direction provided by a transmitting infrastructure

A localisation capability from 1 single receiving element if and only if the transmitting code is known

A share of complexity :

- Hardware (and cost!) on Transmit,
- Software complexity (and banalisation?) on Receive

An intrinsic multi-user service (in-principle no limitation of aircrafts, GPS-users)

MIMO in radar for air surveillance

Conventional Radar *(1 single target direction)*

High energy

4 to > 6 sec.

Track while scan (TWS)

or

Confirm detection & track init

Track mode / Track radar

Analysis mode (ISAR, JEM,..)

MIMO 360° (e.g. RIAS)

Detection + multiple targets Tracking + Long integration / analysis mode

Low energy

There is no free lunch : increase of information by transmit diversity has to be paid by complexity and an *apparent* penalty in terms of energy

MIMO sub-array - The compromise ?

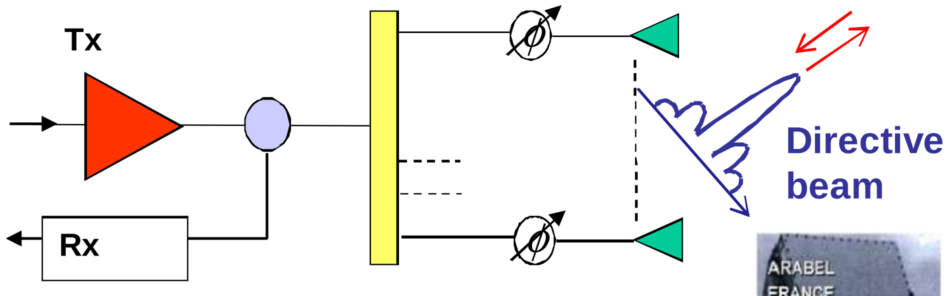
Medium energy

Track while scan (TWS) + Longer integration / Analysis mode

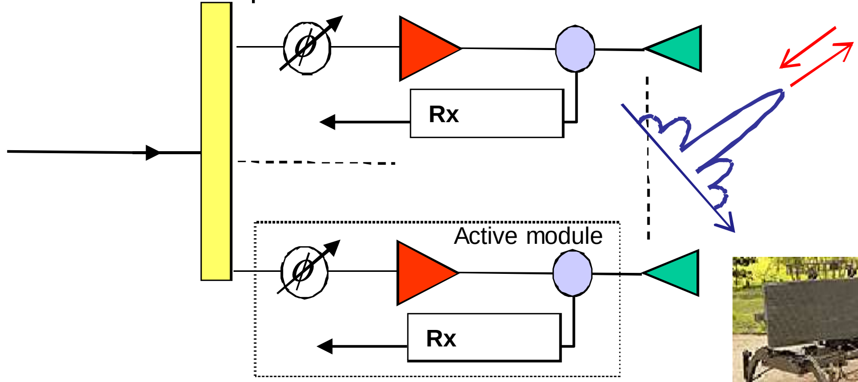
Digital Beam Forming on transmit vs. Electronic Scanning

complexity !!

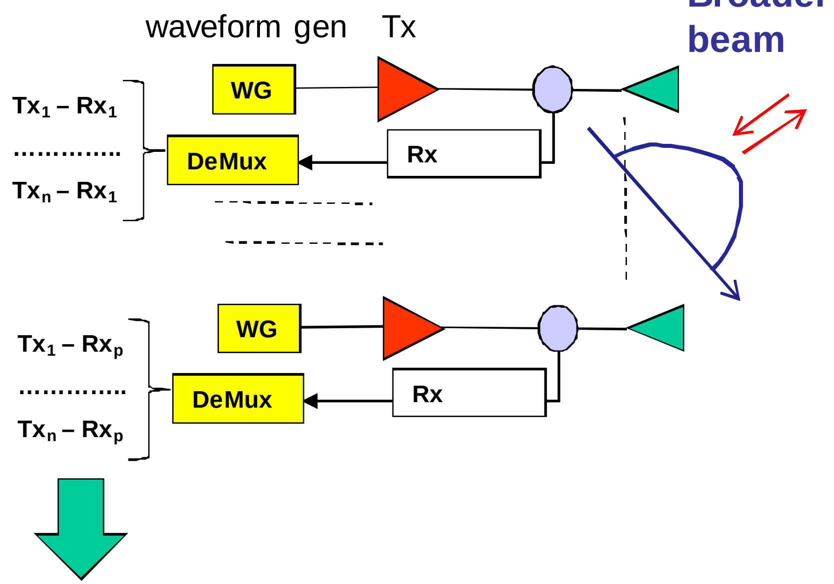
ESA - Electronic Scanning Antenna (Phase only Diversity on transmit)



or



MIMO (Waveform Diversity on transmit)



[n, p] pairs of signals

Complexity !

Circulator or duplexer phase shifters transmitter

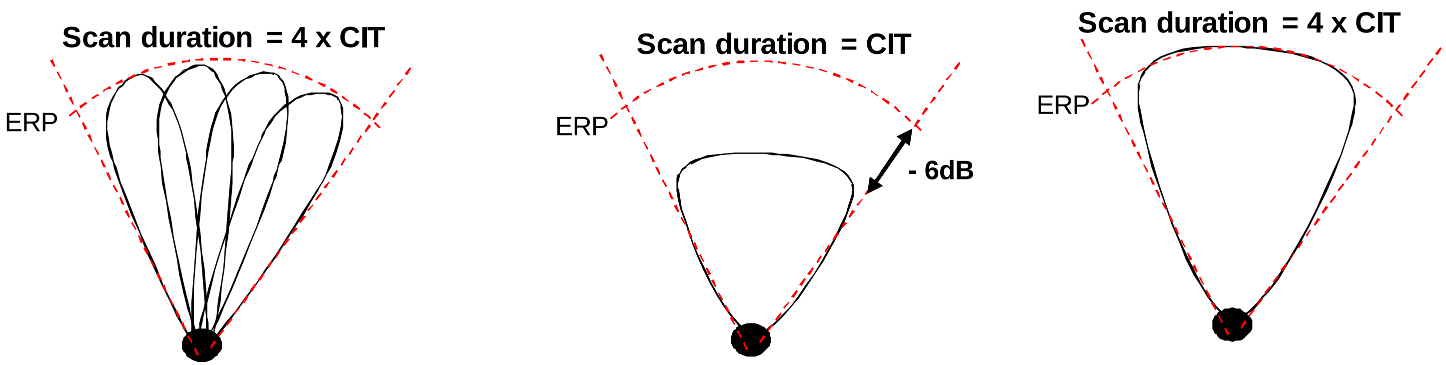
MIMO and energy..

Orthgonal coding is favored as to illuminate **all the directions** **of the airspace within the physical pattern of the individual antenna**

Compared to electronic beam steering antenna power budget penalty for MIMO, varies as **N** instead of **N^2** but all **the directions are illuminated at the same time**.

➔ MIMO requires to **compensate for the defocusing losses (N).**

This can be done by improving the integration time (coherent / integration) which results in an efficient Doppler processing, if the target signature remains coherent



SIMO, 4 elements

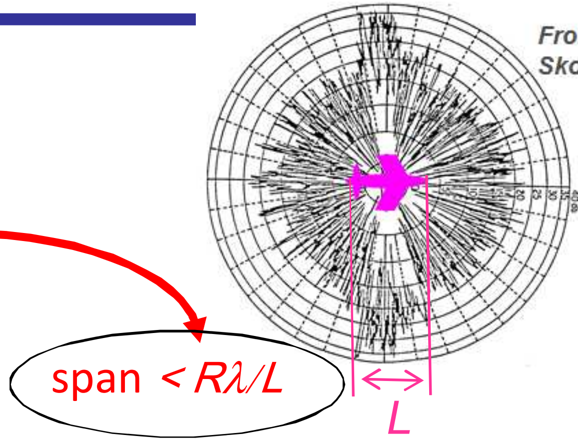
MIMO, 4 elements
CIT (orthogonal coding)

MIMO, 4 elements
4 x CIT (orthogonal coding)

Requires target coherence ! (→ the case at low frequency, e.g. RIAS),

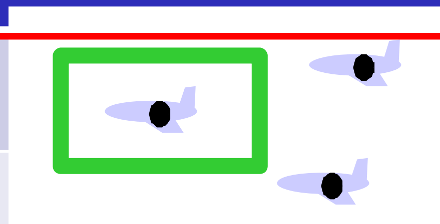
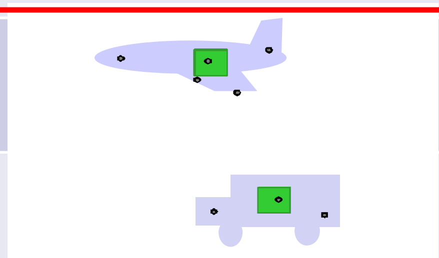
Radar, diversity, coherence and configuration ..

- Radar functions (hereafter)
- MIMO : multiple antenna and diversity on transmit
- Coherence : modern radar is coherent (phase processing)
- For air-surveillance mission, diversity (span) on transmit is limited by the variation of the target RCS pattern



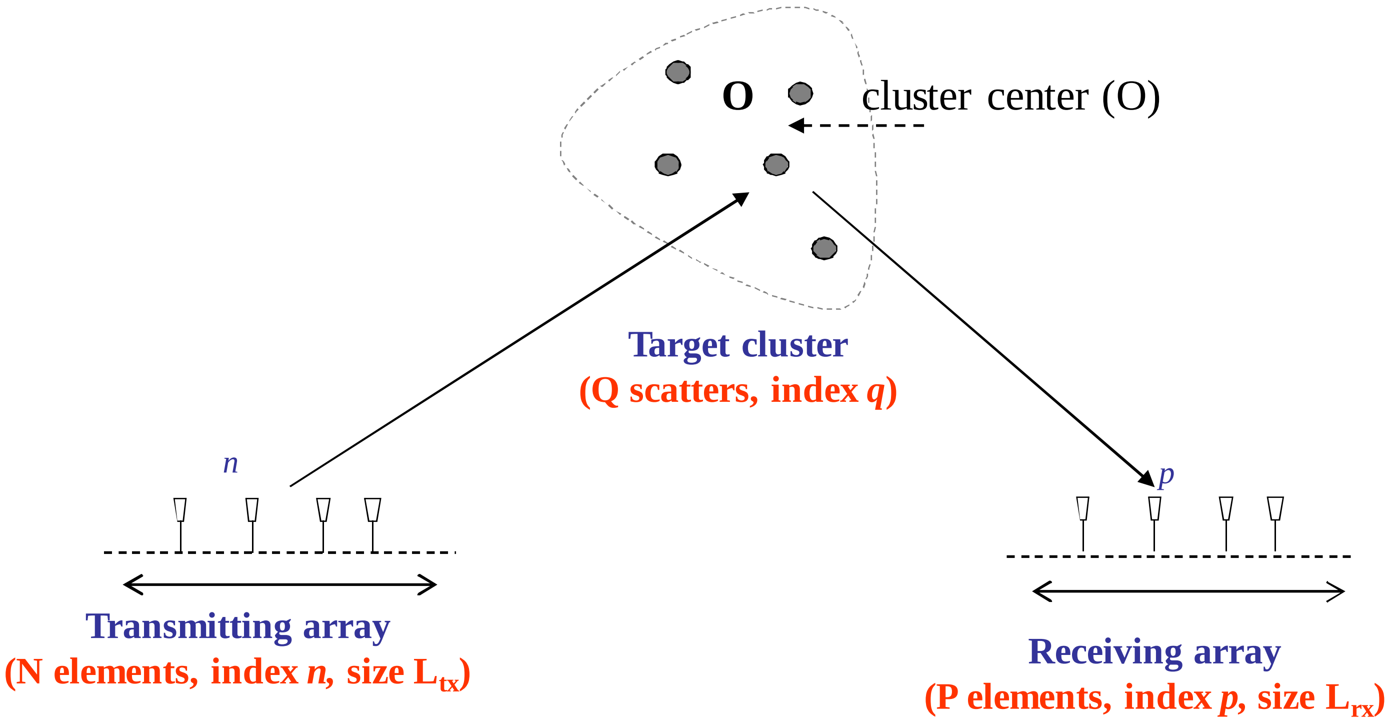
From Merrill Skolnik

The importance of the target model in Radar processing

Radar Mode / Radar technique	Target model	Resolution vs. size	Processing Time scale
1. Surveillance	Point scatter Coherent		10ms to 100ms
2. Tracking	Point scatter Non Coherent		100ms to few seconds
3. ISAR	Multiple Point scatter Coherent		100ms to few seconds
4. SAR	Multiple Point scater Coherent		100ms to few seconds

Configuration, signal and processing

a MIMO system is a multi-port system with independant access on transmit and receiving sides. By essence, such system allows for **measuring the transfer function between each transmitting element (n of N) and each receiving element (p of P).**



The propagation environment is important and we need to define the cluster of scatterers or targets which are precisely composing the transfert function.

The MIMO channel matrix S

The channel matrix (**S**) is the transfert function between each Tx element and each Rx element ;

S= g_t α g_r **dim(S)=[N,P]**

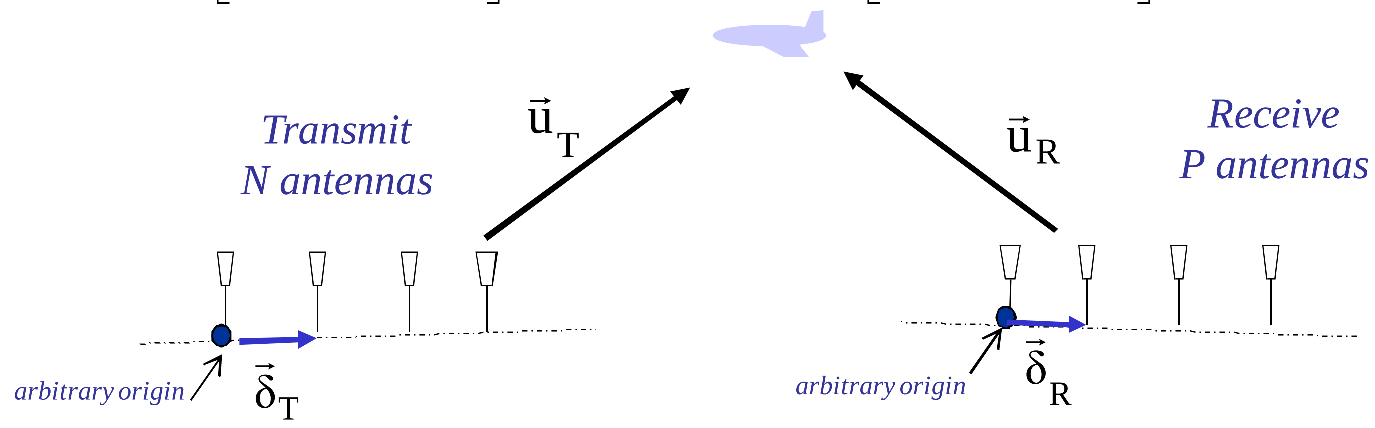
g_t contains the **transmitting steering vector** **D_T** for each scatter; dim=[N,Q]
where Q is the number of scatters, N the number of transmitting elements

g_r contains the **receiving steering vector** **D_R** for each scatter; dim=[Q,P]
where P is the number of receiving elements

α is a diagonal matrix which contains the complex amplitude of the Q scatters

$$D_T = \begin{bmatrix} d_1(\vec{u}_T) \\ .. \\ .. \\ d_N(\vec{u}_T) \end{bmatrix} = \begin{bmatrix} 0 \\ e^{j\left(\frac{2\pi}{\lambda}\vec{\delta}_T.\vec{u}_T\right)} \\ .. \\ e^{j\left(\frac{2\pi}{\lambda}(N-1)\,\vec{\delta}_T.\vec{u}_T\right)} \end{bmatrix} \qquad D_R = \begin{bmatrix} d_1(\vec{u}_R) \\ .. \\ .. \\ d_P(\vec{u}_R) \end{bmatrix} = \begin{bmatrix} 0 \\ e^{j\left(\frac{2\pi}{\lambda}\vec{\delta}_R.\vec{u}_R\right)} \\ .. \\ e^{j\left((P-1)\frac{2\pi}{\lambda}\vec{\delta}_R.\vec{u}_R\right)} \end{bmatrix}$$

2 DBF* capabilities !
MIMO steering vector



*Digital Beam Forming

Signal Model : the transmitted code

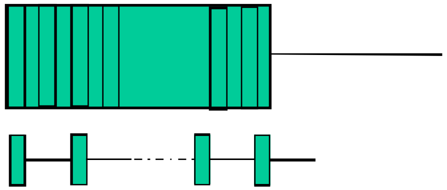
Let's denote C the [K,N] vector and $D_T(\vec{u}_T)$ the steering vector in the direction $\vec{u}_T$

Coding <u>within</u> the pulse

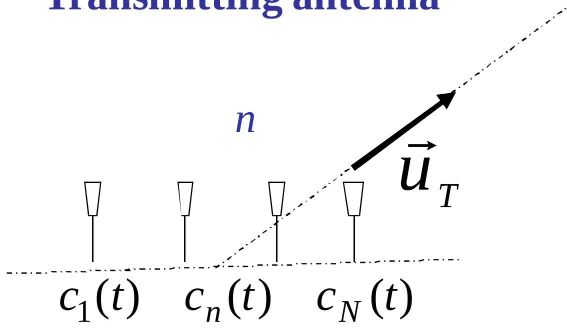
(e.g. frequency code)

Coding <u>from</u> pulse to pulse

(e.g. phase code)



Transmitting antenna



Coding matrix :

Dim. [K,N]

$$\begin{array}{cc} & \text{....antenna.....} \\ C = & \begin{bmatrix} c_1(t_1) & & c_N(t_1) \\ & c_k(t_n) & \\ & & \\ c_1(t_K) & & c_N(t_K) \end{bmatrix} \end{array} \text{....time.....}$$

Steering vector (Tx) :

Dim. [N,1]

$$D_T = \begin{bmatrix} d_1(\vec{u}_T) \\ .. \\ .. \\ d_N(\vec{u}_T) \end{bmatrix}$$

Received signals :

(in the direction $\vec{u}_T$)

$$\boxed{X = \begin{bmatrix} x(t_1) \\ .. \\ .. \\ x(t_K) \end{bmatrix} = C\, D_T(\vec{u}_T)}$$

Dim. [K,1]

<u>**K** is the number of code elements</u>

MIMO transmit codes

FT-CDMA : fast-time code division multiple access

ST-CDMA *: slow time CDMA*

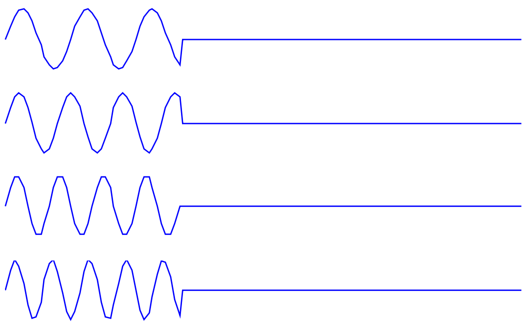
FDMA : frequency division multiple access

TDMA : time division multiple access, *also randomized TDMA (R-TDMA),*

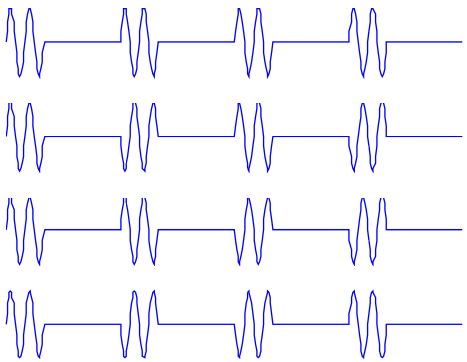
DDMA : Doppler division multiple access,

[Petre Stoica & al.]

Fast Time (within the pulse)



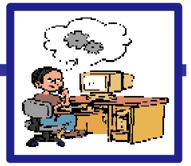
Slow Time (from pulse to pulse)



All these coding scheme should be written as

$$C = \begin{array}{cc} \text{....antenna.....} & \\ \begin{bmatrix} c_1(t_1) & & c_N(t_1) \\ & c_k(t_n) & \\ c_1(t_K) & & c_N(t_K) \end{bmatrix} & \text{....time....} \end{array} \quad \text{or} \quad C(t) = [c_1(t) \ldots c_n(t) \ldots c_N(t)]$$

Average transmitted power (1)



Since $X = [x(t_1) \quad \dots \quad x(t_K)]^t = C\, D_T(\vec{u}_T)$ of dimension [K,1]

the average transmitted power – over a Code periode – is :

$$P(\vec{u}_T) = p(\vec{u}_T)\, X^H X = p(\vec{u}_T)\, D_T(\vec{u}_T)^H C^H C . D_T(\vec{u}_T) = \boxed{p(\vec{u}_T)\, D_T(\vec{u}_T)^H R_{CC} . D_T(\vec{u}_T)}$$

$p(\vec{u}_T)$ **: ERP of individual element**

With $R_{CC} = C^H C$ **correlation matrix of the code**

EXAMPLES

Orthogonal codes (RIAS case)

$$C^H C \approx Id$$

$$\Downarrow$$

$$\boxed{P(\vec{u}_T) = p(\vec{u}_T) N}$$

Fully correlated codes (Scanning antenna)

$$C = [D_T(\vec{u}_0) \quad \dots \quad D_T(\vec{u}_0) \quad \dots \quad D_T(\vec{u}_0)]^t$$

$$\Longrightarrow \quad \boxed{P(\vec{u} = \vec{u}_0) = p(\vec{u}_0) N^2}$$

Different "equivalent" array factors

POWER PENALTY for "pure orthogonal" MIMO

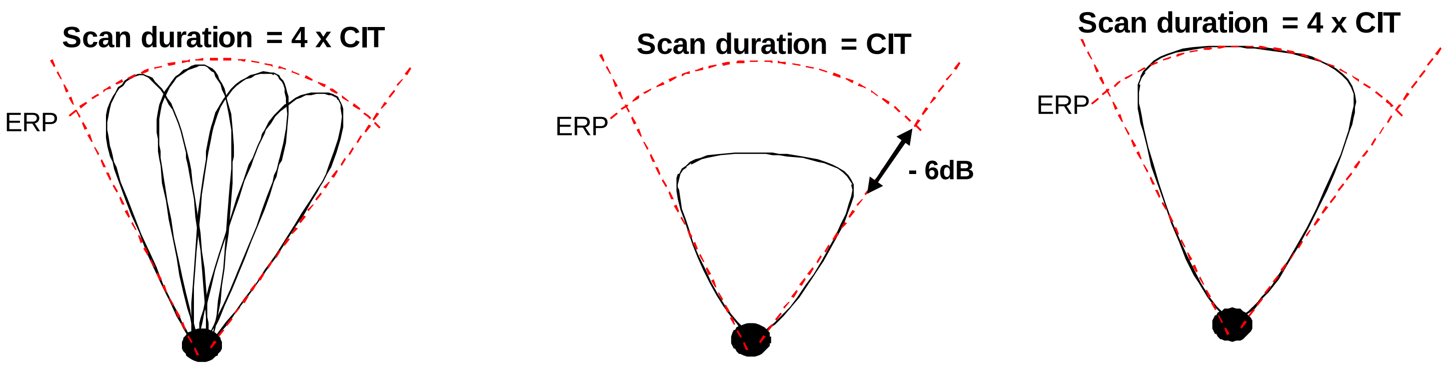
Average transmitted power (2)

Compared to electronic beam steering antenna power budget penalty for MIMO, varies as N instead of N^2

but all **the directions are illuminated at the same time**.

For a **given set of power budget parameters**, (total emitted power, gain, noise figure, ..) MIMO requires to **compensate the defocusing losses.**

This can be done by improving the integration time (coherent / integration)



SIMO, 4 elements

MIMO, 4 elements

CIT (orthogonal coding)

MIMO, 4 elements

4 x CIT (orthogonal coding)

If and only if the target signal remain coherent across the increased CIT !

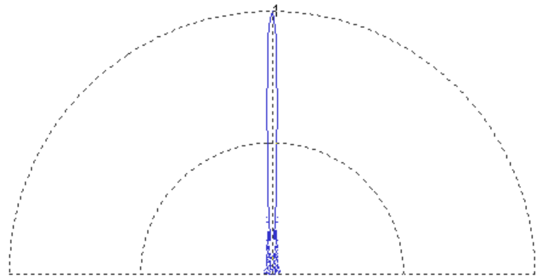
Example of transmit pattern (1)

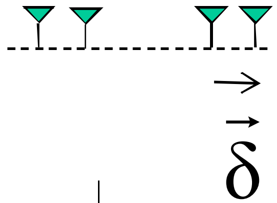
Examples of code - fixed scanning antenna (n=32)

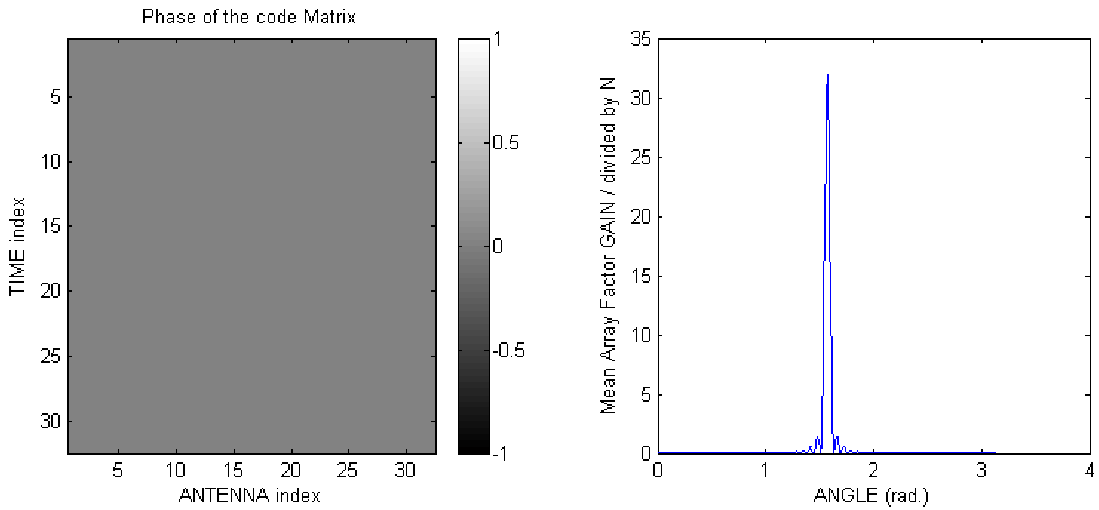
$$C = \left[D_T(\vec{u}_0) \quad \dots \quad D_T(\vec{u}_0)\right]^t$$

$$\text{with} \begin{cases} d_n(\vec{u}_0) = \exp(-j\dfrac{2\pi}{\lambda}\vec{r}_n.\vec{u}_0) \\ d_n(\vec{u}_0) = \exp(-j\dfrac{2\pi}{\lambda}n\vec{\delta}.\vec{u}_0) \quad \text{for ULA case} \end{cases}$$

Display of the instantaneous « temporal pattern »





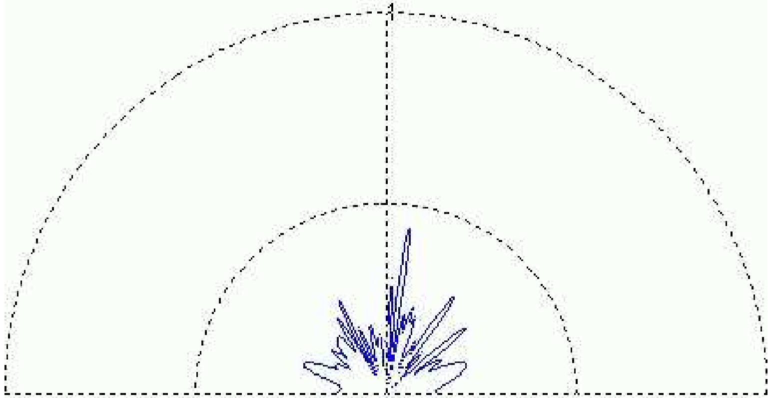


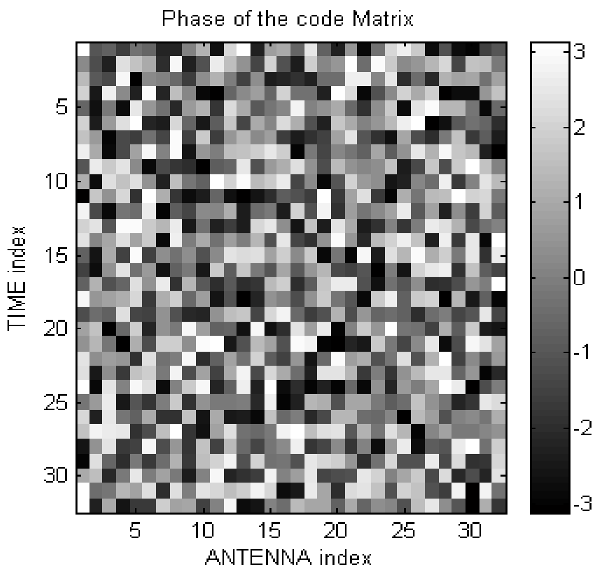
Example of transmit pattern (2)

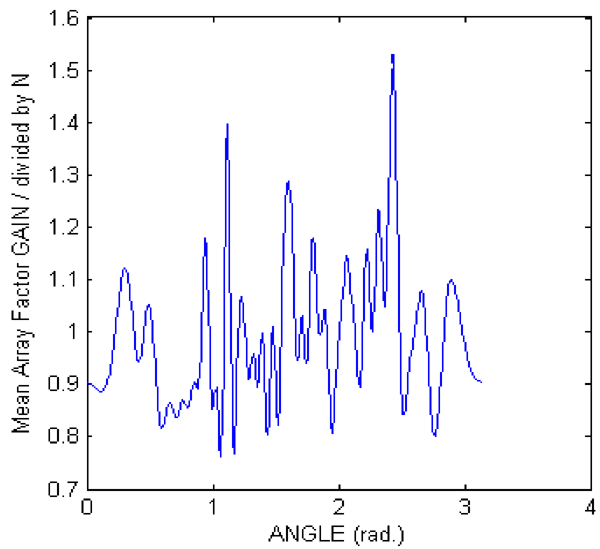
Examples of code - random Phase Code (n=32)

$$C = \begin{bmatrix} .. & \exp(j2\pi rand) & .. \\ .. & & .. \end{bmatrix}$$

Display of the instantaneous « temporal pattern »





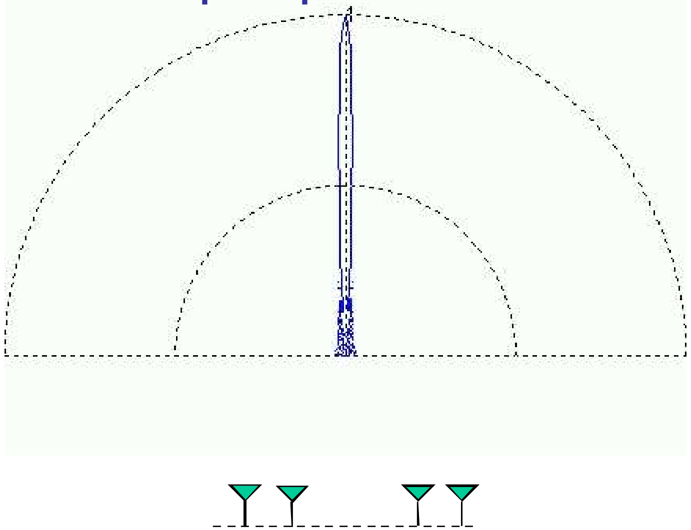


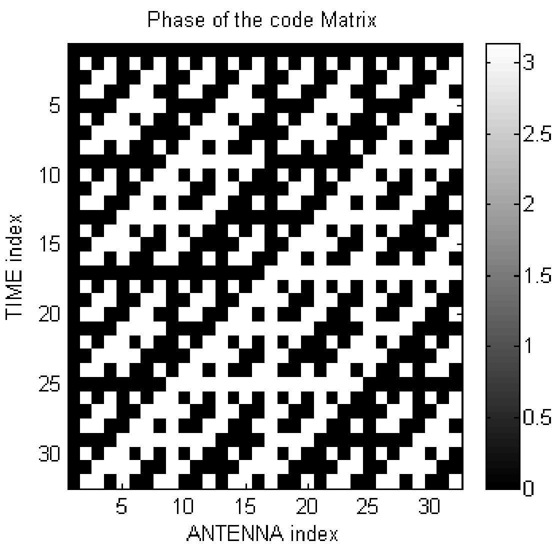
Example of transmit pattern (3)

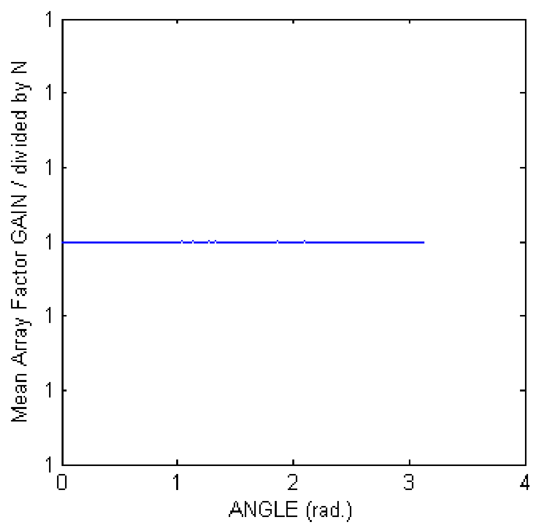
Examples of code - Hadamard Code (n=32)

$$C = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1.... \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1.... \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1.... \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1.... \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1.... \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1.... \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1.... \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1.... \\ \multicolumn{8}{c}{\cdots\cdots\cdots\cdots\cdots\cdots} \\ \multicolumn{8}{c}{\cdots\cdots\cdots\cdots\cdots\cdots} \end{bmatrix}$$

Display of the instantaneous « temporal pattern »



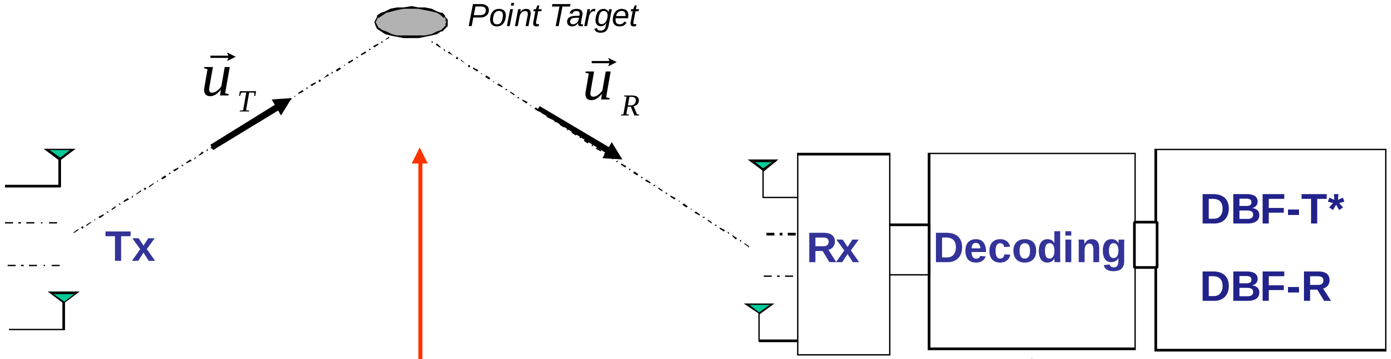




MIMO Signal chain : DBF*-T and DBF-R

Let's denote C the [N,K] code matrix and $D_T(\vec{u}_T)$ the steering vector in the direction $\vec{u}_T$

$$C = \begin{bmatrix} c_1(t_1) & & c_N(t_1) \\ & c_k(t_n) & \\ c_1(t_K) & & c_N(t_K) \end{bmatrix}$$



$$\alpha_T C D_T(\vec{u}_T)$$

Steering vector (transmit)

$$D_T = \begin{bmatrix} d_1(\vec{u}_T) \\ .. \\ .. \\ d_N(\vec{u}_T) \end{bmatrix}$$

Steering vector (receive)

$$D_R = \begin{bmatrix} d_1(\vec{u}_R) \\ .. \\ .. \\ d_P(\vec{u}_R) \end{bmatrix}$$

$$X = \alpha_R \alpha_T C D_T(\vec{u}_T).D_R^t(\vec{u}_R)$$

[K,P] : [K,N] x [N,1] x [1,P]

$$S = C^H X = \alpha_R \alpha_T C^H C D_T(\vec{u}_T).D_R^t(\vec{u}_R)$$

MIMO Channel Matrix dim=[N,P]

reshaping $\hat{S} = \alpha_R \alpha_T D_R(\vec{u}_R) \otimes D_T(\vec{u}_T)$

[NP,1]

S : Matrix of dimension [P,N]

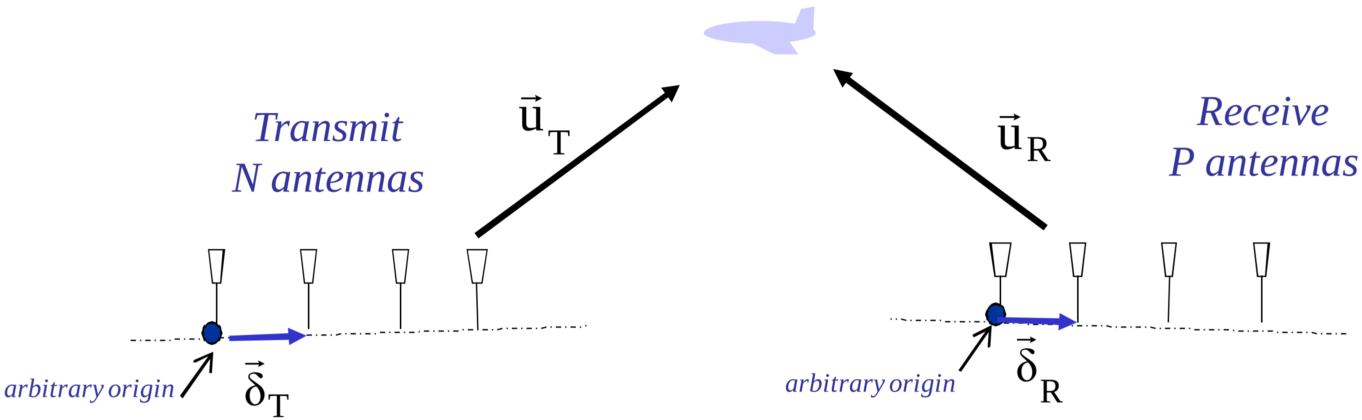
***DBF : Digital Beam Forming**

ONERA
THE FRENCH AEROSPACE LAB

The MIMO steering vector (1)

ULAs case (as an example)

$$D_T = \begin{bmatrix} d_1(\vec{u}_T) \\ .. \\ .. \\ d_N(\vec{u}_T) \end{bmatrix} = \begin{bmatrix} 0 \\ e^{j\left(\frac{2\pi}{\lambda}\vec{\delta}_T.\vec{u}_T\right)}. \\ .. \\ e^{j\left(\frac{2\pi}{\lambda}(N-1)\vec{\delta}_T.\vec{u}_T\right)} \end{bmatrix} \qquad D_R = \begin{bmatrix} d_1(\vec{u}_R) \\ .. \\ .. \\ d_P(\vec{u}_R) \end{bmatrix} = \begin{bmatrix} 0 \\ e^{j\left(\frac{2\pi}{\lambda}\vec{\delta}_R.\vec{u}_R\right)}. \\ .. \\ e^{j\left((P-1)\frac{2\pi}{\lambda}\vec{\delta}_R.\vec{u}_R\right)} \end{bmatrix}$$



$$V_{mimo}(\vec{u}_T,\vec{u}_T) = D_R(\vec{u}_T) \otimes D_T(\vec{u}_T) = \left[\exp j\frac{2\pi}{\lambda}\left(n\,\vec{\delta}_T.\vec{u}_T + p\,\vec{\delta}_R.\vec{u}_R\right)\right]_{n=1,N;\,p=1,P}$$

$$= \left[\exp j\frac{2\pi}{\lambda}\vec{u}\left(n.\vec{\delta}_T + p.\vec{\delta}_R\right)\right]_{n=1,N;\,p=1,P}$$

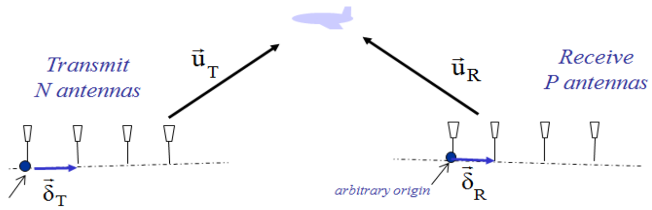
(for monostatic case) $\vec{u}_T = \vec{u}_R$

The MIMO steering vector (2)

$$V_{mimo}(\vec{u}_T,\vec{u}_T) = D_R(\vec{u}_T) \otimes D_T(\vec{u}_T) = \left[\exp j\frac{2\pi}{\lambda}\left(n\,\vec{\delta}_T.\vec{u}_T + p\,\vec{\delta}_R.\vec{u}_R\right) \right]_{n=1,N;\,p=1,P}$$

$$= \left[\exp j\frac{2\pi}{\lambda}\,\vec{u}\left(n\,.\vec{\delta}_T + p\,.\vec{\delta}_R\right) \right]_{n=1,N;\,p=1,P}$$

(for monostatic case only)



Convolution of the array footprints

$$(f*g)[n] \stackrel{\text{def}}{=} \sum_{m=-\infty}^{\infty} f[m]\,g[n-m] = \sum_{m=-\infty}^{\infty} f[n-m]\,g[m].$$

Space domain

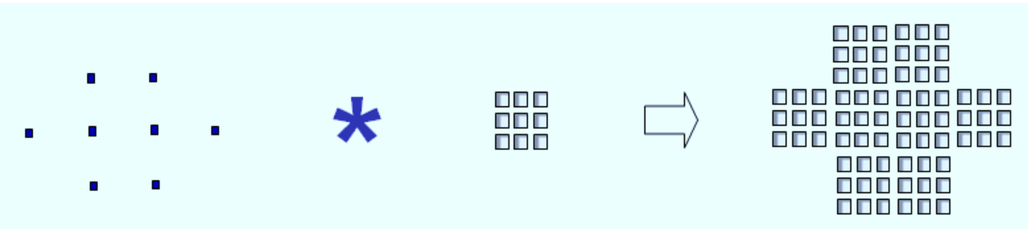
$$(f*g)[n] \stackrel{\text{def}}{=} \sum_{m=-\infty}^{\infty} f[m]\,g[n-m] = \sum_{m=-\infty}^{\infty} f[n-m]\,g[m].$$

Convolution

spectral (angular) domain

$$G_t(\theta_t,\theta_{to})\,G_r(\theta_r,\theta_{ro})$$

Product



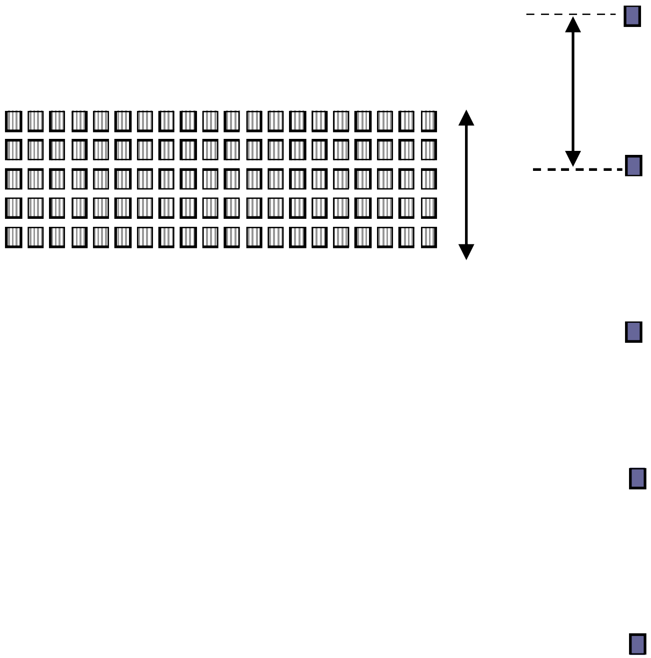
Improved angle resolution

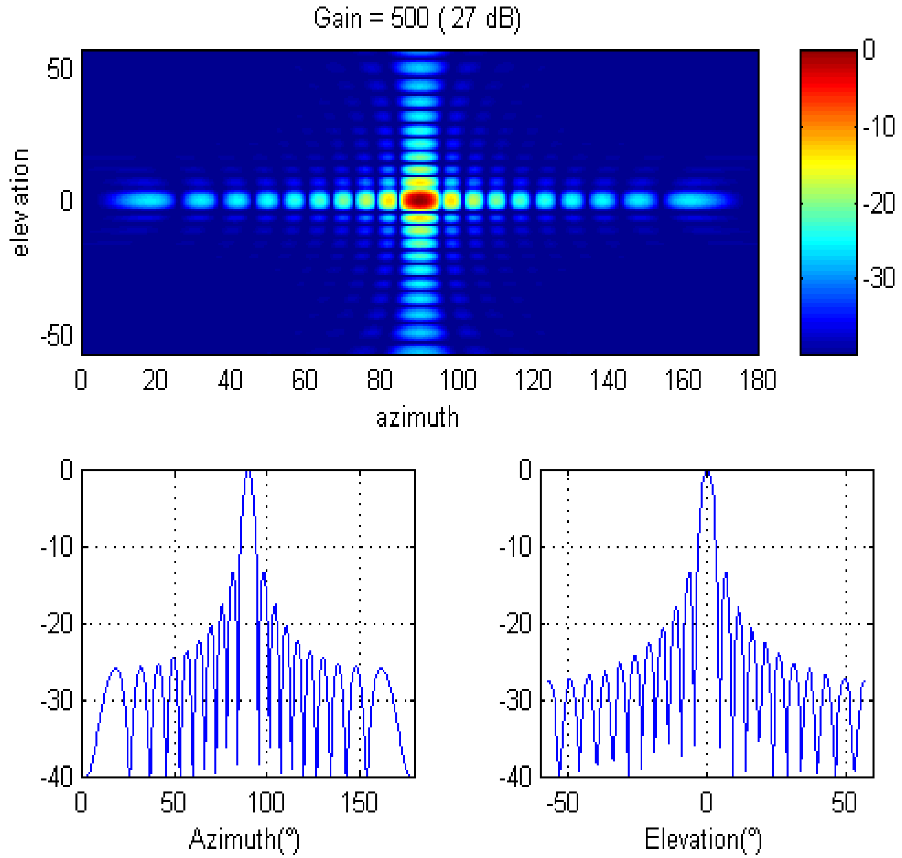
Sidelobes are not those of the full physical aperture !

F. Robey, S. Coutts, D. Weikle, J. McHarg, and K. Cuomo, "MIMO radar theory and experimental results," in *Signals, Systems and Computers, 2004. Conference Record of the Thirty-Eighth Asilomar Conference on*, vol. 1, Nov. 2004, pp. 300–304 Vol.1.

Example of MIMO « Tx & Rx » pattern

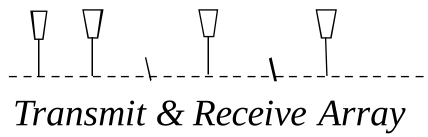
Quasi-monostatic configuration





Conventional digital beam-forming, based on direct compensation of the geometric phase, at each antenna of the transmit and receive array.

Information (diversity) vs. SNR



conv([1 1 0 1 0 1],[1 1 0 1 0 1])

= 1 2 1 2 2 2 3 0 2 0 1

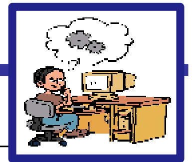
Increased SNR

Vitrtual array sensor providing diversity **→ 1 1 1 1 1 1 1 0 1 0 1**

If we keep only the Tx/Rx pairs of different virtual positions, the SNR is reduced but the directivity can be enhanced.

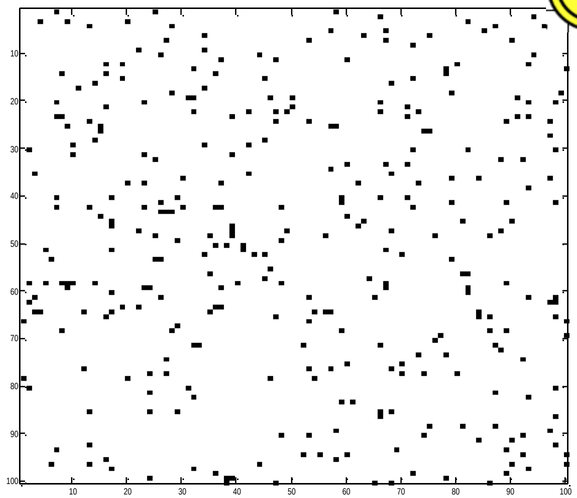
However, the possibilities in 1D are rather limited…

A simple example in 2D



Pupil of 100 x 100 transceivers

3,3% of transceivers only !



Virtual array

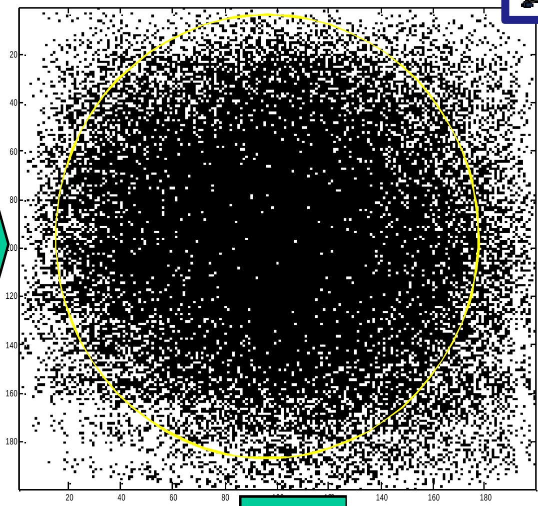
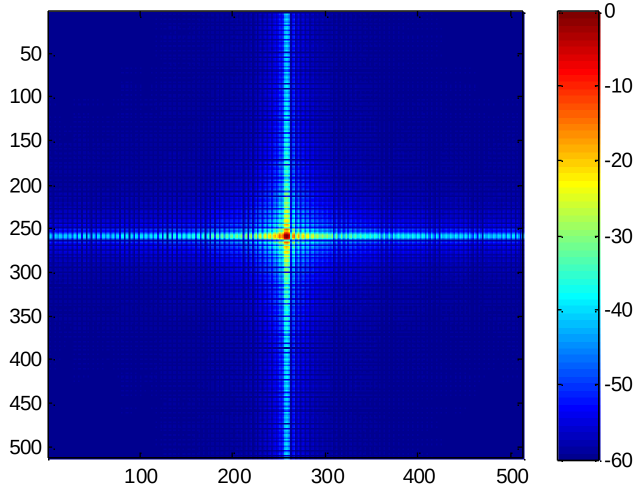
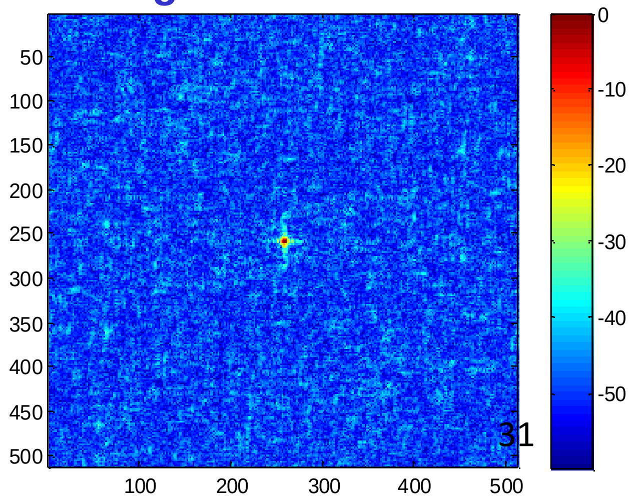


Image of one scatter pupil 100 x 100 transceivers



Sidelobes !

Image of one scatter

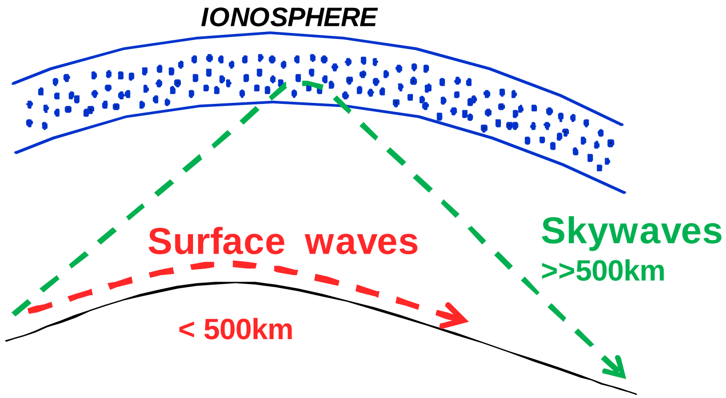


Example 1 : HF Surface Waves Radar (HFSWR)

ROS - The French HFSWR

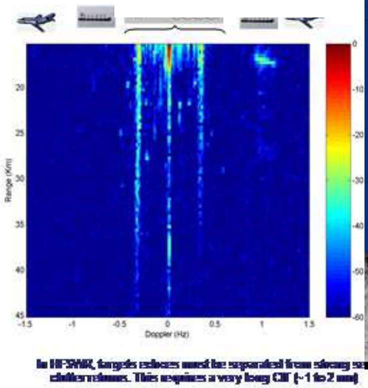
Maritime surveillance of altlantic ocean and mediterranean sea

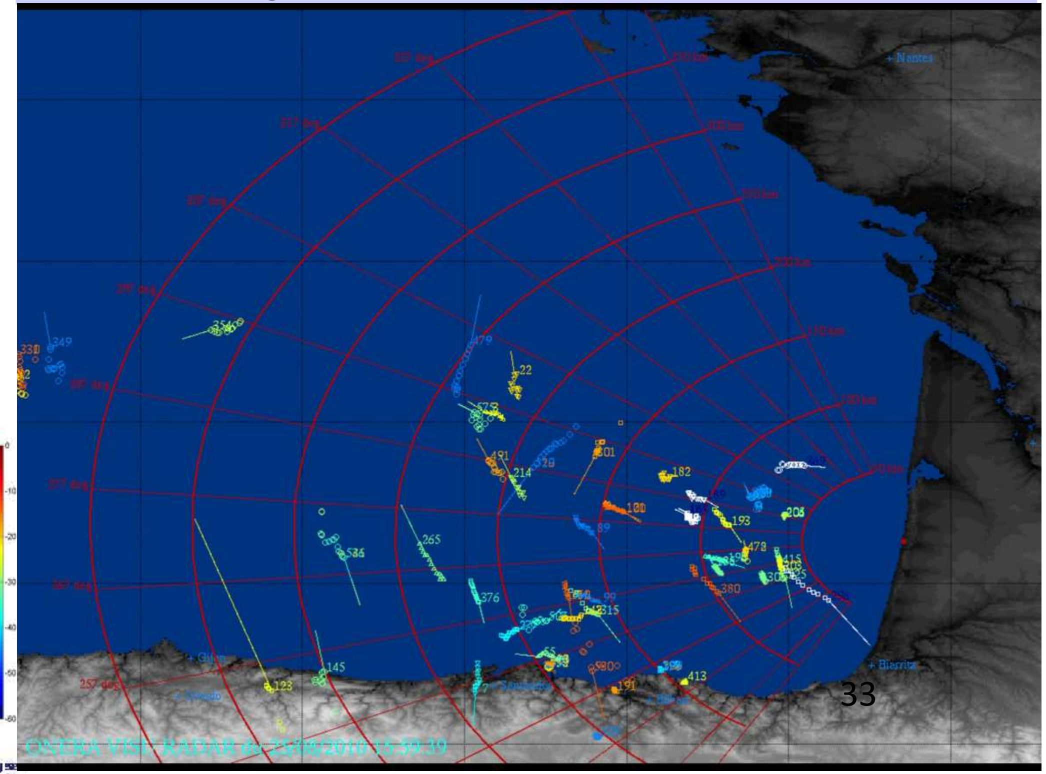
Propagation (HF band)



3 main limitations

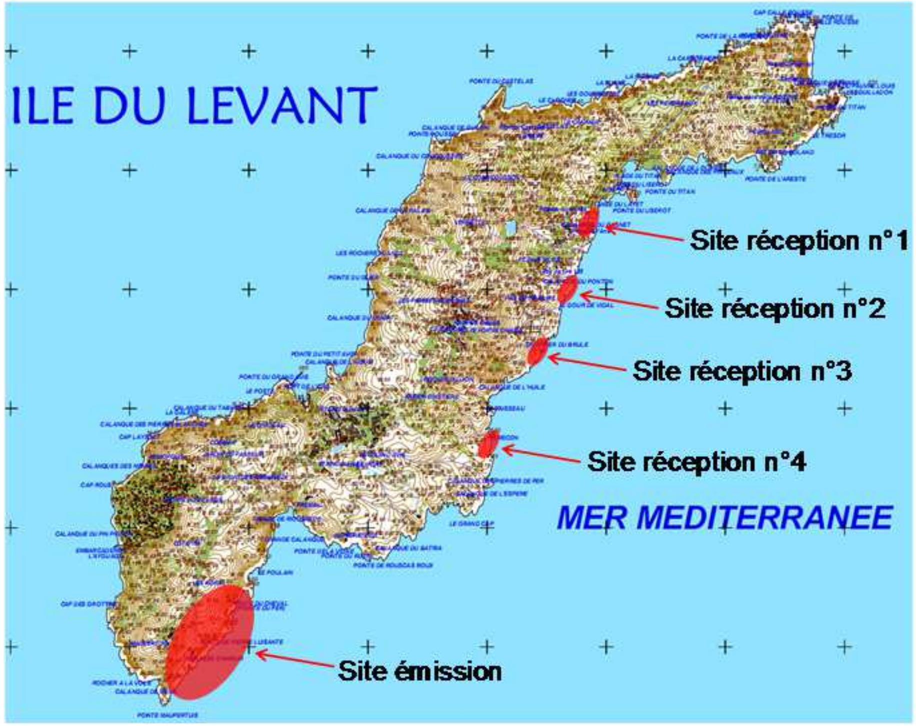
- Low Azimut resolution
- Range resolution
- Small boat vs clutter





Example 1 : HFSWR based on MIMO technology

- MIMO virtual antenna of 2500m
- 1 Tx site (4 antennas)
- 4 Rx sites (8 antennes)
- Dual fréquency mode (5 / 9MHz)
- Remote control from main land

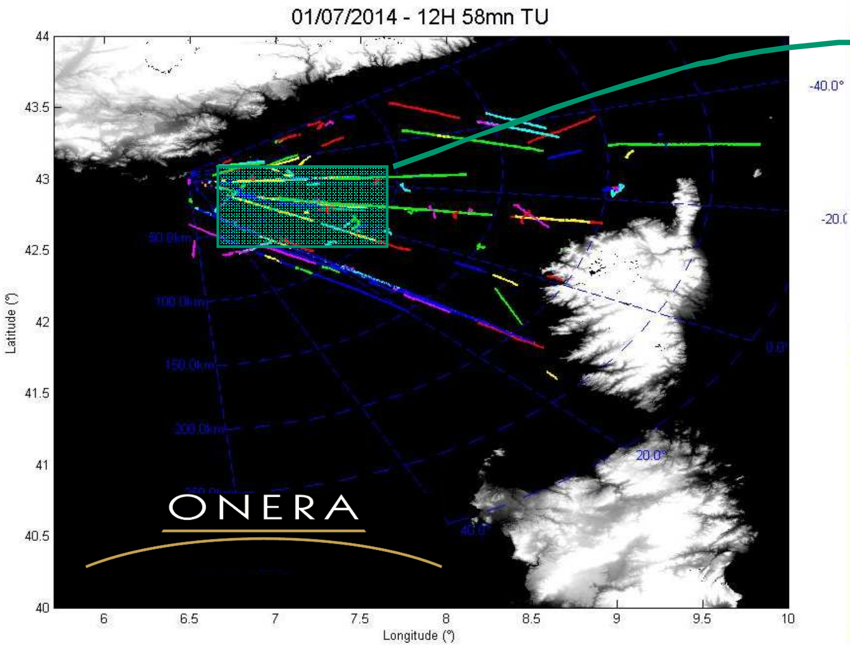


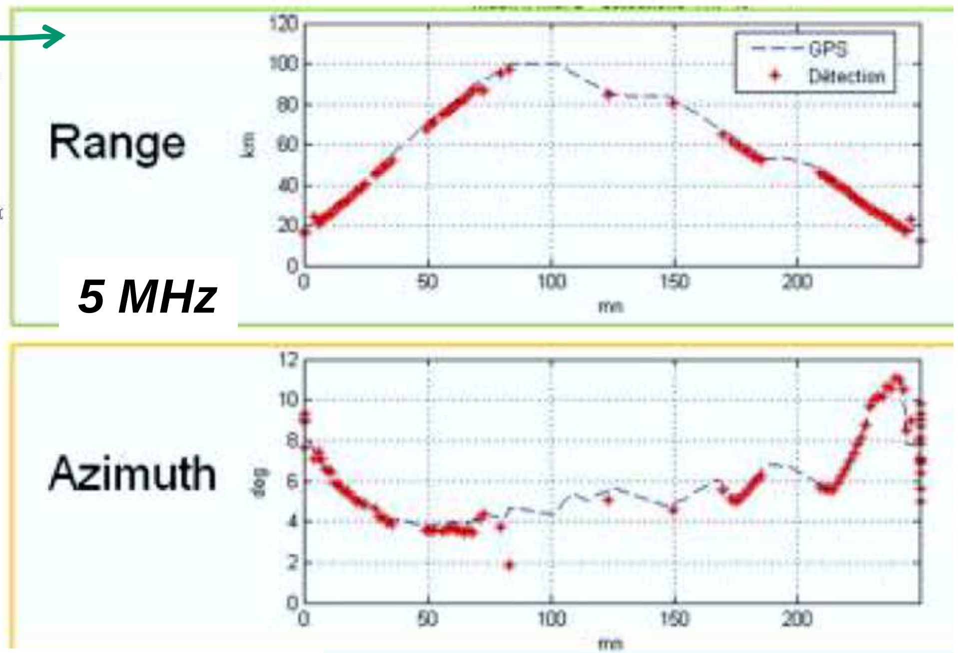
F. Jangal , M. Menelle "French HFSWR contribution to the European integrated maritime surveillance system I2C", IET radar conference, Hangzhou, October 2015.

MIMO Virtual array principle

ONERA
THE FRENCH AEROSPACE LAB

Example 1 : HFSWR based on MIMO technology

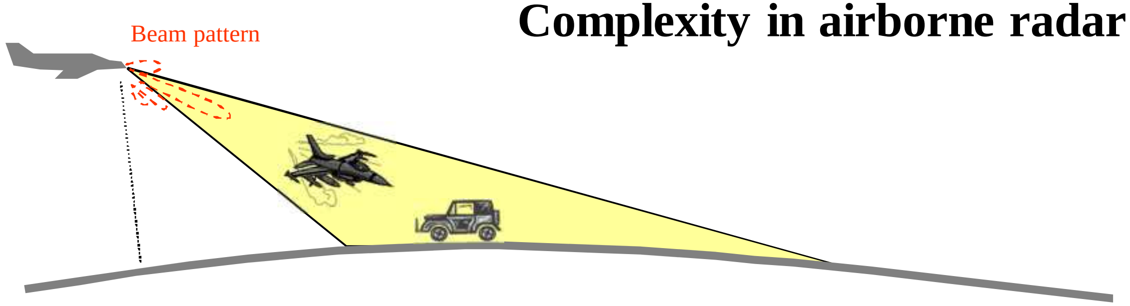


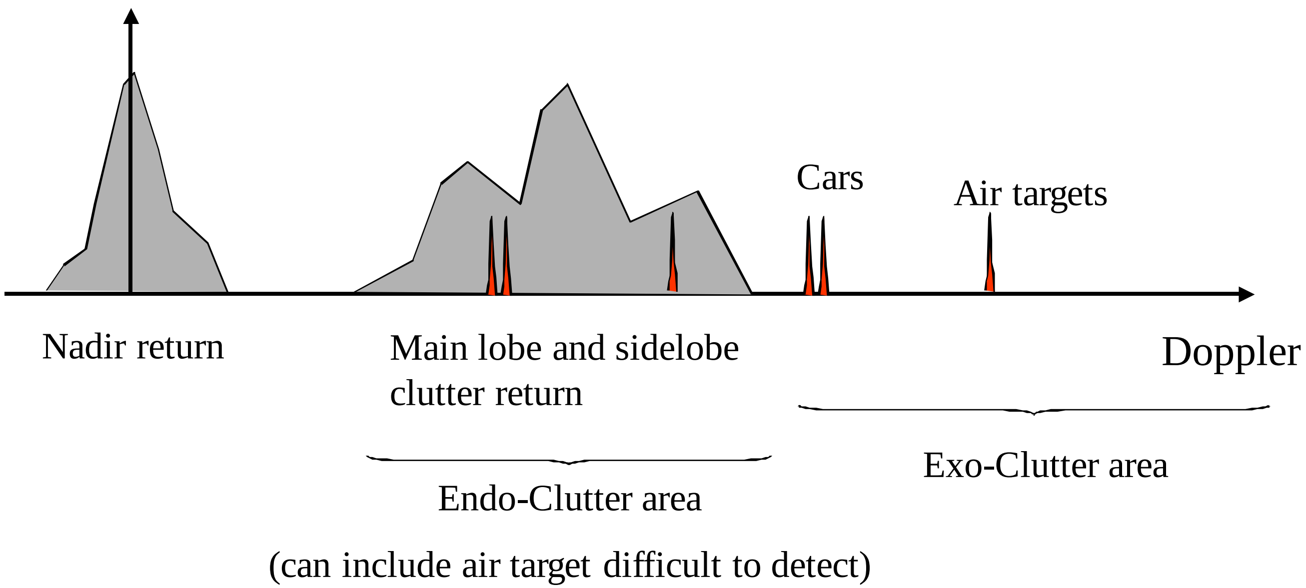


F. Jangal , M. Menelle "French HFSWR contribution to the European integrated maritime surveillance system I2C", IET radar conference, Hangzhou, October 2015

Example 2 : Ground Moving Target detection / STAP (Space Time Adaptive Processing)

Complexity in airborne radar processing





New processing schemes are considered to mitigate clutter contamination, both for air and ground targets : STAP (Space Time Adaptive Processing)

ONERA
THE FRENCH AEROSPACE LAB

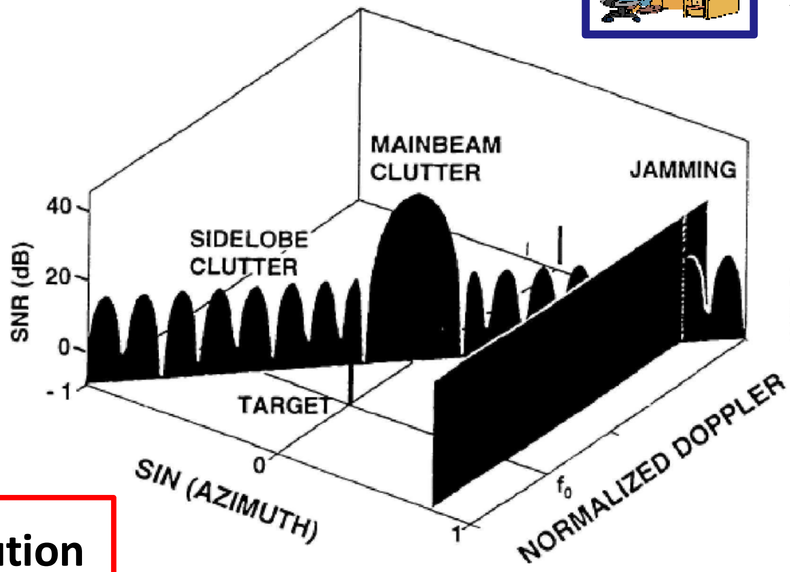
Example 2 : Ground Moving Target detection / STAP (Space Time Adaptive Processing)

What is STAP ?

A technique to form a 2-dimension notch filter (in angle-Doppler domain) to reject all stationary clutter echoes and improve the detection of moving targets

STAP vs. Non-STAP GMTI

- **Gain of 2** on the Minimum Detectable Velocity (MDV)
- **Gain > 4** on the angle localisation error



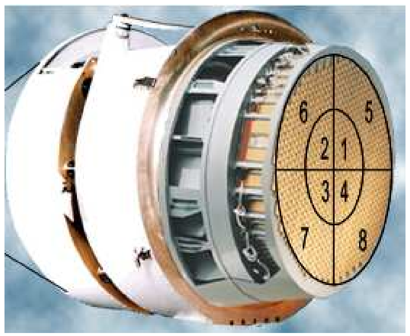
Fine resolution in velocity requires a fine angle resolution

$$MDV \sim V_{platform} \cdot \lambda / (2L_{array})$$

Europe

US - (JSTARS)

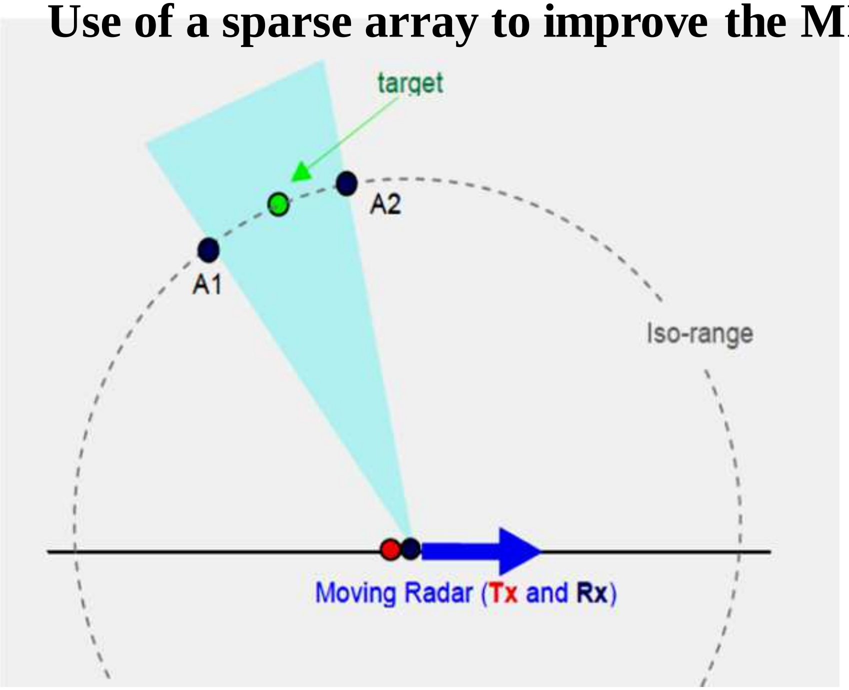
AMSAR

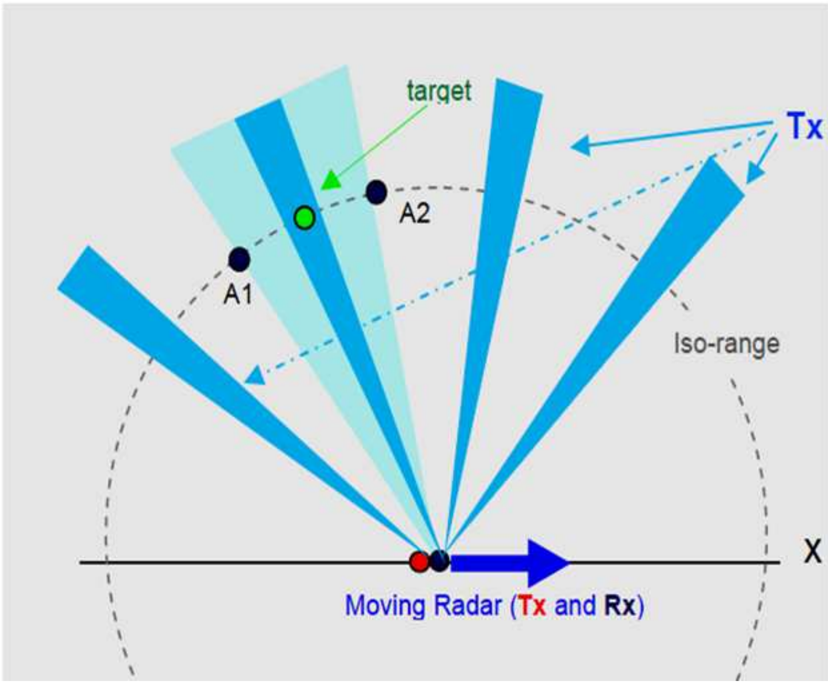


SOSTAR-X

Example 2 : MIMO – STAP – sparse & non sparse array (1)

Use of a sparse array to improve the MDV

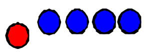


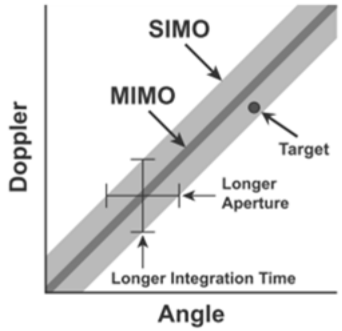


Conventional

1 Rx arrray (non sparse)

$MDV \sim V_{platform} \cdot \lambda / (2L_{array})$





MIMO - sparse

1 Rx arrray (non sparse) + 1 Tx array (sparse)

This configuration can be helpful to **improve the MDV** of low frequency airborne radar

Example 2 : MIMO – STAP – sparse & non sparse array (2)

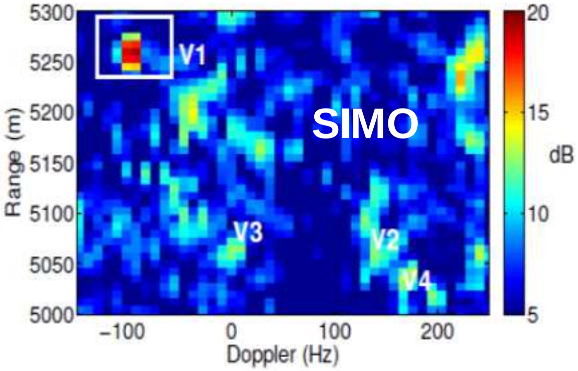


Fig. 5. SIMO detection results for four instrumented vehicles after adaptive processing of a single dwell.

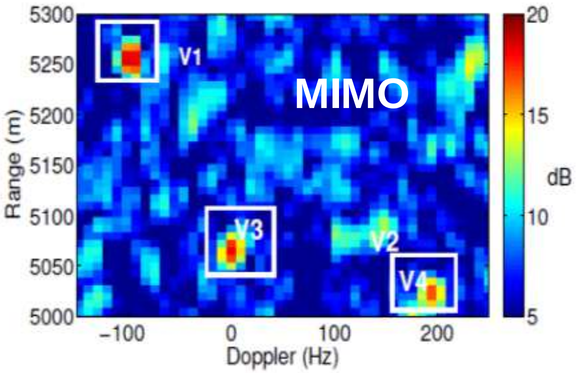
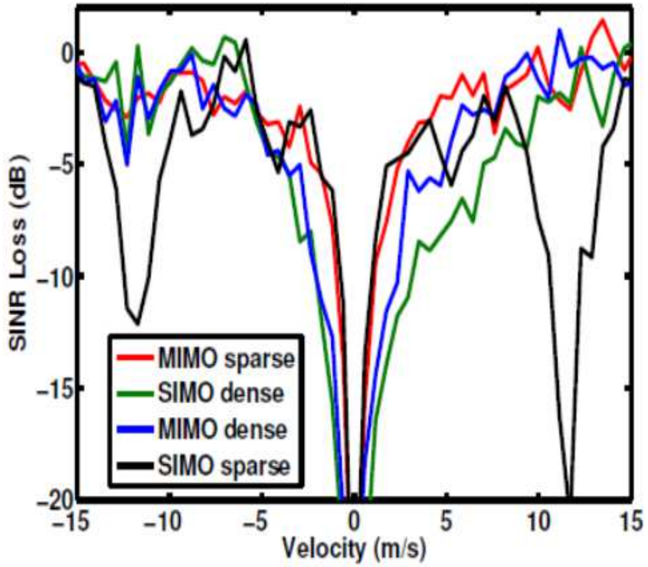
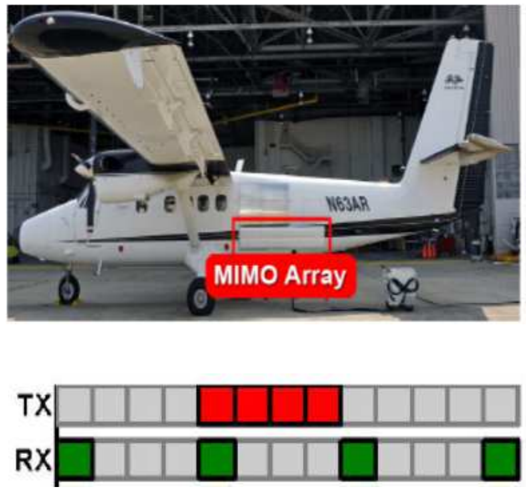


Fig. 6. DDMA MIMO detections for four instrumented vehicles after adaptive processing in a single dwell.





From J. Kantor and S. Davis, "Airborne GMTI using MIMO techniques," in *Radar Conference, 2010 IEEE*, May 2010, pp. 1344–1349.

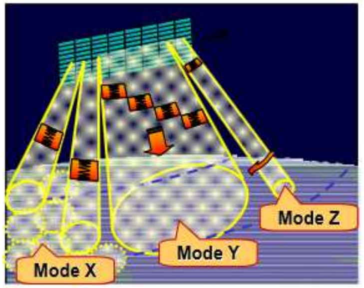
Example 3 : MIMO in future space borne SAR (1)

State-of-the-art on spaceborne SAR imaging

State of the Art (TerraSAR-X)	Imaging Mode (single pol)		
	ScanSAR	Stripmap	Spotlight
Resolution	16 m	3 m	1 m
Swath Width	100 km	30 km	10 km
Orbit Duty Cycle	3 minutes per orbit		

Resolution ⟷ Swath Width ⟷ Repeat Cycle

→ **Trade-off to overcome with MIMO ?**



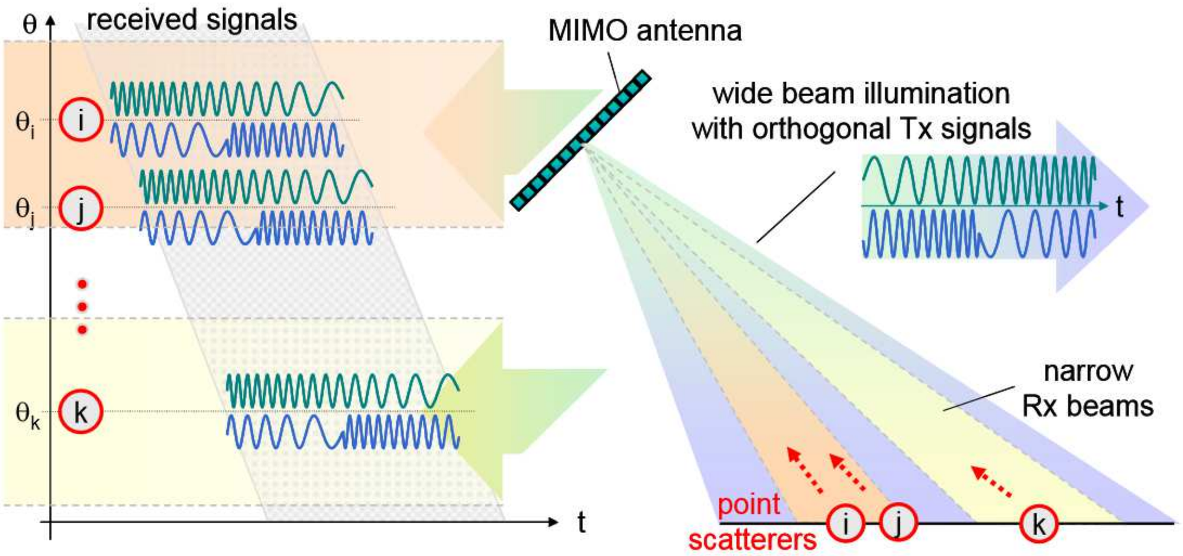
Future Requirements	Imaging Mode (quad pol)		
	Mode X	Mode Y	Mode Z
Resolution	5 m	1 m	<< 1 m
Swath Width	400 km	100 km	30 km
Orbit Duty Cycle	30 minutes per orbit		

From :

Digital Beamforming and MIMO SAR: Review and New Concepts
G. Krieger, M. Younis, S. Huber, F. Bordoni, A. Patyuchenko, J. Kim, P. Laskowski, M. Villano, T. Rommel, P. Lopez-Dekker, and A. Moreira
DLR, Microwaves and Radar Institute, Oberpfaffenhofen, Germany

Example 3 : MIMO in future space borne SAR (2)

Issue on selection of orthorgonal waveform.
Non orthogonal waveform generates cross-correlation products / interference between the channels
Strong and diffuse scattering may affect the quality of the image in the region where the orthogonality is not perfect.



Two-transmitter diversity is used to extend the high resolution wide swath (HRWS)

From :

Digital Beamforming and MIMO SAR: Review and New Concepts
G. Krieger, M. Younis, S. Huber, F. Bordoni, A. Patyuchenko, J. Kim, P. Laskowski,
M. Villano, T. Rommel, P. Lopez-Dekker, and A. Moreira
DLR, Microwaves and Radar Institute, Oberpfaffenhofen, Germany

Example 4 : milimeter-waves radar

A STAND-OFF
35GHz BODY
SCANNER

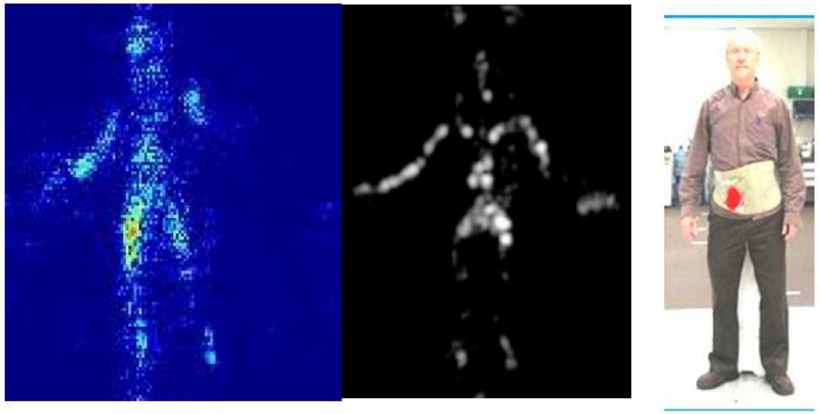
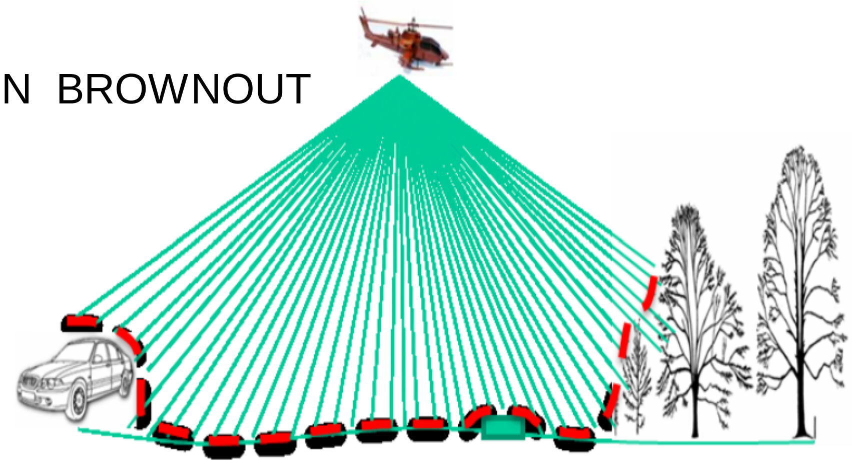


Figure 2. (a) A Raw body Image, (b) With four-look speckle reduction, (c) Cross polar returns from a hidden simulated target, superimposed on a visual image

A MIMO RADAR FOR LANDING HELICOPTERS IN BROWNOUT
(multi-beam radar altimeter)



T-shape array
TDMA, X (24 x 24) or Ka (32 x 32)

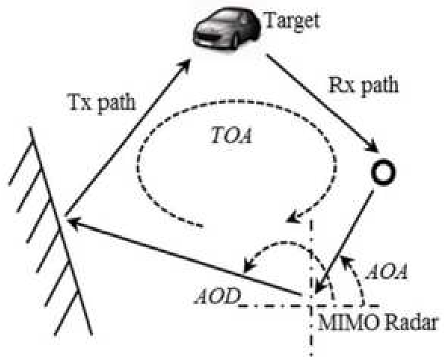
From : MIMO Radar Developments at Teledyne Australia , I. Dennis Longstaff , Halappa Ashoka , Troy Kilpatrick *, Radar 2013 Conference, Adelaide

Other examples

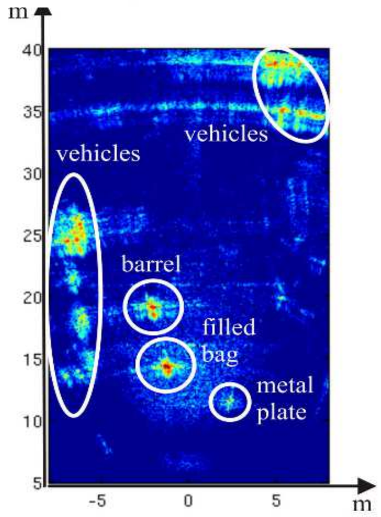
Urban environment

J Yu, J Krolik, "Simultaneous target and multipath positioning with MIMO radar", IET Radar 2012 conference

J Yu, J Krolik, " MIMO multipath clutter mitigation for GMTI automotive radar in urban environments, "IET Radar 2012 conference



A J Kirschner, J Guetlein, S Bertl, J Detlefsen, " A millimetre-wave MIMO radar system for threat detection in patrol or checkpoint scenarios", IET Radar 2012 conference



Interferences mitigation

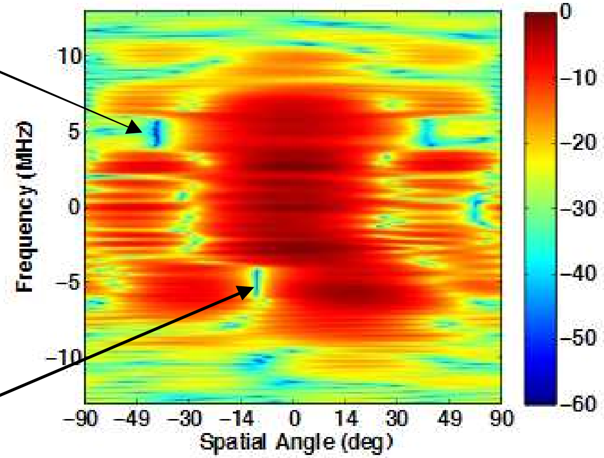


Figure 11: Normalized beam pattern power (in dB) of the chirp waveform with space-frequency nulls at −10° and −5 MHz, 60° and 0 MHz, and both −40° and 40° at 5 MHz, four-channel experimental configuration.

T Higgins, T Webster, A K Shackelford, "Mitigating interference via spatial and spectral nulls", IET Radar 2012 conference

Conclusion

Pros	Cons E : engineering issue P : physical limitation
1. Resolution enhancement or 2. Undersampling of array manifold antenna 3. Access to new information (Doppler, permanent track while scan) 4. Key enabler for low freq radar	1. Complexity : Waveform, processing **(E)** 2. SNR to compensate **(P+E)** 3. Diffuse clutter suppression **(P+E)** 4. Coherence of the target response **(P)**

Potential applications

- Low frequency air surveillance radar (1,2,3,4 – -,-,-,-)
- Short range radar (-,2,-,- – -,-,-,-)
- Air defense radar in combination with conventional scanning (-,-,3,- – -,2,-,4)
- STAP at low frequency (1,2,-,4 – 1,-,3,-)
- Space borne SAR MIMO : very challenging (-,-,3,- – 1,-,3,-)