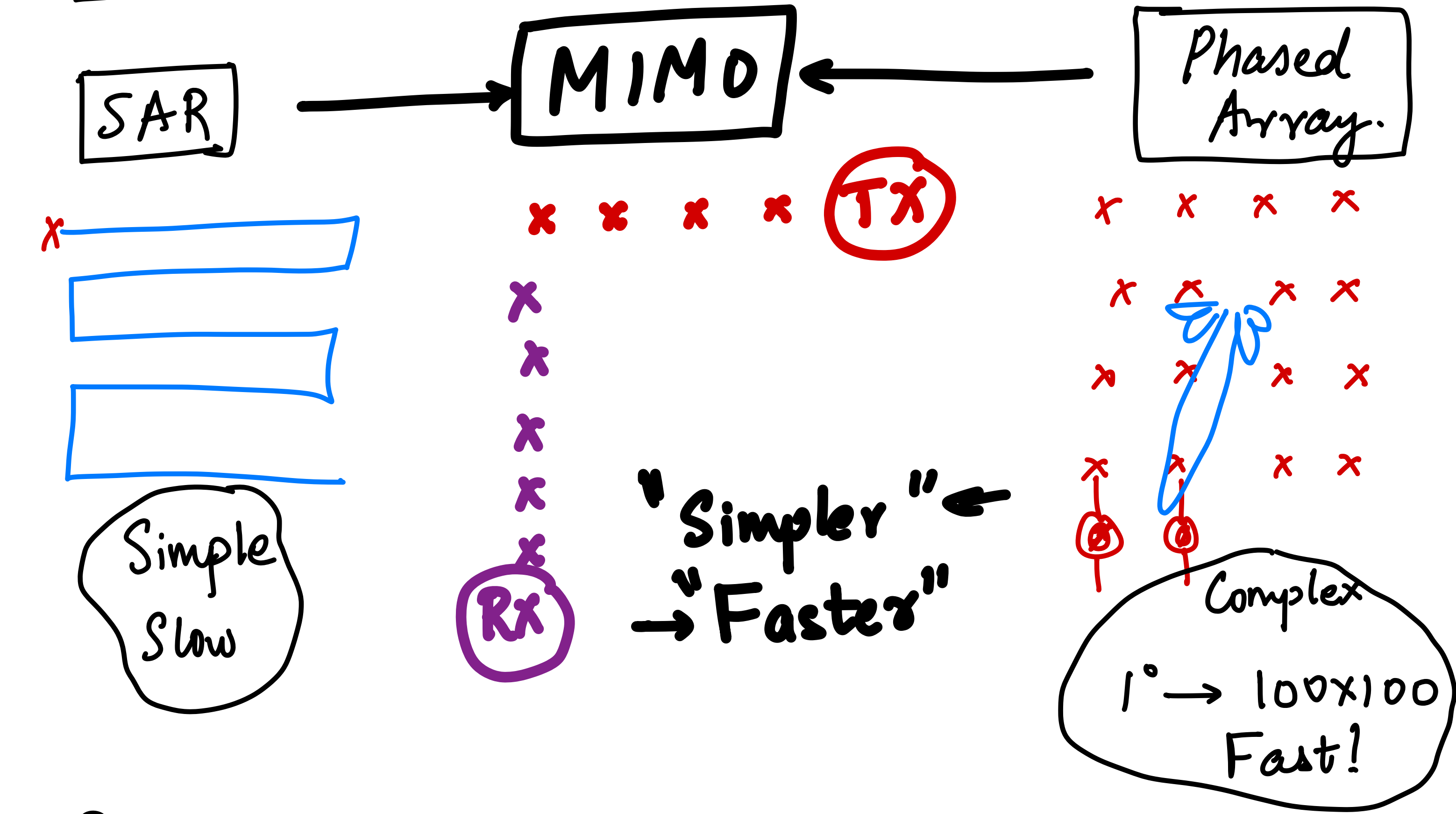
V MIMO Radar

Multiple Input Multiple Output Radar



Pre-requisites

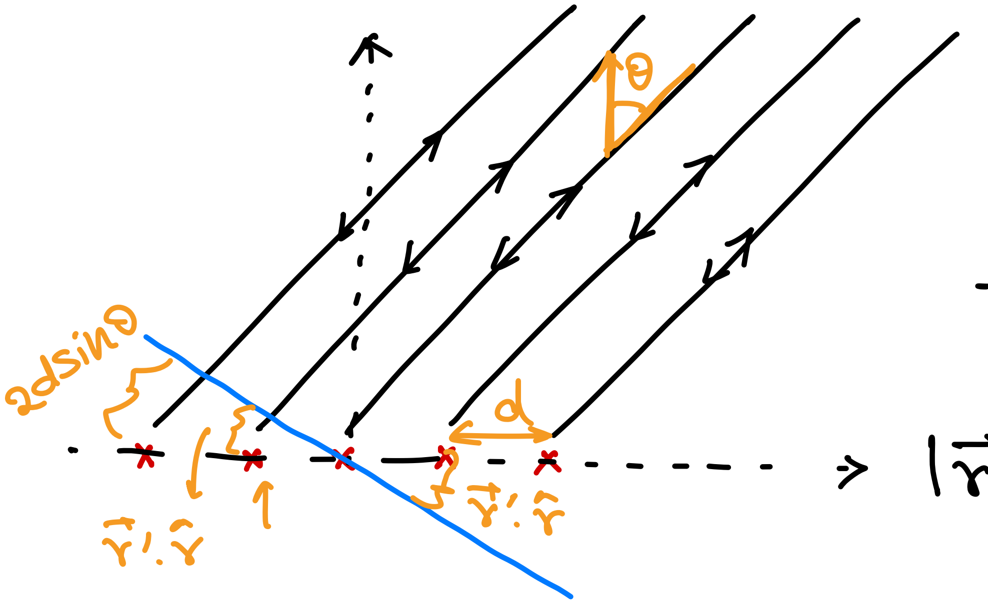
> FMCW, Stepped Freq, (or) Pulsed.

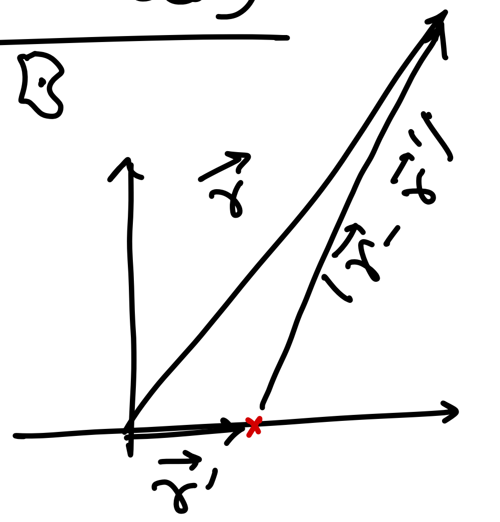
> Backprojection / JDC SAR video.

Outline

1) 1-D steering beamsteering.
2) Far-field MIMO. "Virtual array"
3) Signal diversity.
4) 3-D Imaging using MIMO BP/JDC.

5.1 1D Beamsteering (Far-Field)





$$|\vec r-\vec r'| \simeq \underbrace{r}_{|\vec r|} - \vec r'\cdot\underbrace{\hat r}_{\frac{\vec r}{|\vec r|}}$$

$$\vec r'\cdot\hat r = d\sin\theta.$$

$$S_b = e^{-2jk|\vec r-\vec r'|} = e^{-2jkr-2jk\vec r'\cdot\hat r}$$

$$= e^{-2jkr}\,e^{-2jknd\sin\theta}.$$

$$n\in\{-2,-1,0,1,2\}.$$

$$\phi_n = nkd\sin\theta$$

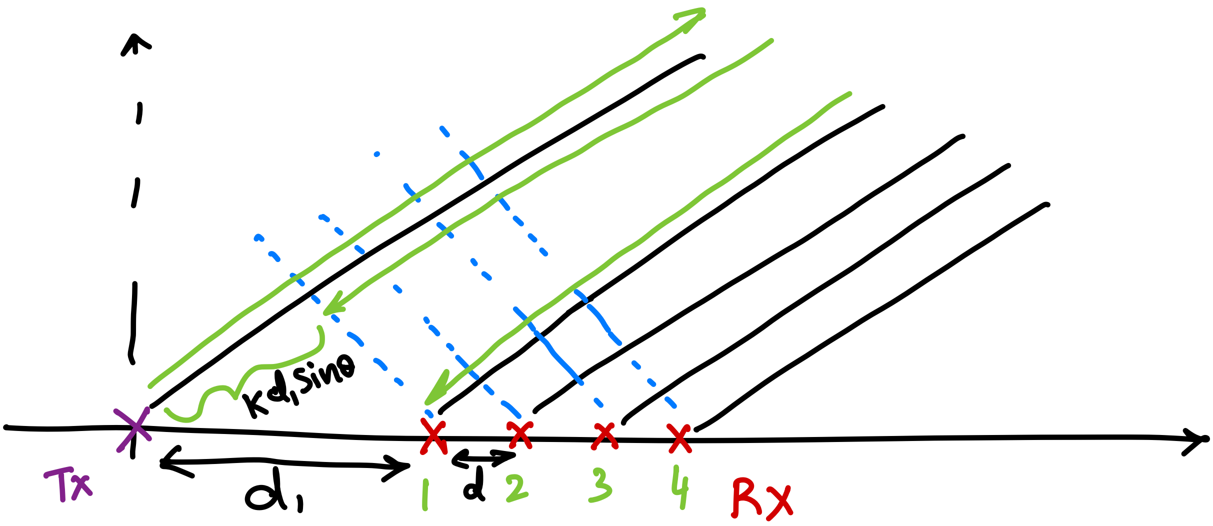
$$S_b^n = e^{-2jkr}\,e^{-2j\phi_n}$$

$$\tilde f = \sum_n S_b^n\, e^{2j\phi_n} \rightarrow$$ FAR FIELD Beamsteering.

If each element has both TX & RX can we also use the cross coupling (multi-static) signals in the image reconstruction?

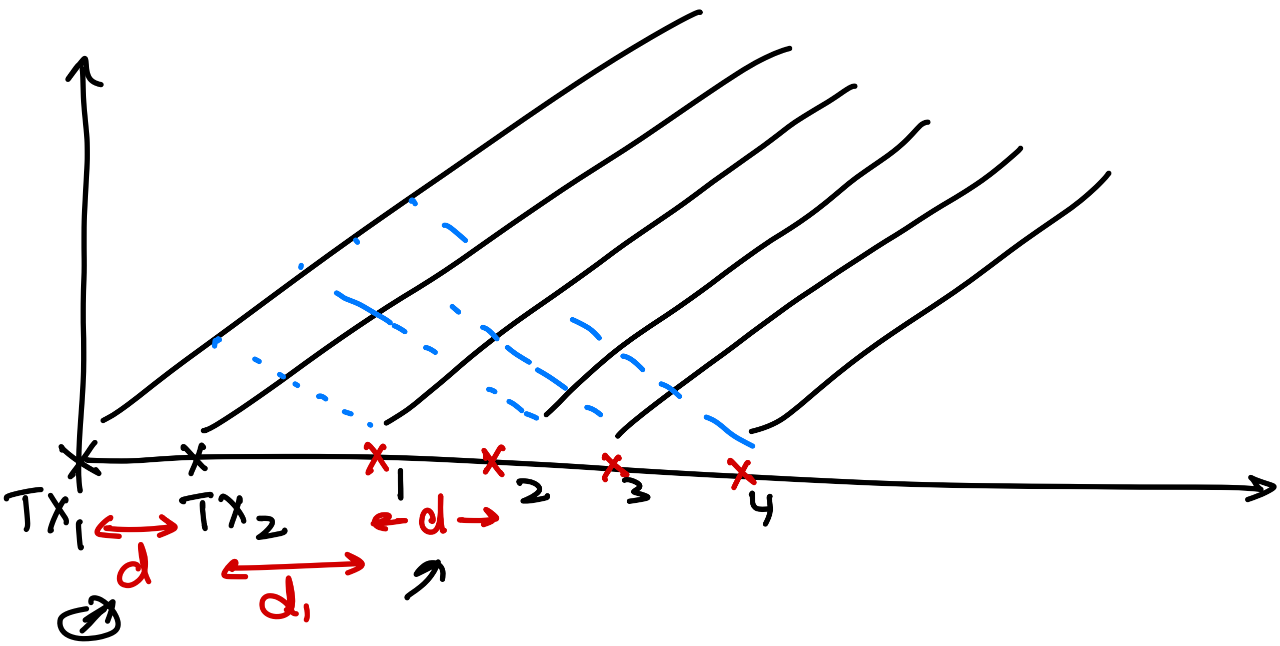
"YES! But need to have a clever design"

MISO Multiple Input Single Output



$$\left.\begin{aligned}\phi^1 &= kd_1\sin\theta\\ \phi^2 &= k(d_1+d)\sin\theta\\ \phi^3 &= k(d_1+2d)\sin\theta\\ \phi^4 &= k(d_1+3d)\sin\theta.\end{aligned}\right\} \quad \sum_n S_b\, e^{2j\phi_n} = \tilde{f}$$

MIMO (naive)



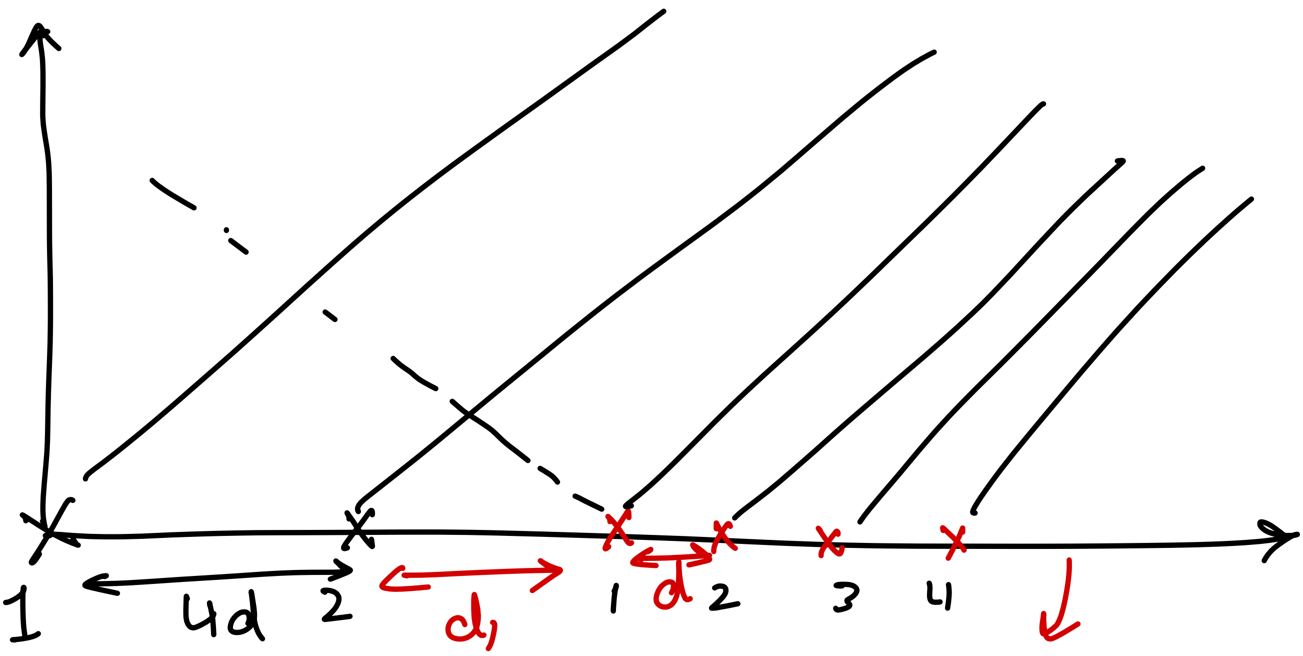
$$\phi_{11} = k(d+d_1)\sin\theta$$

$$\phi_{21} = k(d+d_1+d)\sin\theta = k(d_1+2d\sin\theta)$$

$$\phi_{31} = k(d+d_1+2d)\sin\theta = k(d_1+3d\sin\theta)$$
$$\phi_{41} = k(d_1+4d\sin\theta)$$
$$\phi_{12} = k(d_1)\sin\theta$$
$$\phi_{22} = k(d_1+d\sin\theta)$$
$$\phi_{32} = k(d_1+2d\sin\theta)$$
$$\phi_{42} = k(d_1+3d\sin\theta)$$

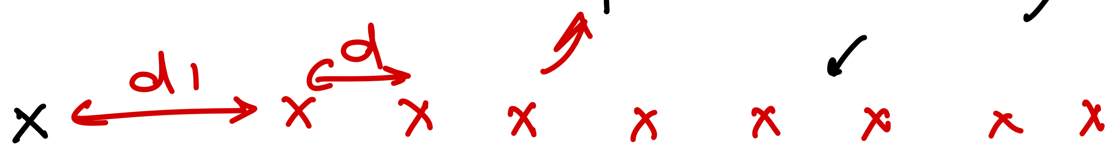
8 measurements but only 5 are unique.

MIMO (smart)



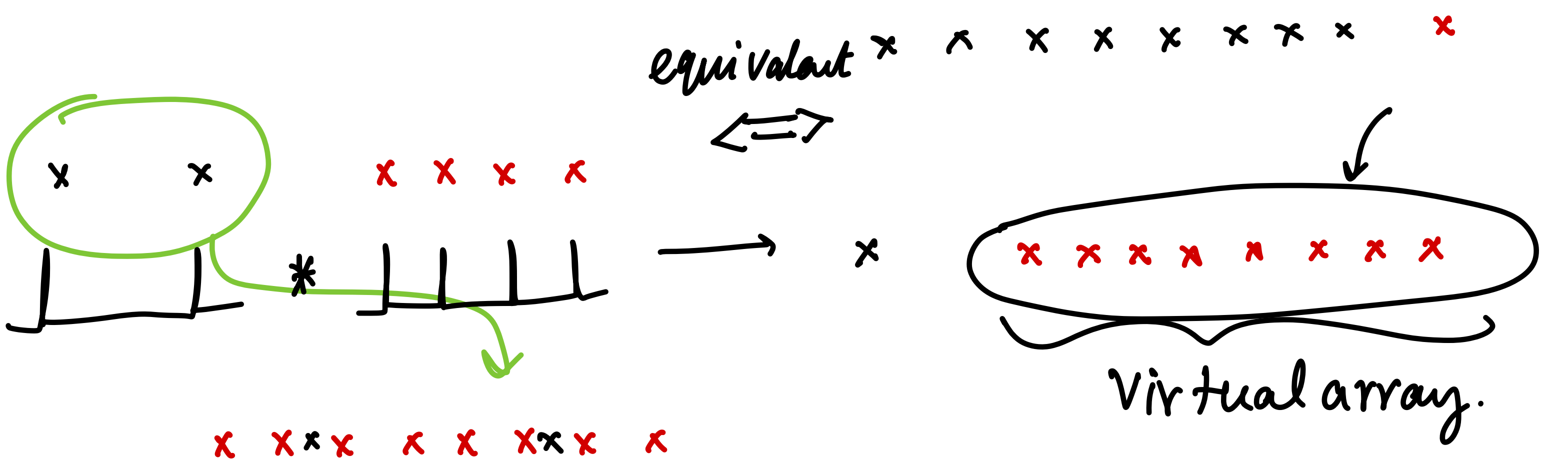
$$\phi_{11} = k(d_1+4d)\sin\theta$$
$$\phi_{21} = k(d_1+5d)\sin\theta$$
$$\phi_{31} = k(d_1+6d)\sin\theta$$
$$\phi_{41} = k(d_1+7d)\sin\theta$$

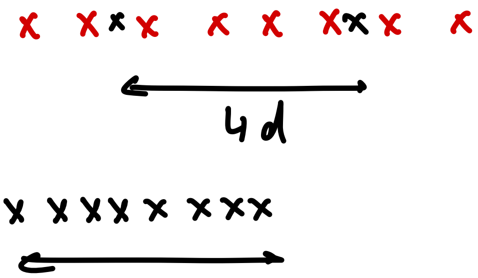
$$\phi_{12} = k(d_1)\sin\theta$$
$$\phi_{22} = k(d_1+d)\sin\theta$$
$$\phi_{32} = k(d_1+2d)\sin\theta$$
$$\phi_{42} = k(d_1+3d)\sin\theta.$$



> An M×N MIMO system (M+N elements) is equivalent to M 1×N MISO arrays! (M×N elements)

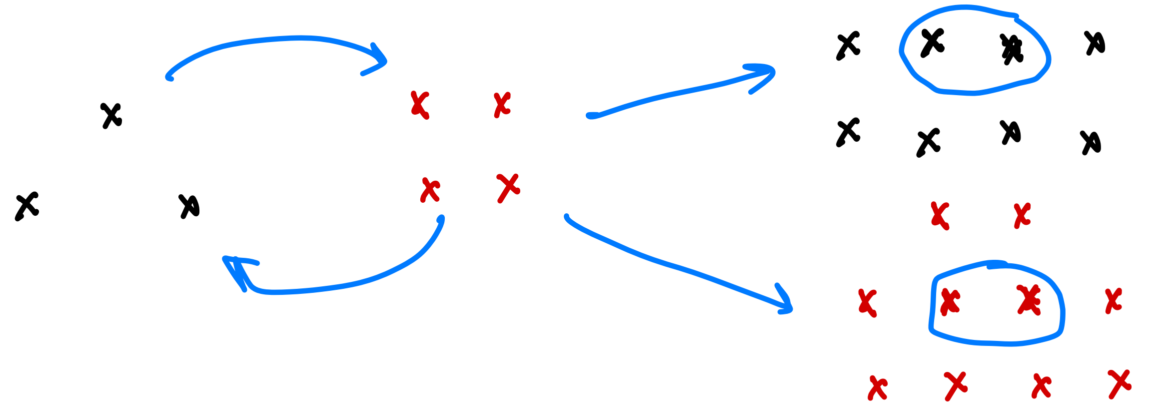
5.2 Virtual array equivalency.

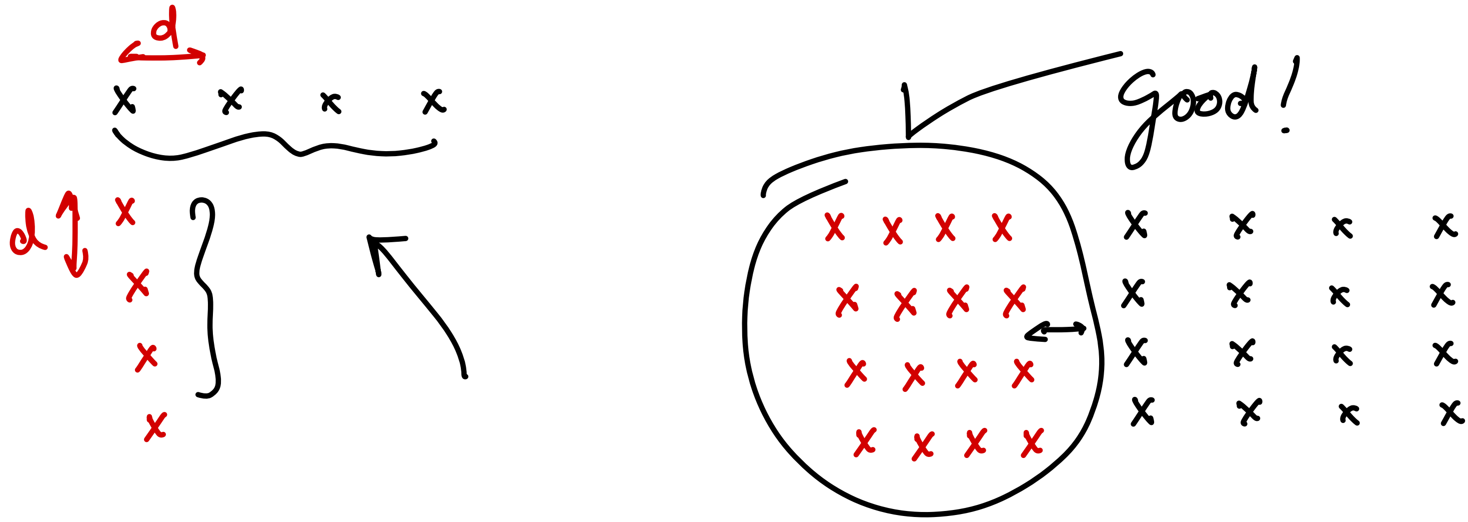




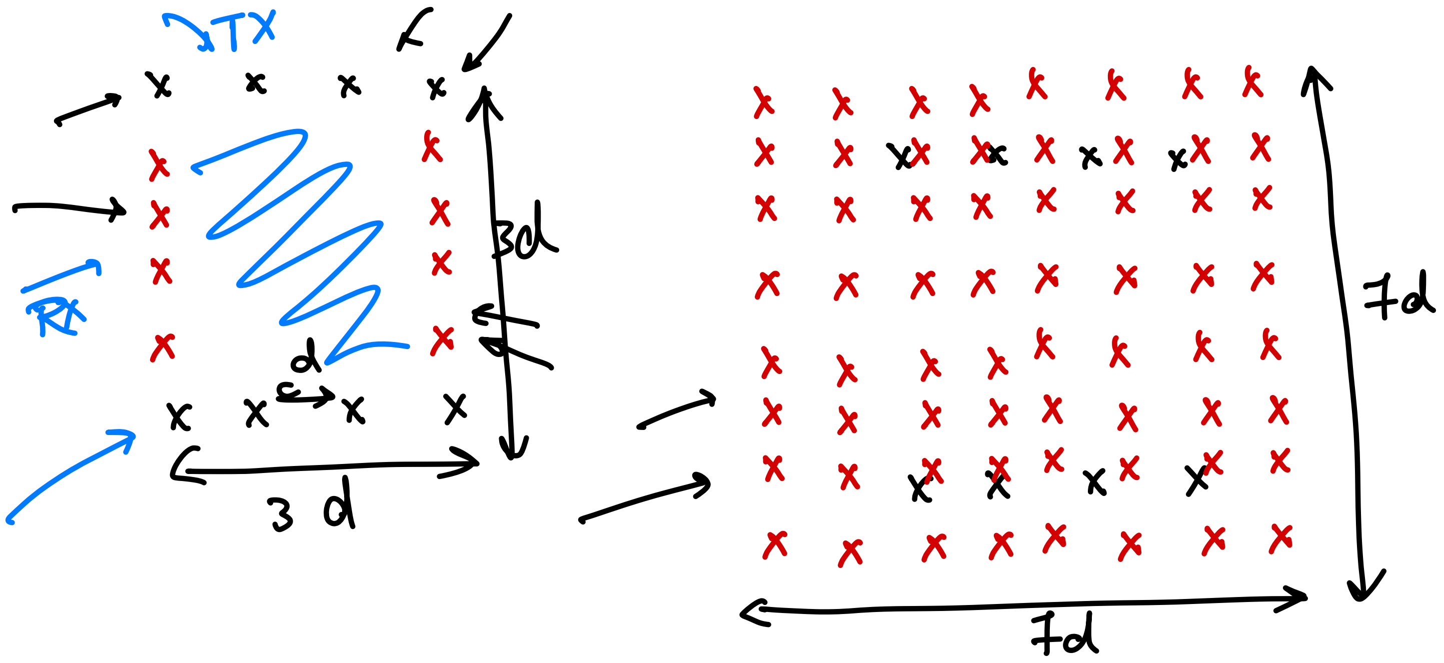
DISCRETE CONVOLUTION B/W TX & RX ARRAYS!

Examples





$$\boxed{2N \longrightarrow N^2}$$



Array size $\longrightarrow$ doubled.

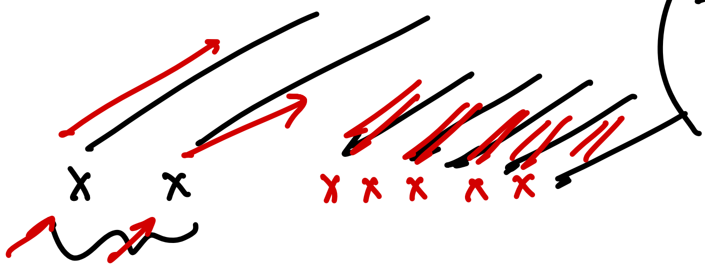
Resolution $\longrightarrow$ halved.

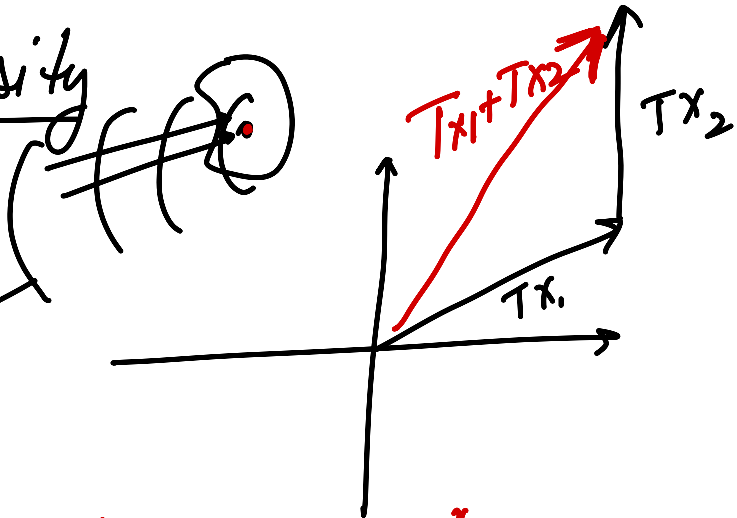
<u>Problem</u>: Purchase 100 (TX/RX) T/R modules.

What is the best MIMO geometry for highest signal diversity?

CAUTION Virtual array concept is only valid in the far-field. For near-field, must rely on the point-spread function.

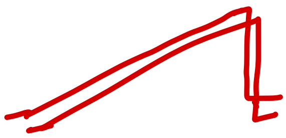
5.3 Signal diversity





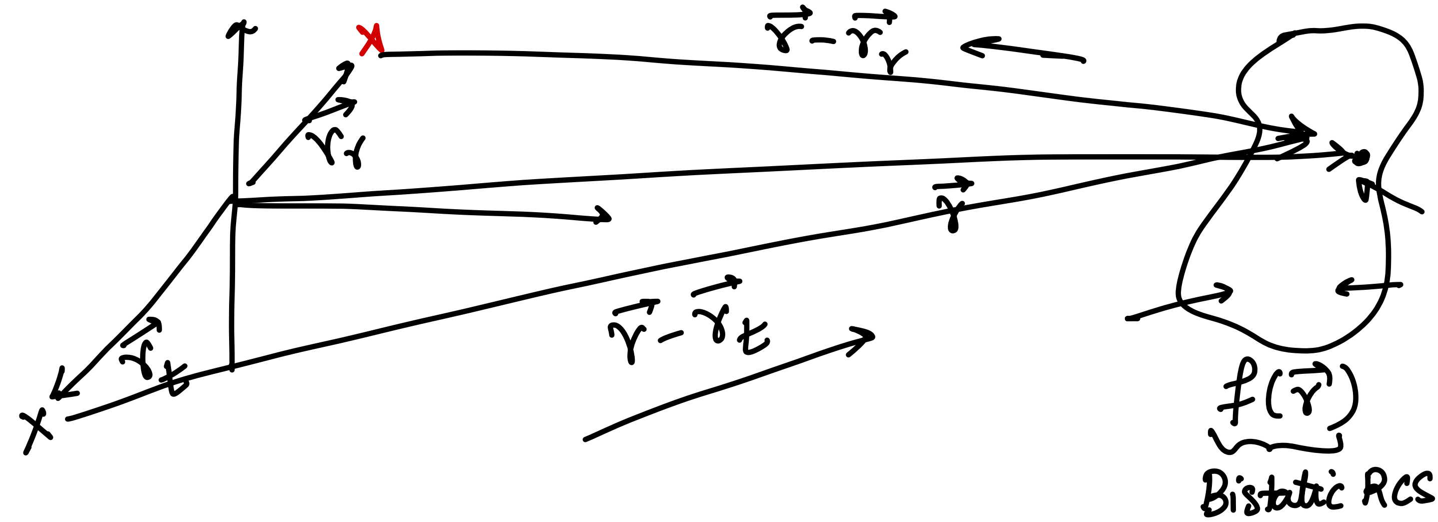
Tx signals must be "multiplexed".

- TDM.
- OFDM ←
- CDM
- Orthogonal chirps



ϕ_n^m

5.4 Back-projection for MIMO imaging (Near Field)



$$S_b^r(\vec{r}, \vec{r}_t, \vec{r}_r, k) = \underbrace{\frac{f(\vec{r})\, e^{-jk|\vec{r}-\vec{r}_t|}\, e^{-jk|\vec{r}-\vec{r}_r|}}{|\vec{r}-\vec{r}_t|\,|\vec{r}-\vec{r}_t|}}$$

$$\tilde{S}_b = \iiint_{\vec{r}=(x\ y\ z)} \frac{f(\vec{r})\, e^{-jk(|\vec{r}-\vec{r}_t|+|\vec{r}-\vec{r}_r|)}}{|\vec{r}-\vec{r}_t|\,|\vec{r}-\vec{r}_r|}\, dx\, dy\, dz$$

$$\tilde{f}(x,y,z) = \sum_{k} \sum_{\vec{r}_t} \sum_{\vec{r}_r} \tilde{S}_b\, \underbrace{e^{jk(|\vec{r}-\vec{r}_t|+|\vec{r}-\vec{r}_r|)}}_{\text{Steering Matrix.}}$$

$$|\vec{r}-\vec{r}_t| = \sqrt{(x-x_t)^2 + (y-y_t)^2 + (z-0)^2}$$

$$|\vec{r}-\vec{r}_r| = \sqrt{(x-x_r)^2 + (y-y_r)^2 + z^2} \quad //$$

Advantages & Limitations

SAR ⟷ MIMO PA

1) Fast DAQ. What about processing? RMA.
2) Reduced no. of elements $N^2 \rightsquigarrow 2N$
3) Higher resolution!
4) Mutual coupling improvement. But still exists!
5) Moderate complexity! (Signal diversity)

Upcoming: > HFSS + MATLAB demo. SAR/MIMO FMCW

> Fast reconstruction! (RMA, ωk, WR, HR, ...)