

Основные темы:

- **Ошибки при синхронизации**
- **Beamforming**
- **Перераспределение частот**

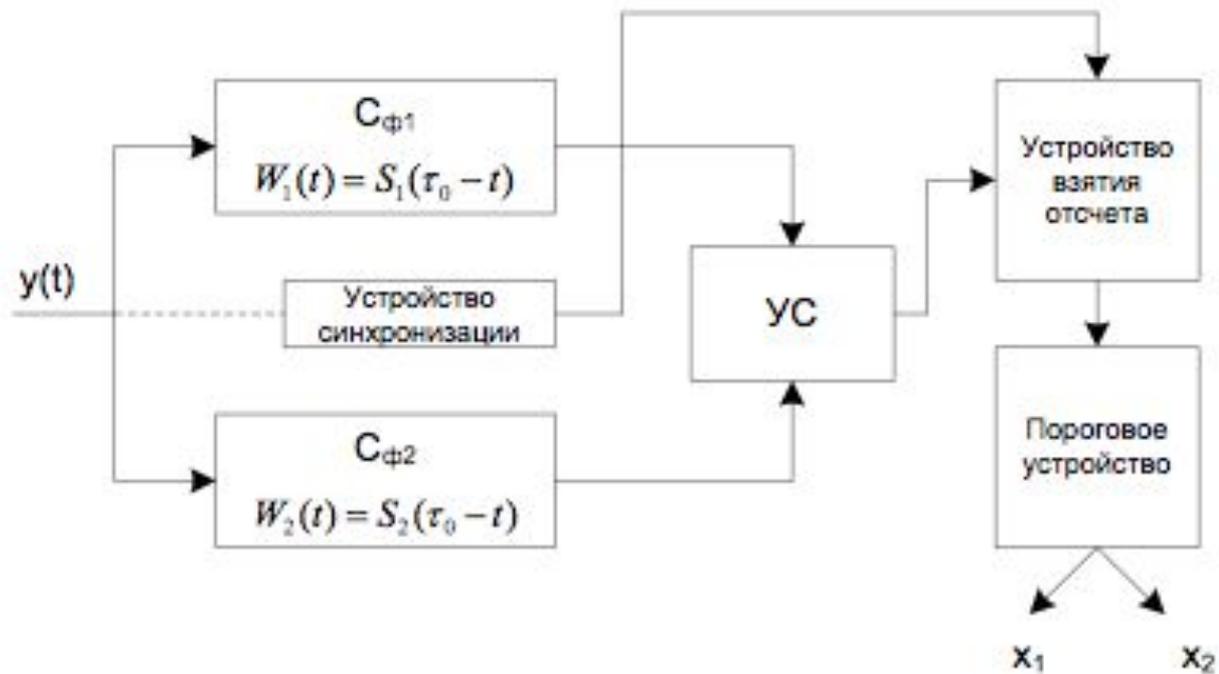
Ошибки при синхронизации

Вид синхронизации	Величина рассогласования	Требуемая Р	Необходимое увеличение энергии
ВЧ частота	$\Delta f_p \leq \frac{0,1}{\tau_0}$	$10^{-4} - 10^{-5}$	1,5 - 1,25
ВЧ фаза	$\Delta \varphi_p \leq 10^{-15}^\circ$	$10^{-4} - 10^{-5}$	1,1 - 1,15
Временная тактовая	$\Delta \tau_p \leq 0,1\tau_0$	$10^{-4} - 10^{-5}$	1,3 - 1,5

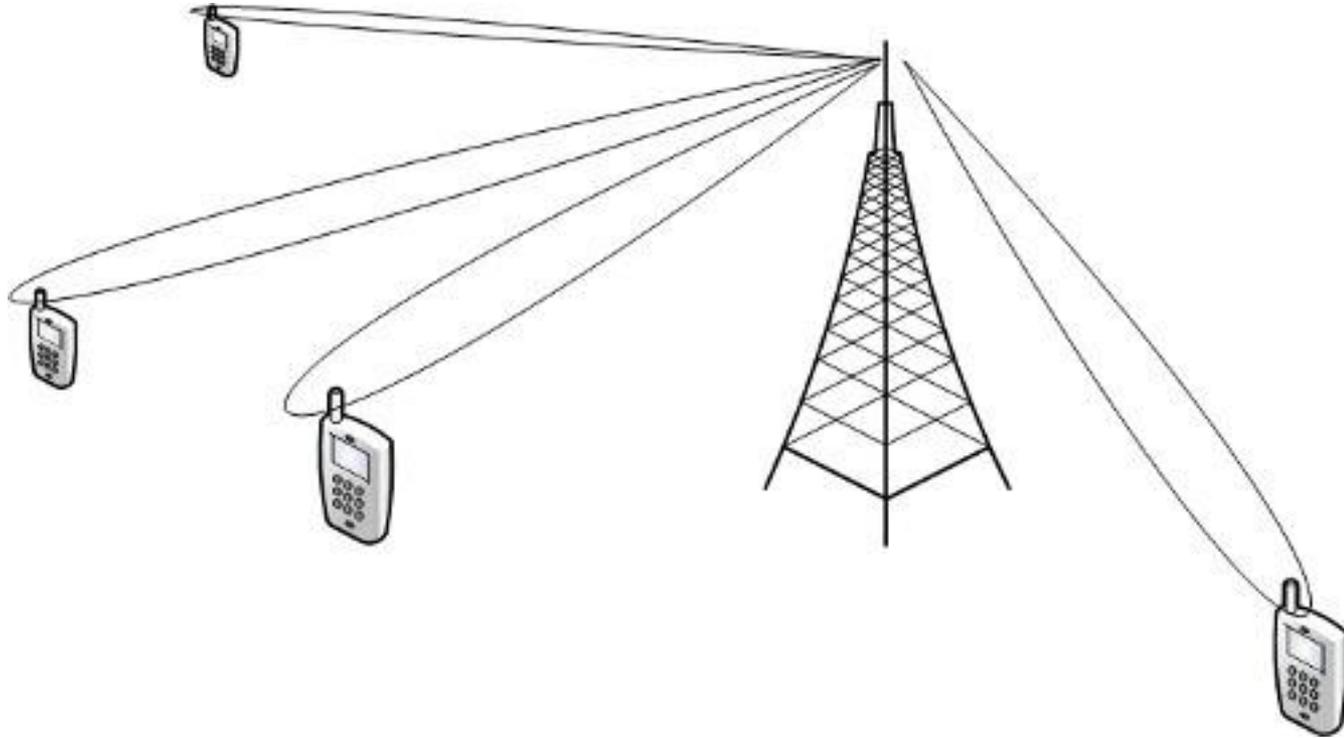
Ошибки при синхронизации



Ошибки при синхронизации



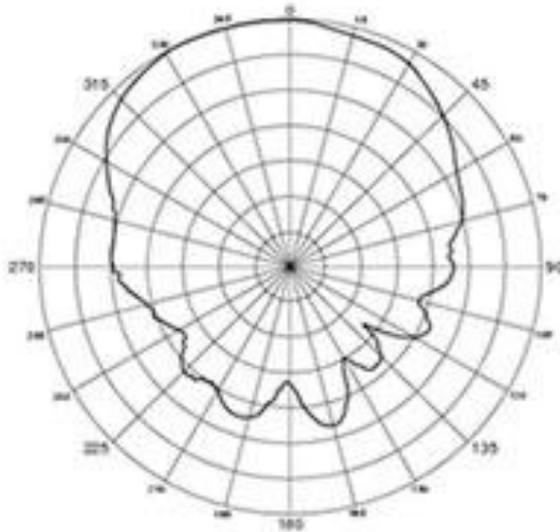
Smart Antenna



Smart Antenna

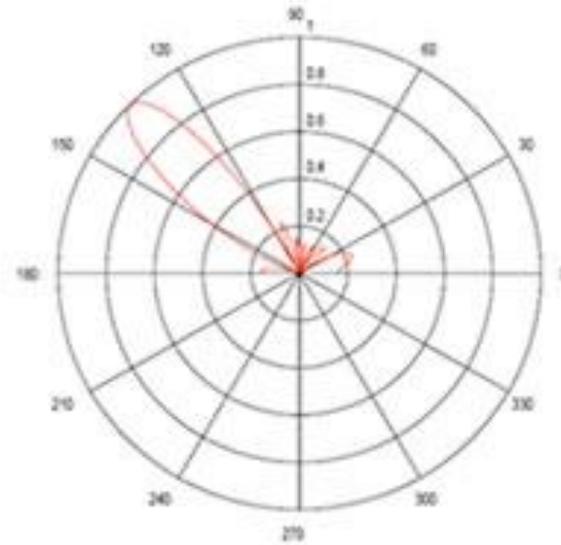
Regular Antenna:

Like a Light Bulb: radiates energy in all directions.
This results in wasted RF energy and interference.

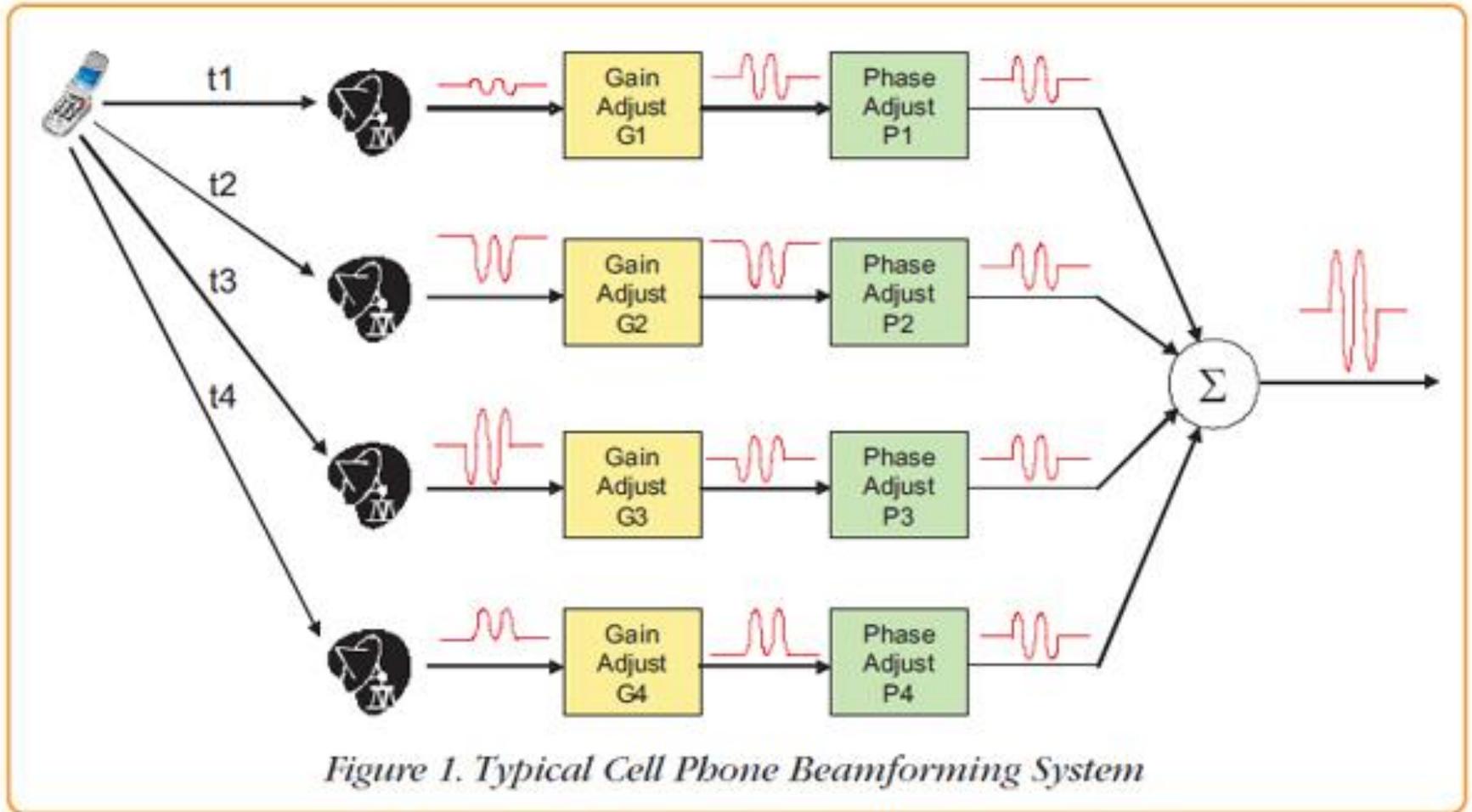


Smart Antenna (Beamforming):

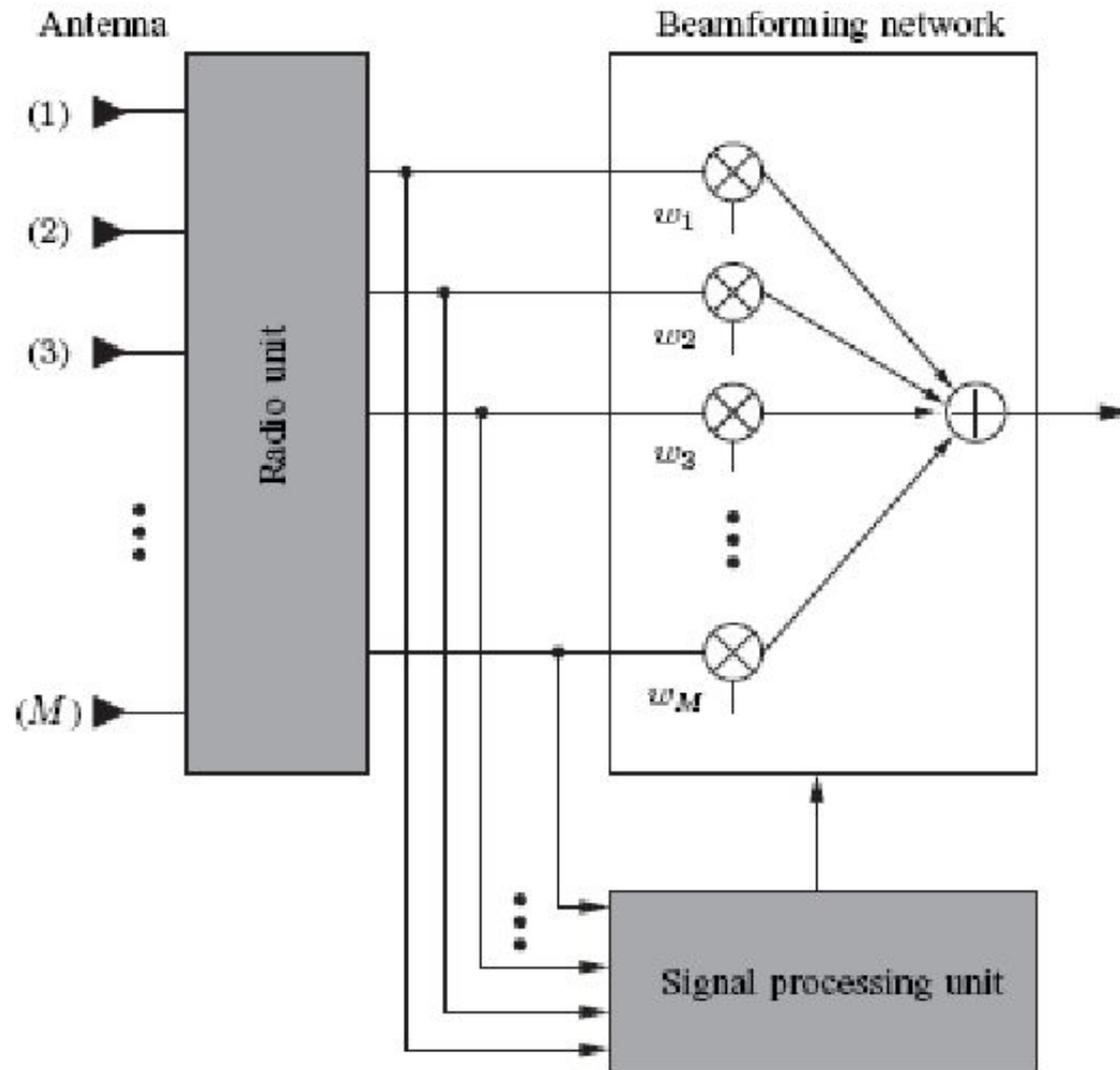
Like a Torchlight: focuses the radio beam in the needed direction.
This results in stronger signal and less wasted RF energy.



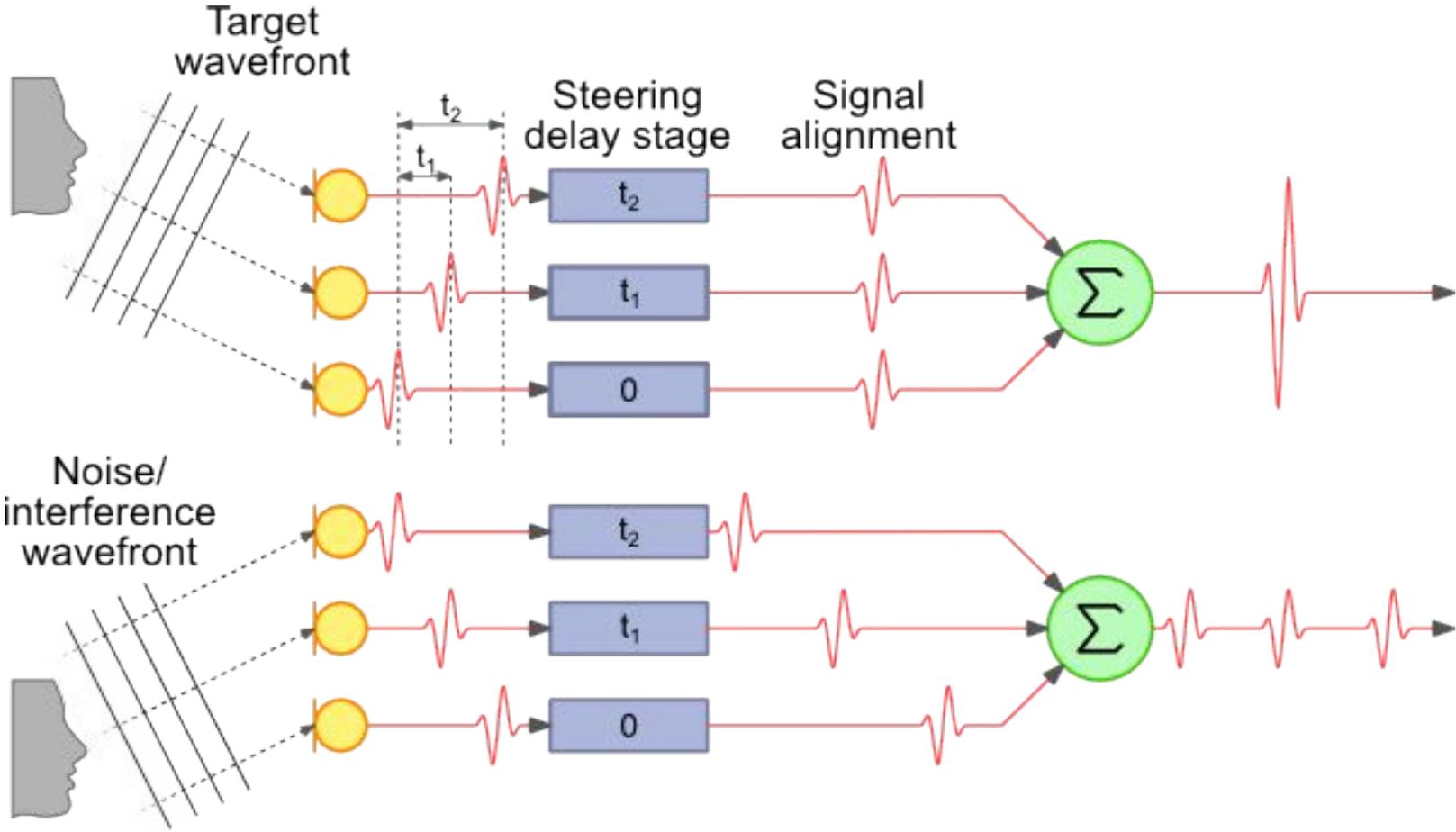
Smart Antenna



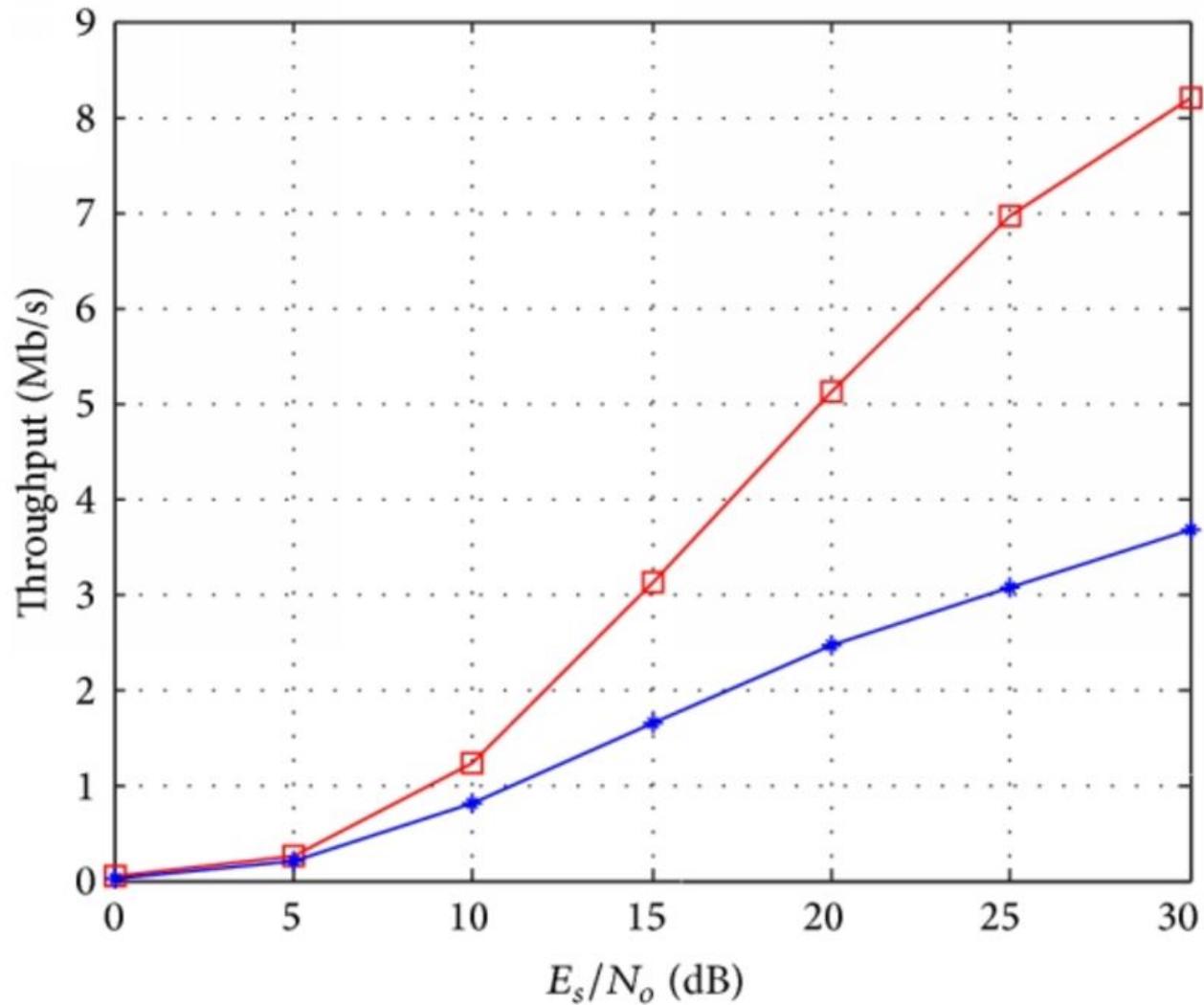
Smart Antenna



Smart Antenna

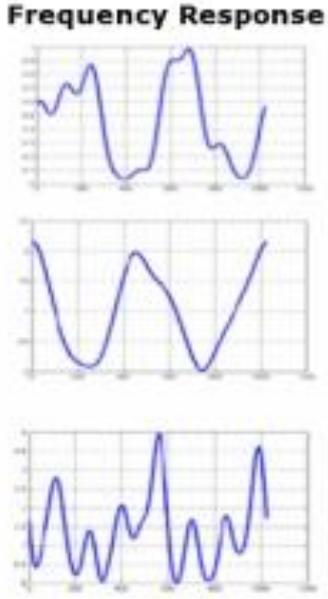
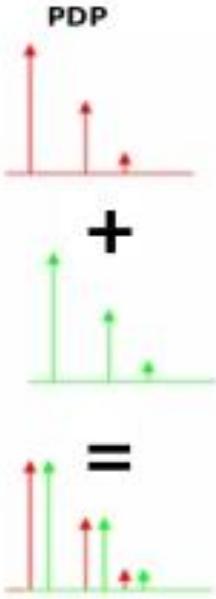
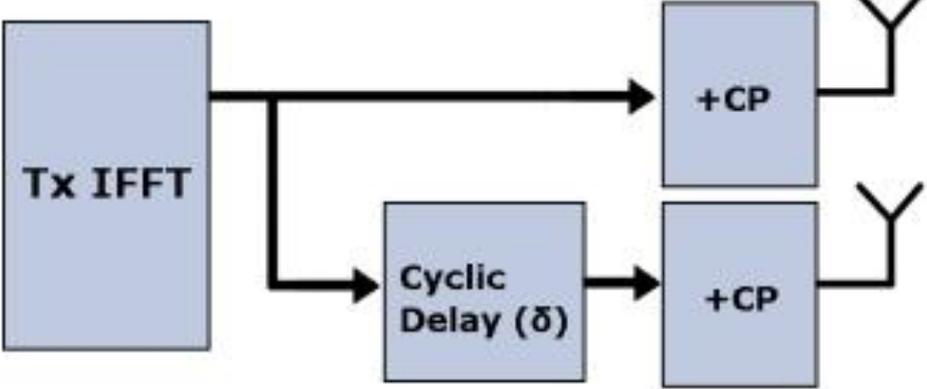


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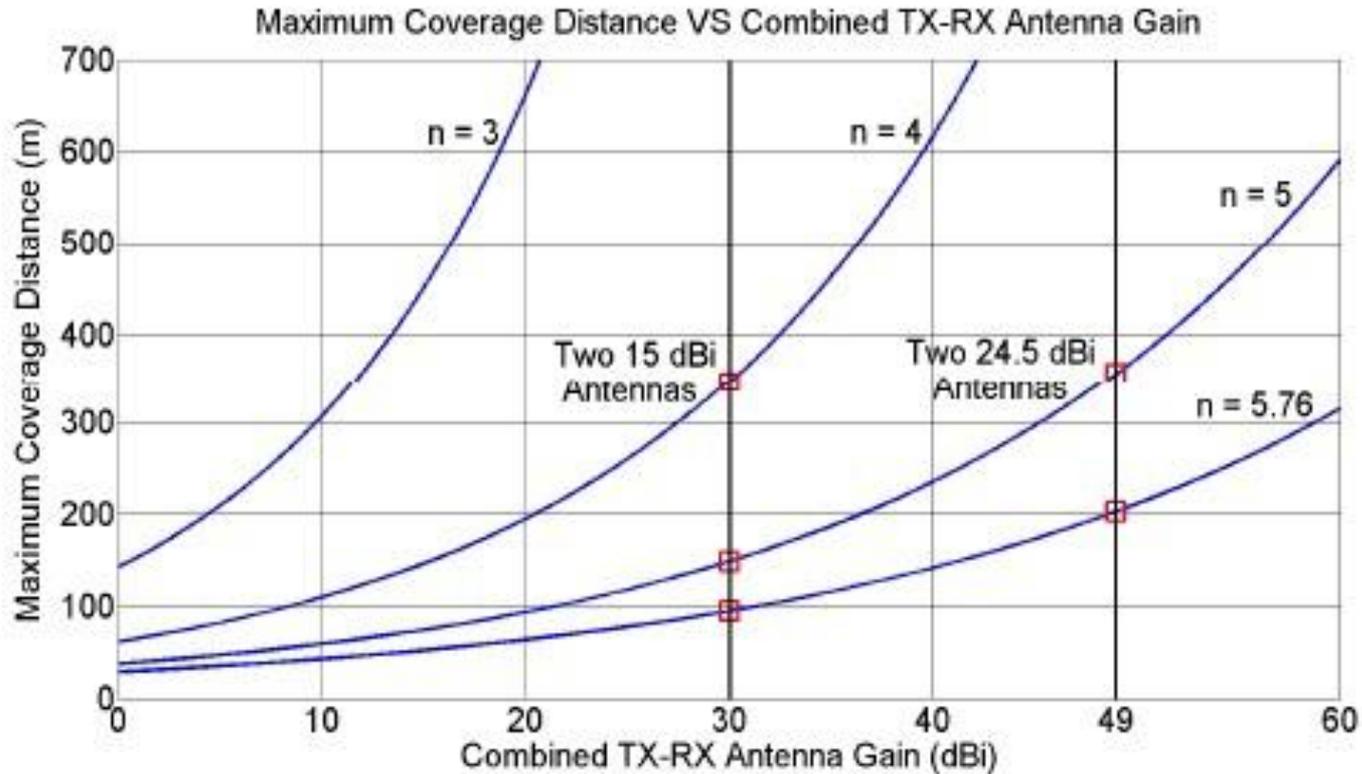
- Cooperative beamforming
- *— Selective random CDD

Smart Antenna



Smart Antenna

METIS Deliverable D 8.4, "METIS final project report"

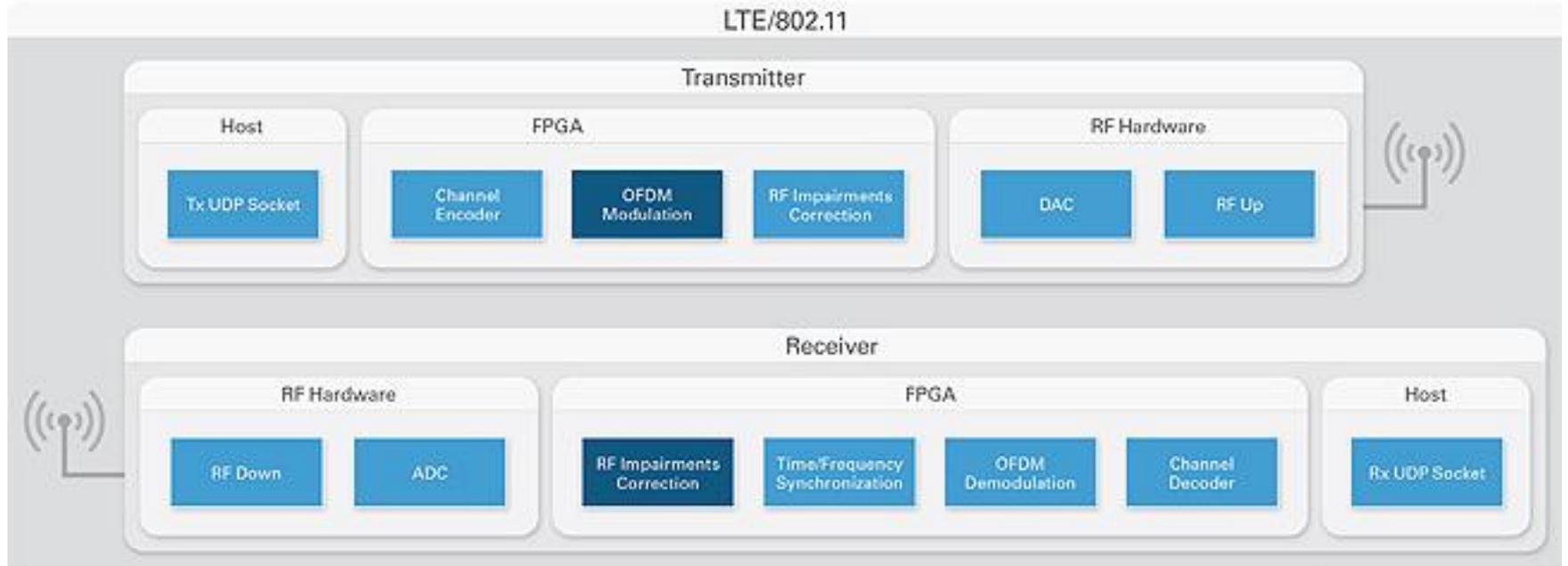


Maximum coverage distance at 28 GHz with 119 dB maximum path loss dynamic range without antenna gains and 10 dB SNR, as a function of path loss exponent n .

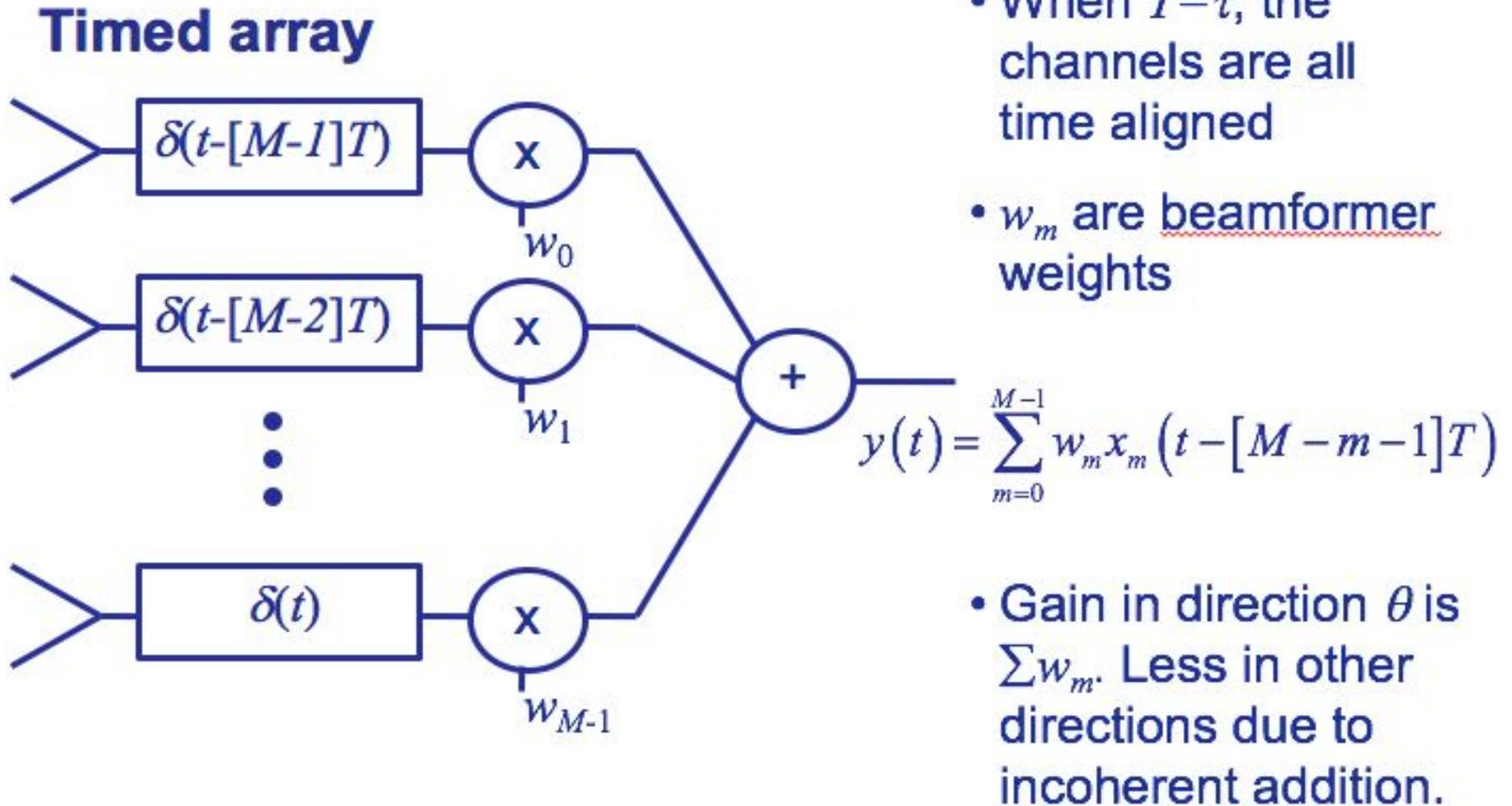
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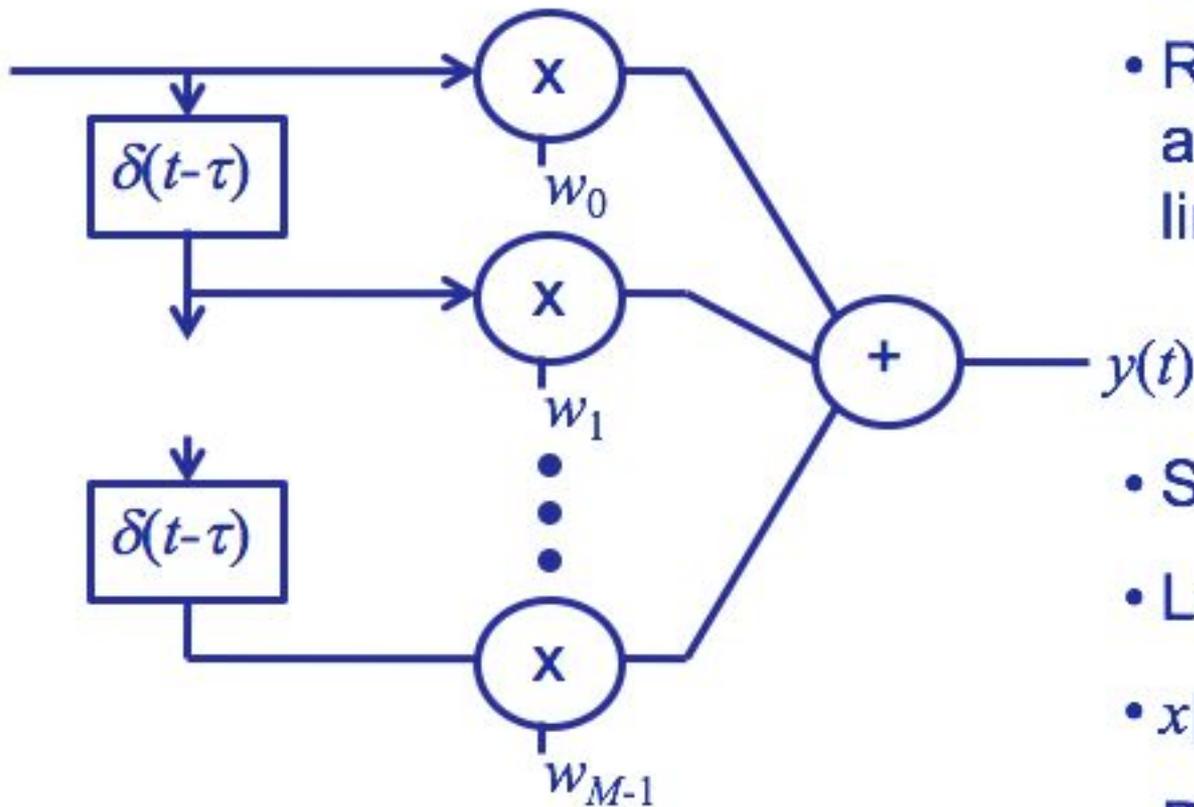
Smart Antenna



Beamforming



Beamforming



- Let $T=0$ (broadside)
- Represent signal delay across array as a delay line
- Sample: $x[n]=x_0(nT)$
- Looks like an FIR filter!
- $x[n]*w[n]$
- Design w with FIR methods

Beamforming

Suppose you want to form many beams at once, in different directions.

If beam k steered to θ_k , has strongest signal, we assume sources is in that direction.

$$y_k[n] = \mathbf{w}_k^H \mathbf{x}[n]$$

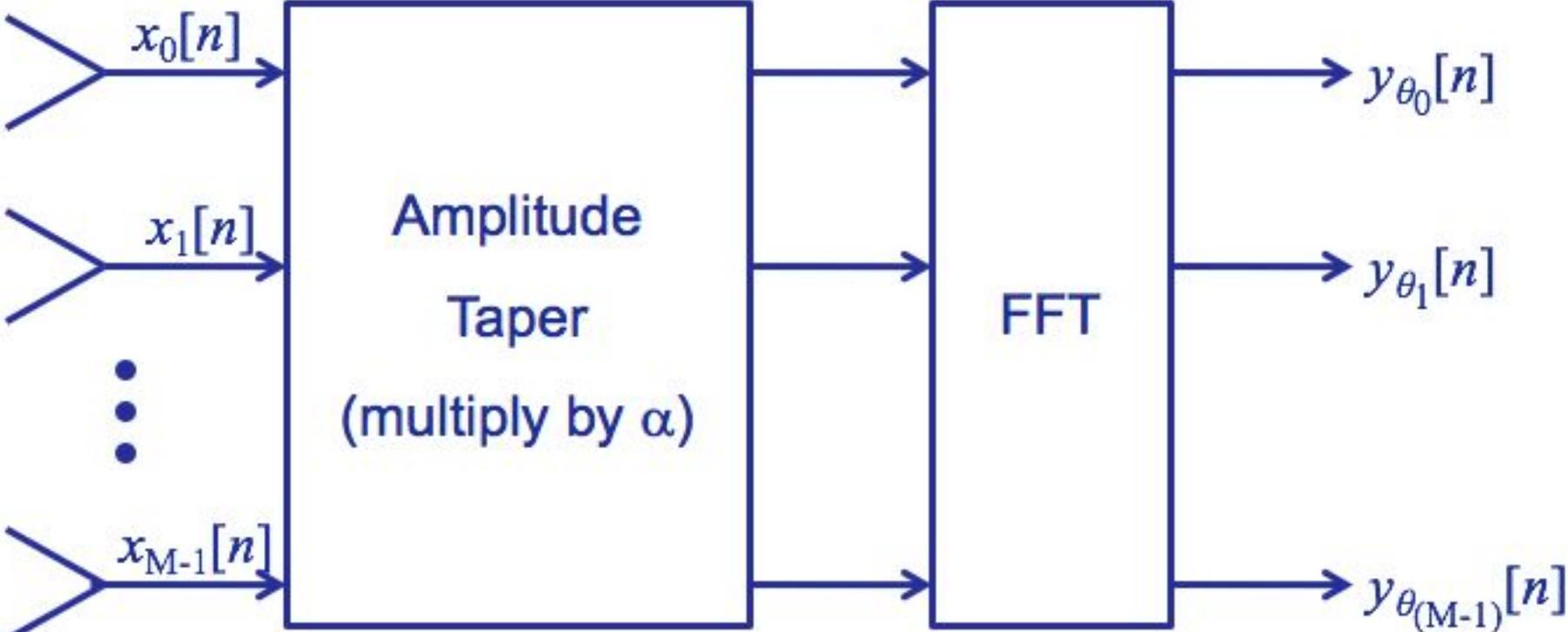
$$\mathbf{w}_k = \left[\alpha_0, \alpha_1 e^{-j\zeta_k}, \dots, \alpha_{M-1} e^{-j(M-1)\zeta_k} \right]^T,$$

$$\zeta_k = \frac{2\pi f_0 d}{c} \sin \theta_k = \frac{k2\pi}{M}$$

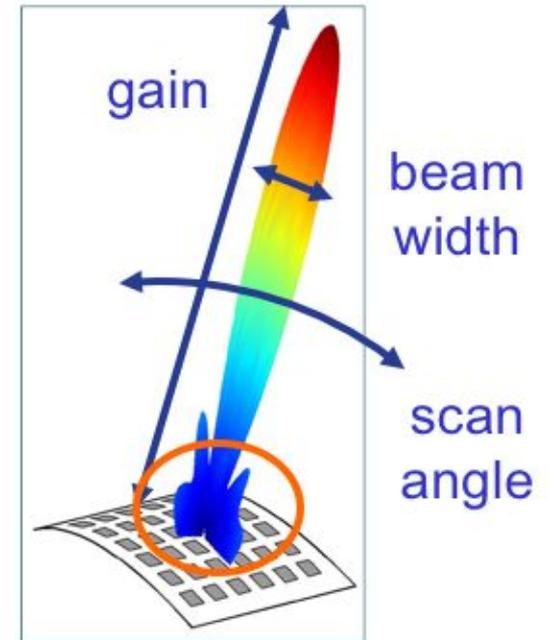
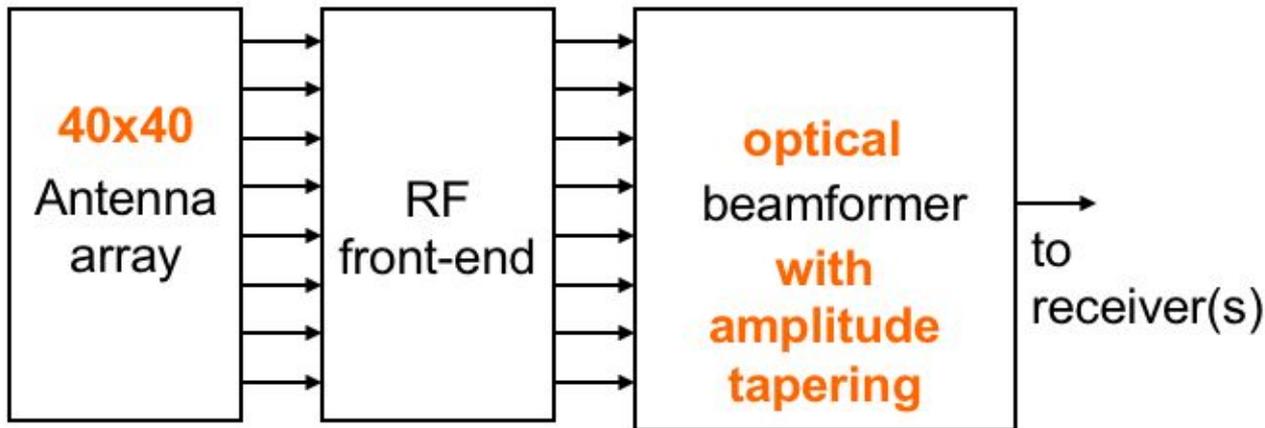
$$y_k[n] = \sum_{m=0}^{M-1} \alpha_m \mathbf{x}_m[n] e^{-jm\zeta_k} = \sum_{m=0}^{M-1} \alpha_m \mathbf{x}_m[n] e^{-j \frac{mk2\pi}{M}}$$

Beamforming: FFT Implementation

many beams at once



System overview



Frequency range: 10.7 – 12.75 GHz (K_u band)

Polarization: 2 linear (H/V)

Scan angle: -60 to +60 degrees

Gain: > 32 dB

Selectivity: << 2 degrees → **Continuous delay tuning required !**

No. elements: ~1600

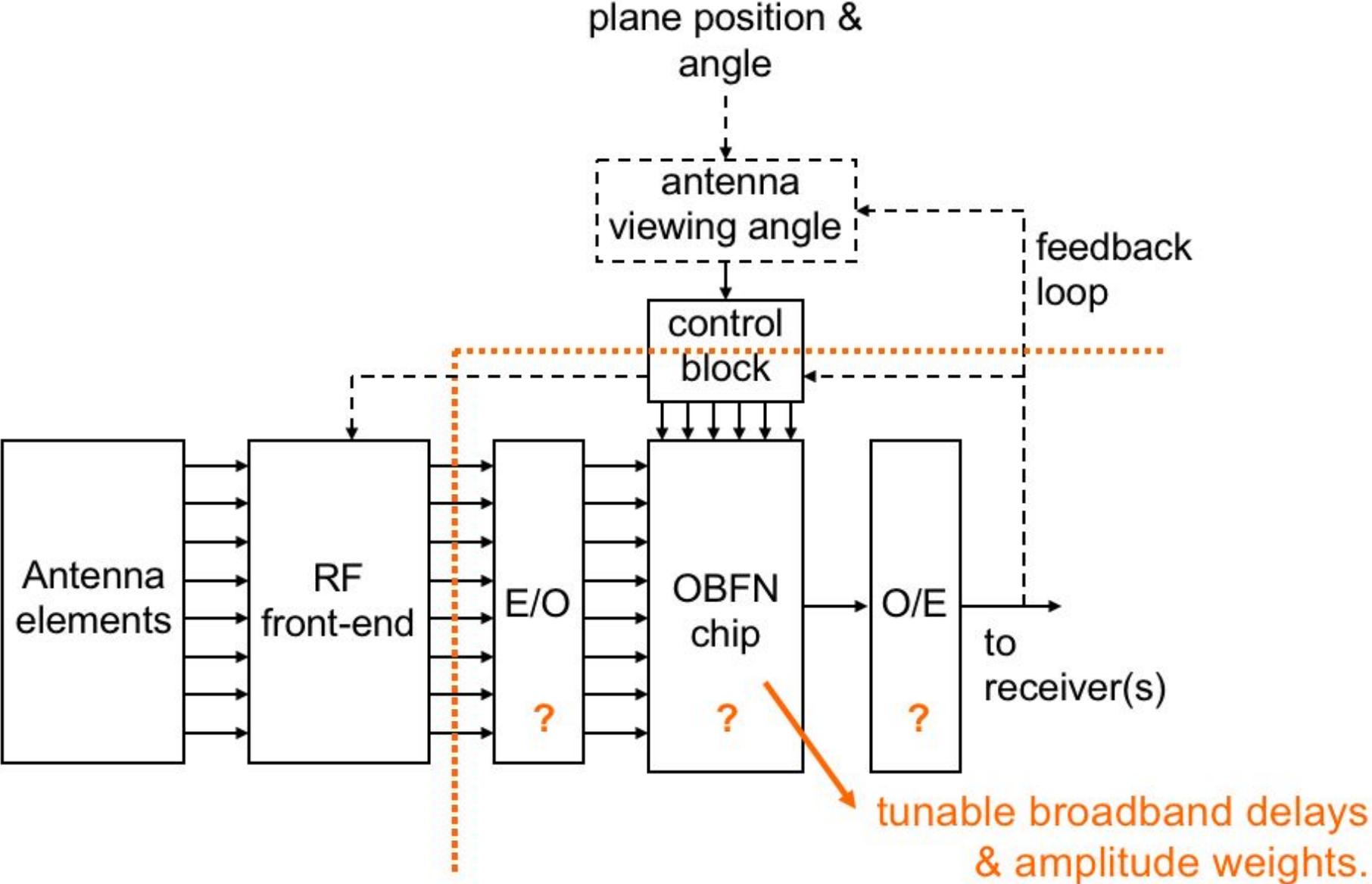
Element spacing: $\sim \lambda/2$ (~ 1.5 cm, or ~ 50 ps)

Maximum delay: ~ 2 ns

Delay compensation by phase shifters? → beam squint at outer frequencies!

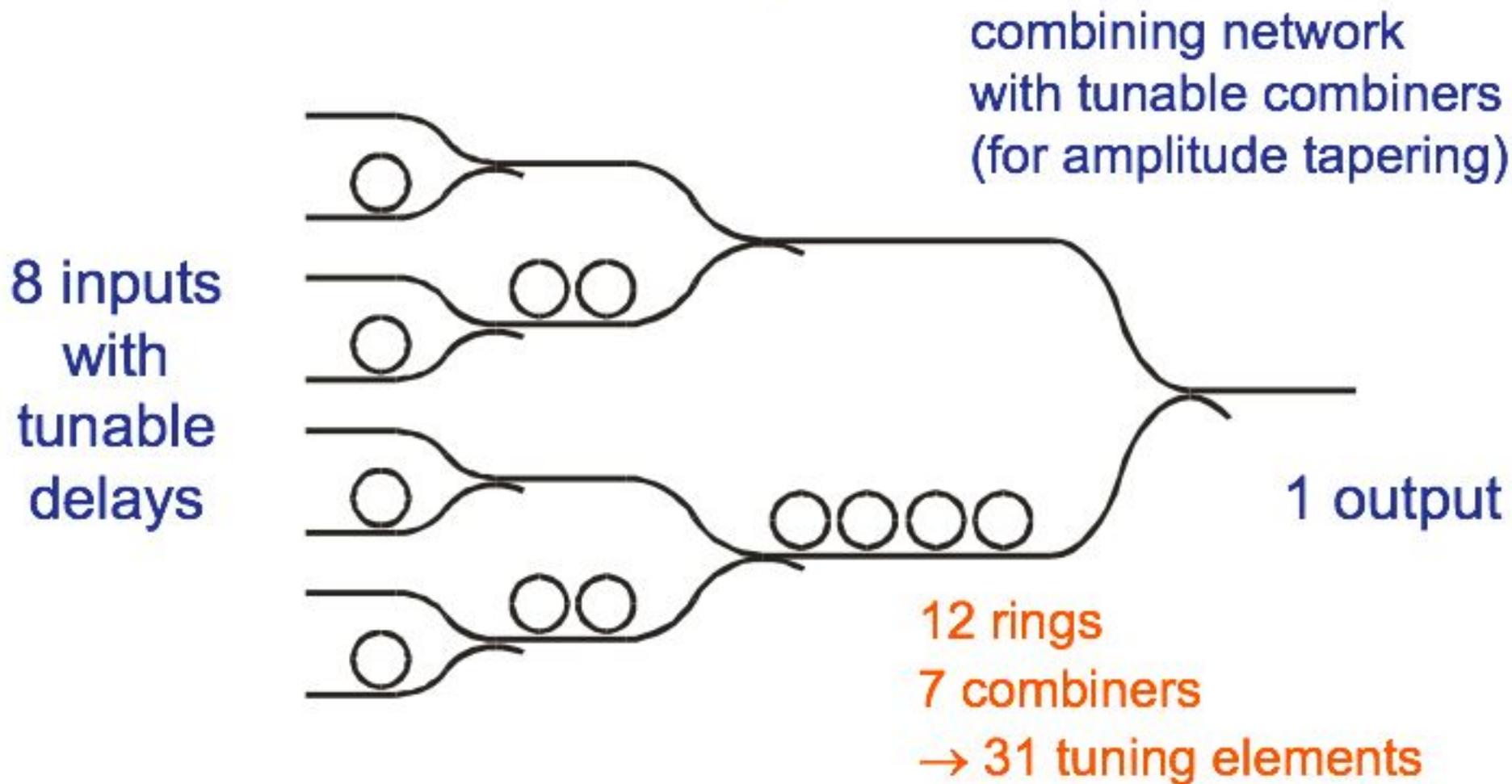
→ **(Broadband) time delay compensation required !**

Optical beam former



Optical beamformer

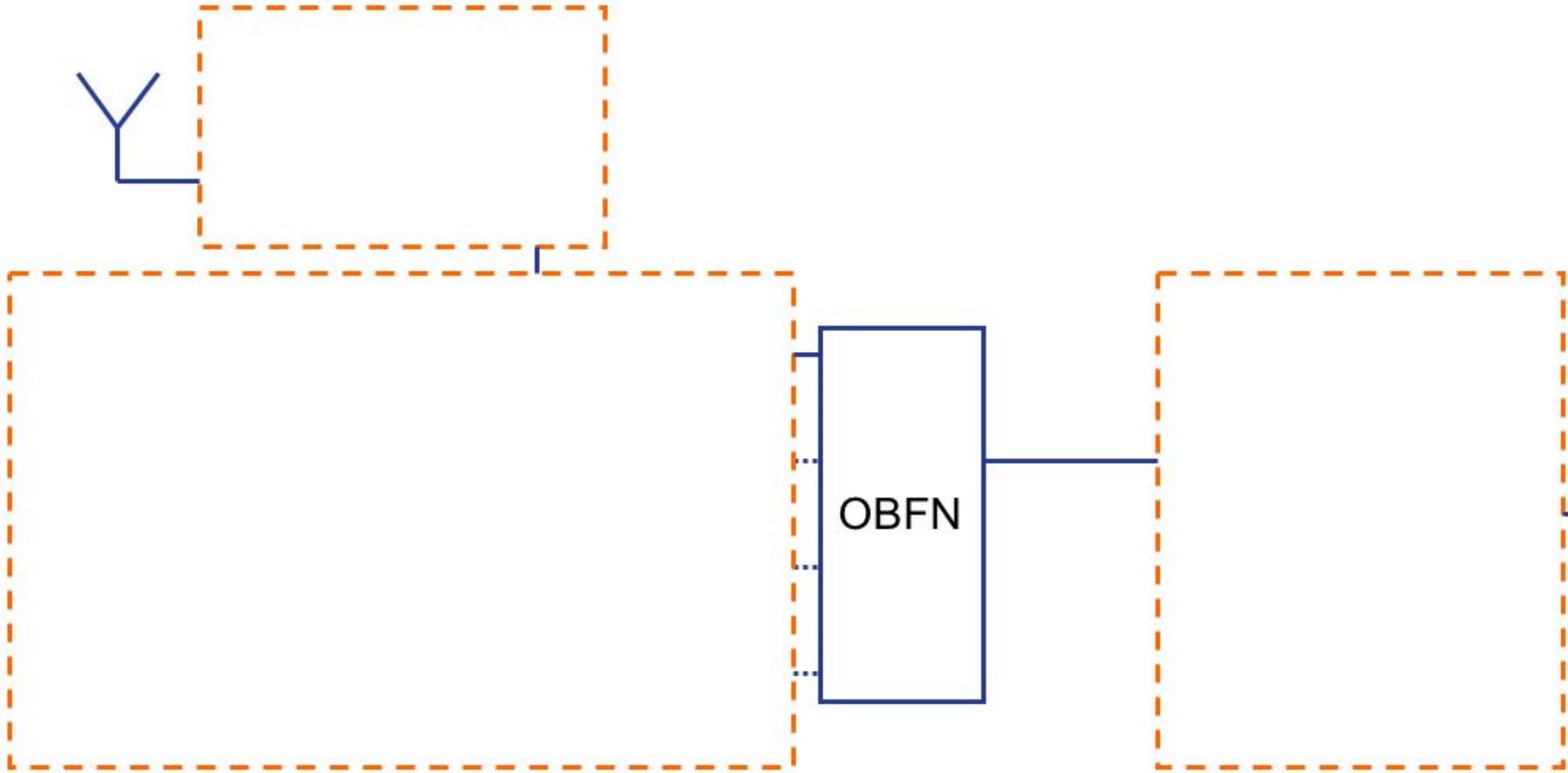
8x1 Optical beam forming network (OBFN)



Optical beamformer

RF front-end

E/O and O/E conversions?



electrical » optical

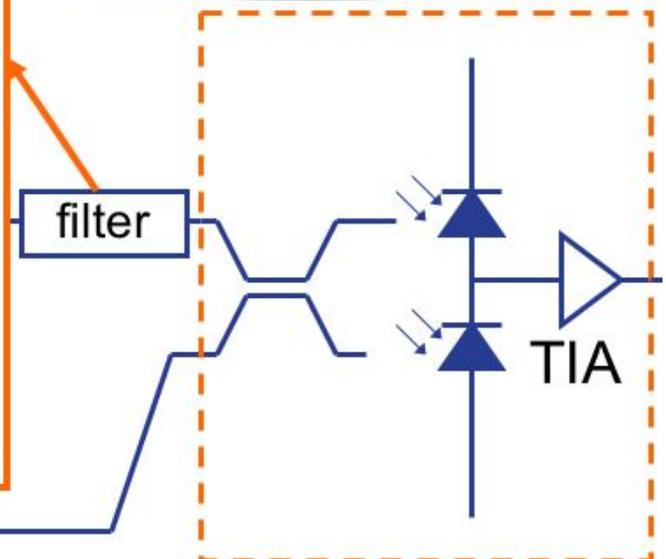
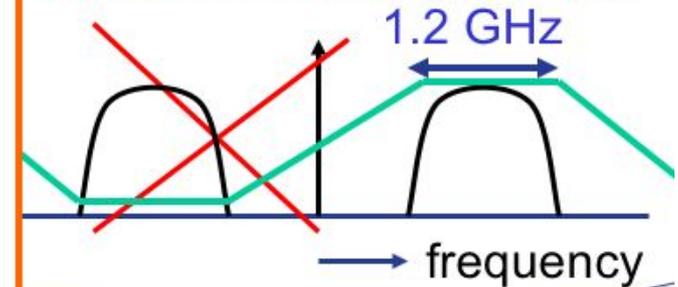
optical » electrical

Optical beamformer

Filter requirements:

- Broad pass band and stop band (1.2 GHz);
- 1.9 GHz guard band;
- High stop band suppression;
- Low pass band ripple and dispersion;
- Low loss;
- Compact;
- Same technology as OBFN.

single-sideband modulation with suppressed carrier (SSB-SC)



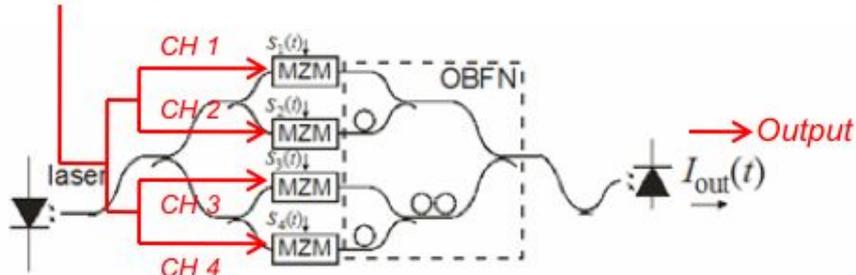
electrical » optical

optical » electrical

Optical beamformer

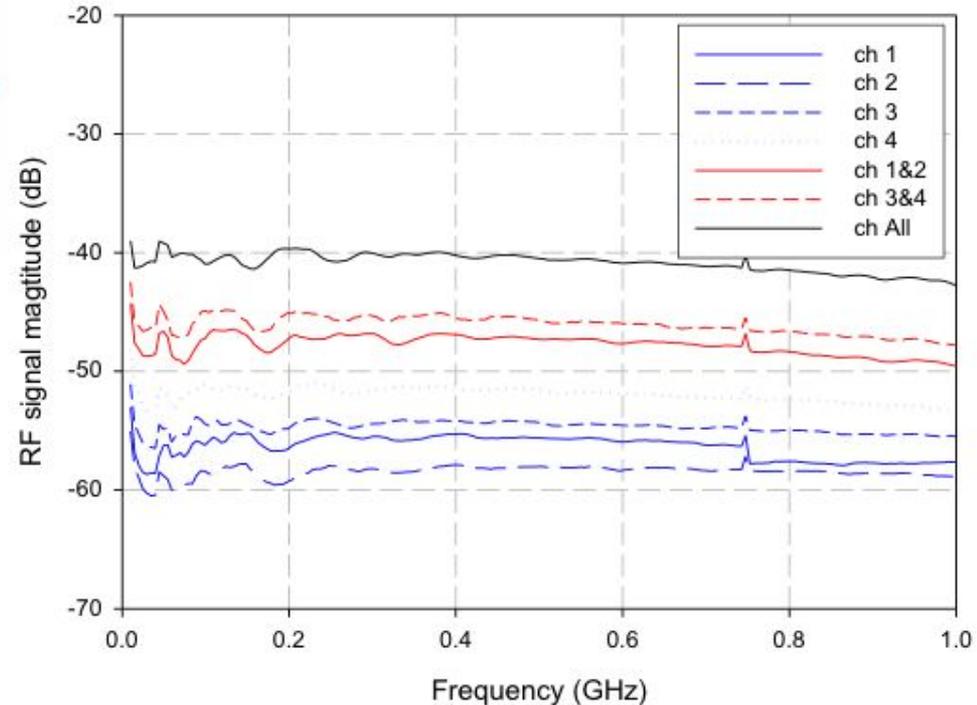
Signal combination measurements

RF input 0-1 GHz



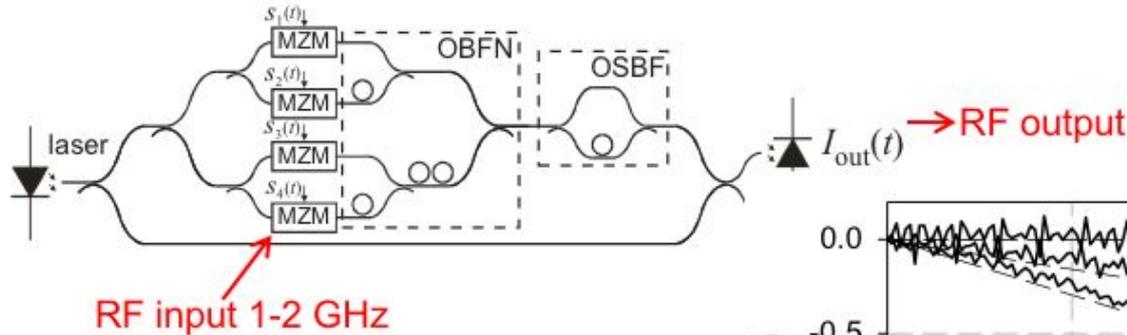
Measured output RF power of beamformer with intensity modulation and direct detection, for

- 1 channel,
- 2 combined channels,
- 4 combined channels



Optical beamformer

RF phase response measurements



Measured RF phase response of one beamformer channel, for different delay values.

