Phased Array History, Benefits and Architectures

Outline

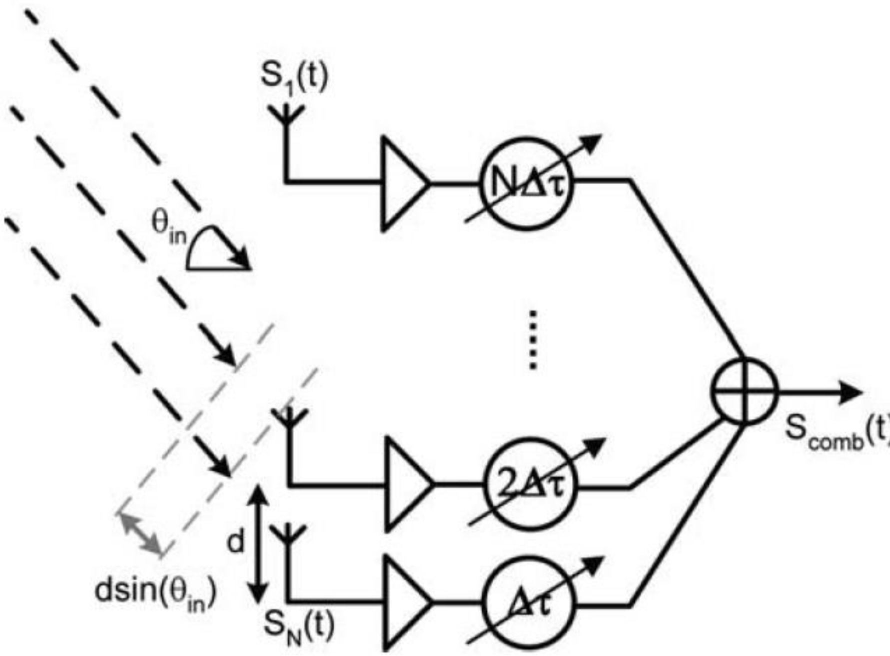
- Phased Array History, Benefits and Architectures
- Phased array metric and architectural study
- Mm-Wave Phase Shifter and Phased Array IC Design

Outline

- What is a phased array?
- Why an array???
- Case Study: A 60 GHz WPAN link budget
- Phased array versus timed array

What is a phased array?

A phased array *electronically modifies the direction* of transmission or reception of the **electromagnetic beam**



HOW?

By introducing a **variable time delay**

Time delay equal to

$d\sin\theta_{in}/C$.

$$S_i(t) = A\cos\left(\omega(t-(i-1)\frac{d\sin\theta_{in}}{c})\right)$$

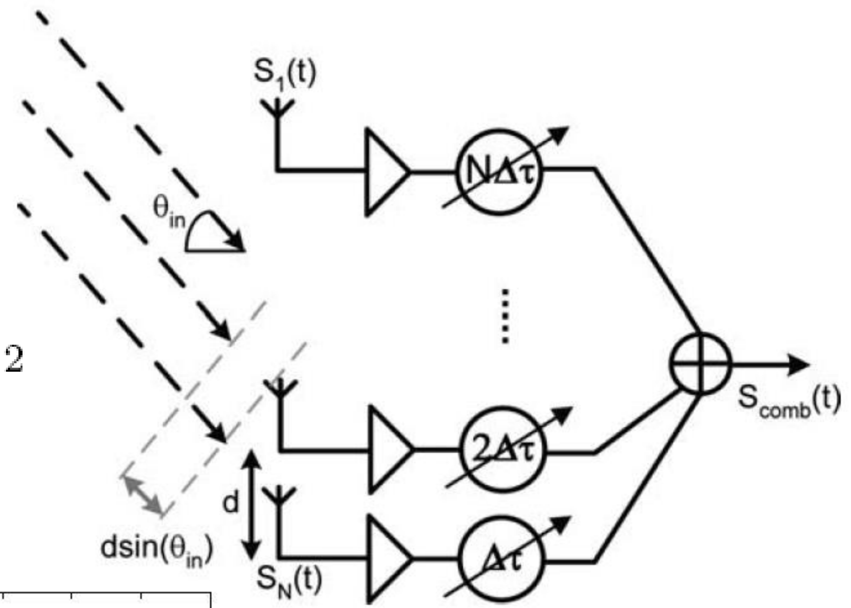
$$S_{i,delayed}(t) = G \times A\cos\left(\omega(t-(i-1)\frac{d\sin\theta_{in}}{c}-(N-i+1)\Delta\tau)\right)$$

What is a phased array?

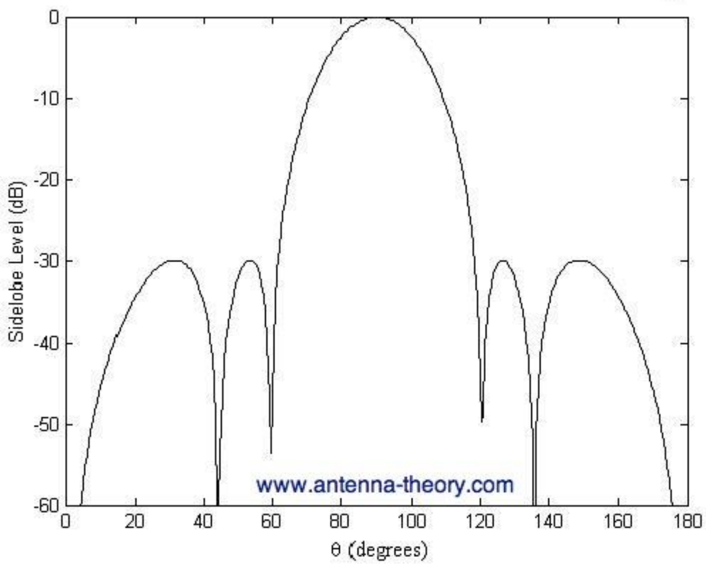
Additional power gain of N^2.

AF is lower for other angles of incidence,

$$AF(\Delta\tau,\theta_{in}) = \left(\frac{\sin \frac{N(\omega\Delta\tau - \frac{\omega d}{c}\sin\theta_{in})}{2}}{\sin \frac{\omega\Delta\tau - \frac{\omega d}{c}\sin\theta_{in}}{2}} \right)^2$$

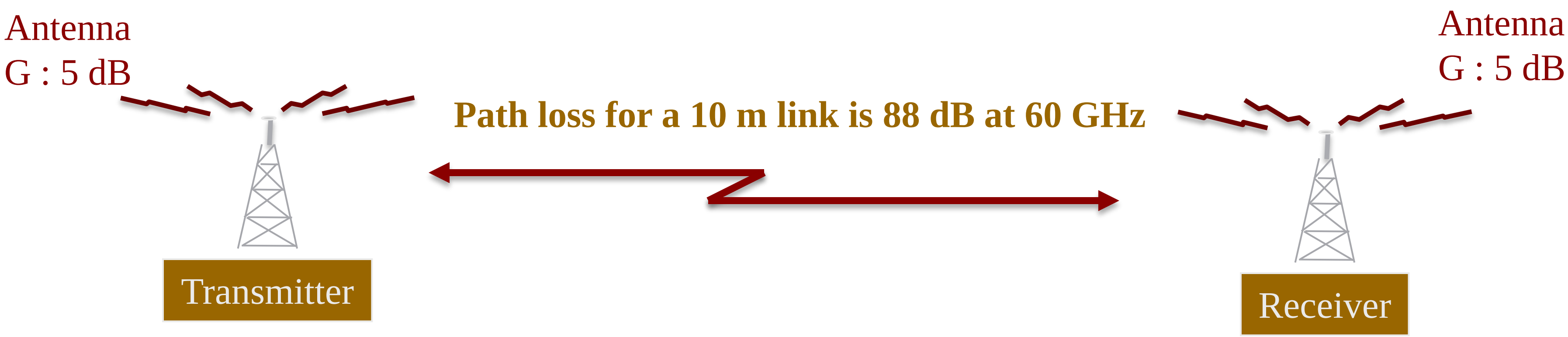


Spatial Selectivity.



Why an Array???

A 60 GHz WPAN Link Budget:



OFDM (BW:325 MHz)

NF= 10 dB

60 GHz CMOS PAs

$P_{1\text{-dB}}$: 6 dBm (6 dBm back off)

Transmitted power is around **0 dBm.**

$$P_{noise}=-174+10\,log\,(325)+NF=-79\text{ dBm}$$

$$P_{RX}=0-88+5+5-5=-93\text{ dBm.}$$

This CMOS-based WPAN link budget is deep in the negative SNR regime by 14 dB !!!

Phased array techniques can come to the rescue

8-channel phased array on the transmitter side, → gain enhances by **18 dB.**

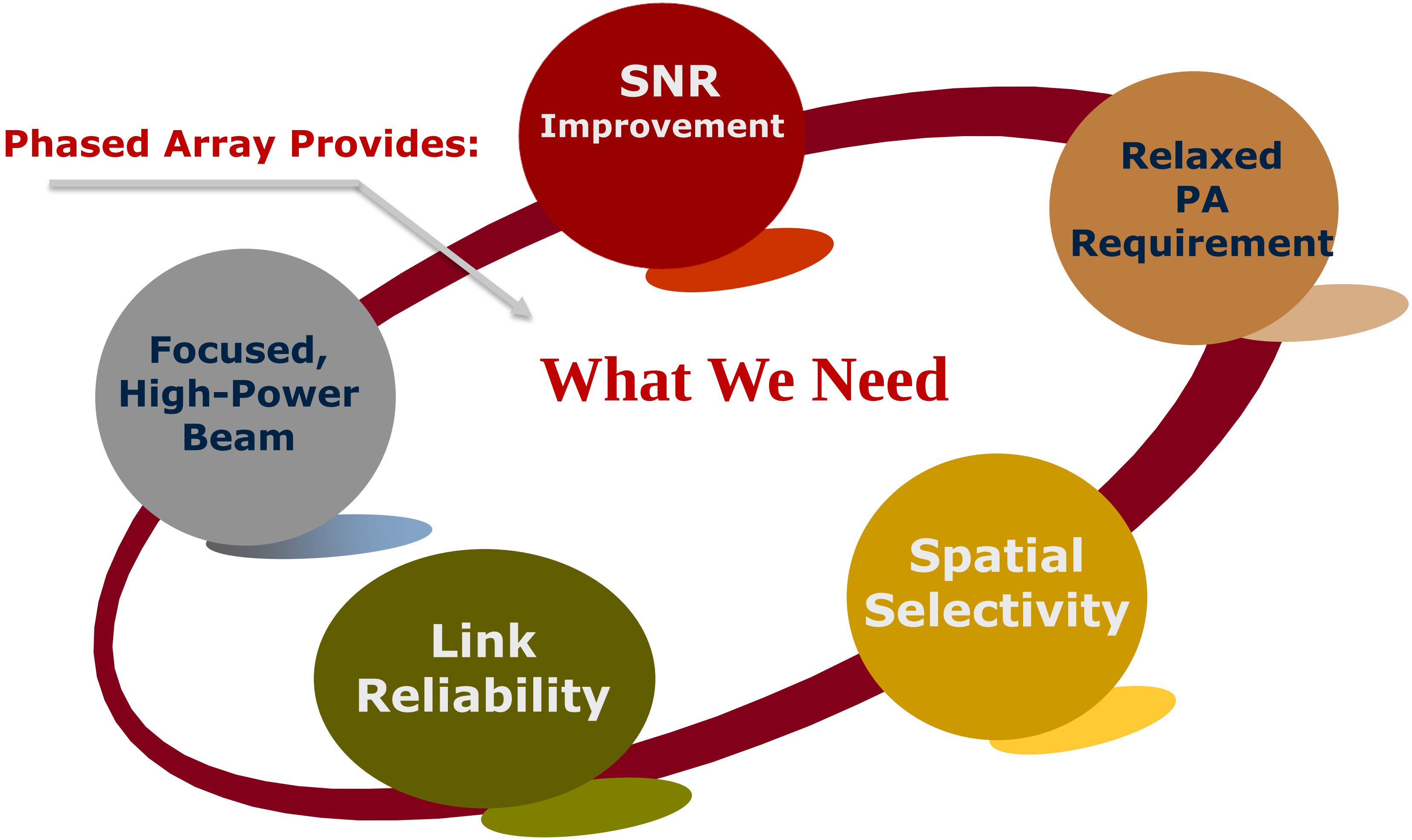
A 4-channel receiver phased array enhances **SNR by 6 dB.**

The SNR is boosted to a positive 10 dB

Why an Array???

	Conventional (>50 years)	Emerging (≈5 years)
Application	Military Radar Radio Astronomy	Wireless Comm. Automotive Radar
Typical Range Array Size	Long Range (> 1km) Large (100-10000)	Short Range (< 100m) Small (4-64)
Why an Array?	• Focused, High-Power Beam • Multiple, Simultaneous Beams • Spatial Interference Cancellation • SNR Improvement in RX	• SNR Improvement in RX • Relaxed PA Requirement • Link Reliability (Comm.) • Spatial Selectivity (Radar)
Driver	• Performance • Size • Cost	• Cost • Size • Power Consumption
Realization Technology	• Module-based III-V	• Single Chip Silicon

Why an Array???



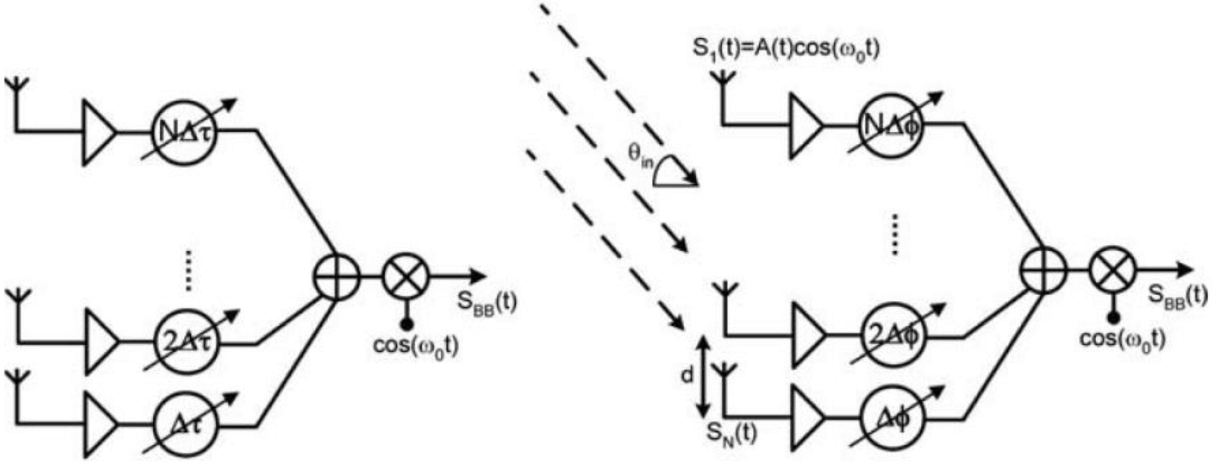
Phased Array Provides:
SNR Improvement
Relaxed PA Requirement
Focused, High-Power Beam
What We Need
Spatial Selectivity
Link Reliability

Phased Arrays versus Timed Arrays

- A phased array modifies the direction of transmission/reception of the electromagnetic beam by introducing a variable time delay.

- Integrated variable time delay blocks are difficult to implement in practice, particularly on silicon.

➡ In narrowband systems, the required variable time delay is often approximated with a variable phase shift, and the variable delay elements are replaced with phase shifters.



Phased Arrays versus Timed Arrays

The validity of the delay-phase approximation in phased arrays naturally depends on the **instantaneous bandwidth !!!**

Array-induced Inter-Symbol Interference is a **direct result of this approximation.**

Another reason to go to mm-wave frequencies

5GHz of ISI-free bandwidth can easily be achieved in a 60GHz phased array,

but would require a **true-time-delay implementation if deployed in the 3-10GHz** frequency range.

Summary

Phased array provides:

- SNR improvement.
- Spatial selectivity.
- Focused high power beam.

For narrowband signals, the required variable time delay is often approximated with a variable phase shift.

The phase-shifters can be incorporated in different parts of the transmitter/receiver chain. This results in three distinct phased array architectures.

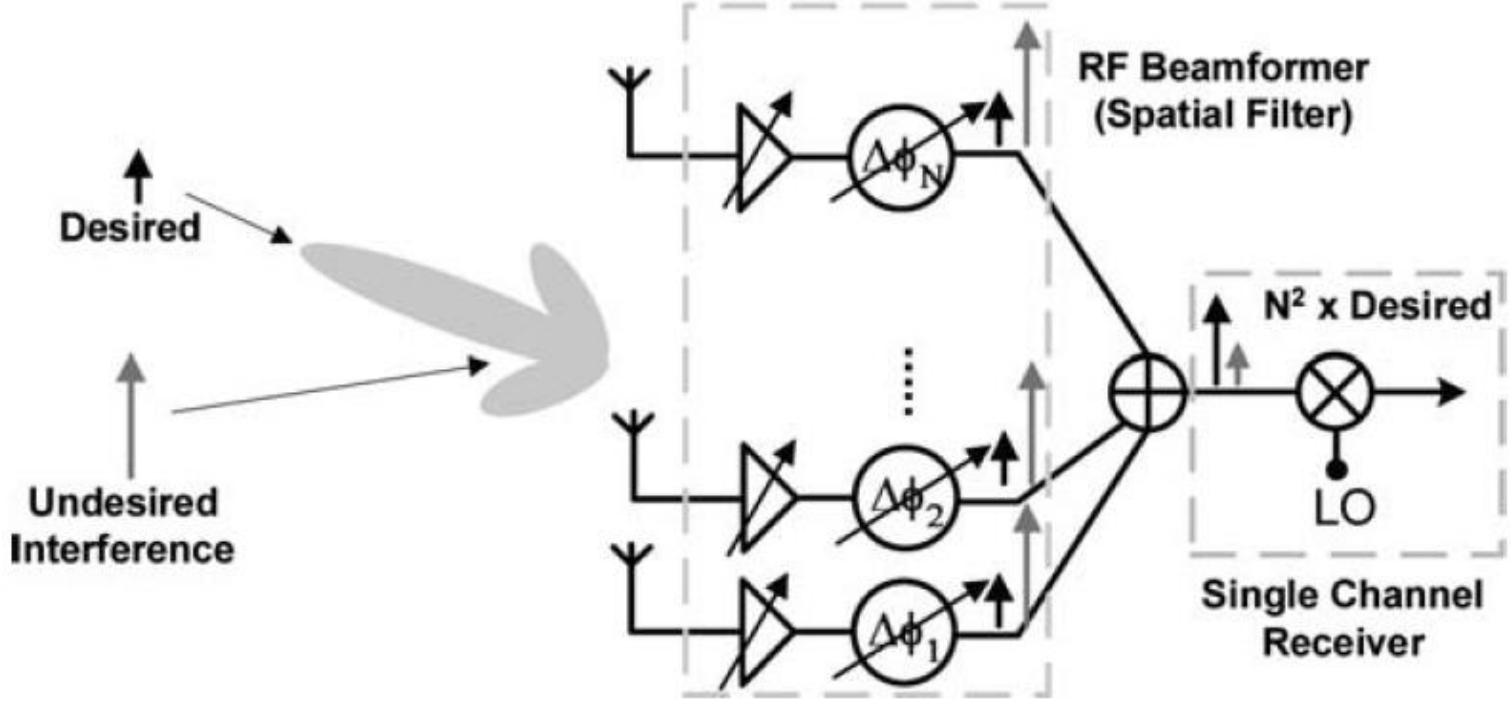
RF Phase-shifting, LO Phase-shifting, Digital Arrays

Conventional phase array architectures

The phase-shifters required to achieve phased-array functionality can be incorporated in different parts of the transmitter/receiver chain. This results in three distinct phased array architectures

- *RF Phase-shifting*
- *LO Phase-shifting*
- *Digital Arrays*

1) RF Phase-shifting



Signals in the various channel are phase-shifted and combined in the RF domain.

After combiner the receiver path can be configured as conventional receivers (**heterodyne**, **homodyne** or other image rejection architectures).

1) RF Phase-shifting

The most widespread phased-array architecture **because of**

insulating a larger portion of the receiver chain from strong, in-band from undesired direction interferers.

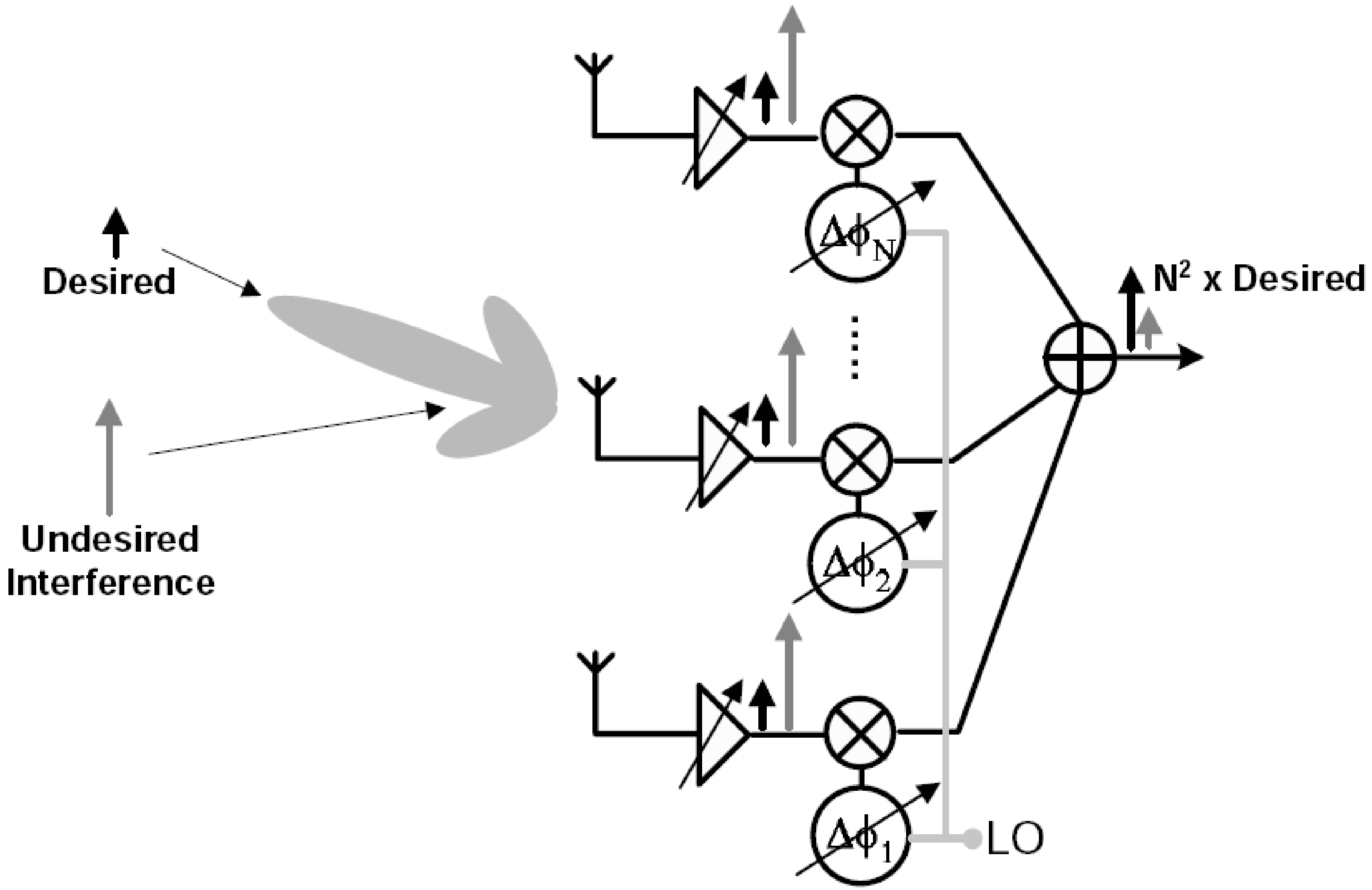
The main advantage:

The dynamic range requirements on the mixer and the blocks that follow it are alleviated.

The main challenge:

Is the implementation of RF phase-shifters in silicon. (Passive- active)

2) LO Phase-shifting



2) LO Phase-shifting

The advantage

The **nonlinearity**, **loss** and **the noise performance** of the phase-shifters no longer have a direct impact on the system performance.

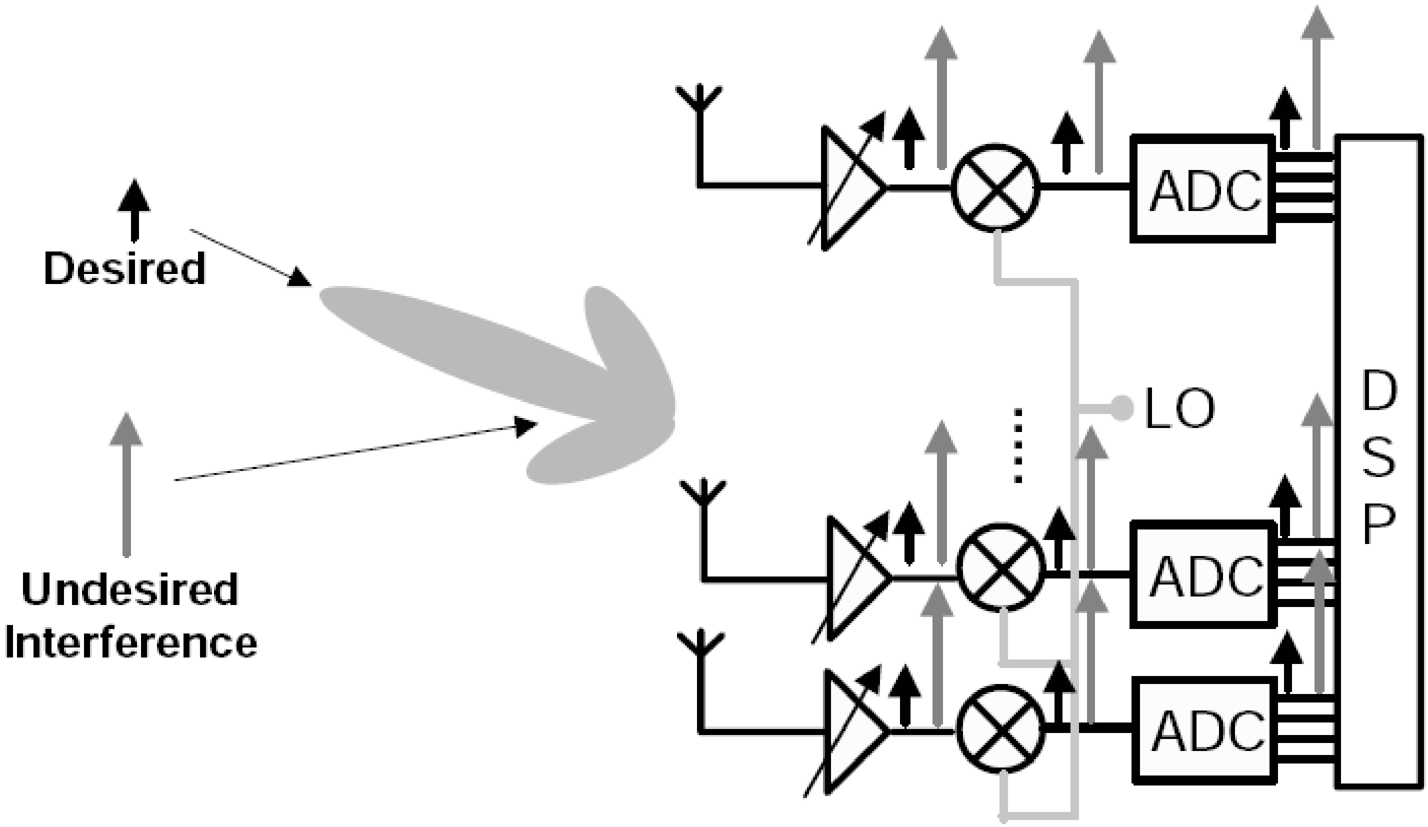
Performance requirements on LO-path phase shifters are more relaxed

→ consume less area/power.

Disadvantage:

- Mixers must have sufficient dynamic range to withstand the interferers.
- Routing of strong LO in different paths.

3) Digital Arrays



3) Digital Arrays

In this architecture each channel is digitized using an (ADC) and the bits of all channels are then processed using a Digital Signal Processing unit (DSP), where the spatial filtering is performed.

The main advantage:

Is its versatility and flexibility.

Such phased arrays *are extensively used in the cellular-phone* industry.

Disadvantage :

- RF mixer and ADC of each channel and the DSP unit must have sufficient dynamic range to handle the interferers.
- The entire RF chain is replicated for each channel which results in a rather power-hungry design.

Comparative View of the Conventional Architectures

Arch.	Phase Shifter	B.W (Data rate)	Area	Power
RF Path	TTD Phase-shifter	High(T. D) Moderate(P-S)	High	Low
LO Path	Phase shifter	Moderate	Moderate	Moderate
BB Path	Digital Array	High	High	High

Conclusion

- Using phase array architectures provides SNR improvement, spatial selectivity, and relaxes PA requirements.
- In RF phase shifting the dynamic range requirements on the mixer and the blocks that follow it are alleviated.
- In LO phase shifting the nonlinearity, loss and the noise performance of the phase-shifters no longer have a direct impact on the system performance.
- Different DSP algorithem can be used to perform spatial filtering.

THANKS

Phased Arrays versus Timed Arrays