# Online Millimeter Wave Phased Array Calibration Based on Channel Estimation

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# Growing Demand on Wireless Bandwidth

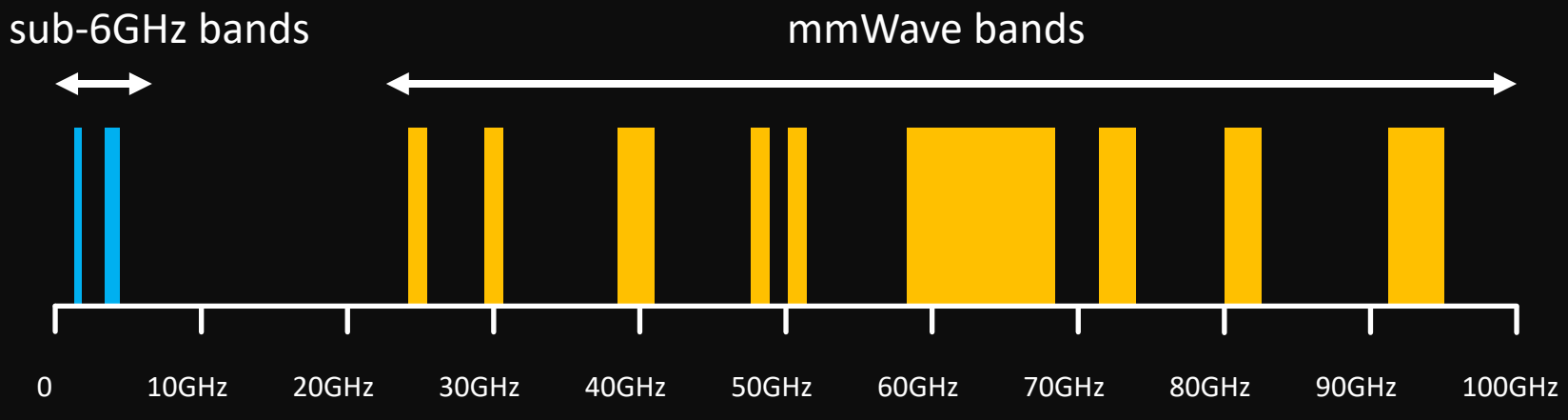
**2009**

4G
1Gbps

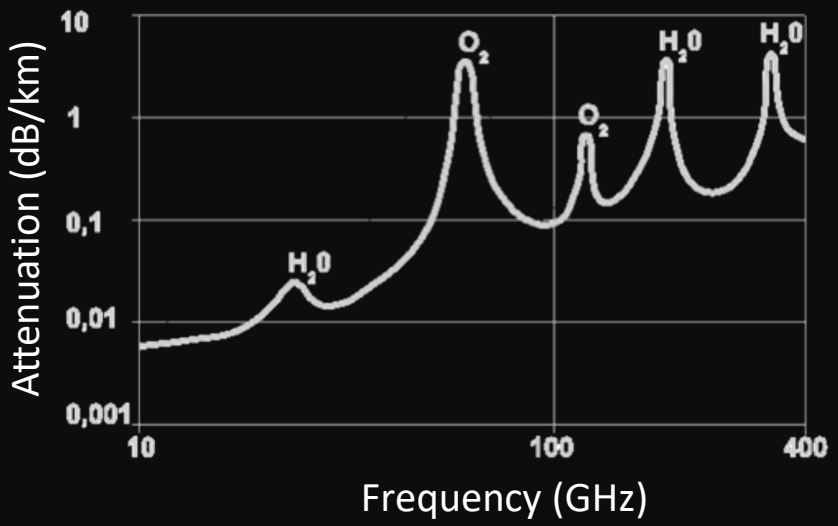
**2019**

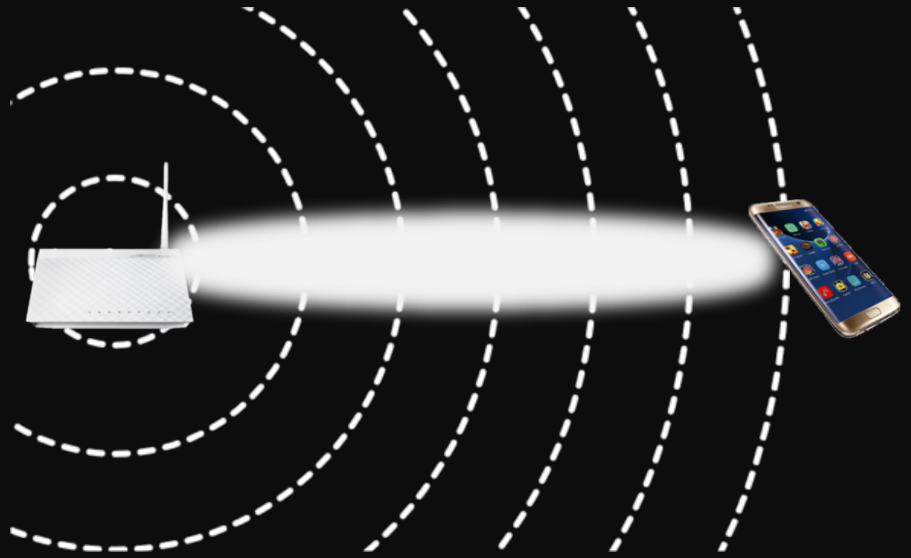

5G
10Gbps

# mmWave Technology

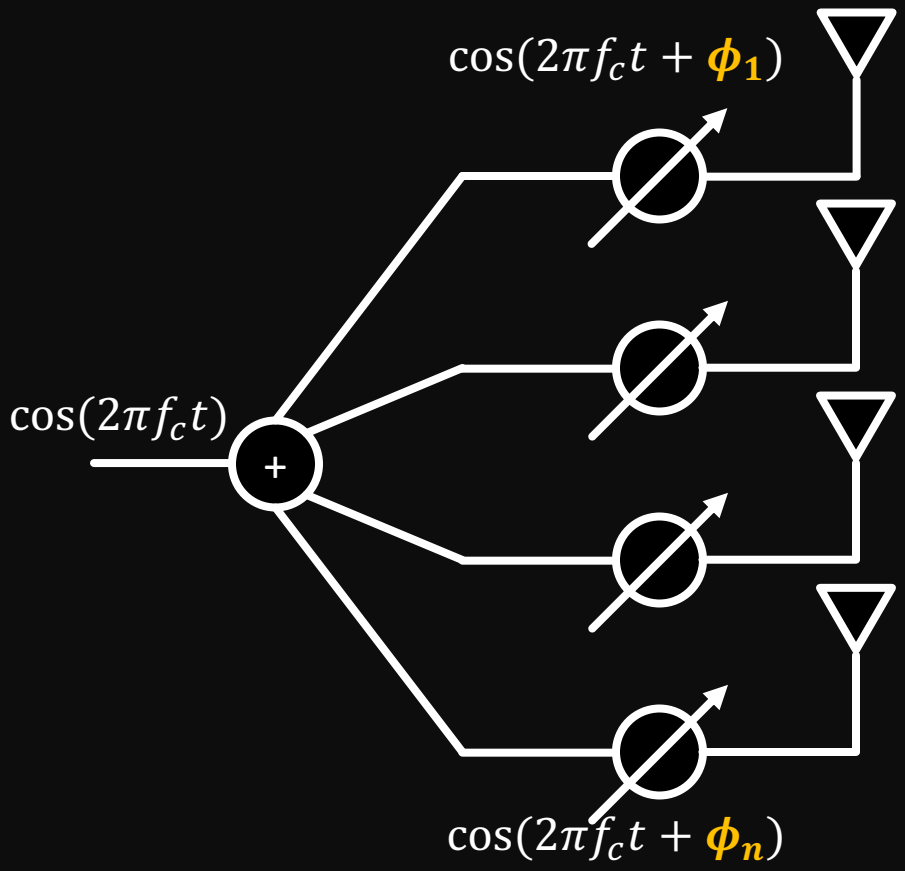



Enables multi-Gbps wireless link

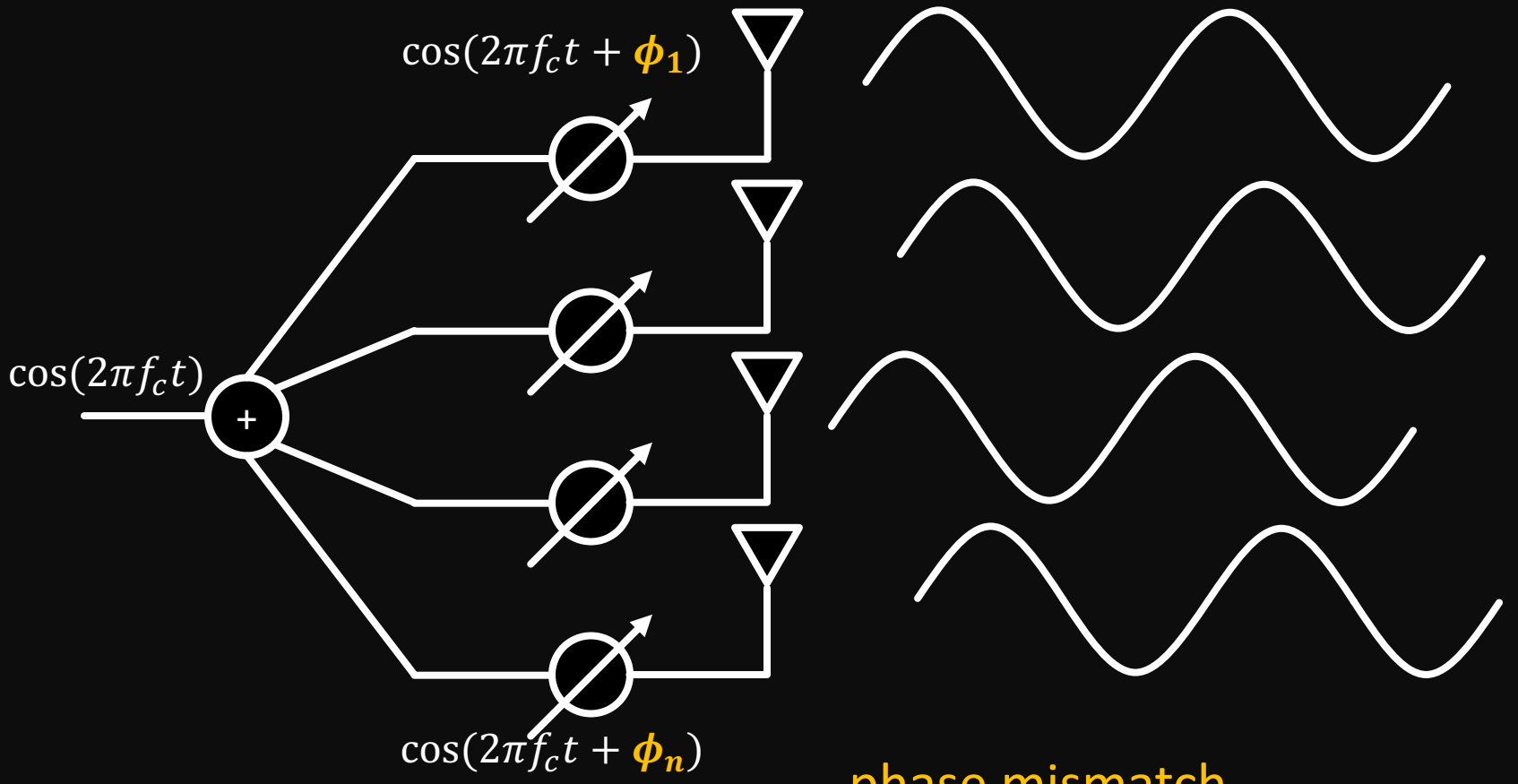


# Phase Array

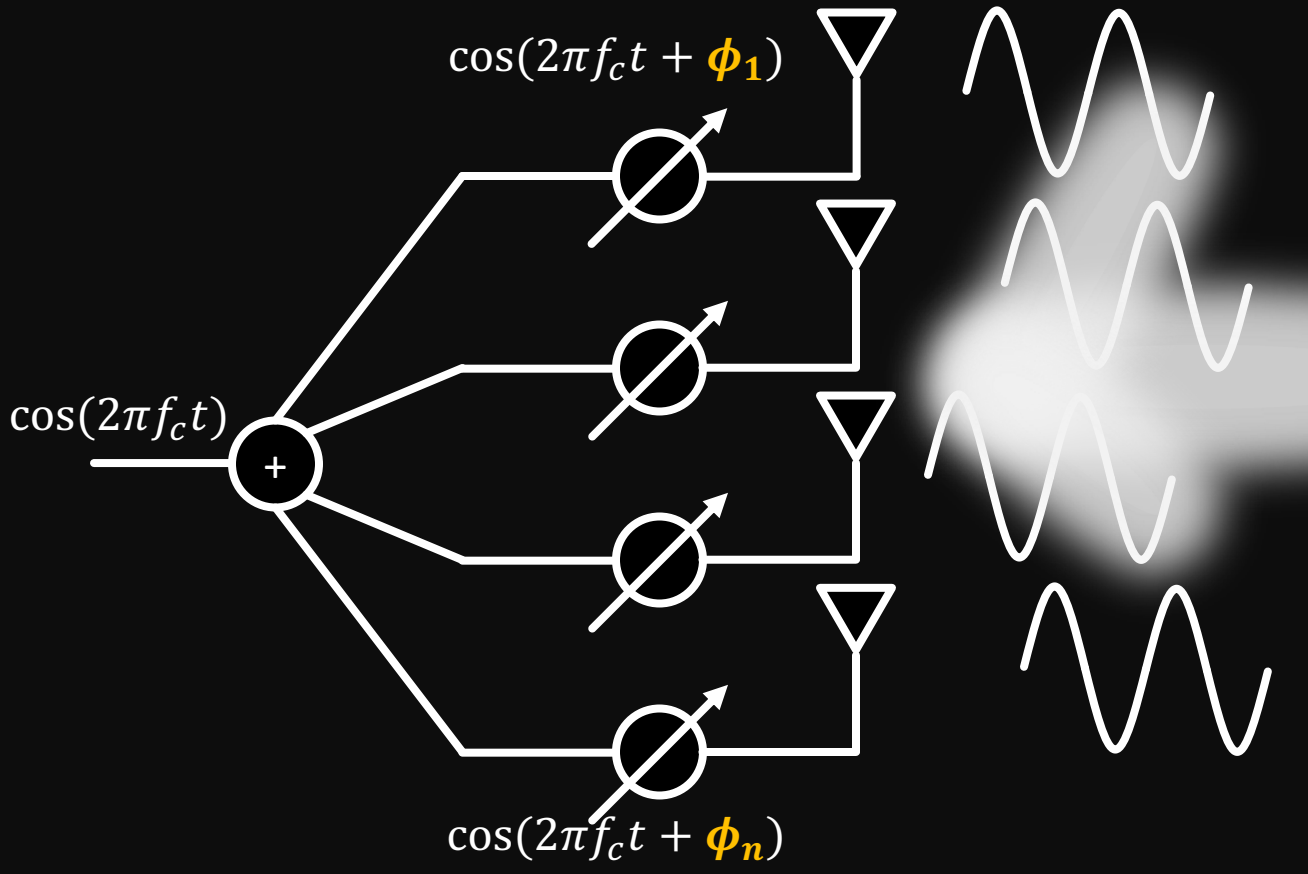

$\cos(2\pi f_c t + \boldsymbol{\phi_1})$
$\cos(2\pi f_c t)$
+
$\cos(2\pi f_c t + \boldsymbol{\phi_n})$

# Phase Array




phase mismatch

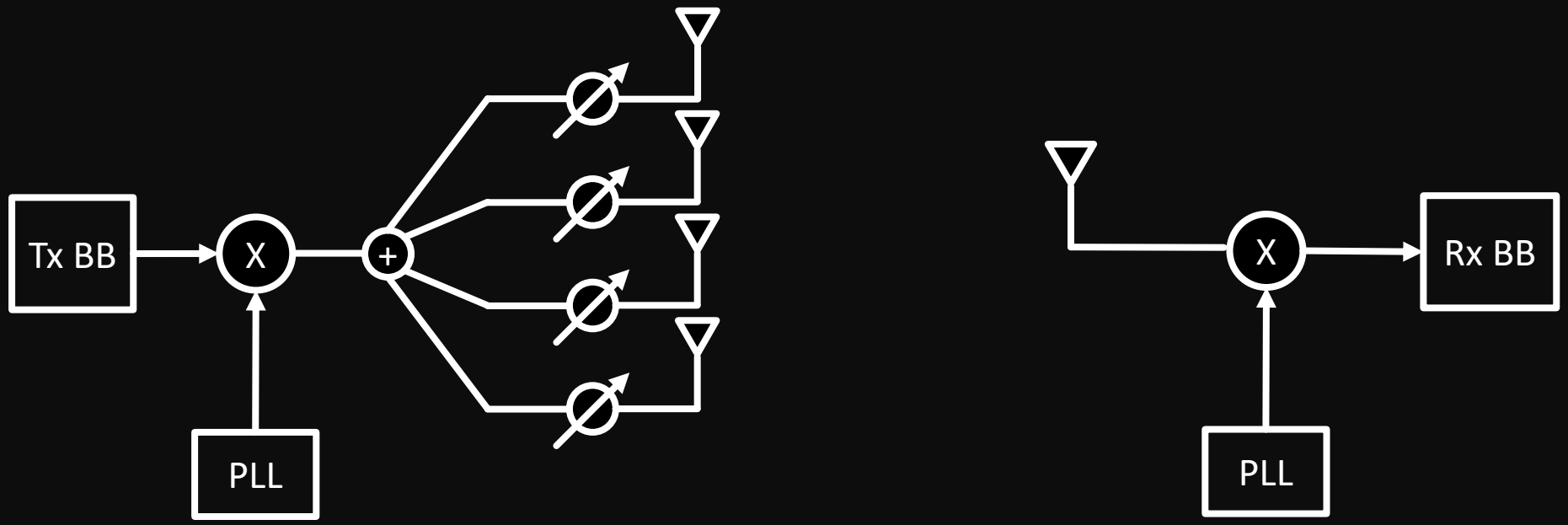
# mmWave Phase Array




sensitive to small offsets

Online phase calibration!

# This Work…

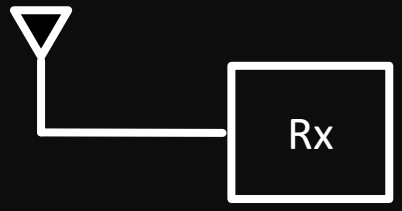



No extra circuit

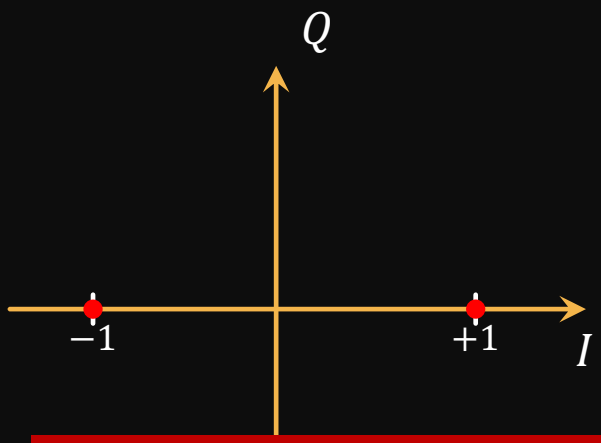
Full-chain OTA calibration

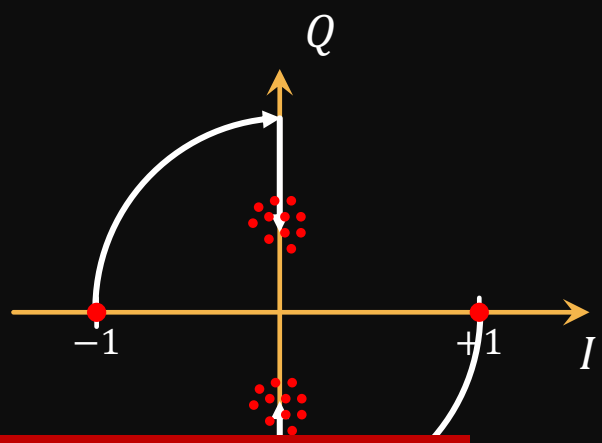
Calibrate during communication

# Channel Estimation

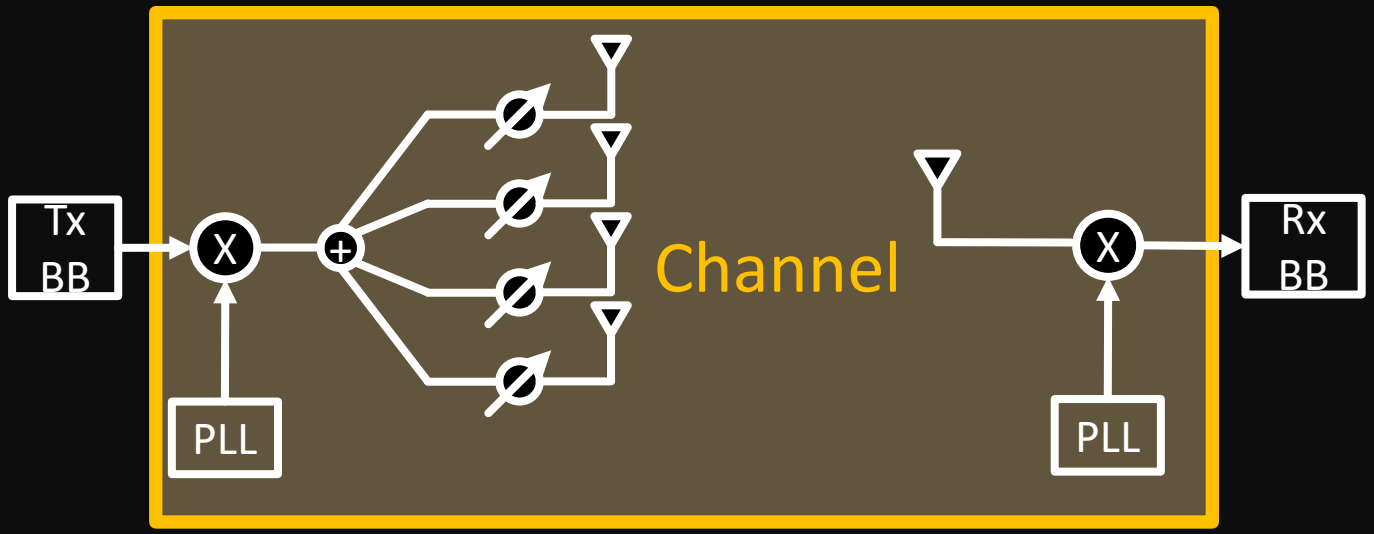

$x(t)$ ⇒ channel ⇒ $y(t) = h \cdot x(t - \tau) + v$

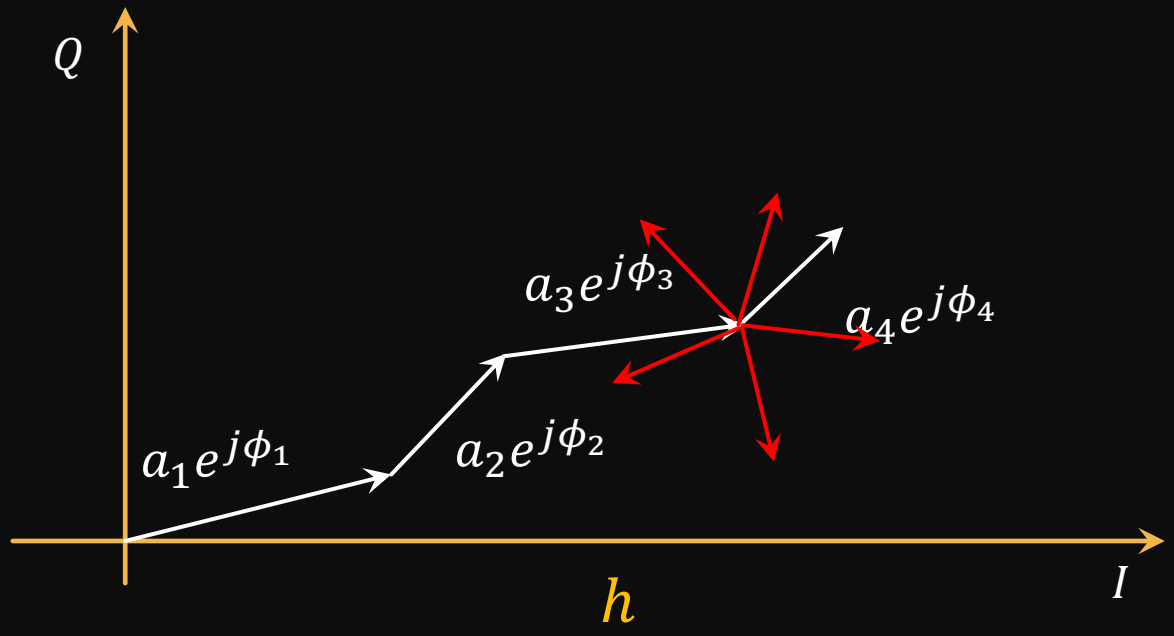



Send preamble to estimate & correct channel

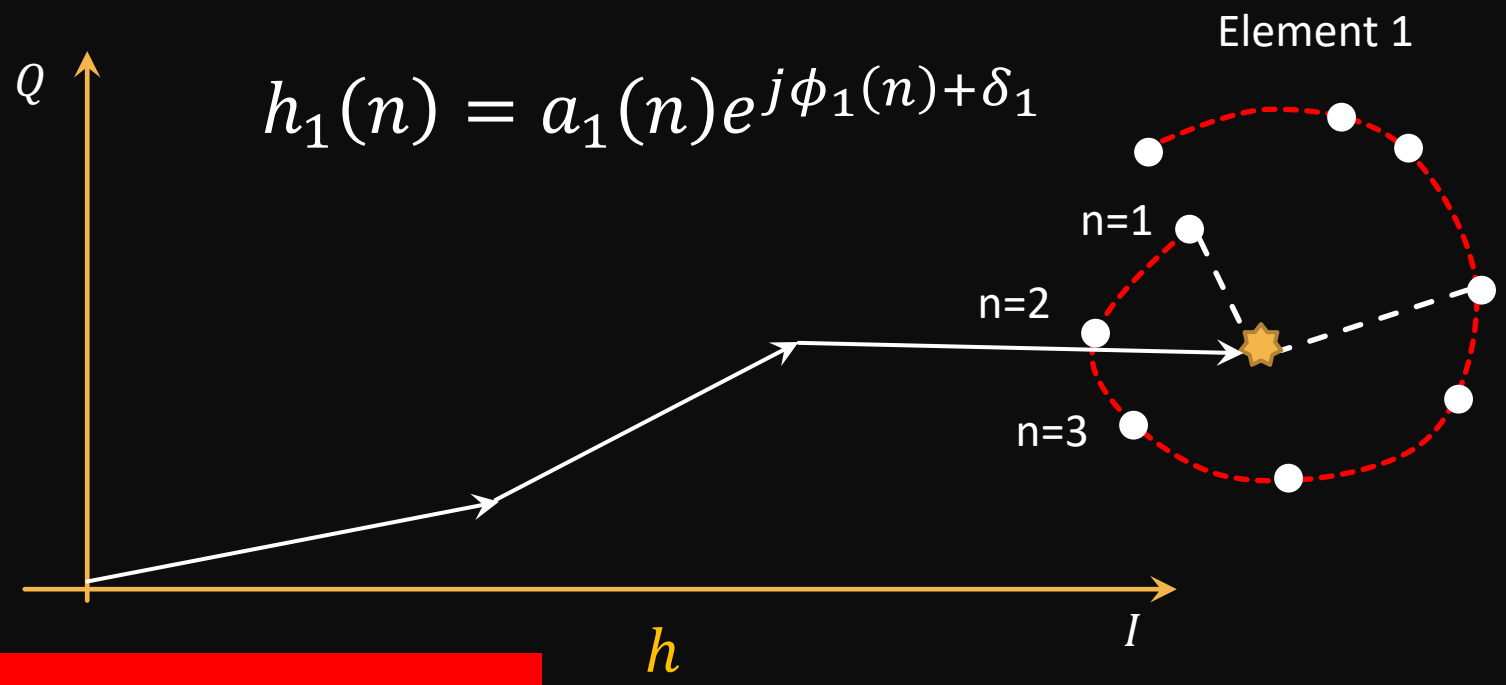
# Channel with Phase Array



# Unknown Parameters

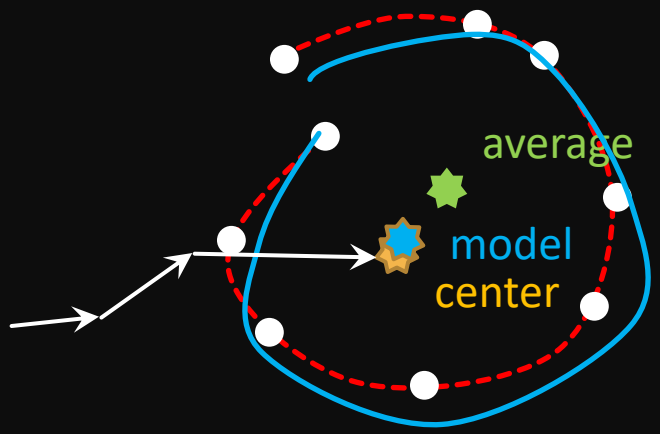
$$h_1(n) = a_1(n)e^{j\phi_1(n)+\delta_1}$$




Estimate
$a(n), \phi(n), \delta$
for each phase shifter

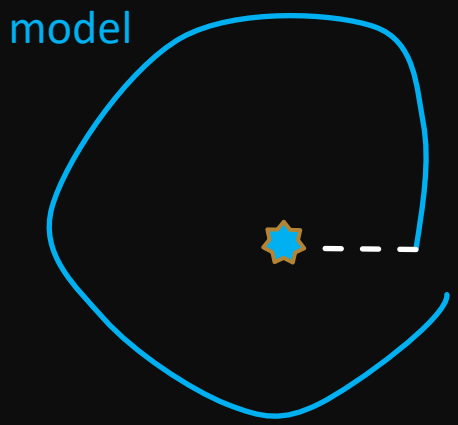
⇔ Estimate the center of trajectory

# Estimating the Center




**Hardware estimation**
center = channel without i-th element

**Blind estimation**
center = average of trajectory




**Model-assisted estimation**
center = fitting model trajectory

# Channel Estimation in OFDM

## 1. Simple channel estimation

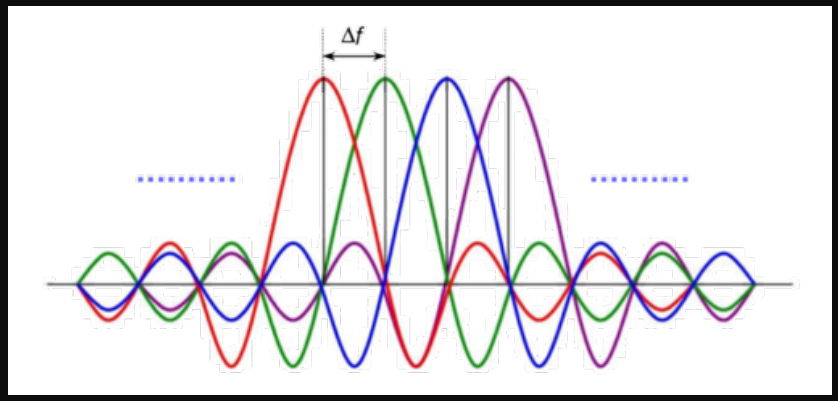
$$y(t) = h(t) * x(t - \tau) + v$$

$$Y(f) = H(f)\,\underline{X(f)} + w$$

send symbols in frequency domain

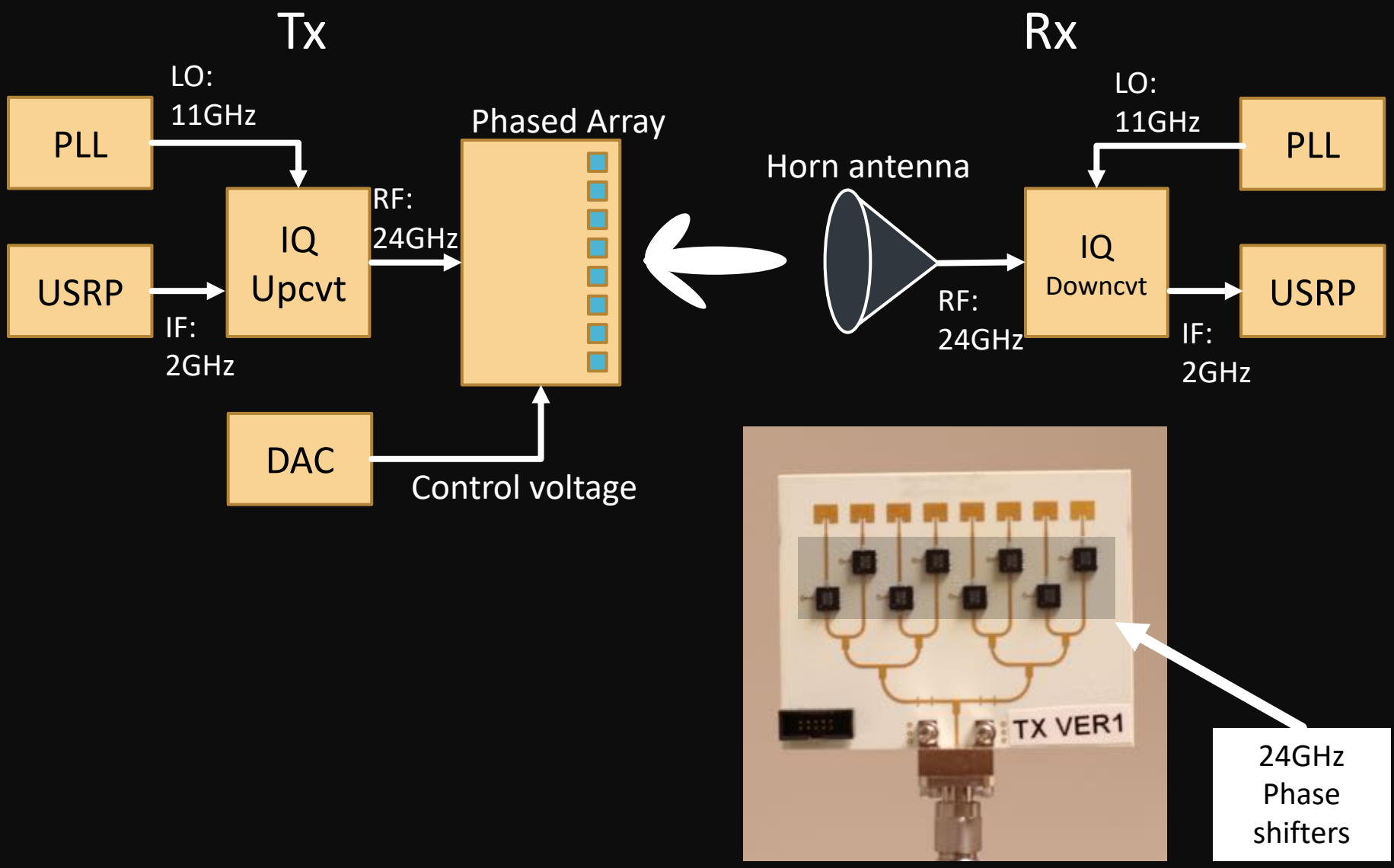
$$\widehat{H}(f) = \frac{Y(f)}{X(f)}$$

## 2. Multi-carrier modulation

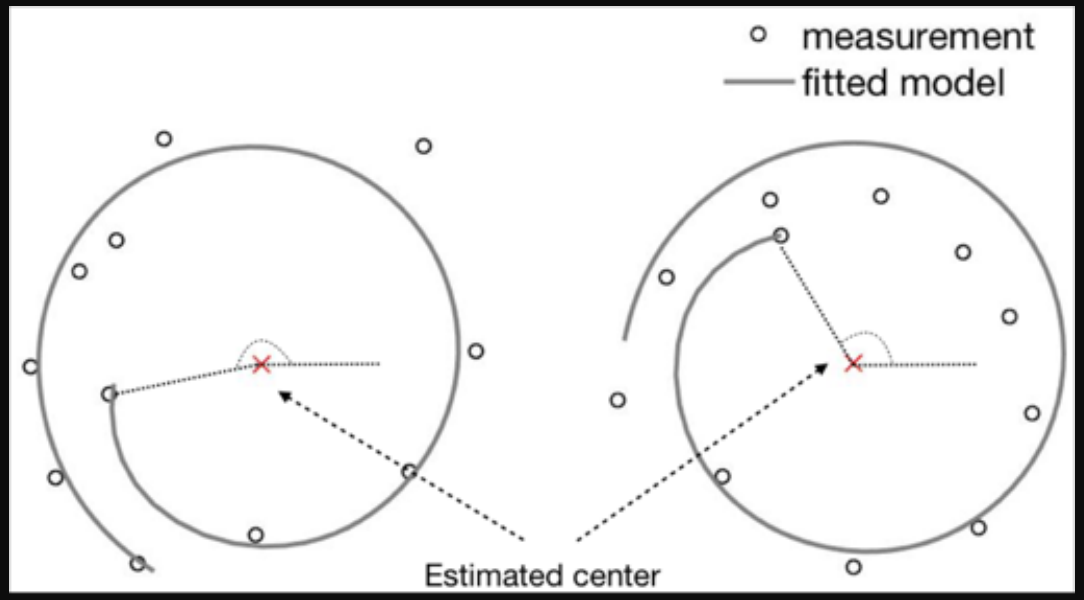



Channel estimation acquired over multiple frequency points

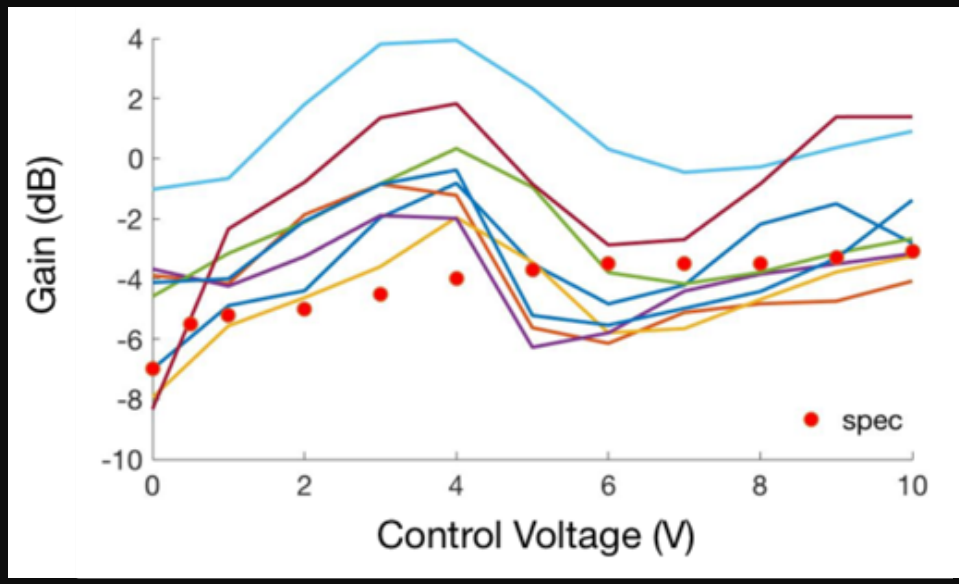
# Hardware Implementation

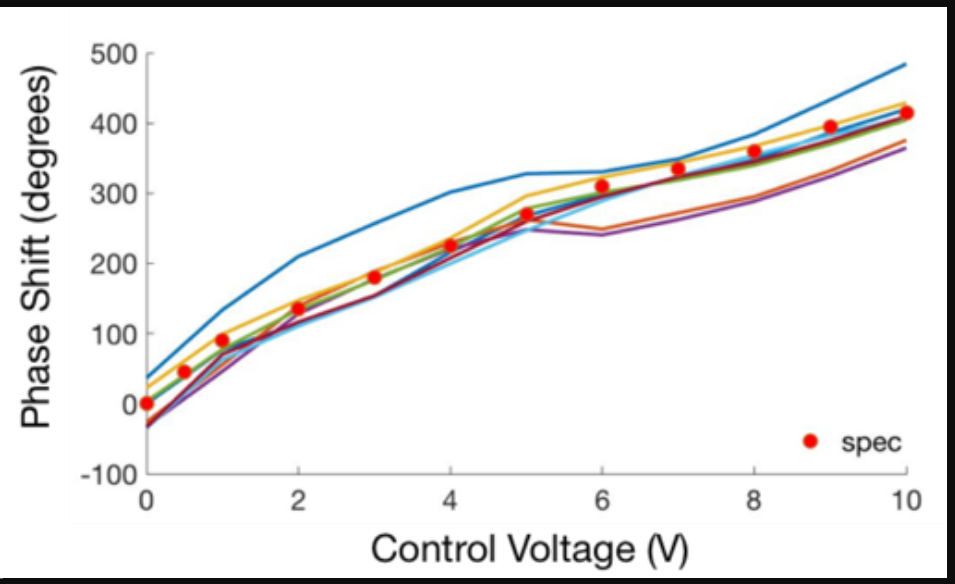


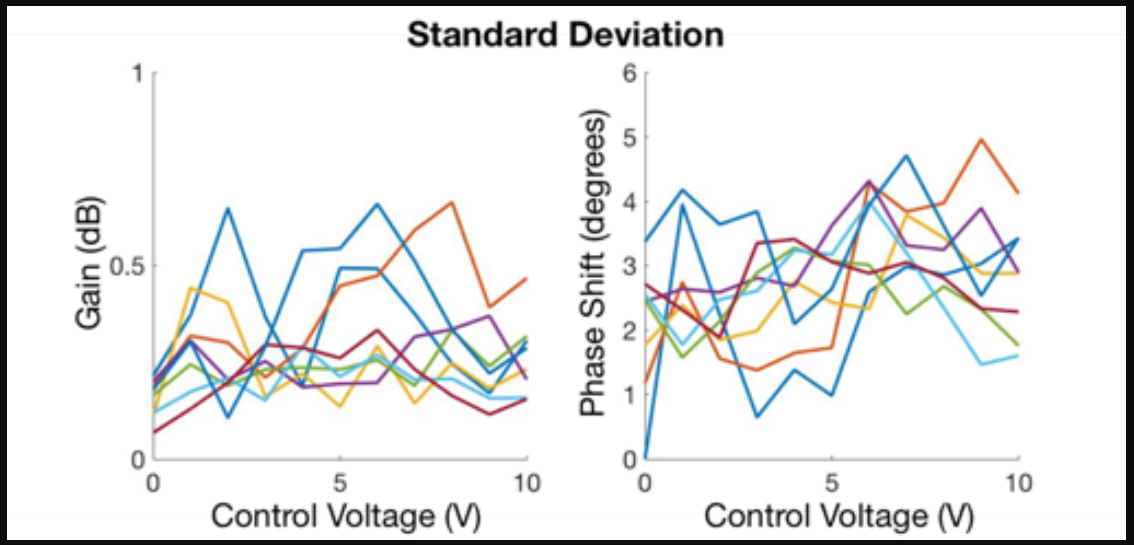
# Measured Channel Constellation



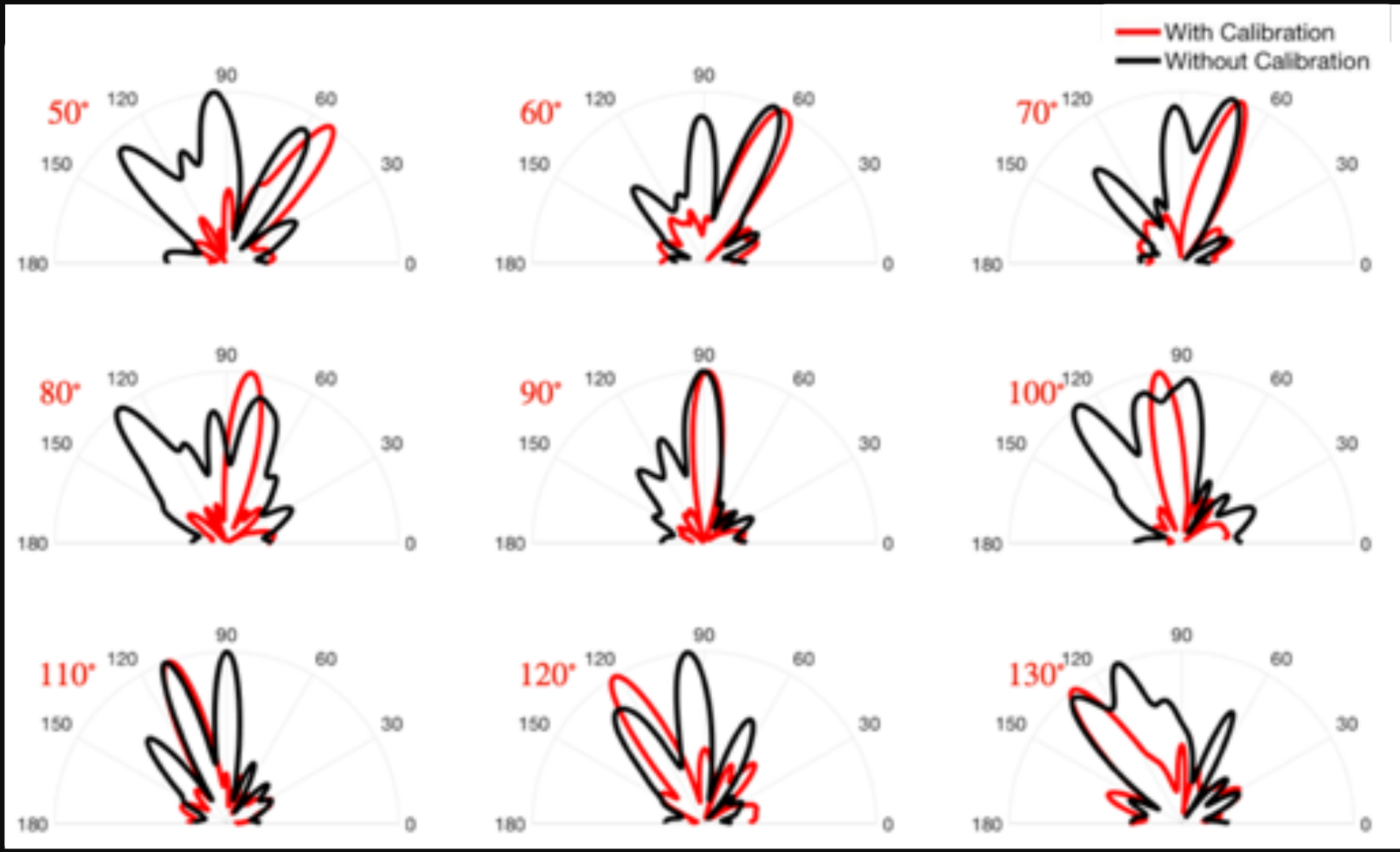
# Magnitude & Phase Response



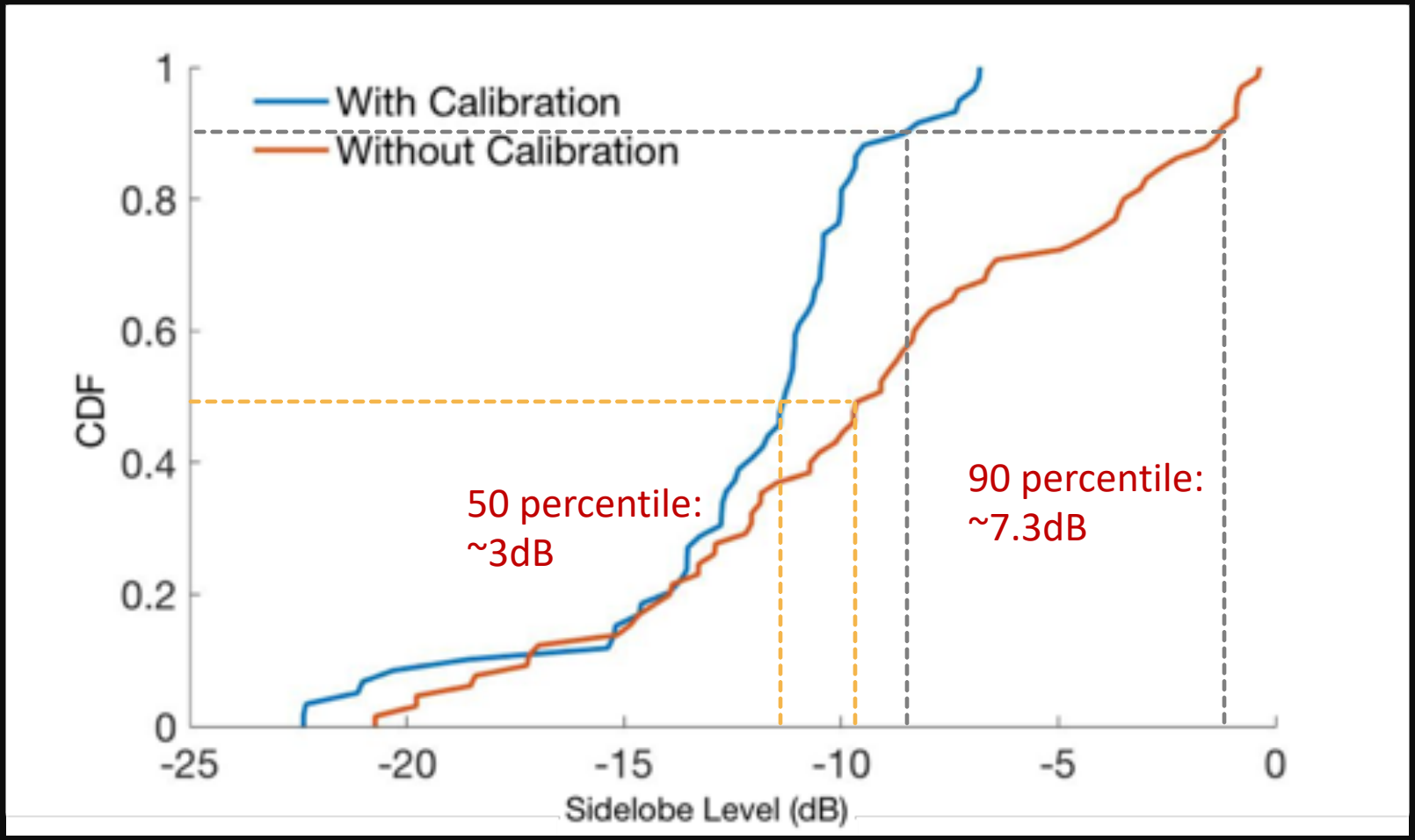



# Beam Patterns



# Performance of Calibration



# Conclusion

- New online OTA phase array calibration
  - No extra circuit required
  - Full-chain OTA calibration
  - Calibrate during the communication
- Evaluate 24GHz 8-element phase array using OFDM
- Improve upto 7.3dB SLL in beam pattern