Ultra-fast Beam Steering of a Phased-Array Antenna Based on Packaged Photonic Integrated Circuits

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ECOC 2018 – Rome, Italy

5G requirements

- Small mm-wave cells (< 100 m in radius)
- Low latency (below 1 ms)
- Above the ‘best effort’ requirement, but higher communication accuracy
- Massive integration
- More spectrum, to accommodate more mobile technologies and the high increase in usage.
- Beamforming, to direct the beam from the base station towards the mobile device(s) while cutting interference to other mobiles.

This requires pencil-beam phased array antennas to direct the beams towards the right target and to steer it for wide coverage.

Photonics can bring advantages as **wide bandwidth** and fast **beam-steering** together with EMI immunity and low losses.

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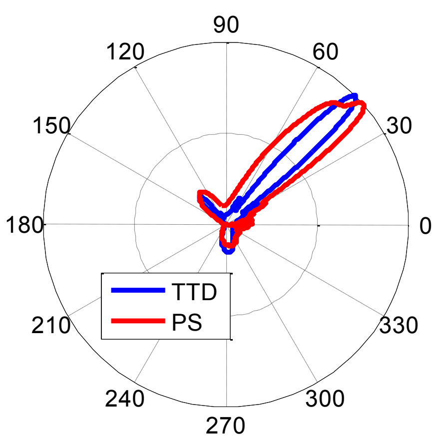
Phase Shift *vs* True Time Delay

- Beam-steering in PAAs exploits either phase-shift (PS) or true-time-delay (TTD)
- **TTD systems**: squint-free ☺, complex, typically stepwise ☹
- **PS systems**: simpler ☺, squint-limited ☹

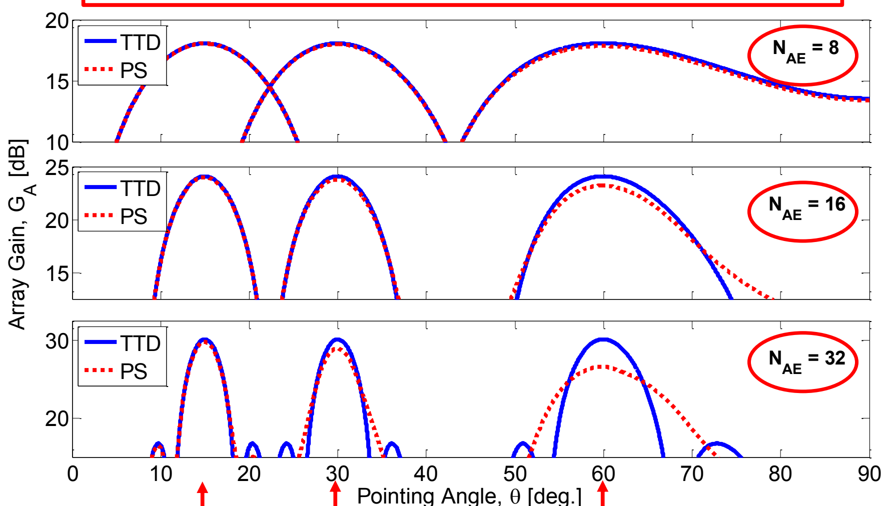


E.g.:

- Radiation patterns for 1x16 array
- Beam squinting ∝ $\Delta f/f_c$
- In the plot: $\mathbf{\Delta f/f_c = 40\%}$

Do we always need TTD?

Antenna gain for linear array, $\Delta f/f_c$=12.5%



Pointing: 15°

Pointing: 30°

Pointing: 60°

Several practical cases (moderate-size PAAs) can be **satisfied by PS**

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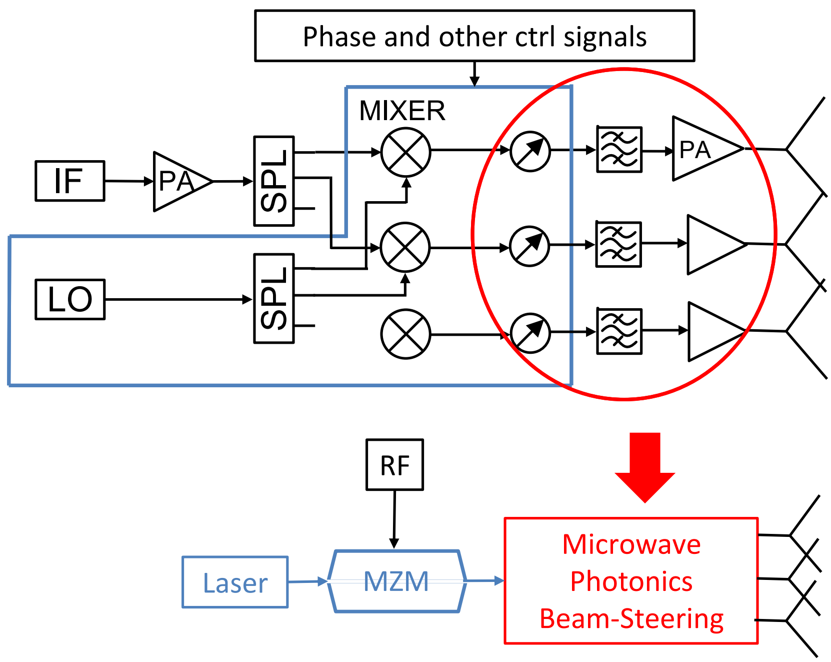
Beam-steering System Architecture



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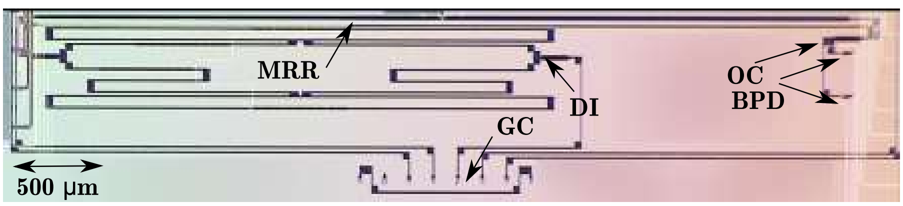
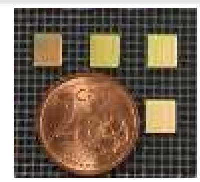
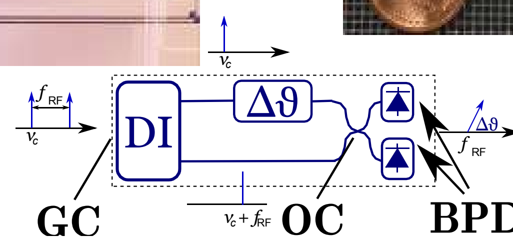
The Photonic Integrated Chip







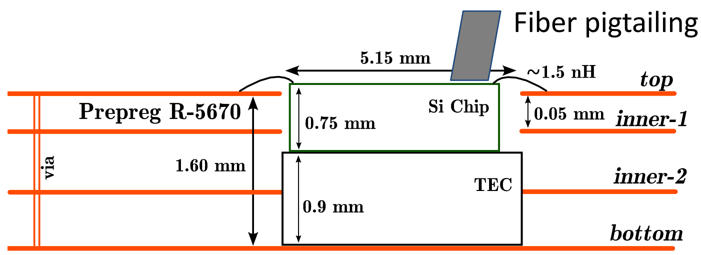
- Overall circuit **dimensions <4.5 mm^2**
- Device fabricated in SOI at IMEC
- **Grating coupler** (GC) for vertical-coupling with optical fiber
- **Deinterleaver** (DI) for carrier-sideband separation through Micro Ring Resonators (MRR) loaded MZI structure
- **Optical phase-shifter** (OPS)
- **Optical Coupler (OC)**: multimode interference (MMI) structure
- **BPD**: p-i-n germanium photodiodes (3dB BW: ~15 GHz)

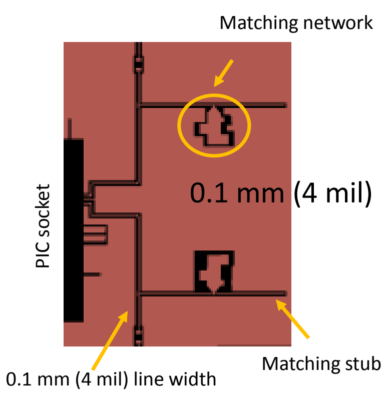
The package

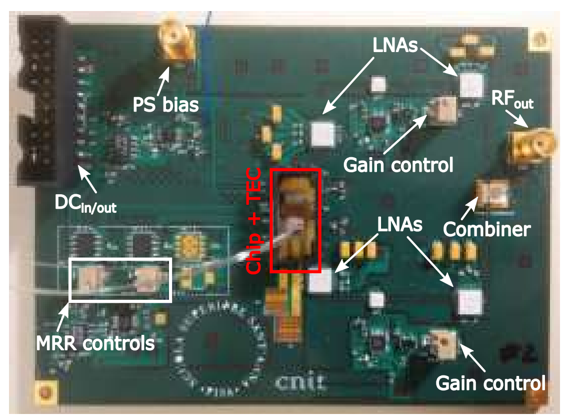
Dk = 3.61 Df = 0.004 @ 10 GHz

Z_{out} 48.9 – 156.4j Ω

f_c = 13 GHZ, BW > 1 GHz







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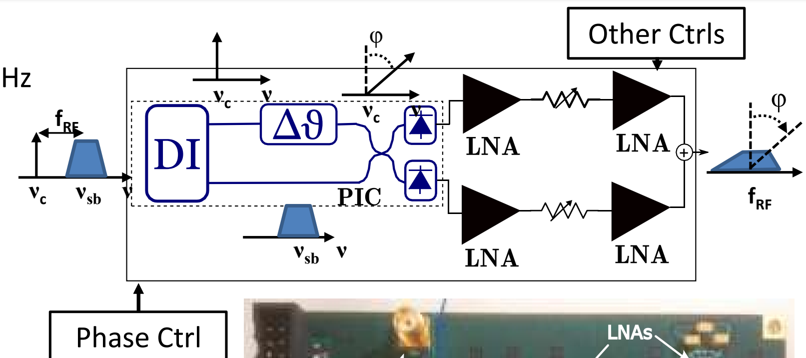
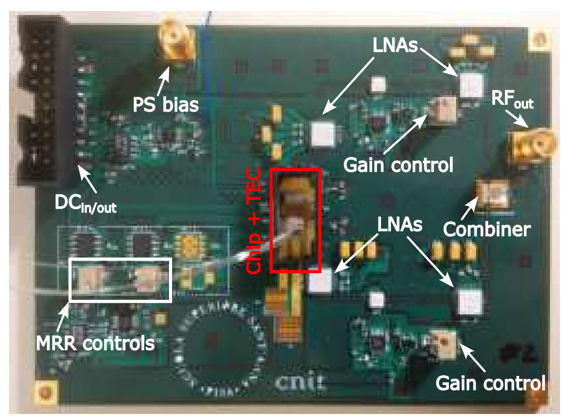


Main Components

- Photonic Integrate Chip
- LNAs HMC516LC5 2 dB NF, 9 GHz BW (9 to 18 GHz range)
- Wilkinson Power Combiner (PD0530SMG)
- Trimmers for tuning RF output and biasing voltage levels



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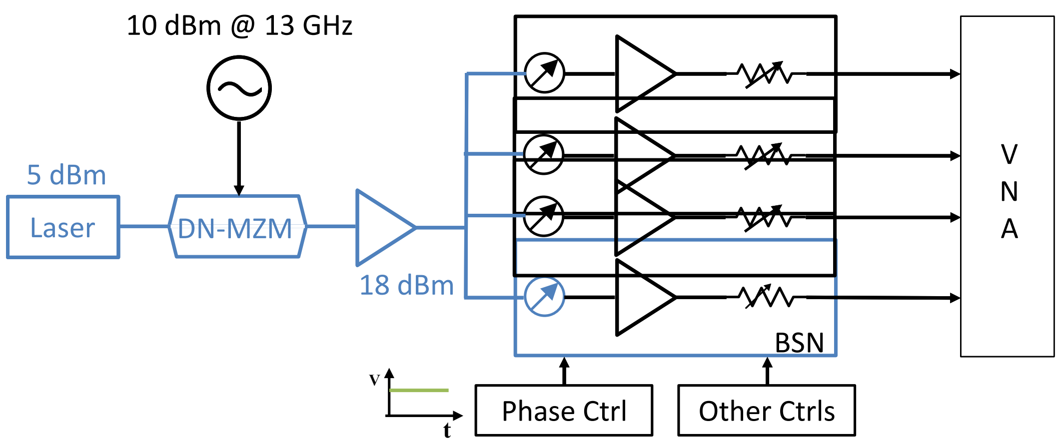
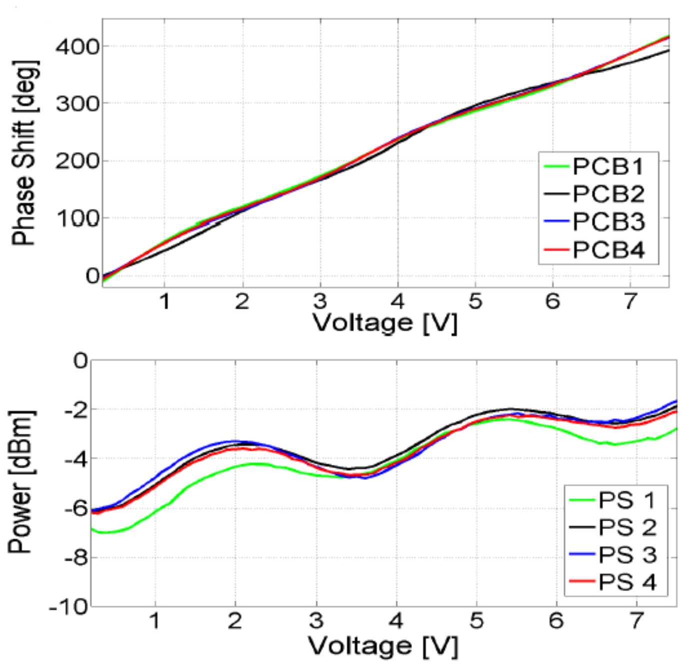
Characterization: Setup



- The RF signal is **SSB modulated** on a laser
- The optical signal is **distributed** to each Beam-Steering Network (BSN)
- At each element, a MWP-PS returns a **phase-controlled RF signal**

Characterization: Results



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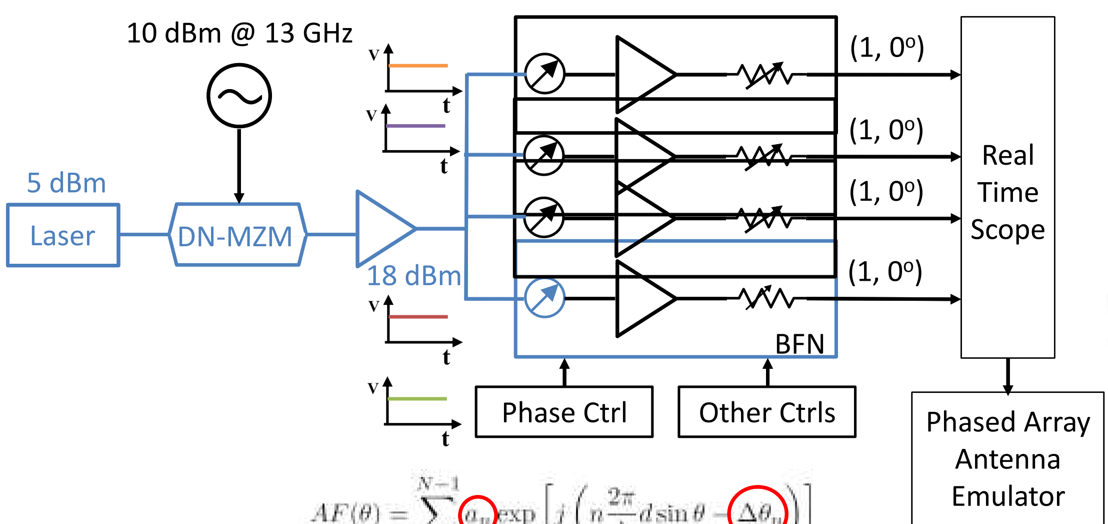
Static Test: Setup 1

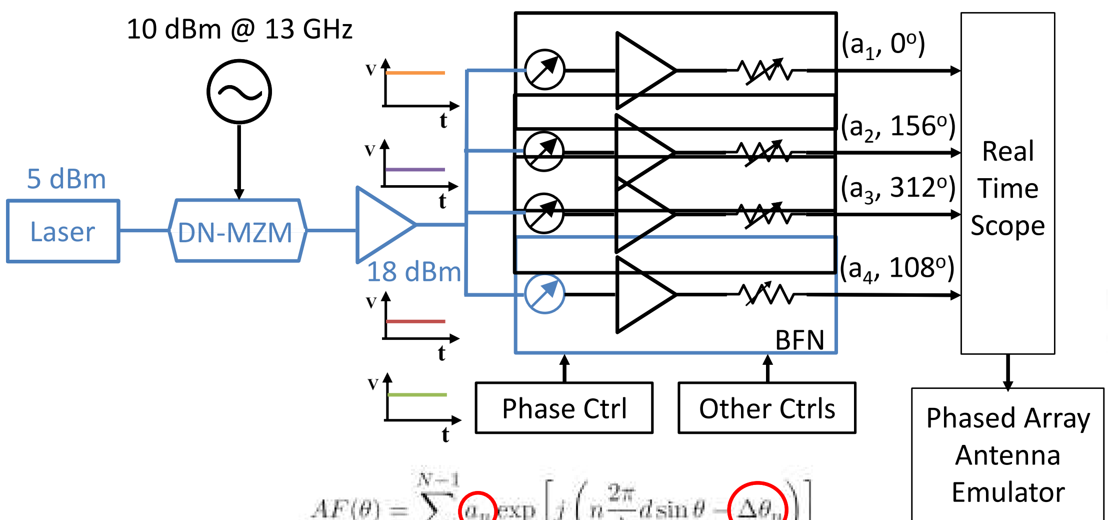
Pointing at 0°



$$AF(\theta) = \sum_{n=0}^{N-1} a_n \exp\left[j\left(n\frac{2\pi}{\lambda}d\sin\theta - \Delta\theta_n\right)\right]$$

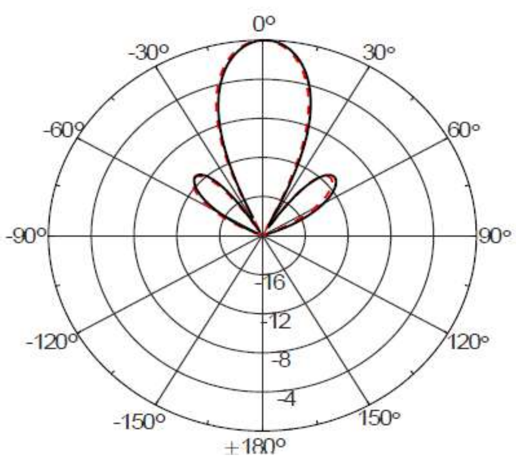
Static Test: Setup 2

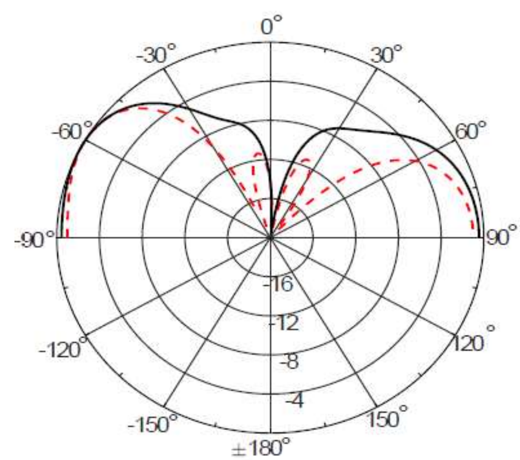
Pointing at -60°



$$AF(\theta) = \sum_{n=0}^{N-1} a_n \exp\left[j\left(n\frac{2\pi}{\lambda}d\sin\theta - \Delta\theta_n\right)\right]$$

Static Test: the Radiation Patterns





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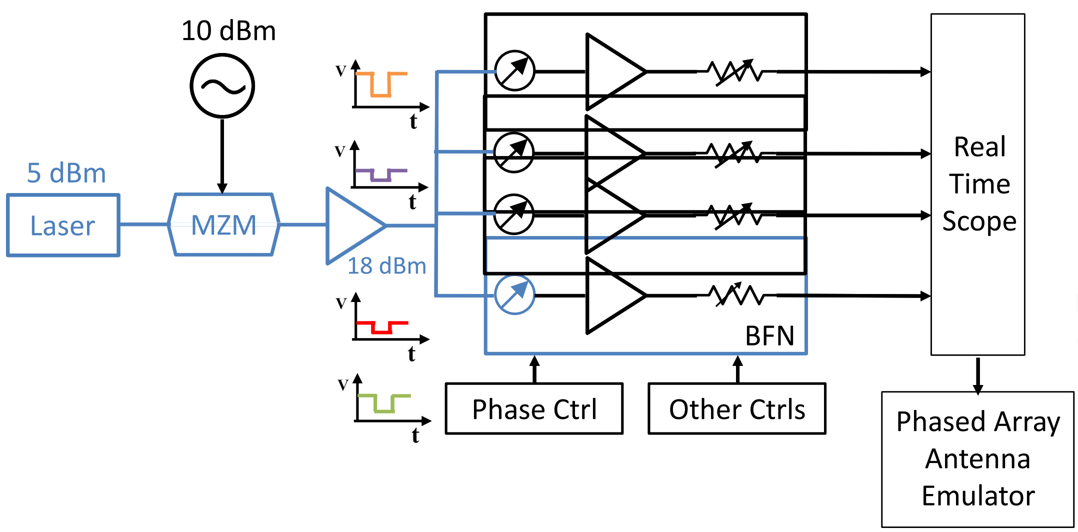
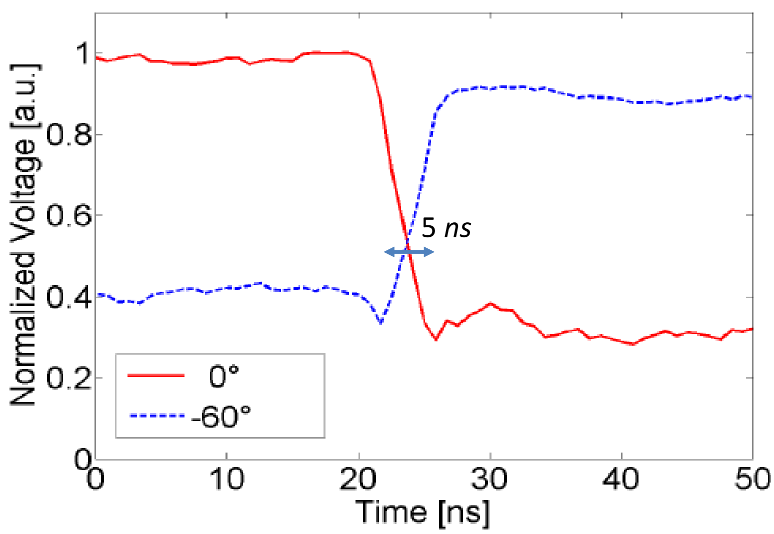
Dynamic Test: Setup

Steering from 0º to -60º



Dynamic Test: Results



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Conclusions

- It was realized and tested an Integrated Microwave Photonics beam-steering network for RF signals at 13 GHz
- Functional packaging
- Performance: phase shift > 360^o, linearity (P_{out} = -5 dBm $\pm$ 1 dBm)
- Emulation of a 4-element Linear Phased-Array Antenna
  - pointing at 0^o and -60^o
  - with switching time measured as < 5 ns
- Potentially **suitable for practically implementing** rapidly-reconfiguring beam-steering in **moderate-size** PAAs for future 5G systems.

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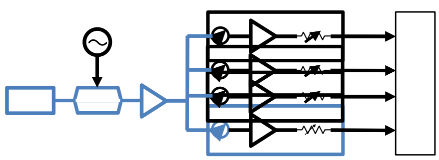

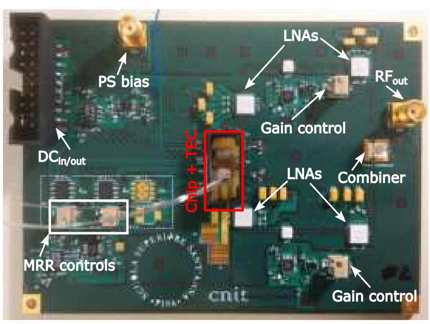

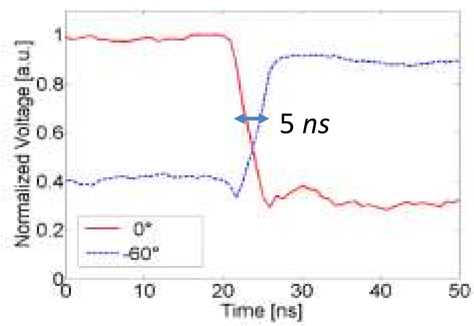

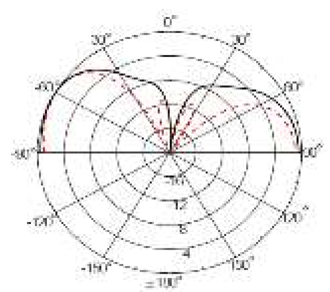

thank you

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Beam-steering System Architecture