MIMO Sensor Array for Short-Range High-Resolution Automotive Sensing

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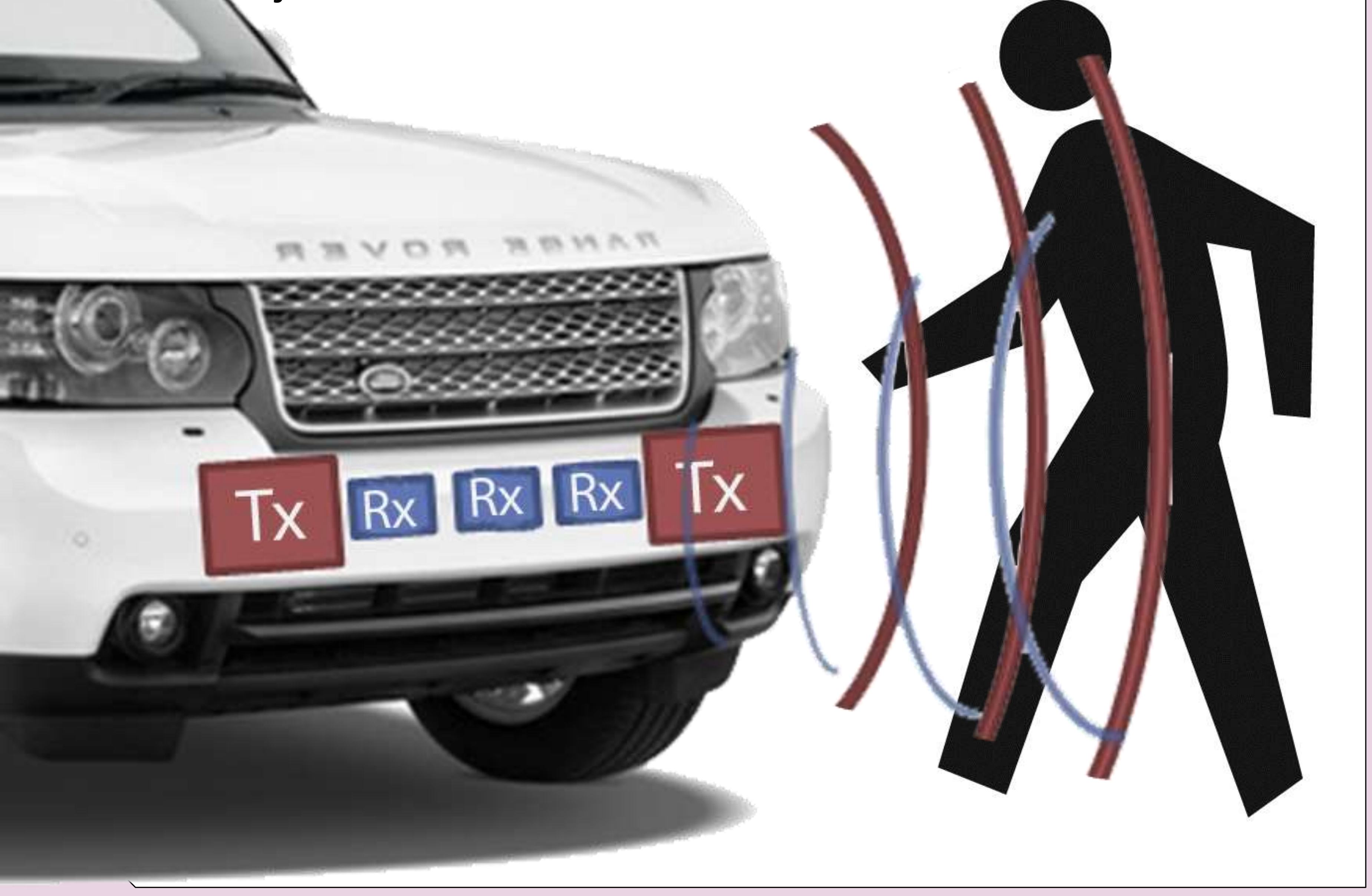
1.Introduction

The aim of the project is to investigate a novel Multiple-Input-Multiple-Output (MIMO) sensor system for automotive applications.

Compared to traditional phased arrays, a MIMO array can achieve the same fine angular resolution, but with a drastically reduced amount of sensor elements. A MIMO array of 12 elements can deliver the same resolution as a phased array of 32 elements [1]. The other highlight of this technology is that it can operate at short ranges, which is physically impossible with a phased array as the beam requires significant distance from the antenna aperture to form [2]. Therefore a MIMO system can potentially provide very high angular resolution at short ranges.

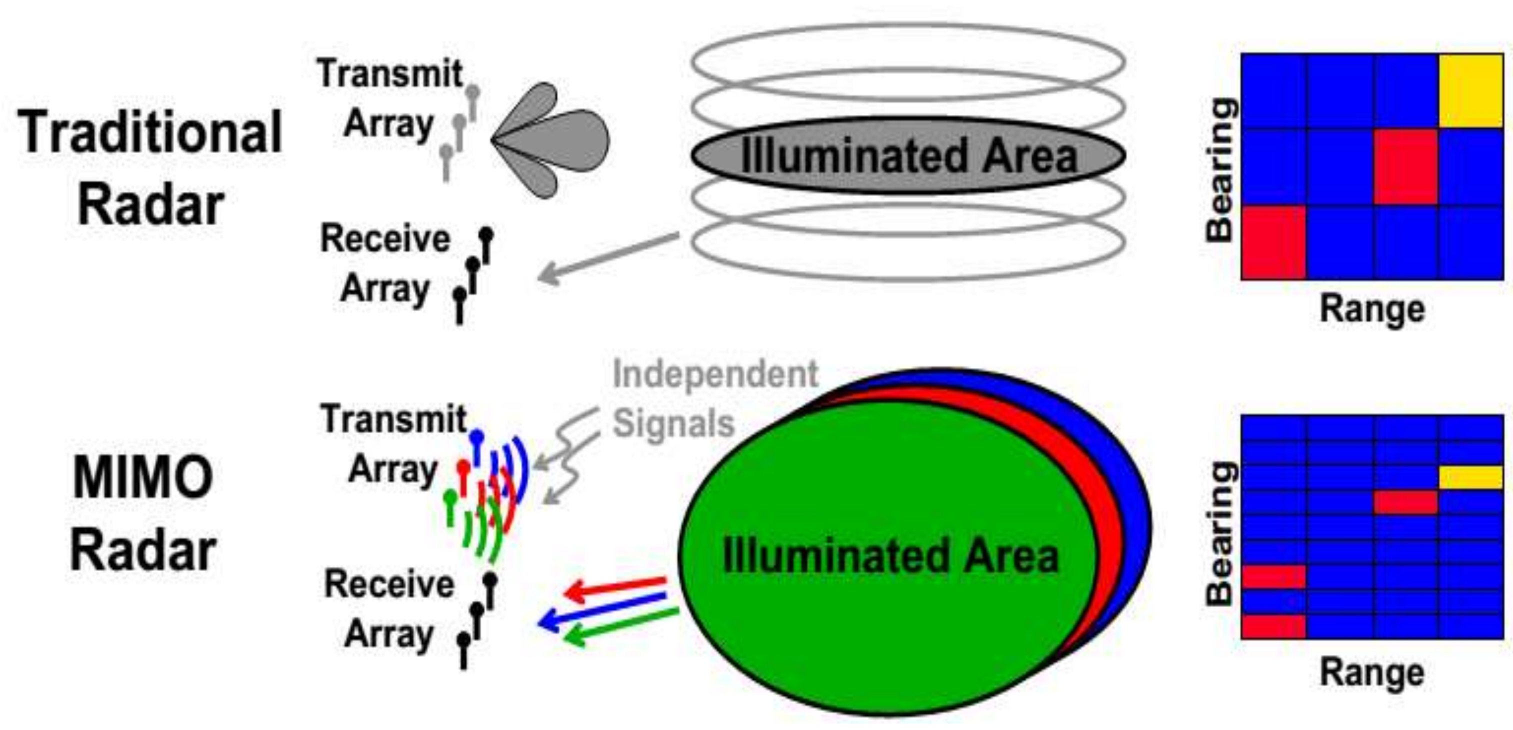
These properties make such a system attractive for a number of automotive applications, including parking aids, short-range cruise control, speed-over-ground estimation, pedestrian and object detection and collision detection.



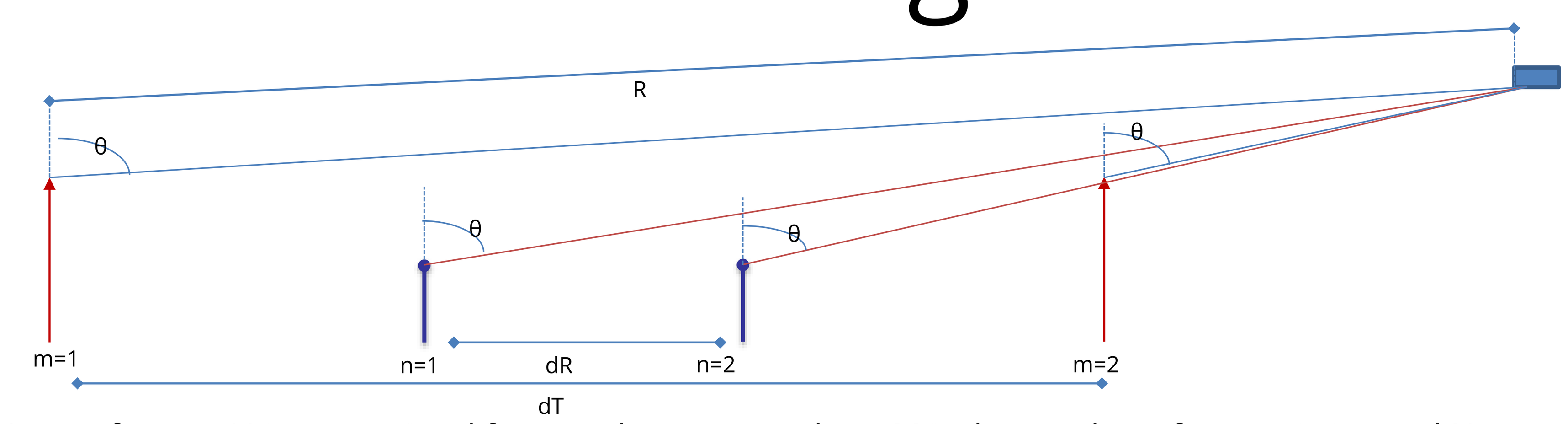
2.Phased vs. MIMO Array

A phased-array-antenna radar can be used with beam-forming techniques to direct a beam to a specific location [3]. And then the radar can scan the desired area electronically. This can be achieved since, the correlated signals from transmit antennas would add up constructively or destructively in different directions in space [2].

On the other hand, a MIMO radar uses the advantage of orthogonality for various advantages [4]. These advantages can be; reduced amount of necessary array elements, increased angular resolution, faster scan time, simultaneous search & track etc. With a MIMO array; beamforming process does not have to happen in the space but in the digital space, so we can "illuminate" the whole space of interest with single transmission [1].



3.MIMO Signal



A waveform $s_m(t)$ is transmitted from each antenna, where M is the number of transmitting and N is the number of receiving antennas.

Signal at target from tx #m

$$s_{mt}(t) = s_m(t).e^{jk(R-(m-1)sin\theta dT)}$$

All signals at target

$$s_t(t) = \sum_{m=1}^{M} s_{mt}(t)$$

Signal return at nth antenna

$$s_n(t) = s_t(t).e^{jk(R-(n-1)sin\theta dR)}$$

If all signal return is summed

$$s_r(t) = \sum_{n=1}^{N} s_n(t)$$

After matched filtering

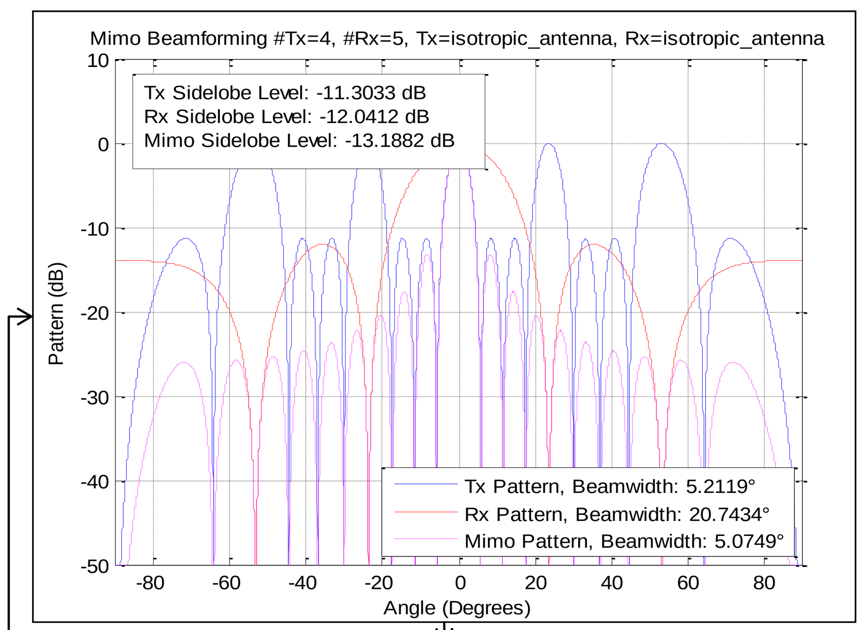
$$s_r(t) = s_{matched}(t).e^{2jkR}.\sum_{m=1}^{M} e^{-jk(m-1)sin\theta dT}.\sum_{n=1}^{N} e^{-jk(n-1)sin\theta dR}$$

$$AF(\theta) = \sum_{m=1}^{M} e^{-jk(m-1)sin\theta dT}.\sum_{n=1}^{N} e^{-jk(n-1)sin\theta dR}$$

$$AF(\theta) = TAF(\theta) * RAF(\theta)$$

$$TAF(\theta) = \sum_{m=1}^{M} e^{-jk(m-1)sin\theta dT}$$

$$RAF(\theta) = \sum_{n=1}^{N} e^{-jk(n-1)sin\theta dR}$$



To have RX nulls cancel TX grating lobes or vice versa

$$sin^{-1}\left(1-\frac{m\lambda}{dT}\right) = sin^{-1}\left(1-\frac{n\lambda}{NdR}\right)$$

$$sin^{-1}\left(1-\frac{m\lambda}{MdT}\right) = sin^{-1}\left(1-\frac{n\lambda}{dR}\right)$$

Simplest solutions are

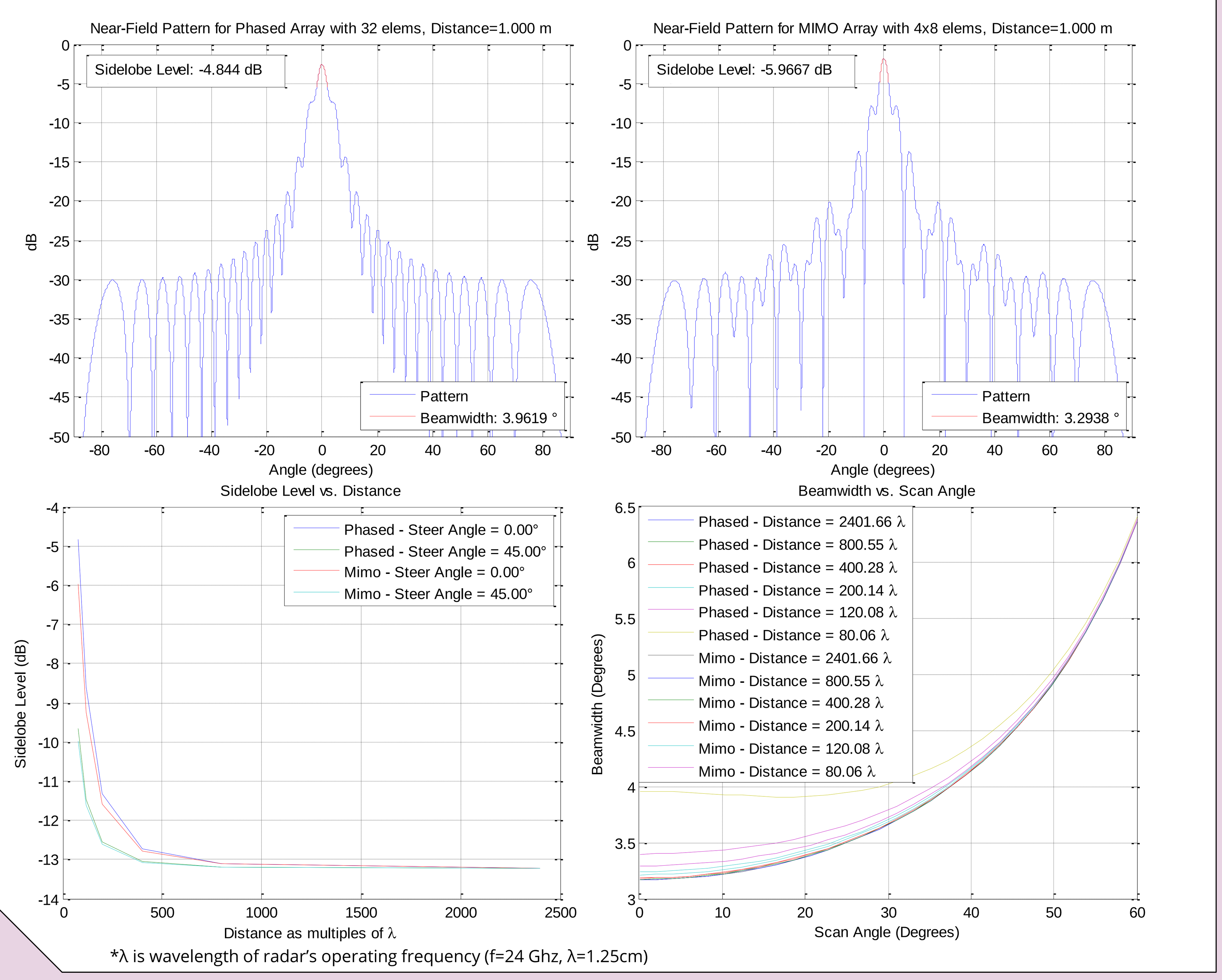
$$dR = MdT$$

or

$$dT = NdR$$

- We need to fully fill one length of gap between the elements of sparse array
- After the first requirement, we can have as many elements in sparse array
- MIMO only makes sense if MxN >> M + N
- This approximation only works when we are in far-field (after Fraunhofer Distance)

4.Initial Results



*λ is wavelength of radar's operating frequency (f=24 Ghz, λ=1.25cm)

5.References

[1] D. Bliss, K. Forsythe, and G. Fawcett, 'MIMO Radar: Resolution, Performance, and Waveforms', in Proc. 14th Annual Adaptive Sensor Array Processing Workshop, MIT, 2006, pp. 6–7.
[2] C. A. Balanis, Antenna theory: analysis and design, 3rd ed. Hoboken, NJ: John Wiley, 2005, ISBN: 047166782X.
[3] P. Z. Peebles, Radar principles. New York: Wiley, 1998, ISBN: 0471252050.
[4] M. Lesturgie, 'Tutorial on MIMO Radar', Glasgow, UK, 21-September-2012.

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