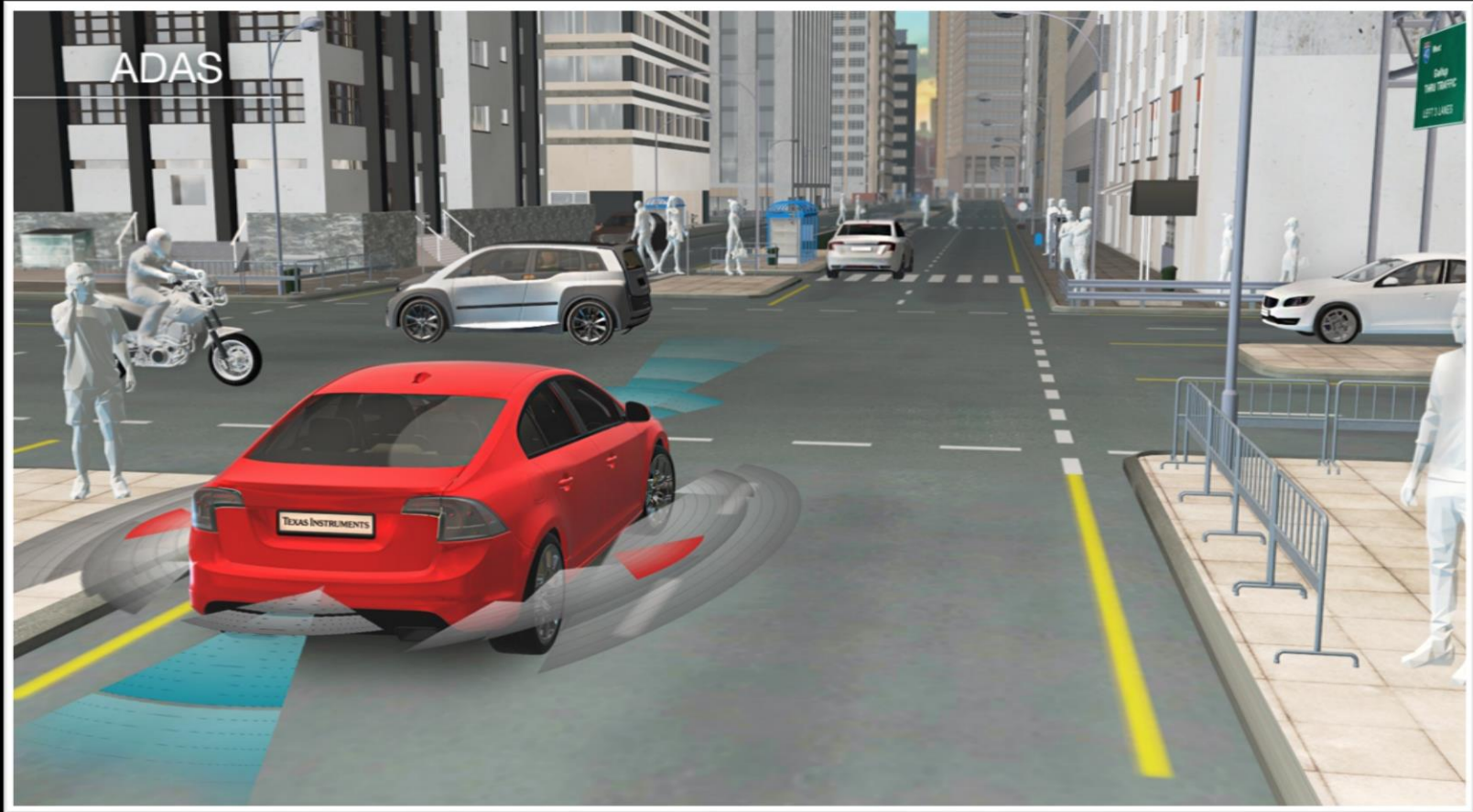


# Imaging Radar - The One Sensor To Rule Them All



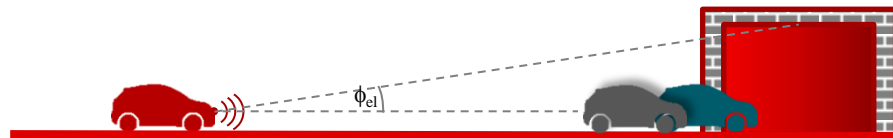
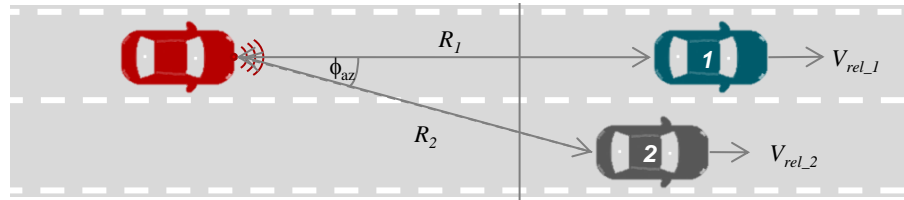
**Amit Benjamin, Texas Instruments**

# **Agenda**

- **Radar in Automotive Today - What is Missing?**
- **Camera Vs Lidar Vs Radar - Strength & Weakness**
- **Which Sensors in Which AV Level?**
- **Imaging Sensor - Why is it a Game Changer?**
- **Imaging Radar Use Case Analysis - Step Function in Radar performance**

# Radar in Automotive

- Determine object range
- Determine object (relative) velocity
- Determine object azimuth & elevation angle
- Object discrimination (multi-target capability)
- Object classification (shape, size)
- Robust against environmental conditions such as bad light & weather



# Sounds Simple – But Something doesn't work Right

## Tesla claims Highway 101 safety barrier was absent at time of fatal crash

Caltrans says it is cooperating with NTSB inquiry, will take 'appropriate action' after panel releases its findings



By **MARK GOMEZ** | mgomez@bayareanewsgroup.com and **JASON GREEN** | jason.green@bayareanewsgroup.com | Bay Area News Group  
PUBLISHED: March 28, 2018 at 5:50 am | UPDATED: March 28, 2018 at 6:32 pm



Google Street View



Thursday, March 22nd, 2018

### Tesla: Car in Fatal Hwy 101 Crash Was on Autopilot - YouTube



<https://www.youtube.com/watch?v=Tr-oF7J0cBw>

Mar 31, 2018 - Uploaded by KPIX CBS SF Bay Area

On Friday, **Tesla** confirmed that a Model X sedan involved in a fatal **crash** on Highway 101 last week was ...

Media does not understand this  
Totally..

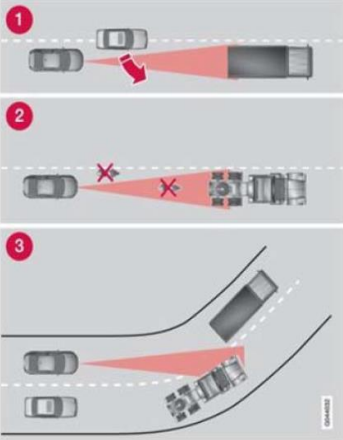
BBC tests done 2 weeks ago were  
Flawed and did not bring out the  
Test limitations in their report

<https://www.bbc.com/news/av/business-44460980/this-car-is-on-autopilot>

INSTRUMENTS

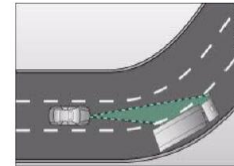
# Sounds Simple – But Something is missing

## From Volvo owner's manual

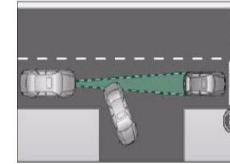


- 1 In certain situations, the radar sensor cannot detect vehicles at close quarters, for example a vehicle that suddenly enters the lane between your vehicle and the target vehicle.
- 2 Small vehicles, such as motorcycles, or vehicles not driving in the center of the lane may remain undetected.
- 3 In curves, the radar sensor may detect the wrong vehicle or lose sight of the target vehicle.

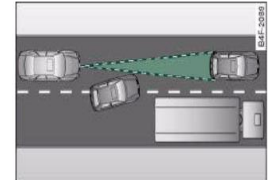
## From Audi owner's manual



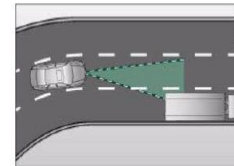
Driving into a bend



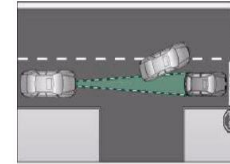
Vehicle turning off and vehicle stationary



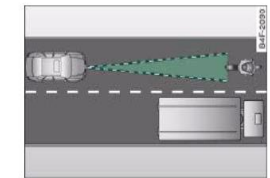
A vehicle is changing lanes



Driving out of a bend



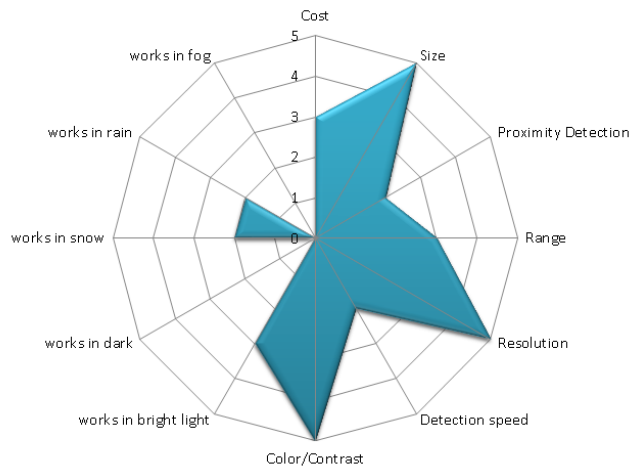
Vehicle changing lane and vehicle stationary



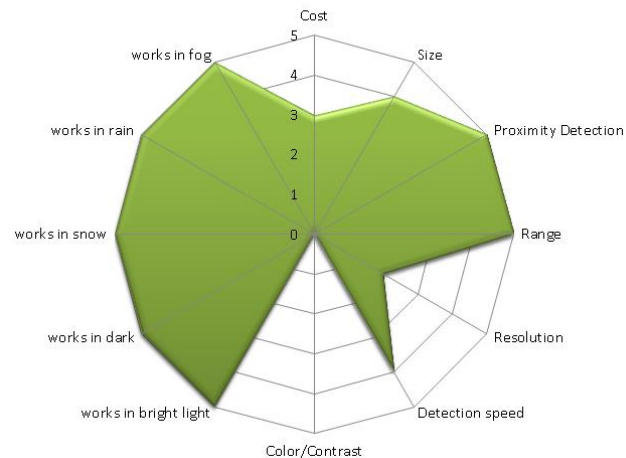
Motorcycle in front

# LiDAR vs Camera vs RADAR

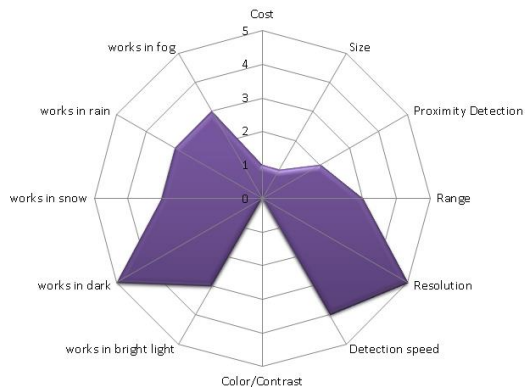
**CAMERA**



**Radar**

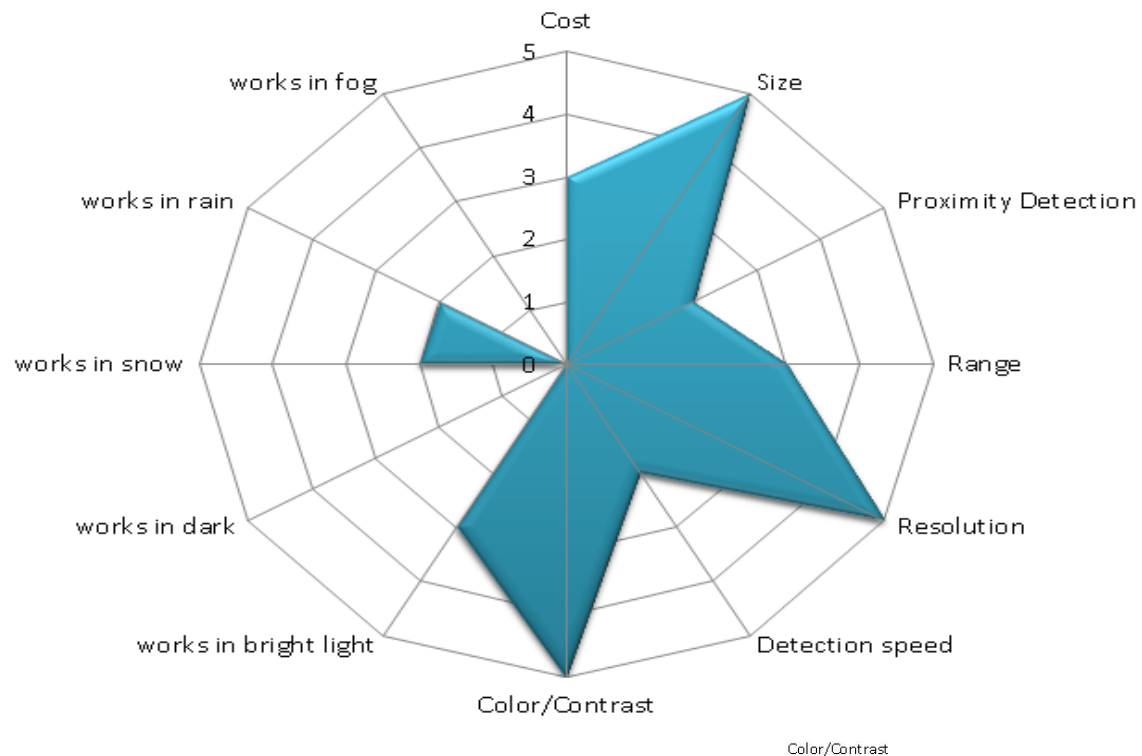


**Lidar**

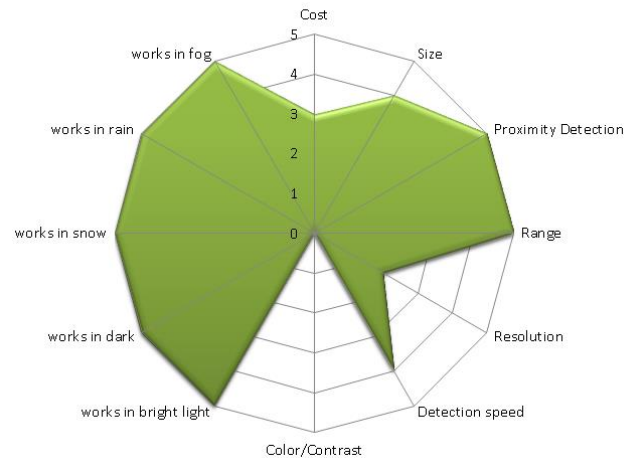


# LiDAR vs Camera vs RADAR

## CAMERA

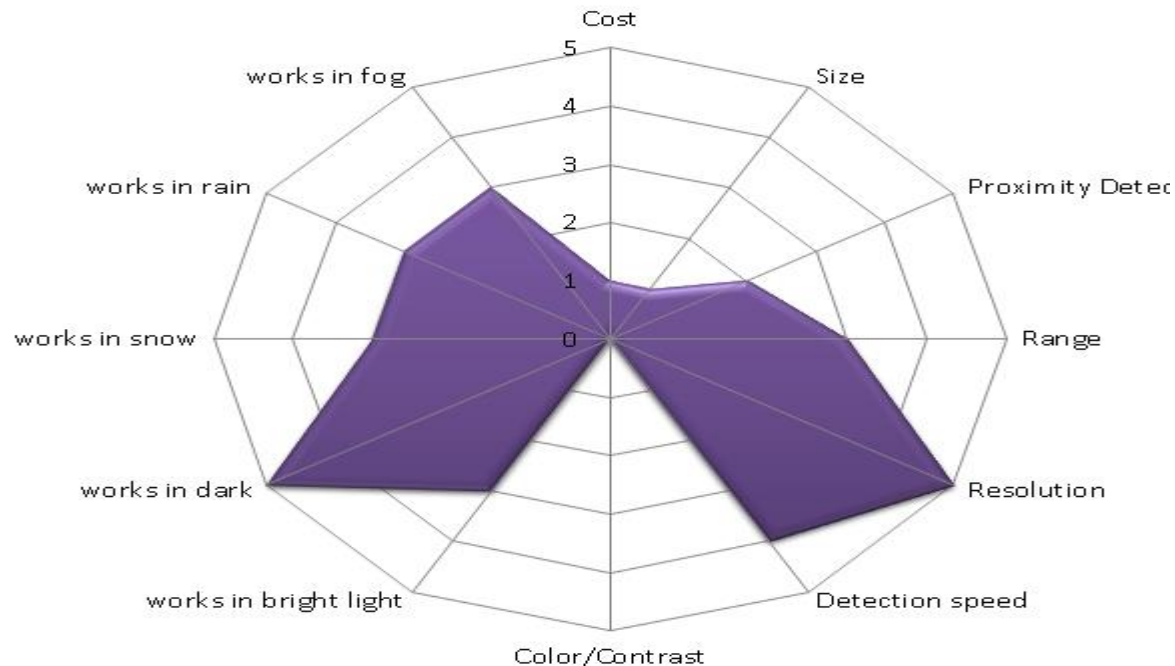


## Radar

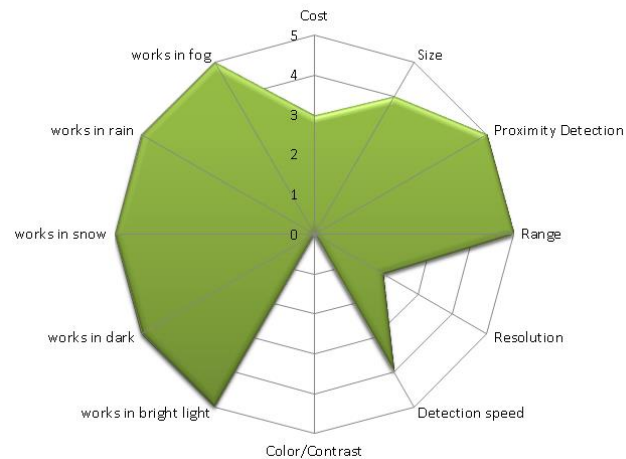


# LiDAR vs Camera vs RADAR

## Lidar

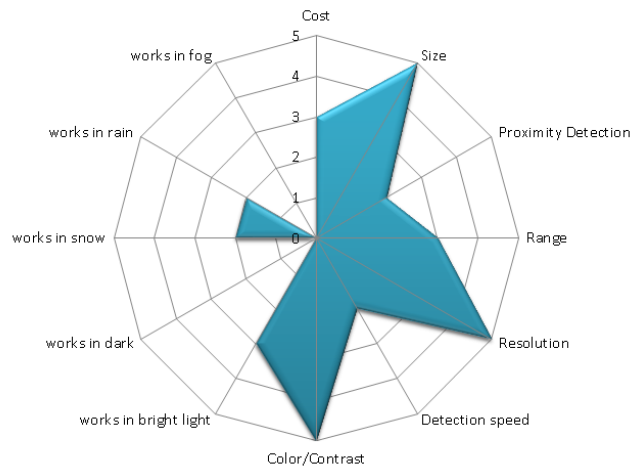


## Radar

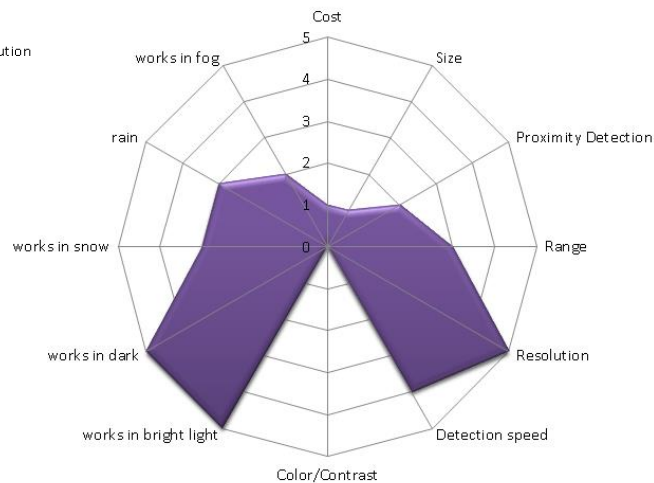


# LiDAR vs Camera vs RADAR

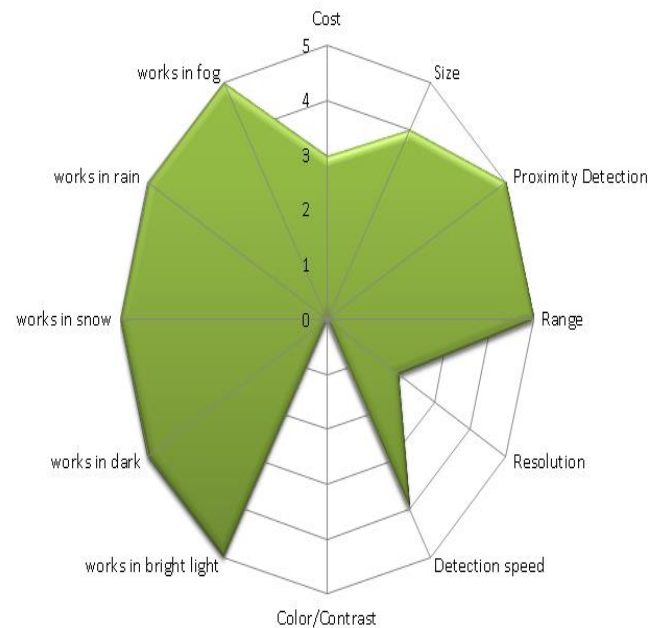
## CAMERA



## LIDAR

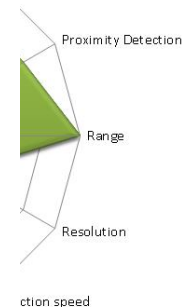
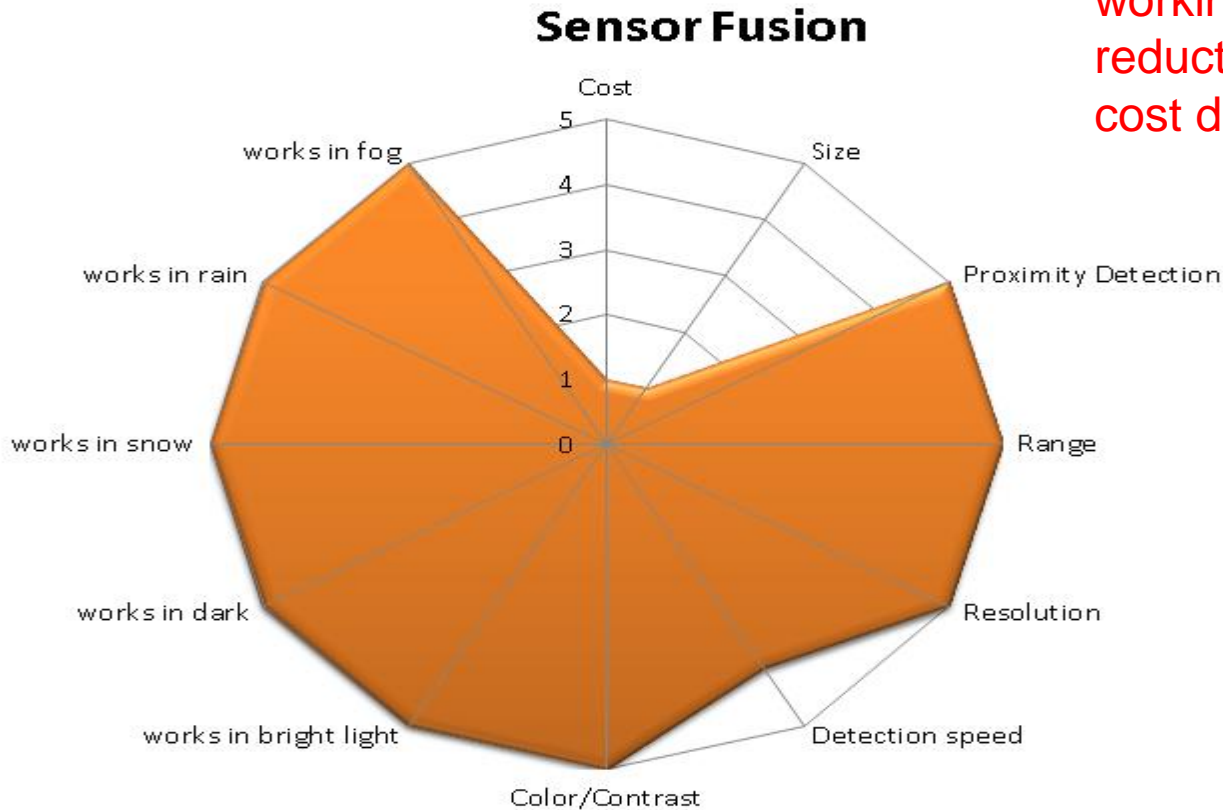
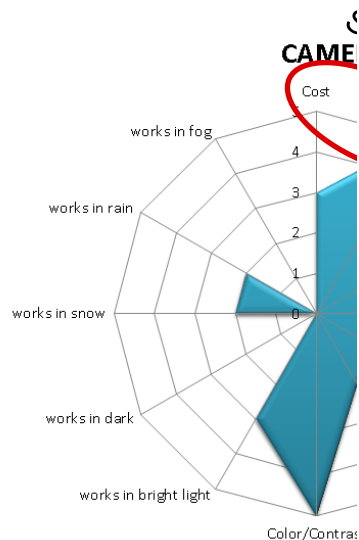


## Radar

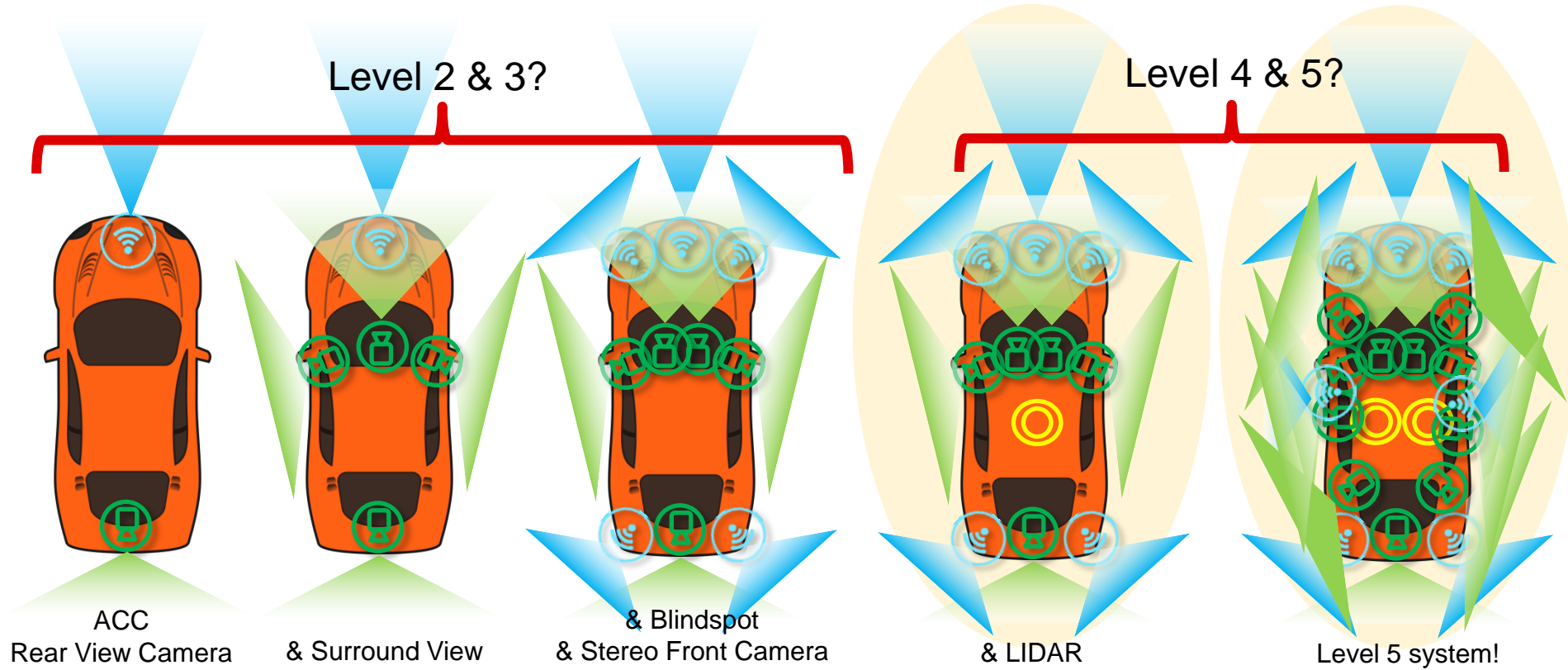


# LiDAR vs Camera vs RADAR

→ Industry is working on size reduction and cost down



# Does all Sensors are needed for level 2 & 3 ? For 4 & 5?



# Does all Sensors are needed for level 2 & 3 ? For 4 & 5?

Elon Musk still doesn't think LIDAR is necessary for fully driverless cars

*'In my view, it's a crutch'*

By Andrew O'Hanlon | @andrewohanlon | Feb 7, 2018, 6:45pm EST

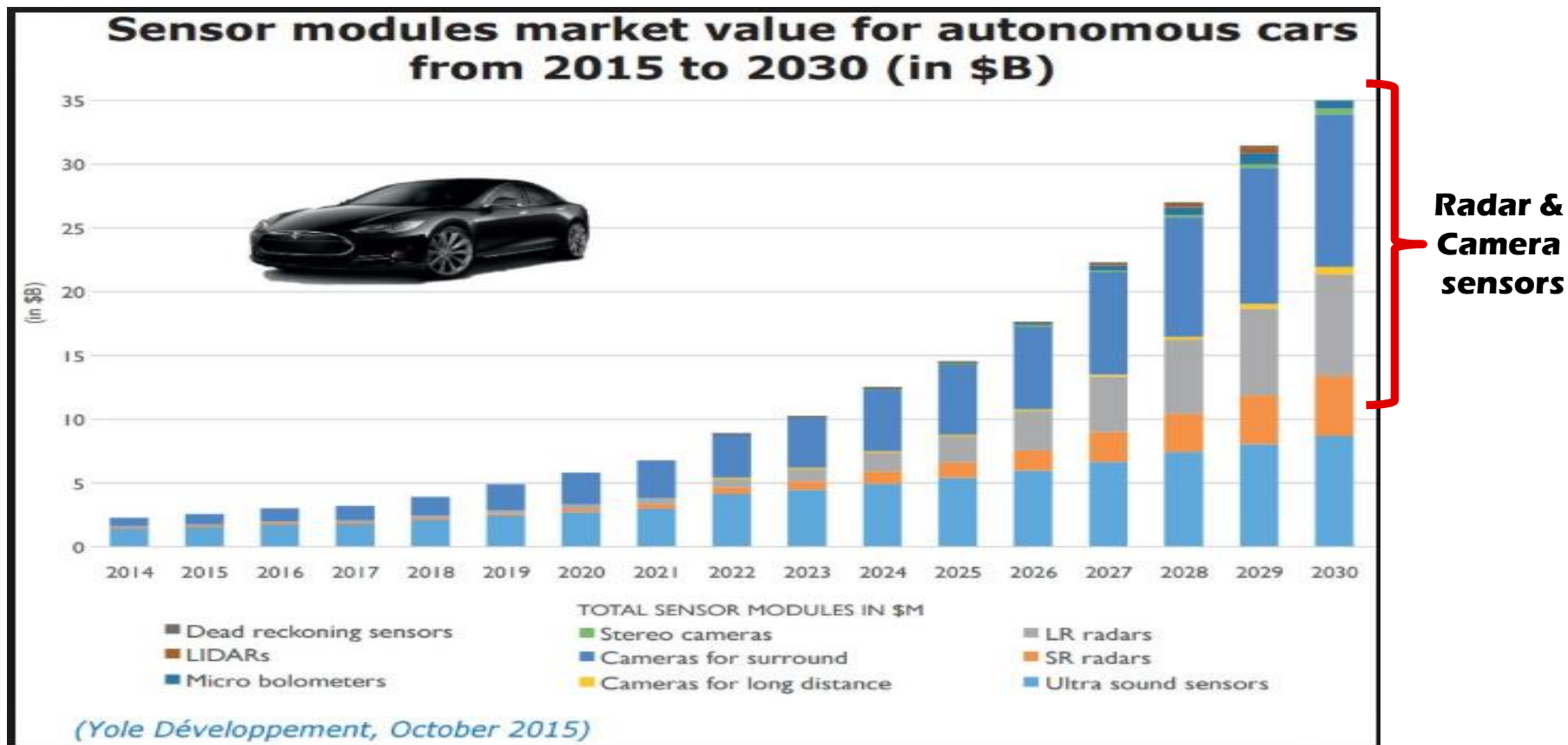
f t SHARE



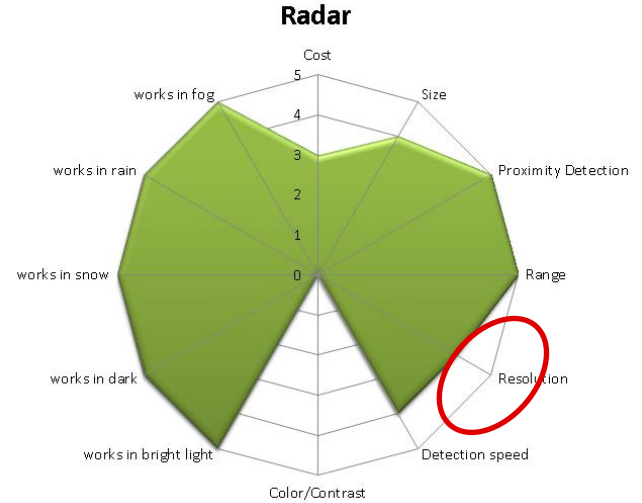
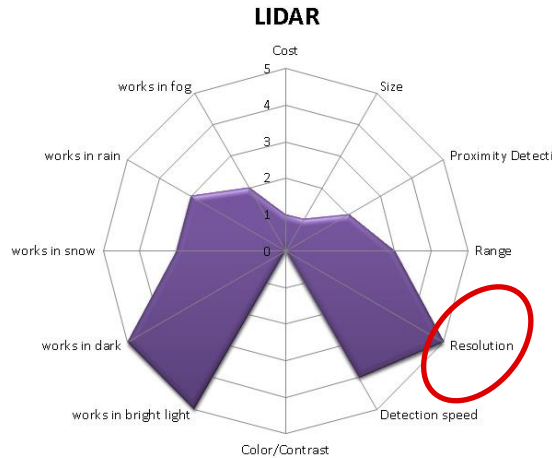
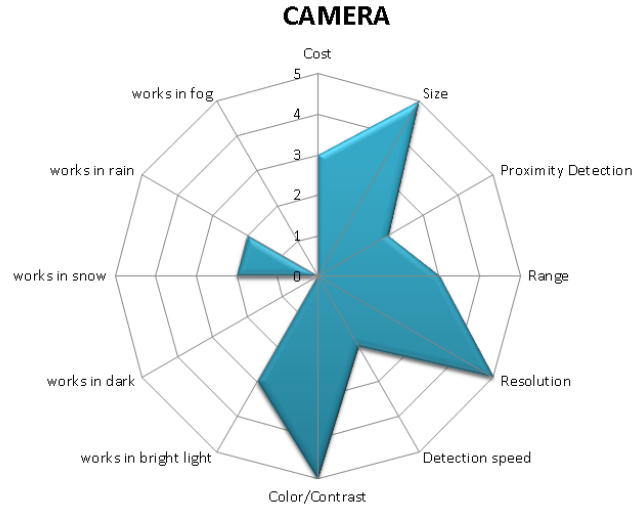
Photo by Asa Mathat



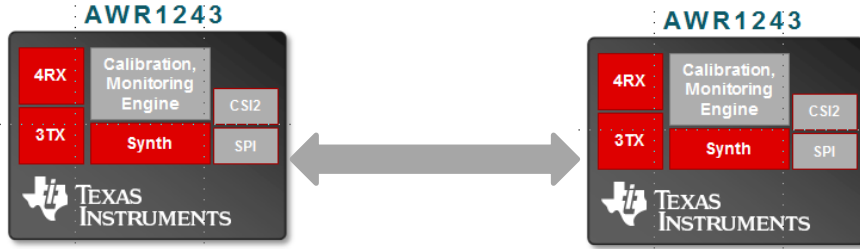
# Does all Sensors are needed for level 2 & 3 ? For 4 & 5?



# Why Imaging Radar is a Game Changer?

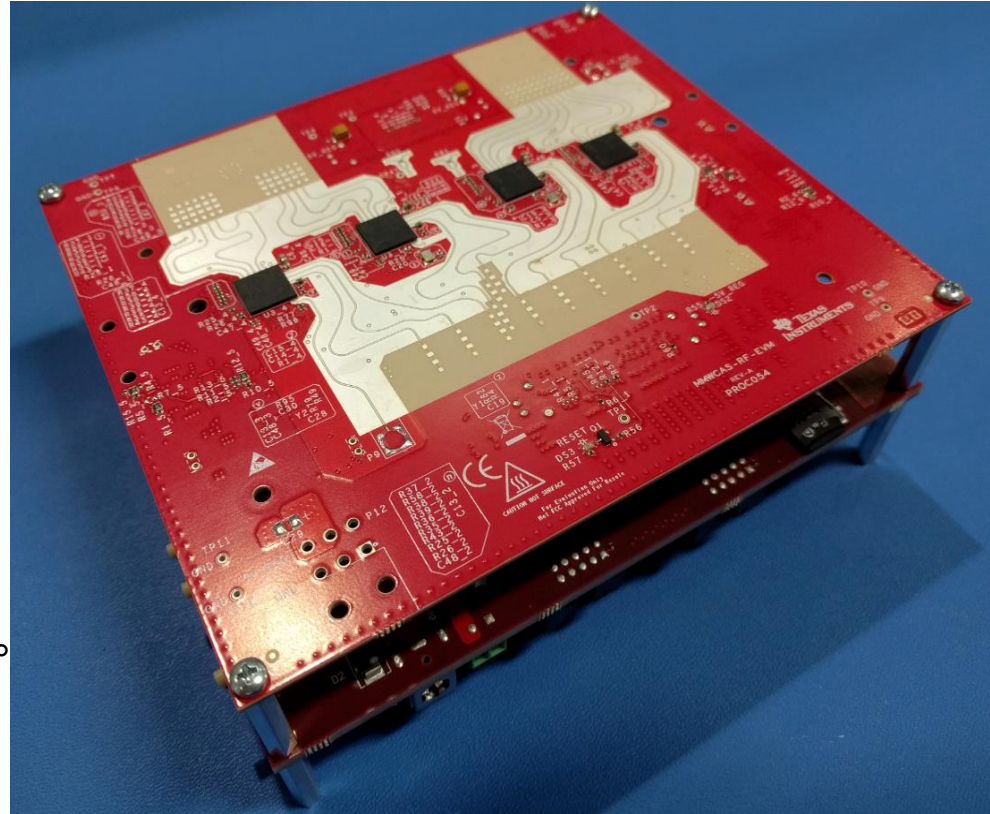


# Imaging Radar – First RF CMOS Cascade solution



The four devices are synchronized and work as a single unit, coherently processing data from all the antennas

- Pedestrian detection at  $> 140\text{m}$
- Car detection at  $> 350\text{m}$
- Azimuth / Elevation\* angular resolution  $< 1^\circ$

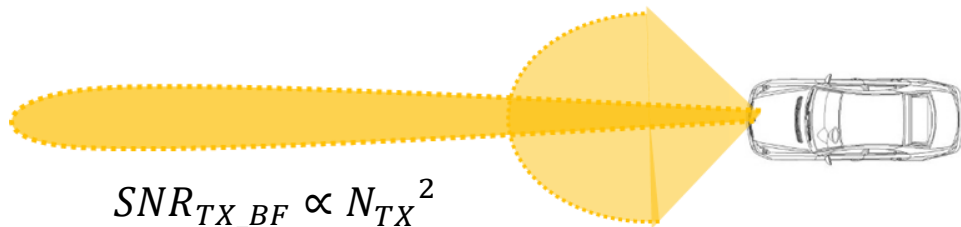
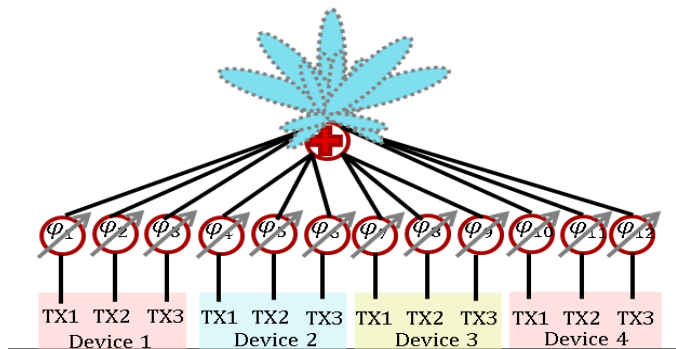


\* Might require Super Resolution

# Why Cascading?

## ➤ BeamForming

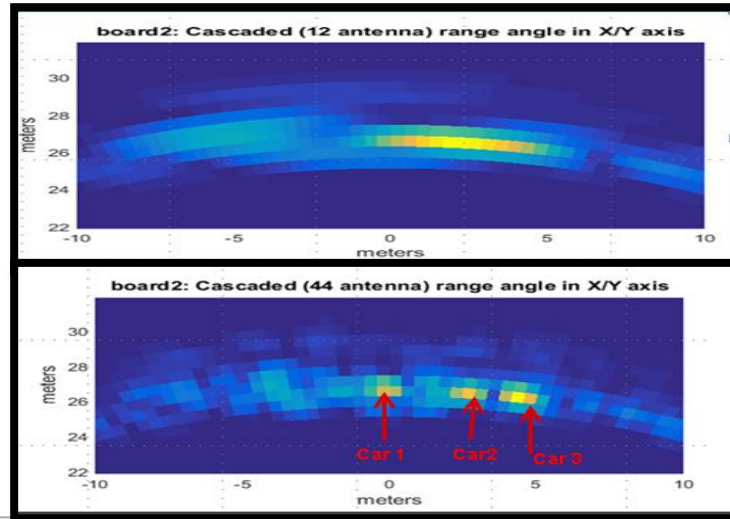
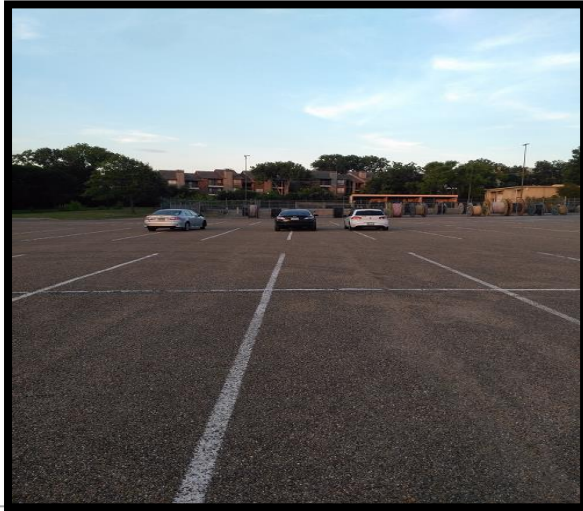
- Multiple TX antennas transmit simultaneously & coherently to create a focused beam.
- Phase shifts across TX antennas can steer the beam in a desired direction
- Coherent gain across the  $N_{TX}$  antennas improves SNR ( $20\log_{10}(N_{TX})$  vs.  $10\log_{10}(N_{TX})$  in MIMO)  
➔ **Maximum detection range - 350m Vs 120m with single chip**



$$SNR_{TX\_BF} \propto N_{TX}^2$$

# Why Cascading?

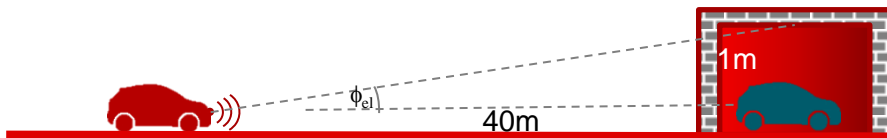
- **MiMo** - Angle resolution ( $\theta_{\text{res}}$ ) is the minimum angle separation for two objects to appear as separate peaks in the angle-FFT.
- Improving angle resolution
- A 2 TX / 4 RX can achieve a theoretical angle resolution of only  $15^\circ$
- TI imaging Radar with 192 virtual channels (four chip cascade) can achieve down to 0.6 degree of Azimuth and Elevation\* Angle resolution



$$\theta_{\text{res}} = \frac{2}{N_{TX}N_{RX}}$$

\* Might required Super Resolution

# Why Imaging Radar is a Game Changer?



static truck stalled under a bridge

$$\phi_{el} = 1.4^\circ = \arctan(1\text{m}/40\text{m})$$

Today: Typical  $5^\circ$ \* Angle Resolution Front Radar →

$$\tan(5^\circ) = X/40 \rightarrow X = 3.5\text{meter}$$

**Imaging Radar <  $1^\circ$  both Azimuth & Elevation**



"...radar system is programmed to ignore high-mounted objects such as road signs and, possibly, the flanks of a semi truck, to avoid undesired braking events..."

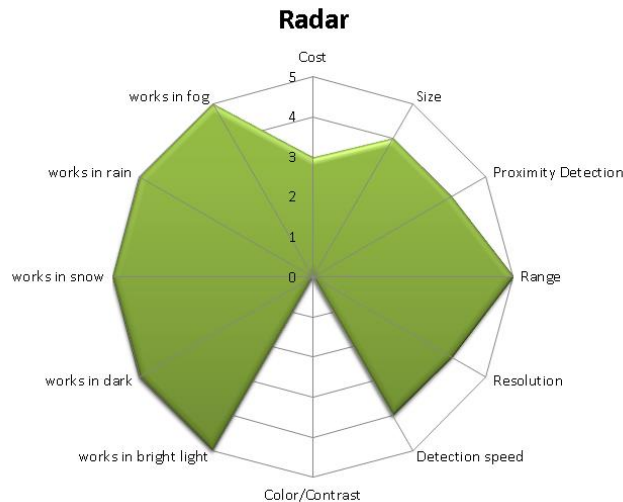
**The Radar Sensor will become the primary sensor in the car**

\* Might required Super Resolution

# Summary - Why Imaging Radar is a Game Changer?

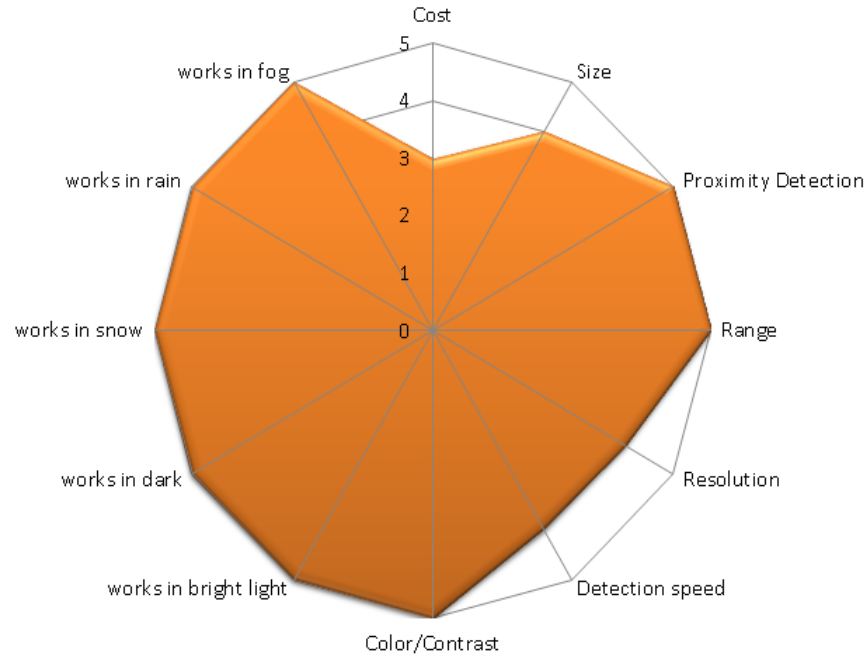
With Imaging Radar we are able to:

- ✓ Improve the Angle Resolution by a factor of  $\sim N_{TX}N_{RX}$
- ✓ Improves SNR ( $20\log_{10}(N_{TX})$  vs.  $10\log_{10}(N_{TX})$  in MIMO) to significantly increase the range
- ✓ Significantly improve AV level 2 & 3 system cost by potentially Eliminate few of the sensor

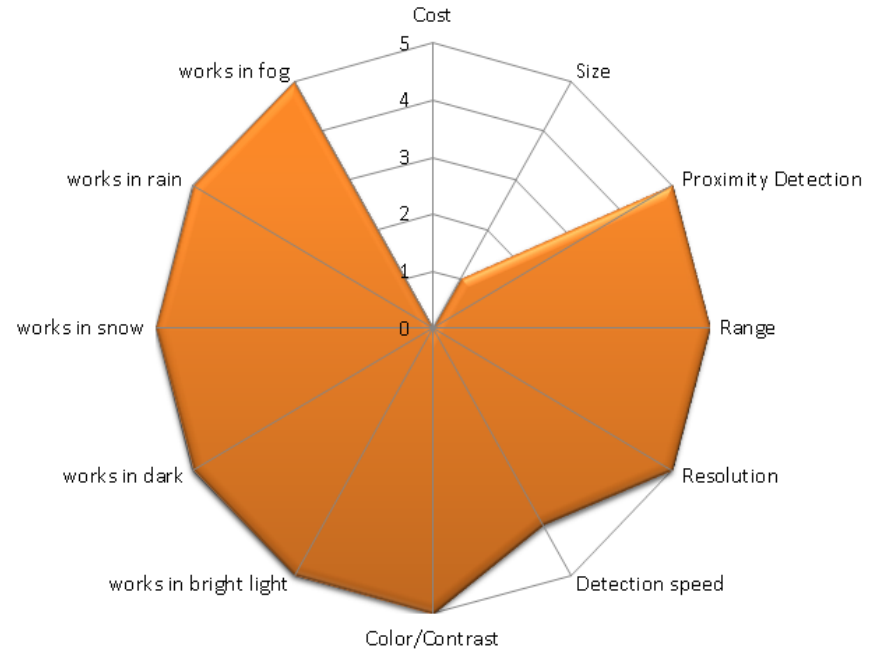


# Summary - Why Imaging Radar is a Game Changer?

## Sensor Fusion - Camera + Radar



## Sensor Fusion - Camera + Radar + Lidar



**Questions?  
Thank You**