MSO Meßtechnik und Ortung GmbH

Radar Sensors for agricultural and construction machinery – Technologies and Applications

Dr. Peter Hien, MSO Meßtechnik und Ortung GmbH, 06 February 2017

This Whitepaper does – based on [1] - give an overview and outlook on selected Radar sensors technology and applications for off-highway agricultural and construction machinery. The Focus is put on deployment and modification of selected industrially mass-produced components and modules.

1 Radar History

Radar : Radio Detection and Ranging stands for several techniques and devices for detection and ranging based on radio frequency electromagnetic waves (at least for non-quantum-physicists). Radar provides for contactless detection, positioning and identification of ojects and its parameters e.g. speed, distance and angle.

The development of Radar began more then a hundred years ago. Christian Hülsmeyer applied in 1904 for a patent on a „procedure to signal metal objects to an observer by means of electro-magnetic waves“. This so-called Telemobiloskop from Hülsmeyer has been successfully demonstrated but didn´t become a commercial success.

Military technology has been and is a prime application area of Radar technology. With regard to military applications Radar has been expedited for e.g. aerial surveillance, shipping traffic and on-board Radar for airplanes.

In agricultural machinery Radar has been adopted early beginning already more then 30 years ago for contactless measurement of true-ground speed (TGSS True Ground Speed Sensor). TGSS is based on the measurement of the Doppler frequency shift proportional to speed by means of Gunn elements and Horn antennas (today in combination with dielectric focussing lenses with smaller overall size).

Up-to-date these TGSS´s are applied in volume on e.g. Tractors as a basis for closed-loop control systems for spreading application (Seeding, fertilizer application, plant protection) and for wheel slip control.

In recent years Motion Detectors based on Doppler–Radar found wide-spread use e.g. for automatic door-openers. These Radar Doppler Frontends can be versatily applied e.g. for speed measurement and detection of material flow parameters as exemplified below.

An exponential growth in development and unit numbers in combination with massive cost reduction comes in the last years out of the automotive sector and motion detectors. As one of the first car manufacturers Mercedes-Benz introduced the ACC Bosch Distronic in serie´s production. At first applications were in the premium segment. Nowadays radar technologies are widely spread in applications in vehicules. Keywords outlining the applications for automotive detection and surveillance are (see Fig. 1) :
ACC Adaptive Cruise Control, blind spot monitoring, cross-traffic alert, pre-crash detection, automated parking, perimeter surveillance, Radar Cocoon ….

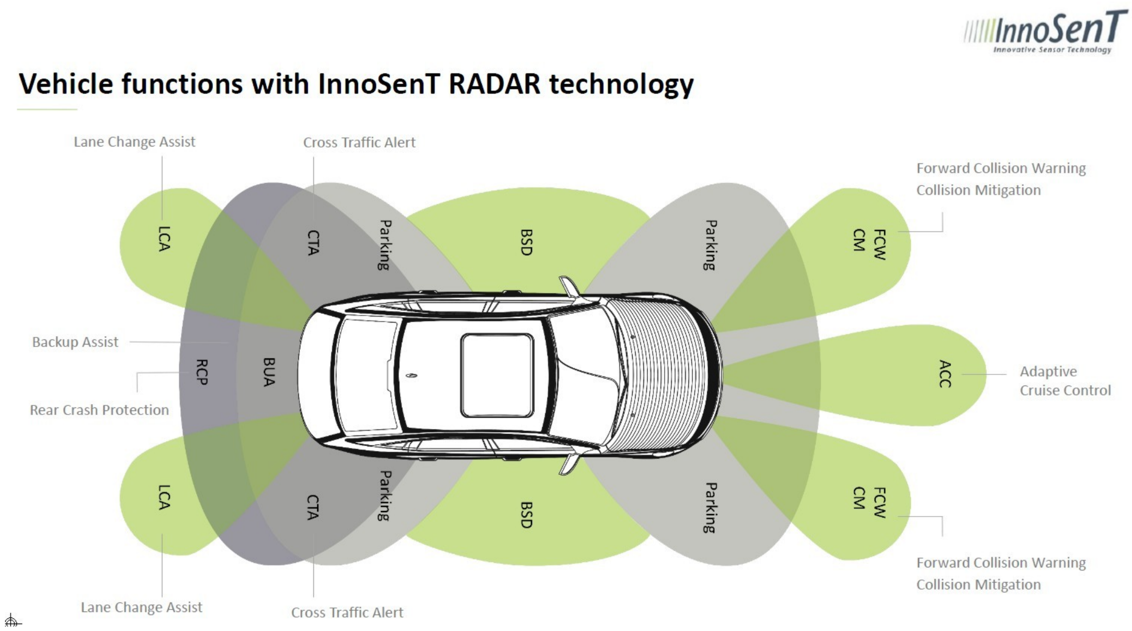

Fig. 1 : Radar applications on vehicles [2]

The further development of ADAS Advanced Driver Assistance Systems towards partial and fully autonomous Systems is foreseeable. Whereas Radar Sensor Technology is **one** element in sensor fusion systems with eg. Cameras and LIDAR (light detection and ranging).

The recent exponential development of Radar Technology has been enabled by parallel development in semiconductor Technology, digital signal processing, powerfull MCUs, DSPs and FPGAs, Algorithms and their software implementation.

2 Radar - Basics

The frequency band of radar systems in practical use is mainly between 24 GHz to 129 GHz. International reglementations do apply for so-called ISM (Industrial Scientific Medical) frequency band at 24, 60, 77 and 120 GHz.
The irradiated power of up-to-date small Radars is very low at e.g. 10 to 20 mW EIRP (Equivalent Isotropically Radiated Power) compared to the peak power of a GSM-1800 mobile phone of 1,000 mW or 200 mW of a LTE mobile phone.
The signal power received after diffuse reflection from an object is computed according to the so-called „Radar equation".

$$\frac{P_e}{P_s} = \frac{g^2 \cdot \lambda^2 \cdot \sigma}{(4\Pi) \cdot D^4}$$

Whereas meaning:

P_e	Power of the signal received
P_s	Power transmitted
λ	Wavelength of the Signal transmitted (e.g. 12 mm at 24 GHz, 5 mm at 60 GHz)
σ	Radar Cross Section of an object (RCS)
D	Distance between Radar Sensor and object
g	Antenna gain with the same transmitting and receiving antenna

The Radar equation allows to determine the Power received P_e depending on the power transmitted P_s, the distance and properties of the object.

The RCS of an object is a complex quantity to be determined experimentally. The RCS depends on the form and material properties of the object. The RCS of a human equals that of a squashed Soda Can. Whereas the convex bottom of the Soda Can due to focussing depending on the alignment to the Radar has a very big RCS.

3 Radar – Applications on agricultural and construction machinery

Agricultural and construction Off-Highway machinery are applied in an exceptionally tough and challenging environment characterized by dust, extreme temperatures and temperature variations, fog, rain, humidity, soiling, wind etc.

3.1 Speed of vehicles and material flow

First deployments of Doppler-Radar for contact-less, slip-free speed measurement of vehicles – so called TGSS True Ground Speed Sensors (Fig. 2) – do reach back well over 30 years. On agricultural machinery this technology has been early adopted and is still in use in high quantities. The necessity of high precision slip-free speed measurement as a basis for all kinds of monitoring and control applications is undisputable.

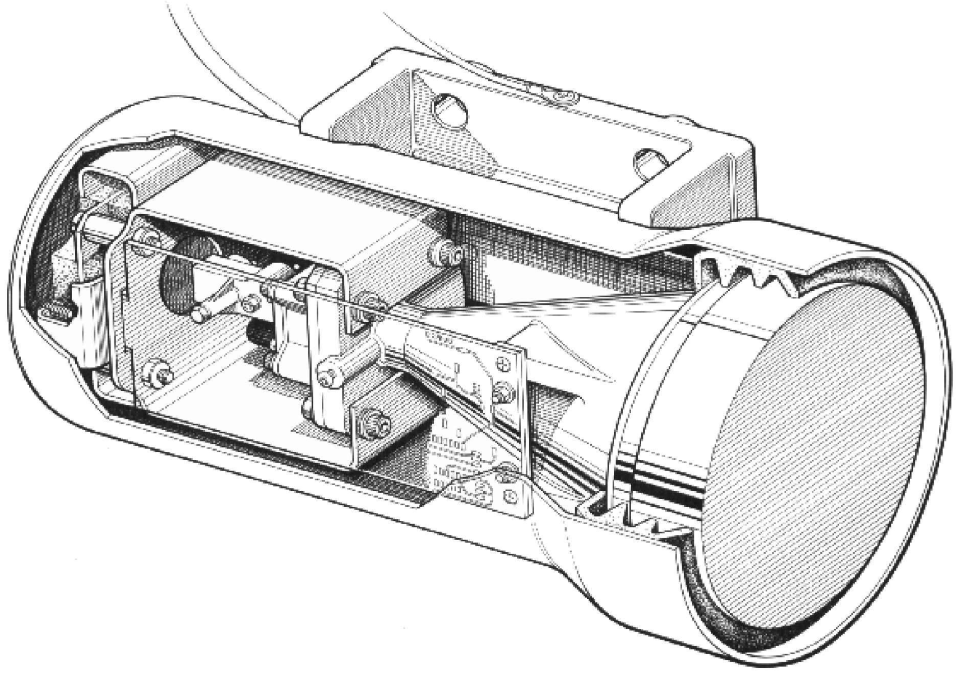

Fig. 2: TGSS from RDS Technology of an early make [3]

Radar speed sensors in a so-called Janus Configuration (see Fig. 3) with two Radar-Frontends Pointing forwards and backwards are state-of-the-art decreasing errors due to varying angle of incidence and pitch, yaw and roll movements of the vehicle.

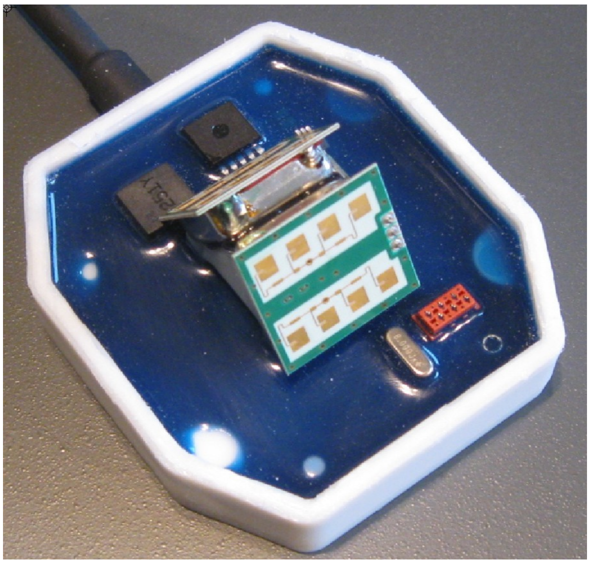

Fig. 3: Radar speed sensors in Janus Configuration, left: MSO SpeedWedge, right: John Deere Radar Sensor; Corporate photographs

Doppler Radar Sensors also do provide for soluitions for speed measurement of product flows (e.g. in the spout of a forage harvester), on conveyor belts etc.

3.2 Measurement of material flow parameters and properties

Radar Sensor Technology does provide for new solutions for detection and monitoring of flow of particulate materials (e.g. Seeds, mineral fertilizer) and liquids in ducts and free thrown material flow.

Fig. 4: MSO SeeDector Sensor mounted (left); MSO SeeDector Sensor opened (mid); Silver medal award for MSO from the DLG novelties comission at Agritechnica 2011 (right); Corporate Photographs MSO

The MSO SeeDector Sensor [4] is applied for measurement of thopughput and speed of material flow of seeds and mineral fertilizer and liquids like slurry or liquid fertilizer conveyed in ductwork. Advantages of Radar are exemplified: unsusceptible to dirt and incrustation inside the ductwork, measuring through dielectric material (plastic pipes / hoses). Due to the Doppler measurement method **only** moving material is being detected.

The MSO SeedMon System for throughput and blockage monitoring integrates the SeeDector Sensors in a flexible system´s solution with Hubs and on-board computer with dedicated software for retrofit or OEM applications (s. Fig. 5).

Fig. 5: MSO SeeDector Sensors and Hub on a seed drill (left), on a slurry distribution head (mid), Integration in the MSO SeedMon System for Blockage Monitoring (right) [5]

Another application which has been implemented based on the Doppler Radar Method is the measurement of the distribution of a thrown flow of particulate material e.g. mineral fertilizer. The systems Axmat (Fig. 6) from the Company Rauch Landmaschinen – a joint development with MSO – and Argus Twin (Fig. 7) from the Company Amazonen Werke detect the distribution of the material in the drop off area of the disc and control it by adjusting the material flow drop point on the disc.

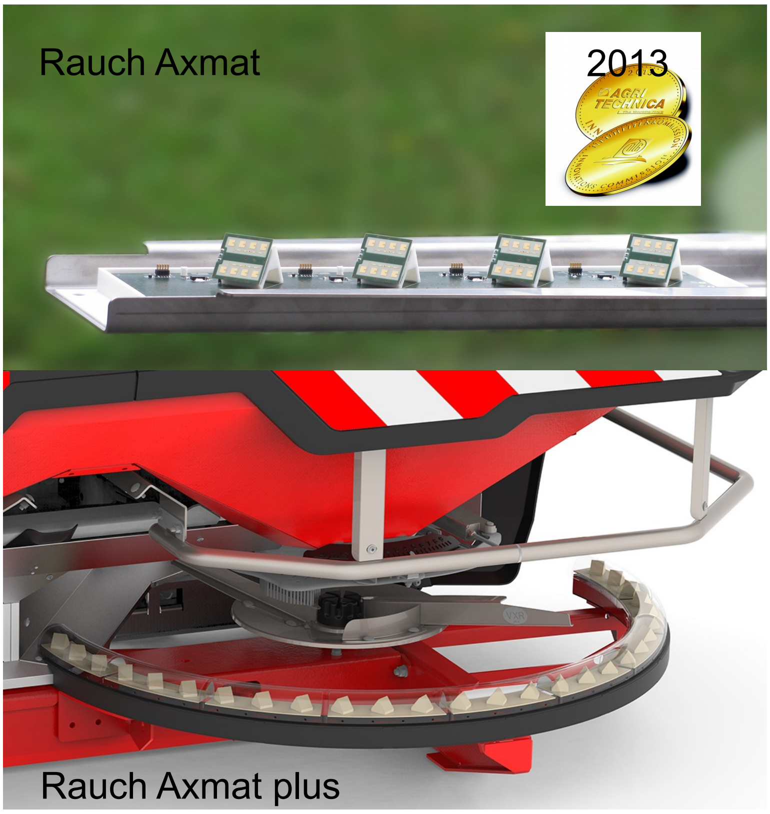

Fig. 6: Rauch Axmat picture above : Swivel arm system for detection of lateral material distribution on a disc spreader (Corporate photograph MSO); below : Rauch Axmat plus as a stationary ring-segment with 27 Radar Sensors (Press-Release Photograph Rauch)

Fig. 7: Argus Twin from Amazonen Werke for the detection of lateral distribution of the material on disc spreader [6]

3.3 Distance Measurement

Up-to-date small FMCW Radar Systems for distance measurement (e.g. see Fig. 8) do have multi-target Capabilities, meaning several distances to objects in the measurement scenario can be detected at the same time thus providing for improved monitoring and control. E.g. measuring the distance to crop canopy / gras / stubble and to the soil at the same time does improve monitoring and control of height and position of cutter bars, booms, pick-ups, screeds etc. In comparison to ultrasonic distance sensors Radars are unsus-ceptible against machine noise, wind and air scintillation due to temperature gradient.

Fig. 8: MSO RaDist distance sensor, Corporate Photograph MSO

4 Radar applications on agricultural and construction machinery – an outlook

4.1 Development Trends

In particular automotive Applications with their exponential growth do provide for a strong technological momentum and new solutions. Developments from other mass markets like HMI Human - Machine Interface respectively gesture control like in Project Google ATAP (Advanced Technologies and Projects) Soli in cooperation with Infineon ([7] and [8]) are on the way and provide for useful applications on agricultural and construction machinery.

Development trends and -lines of recent years do further proceed. Small radars with higher frequencies increasing from 24 to 77 GHz, 120 GHz and 240 GHz accompanied with smaller size and higher integration are implemented.

4.2 Integration

At the current and foreseeable state-of-the-art discret system components are being integrated in digital frontends and chipsets.

- Integration of Radar high frequency elements in SiGe Chips e.g. Infineon BGT24MTR12 at 24 GHz
- Integration of chipsets comprising Radar high frequency part and processing unit with Interface for integration e.g. CAN-FD, Flexray, BroadR-Reach (Example NXP Chip-set [9])

The Integration of Radar Frontend and processing unit in a Chipset enables very compact and efficient small Radars (see Fig. 9).

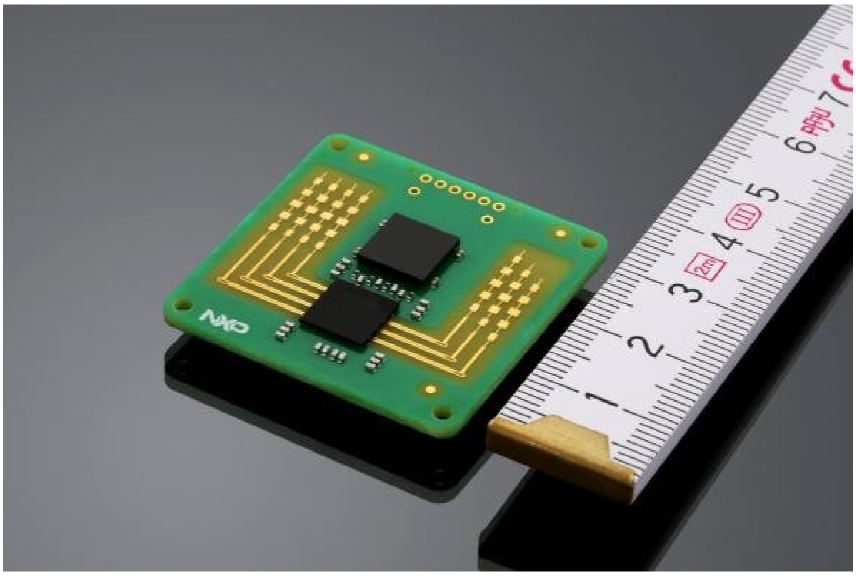

Fig. 9 : 77 GHz Near Field Radar, Design concept from NXP with 3 x Transmit- and 4 x Receive-Antennas [9]

Das Google Soli Project (see Fig. 10, [7], [8]) with a highly integrated 60 GHz Radar system targets the mass market of contactless gesture control.

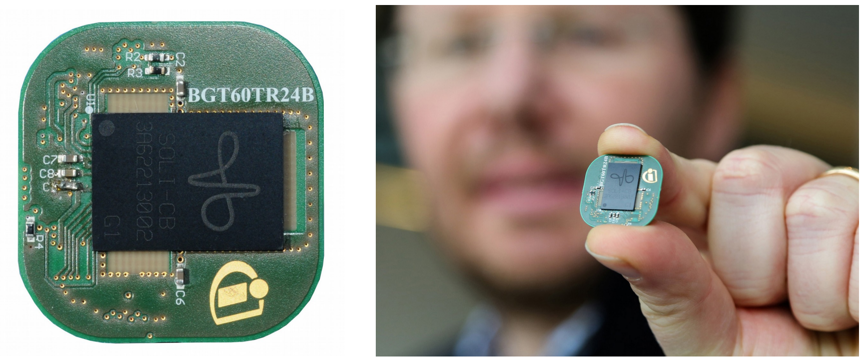

Fig. 10: Development Kit of Google ATAP Soli Project, integrated 60 GHz Radar for gesture control with transmit and receive antennas in one package , left: PCB with Infineon BGT60TR24B Radar Chip [7], right: comparison of size [8]

The joint venture SUCCESS accomplished the Integration of a 120 GHz Radar Chip with Antennas (see Fig. 11) in one Package.

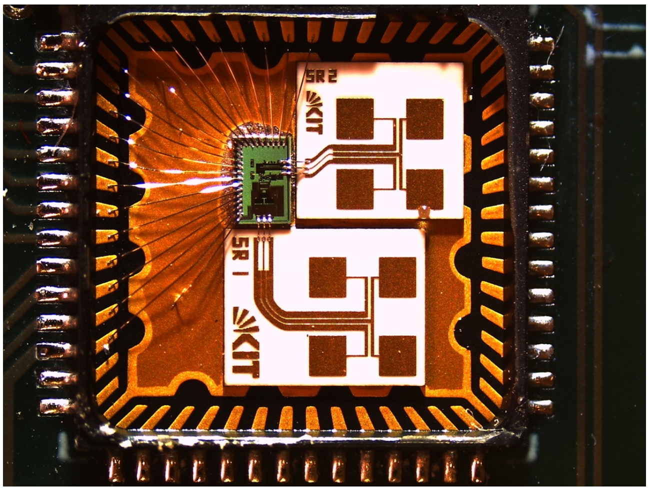

Fig. 11: 120 GHz Radar Chip in a 8x8 mm QFN (quad flat no leads) Package with transmit- and receive antennas, Corporate photograph KIT IHE [10]

The Integration of the Radar Chip with Antennas in one Package enables compact powerfull small radars (see Fig. 12).

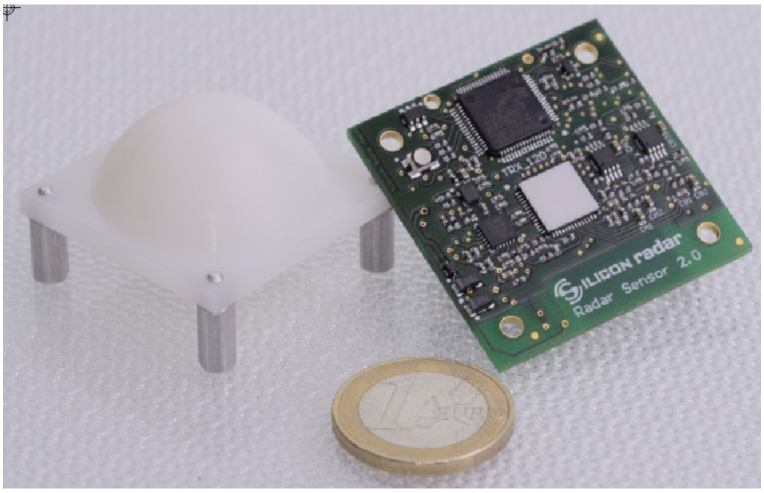

Fig. 12: Evaluation Kit for a 120 GHz FMCW Radar from Silicon Radar [11] with dielectric lens.

4.3 Near Field Perimeter Surveillance

At the current state of semi-autonomous guidance systems („parallel guidance"), high working width and -speed applications the perimeter surveillance of agricultural and construction machinery is a necessity already. It´s the aim to achieve safe and reliable operation and to prevent damage and downtime on machines. Radar offers an approach „stand alone" or in Sensor Fusion with optical

systems (Camera, Cameras with 360° View stitching, Lidar (Light detection and ranging), Scanner) advantageous in the given challenging environment (dust, dirt, fog, ….).
Examples of applications are: Surveillance of boom perimeter on e.g. Sprayer, pneumatic fertilizer spreader, cutter bars and pick-ups, harvesters with trailers driving in parallel.

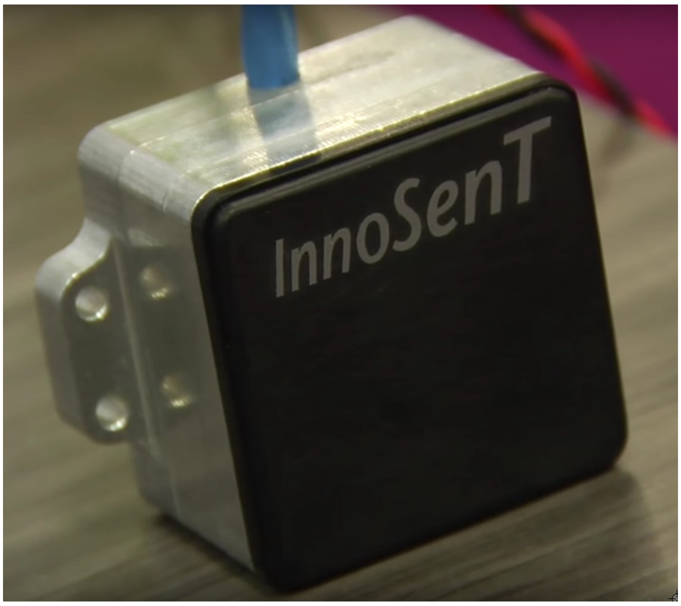

Fig. 13.: Implementation of a 77 GHz near field Radar for Perimeter Suveillance of vehicles from InnoSent [12]

Fig.13 shows a very compact and highly integrated near field Radar based on a 77 GHz Chipset from NXP [9]. The System integrates perimeter surveillance with processing and a BroadR-Reach automotive Ethernet Interface for Integration.
A Prerequisite for future fully autonomous agricultural and construction machines are solutions for safe, robust, reliable and cost-effective perimeter monitoring and surveillance. The application of accordingly adapted and modified solutions from the automotive sector seems promising for these applications.

5 Wrapping up

Radar Technology looks back on a history of well over 100 years. The exponential development of the last years occured in a speed and innovation height never thought possible. Boosting the technology is the automotive sector with a broad range of applications and a very high number of units.

This Whitepaper exemplified novel applications for measuring material flow and multi-target capable distance measurement. An outlook on future developments and applications of perimeter surveillance is given.

It is rewarding to follow the development of Radar Technology and deploy it for optimization of agricultural and construction machinery and applications.

6 References

[1]: Peter Hien: Presentation at the 74. International VDI conference Land.Technik 22.11.2016, Cologne, „Radarsensorik in der Landtechnik – Technologien und Anwendungen“

[2] : Corporate presentation InnoSenT, Donnersdorf : „Leading in Radar“

[3] : TGSS Model 012 from RDS Technology Ltd., Specifications 24/06/98

[4] : „Method for measuring a material flow by means of microwaves“, Patent No. US 8,915,144 B2 Dec. 23, 2014

[5] : Corporate Photographs MSO and data sheet MSO SeedMon (SeedMon-De-2015 V3_2) http://www.mso-technik.de

[6] : Amazonen Werke Corporate brochure ZA-TS Mi 5300 11.15

[7]: Google ATAP & Infineon joint effort on gesture control with radar technology 23.05.2016 from Graham Prophet, EDN Europe http://www.edn-europe.com/news/google-atap-infineon-joint-effort-gesture-control-radar-technology

[8] : Press release Infineon: „Gestensteuerung revolutioniert Bedienung von Geräten – Google ATAP und Infineon erweitern Partnerschaft bei „Soli“-Radartechnologie“; http://www.infineon.com/cms/de/about-infineon/press/press-releases/2016/INFXX201605-061.html

[9] : CES: NXP zeigt weltweit kleinsten 77GHz-Single-Chip-Transceiver, Götz Fuchslocher am 05. Januar 2016; https://www.automobil-produktion.de/maerkte/ces-nxp-zeigt-weltweit-kleinsten-77ghz-single-chip-transceiver-114.html

[10] : Prof. Dr.-Ing. Thomas Zwick, KIT IHE Institut für Hochfrequenztechnik und Elektronik (IHE), „Silicon-based Ultra Compact Cost-Efficient System Design for mmWave-Sensors (SUCCESS)“, https://www.ihe.kit.edu/3670_3701.php

[11] : Corporate brochure from Silicon Radar

[12] : Nao Motoyama NXP, 31.05.2016, „Millimeter Wave Radar for Breakthrough Auto Designs“, https://www.youtube.com/watch?v=9TNbJoqdmxM, Screenshot @ 1:32