Program

Monday, November 23 8:45 - 9:00

Opening Session

Chair: Christoph F Mecklenbräuker (TU Wien, Austria)

Monday, November 23 9:00 - 10:00

Deep Learning for Perception in Autonomous Vehicles

Keynote

Sepp Hochreiter

Chair: Christoph F Mecklenbräuker (TU Wien, Austria)

Monday, November 23 10:00 - 10:35

Machine Learning and Classification

Chair: Christoph F Mecklenbräuker (TU Wien, Austria)

10:00 *Analysis of pedestrian gait patterns using radar based Micro-Doppler Signatures for the protection of vulnerable road users*

Patrick Rippl (University of Applied Sciences Ulm, Germany)

This contribution provides an approach to isolate and mathematically describe the movement of single body parts in the context of Doppler radar measurements. Using a Fourier series approximation, the quasi-periodic Micro-Doppler signatures of single body parts, namely the torso and the knee, are displayed. The motion of these body parts show certain features as the coefficients of the approximation indicate. As a result, the Fourier coefficients deliver a characteristic pattern describing the Micro-Doppler signatures of the single body parts. The frequency component coincides with the stride rate of the pedestrian.

10:07 *Deep Open Space Segmentation using Automotive Radar*

Farzan Erlik Nowruzi (University of Ottawa & Sensor Cortek Inc, Canada); Dhanvin Kolhatkar (Sensor Cortek Inc & University of Ottawa, Canada); Prince Kapoor, Fahed Al Hassanat and Elnaz Jahani Heravi (Sensor Cortek Inc, Canada); Robert Laganiere (University of Ottawa, Canada); Julien Rebut (Valeo, Canada); Waqas Malik (Valeo Schalter und Sensoren, Germany)

In this work, we are proposing the use of radar with advanced deep segmentation models to identify open space in parking scenarios. A dataset of radar observations is collected and annotated. Deep models are evaluated with various radar input representations. Our proposed approach achieves low memory usage and real-time processing speeds, and is thus very well suited for embedded deployment.

10:14 *CNN Based Road Course Estimation on Automotive Radar Data with Various Gridmaps*

Robert Prophet and Yi Jin (Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany); Juan Carlos Fuentes Michel, Anastasios Deligiannis and Ingo Weber (BMW Group, Germany); Martin Vossiek (LHFT, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany)

Automotive radar is a promising technology with regard to path planning, since radar systems offer a comparatively long range and are robust against bad weather conditions. In this paper, we use Convolutional Neural Networks (CNN) to determine the current road course from radar point clouds. For this purpose, we first transform the radar point cloud into various gridmaps, which then serve as an input for the CNN. The quality of the road course estimation is evaluated using a test dataset. Exemplary test results showed an average deviation of less than 91 cm at a range of 100 m between the ground truth and the estimated road course. These excellent results prove that CNN processing of radar measurements is an attractive option for reliable and precise road course estimation.

10:21 *Human Gesture Classification for Autonomous Driving Applications using Radars*

Karim Ishak (University of Ulm, Germany); Nils Appenrodt (DAIMLER AG, Germany); Juergen Dickmann (Daimler AG, Germany); Christian Waldschmidt (University of Ulm, Germany)

The era of fully autonomous driving requires the vehicles to be able to understand the surrounding environment in full. Police officers and pedestrians perform different gestures and movements in streets on a daily basis. Detecting these movements and gestures and classifying them are critical tasks that need to be achieved so as to get ready for autonomous driving. Radars, which are nowadays irreplaceable in the autonomous vehicles, can capture the gestures and their varying signatures with time. Various important traffic scenarios, that occur everyday on the streets are going to be the focus in this paper. A signal processing chain and classification of the scenarios using convolutional neural networks is going to be presented. Data representation is also introduced to have a better insight for the data distribution.

10:28 *Bayesian approach to Point Cloud Processing of Multi Sensor Radar Fusion for effective Pedestrian Classification in Automotive Surround View*

Santhana Raj and Dipanjan Ghosh (PathPartner Technology, India)

Surround view for automotive are being performed using cameras to provide a complete view of the vehicle surrounding to avoid any blind spot while driving or for parking assist. Radar based surround view for automobile further improves the object detection capability. This paper explains the point cloud processing that has been performed on multi sensor Radar data. The initial processing handles the merging of four radar sensors' point cloud data which are positioned on four sides of the automobile. Once the data is merged by appropriate transformation, based on sensor position and facing angle, a Bayesian approach to grouping of object points which appear in the overlapping field of view, and there by avoids it being detected as multiple objects. This merged object provides additional information which can be effectively utilized for pedestrian classification. This paper details the specific challenges related to achieving surround view by using a 77GHz radar sensor and the advantages in pedestrian classification.

Monday, November 23 10:35 - 10:56

Focused Session Vehicular 5G

Chair: Christoph F Mecklenbräuker (TU Wien, Austria)

10:35 *Performance Evaluation of OTFS Over Measured V2V Channels at 60 GHz*

Thomas Blazek (Silicon Austria Labs GmbH, Austria); Danilo Radovic (TU Wien, Austria)

This paper presents an analysis of the Orthogonal Time Frequency Space (OTFS) modulation scheme when applied to realistic channel situations. OTFS modulates symbols in delay-Doppler domain, hoping to exploit diversity in both. The penalty for doing this is the requirement of complex interference cancellation equalizers, as this domain incurs a strong amount of intercarrier and intersymbol interference. We conduct this analysis using measured millimeter Wave vehicular channels, and we assume typical physical layer settings for a performance analysis. Our results show that there is a challenging trade-off between channel conditions that are easy to equalize and channel conditions that exploit the two-dimensional diversity that OTFS provides. We observe either a good overall performance that is barely enhanced by employing OTFS, or we see performance gains through OTFS, with a bad overall performance.

10:42 *Optimized Diffuse Scattering Selection for Large Area Real-Time Geometry-Based Stochastic Modeling of Vehicular Communication Links*

Benjamin Rainer (AIT Austrian Institute of Technology GmbH, Austria); Markus Hofer (AIT Austrian Institute of Technology, Austria); Laura Bernadó (Austrian Institute of Technology, Austria); David Löschenbrand (AIT Austrian Institute of Technology GmbH, Austria); Stefan Zelenbaba (AIT Austrian Institute of Technology, Austria); Anja Dakić (AIT - Austrian Institute of Technology, Austria); Thomas Zemen (AIT Austrian Institute of Technology GmbH, Austria)

In this paper we present a geometry-based stochastic channel model (GSCM) for mobile urban scenarios. GSCMs are very use case specific and high effort is needed to transfer existing ones to other scenarios. We propose to use OpenStreetMap data bootstrapping the geometry including the automatic placement of static, mobile and diffuse scatterers. We propose a method to distribute diffuse scatterers along buildings and roads. Our goal is to model complete city areas having the use case of real-time emulation of the wireless channel for vehicle-to-everything (V2X) communication in mind. In order to achieve this ambitious goal we propose a novel active scattering set selection based on locality-sensitive hashing (LSH). We show the trade-off between the number of selected diffuse scattering points by comparing the resulting power delay profile and Doppler spectral density to a measurement campaign.

10:49 *Co-channel Coexistence: Let ITS-G5 and Sidelink C-V2X Make Peace*

Alessandro Bazzi (University of Bologna, Italy); Alberto Zanella (Istituto di Elettronica e di Ingegneria dell’Inform. e delle Telecomunicazioni, Italy); Ioannis Sarris (U-Blox, Greece); Vincent Martinez (NXP, USA)

In the last few years, two technologies have been developed to enable direct exchange of information between vehicles. These technologies, currently seen as alternatives, are ITS-G5, as commonly referred in Europe, and sidelink LTE-vehicle-to-everything (LTE-V2X) (one of the solutions of the so-called cellular-V2X, C-V2X). For this reason, the attention has been mostly concentrated on comparing them and remarking their strengths and weaknesses to motivate a choice. Differently, in this work we focus on a scenario where both are used in the same area and using the same frequency channels, without the assistance from any infrastructure. Our results show that under co-channel coexistence the range of ITS-G5 is severely degraded, while impact on LTE-V2X is marginal. Additionally, a mitigation method where the CAM data generation is constrained to periodical intervals is shown to reduce the impact of co-channel coexistence, with less degradation on ITS-G5 performance and even improvement for LTE-V2X.

Monday, November 23 10:56 - 11:00

Short Break

Monday, November 23 11:00 - 11:14

Measurements and Characterization

Chair: Christoph F Mecklenbräuker (TU Wien, Austria)

11:00 *Phase Noise Measurements in Chirped FMCW Radar Signals*

Andawattage C. J. Samarasekera and Reinhard Feger (Johannes Kepler University Linz, Austria); Jonathan Bechter (ZF Friedrichshafen, Germany); Andreas Stelzer (Johannes Kepler University Linz, Austria)

Phase noise has a significant effect on the performance of a radar system, especially on loosely coupled cooperative radar systems, where the bi-static or the multi-static signal is down-converted by mixing it with a signal that has been generated by a different frequency synthesizer. As phase noise is known to increase the noise floor level around large target(s), it makes it impossible for detection and tracking of small target(s). Therefore, it is imperative that we are able to measure and evaluate the performance of phase noise in FMCW radar systems. In this paper, we will be presenting an experimental method to measure and evaluate the phase noise of an FMCW radar system on the chirp. The measurements have been performed for a tone frequency and for a FMCW radar chirp on the chirp. The results have been verified by comparing the tone-frequency measurements carried out by the proposed measurement method to the measurements that were performed by a signal source analyzer. The phase noise measurements were conducted using two 77-GHz FMCW radar units from different generations.

11:07 *On UWB Pulse Distortion Caused by Amplifiers and Mismatched Antennas*

David Veit (NXP Semiconductors Austria GmbH, Austria); Michael Gadringer and Erich Leitgeb (Graz University of Technology, Austria)

This publication examines the influence of amplifiers and antenna mismatch on an ultra-wideband pulse. Using a state of the art ultra-wideband chip and an external power amplifier, we analyzed the impact of gain compression on the estimated channel impulse response. In addition, the impact of multiple reflections between a mismatched antenna and the amplifier output was investigated for different electrical lengths between the two. We showed that the peak power of an ultra-wideband signal is significant for the dynamic range of the calculated cross correlation function. Furthermore, we discussed which distortion and multipath effects really have an influence on the ranging estimate of an UWB system.

Monday, November 23 11:14 - 11:56

Radar Signal Processing/Imaging

Chair: Christoph F Mecklenbräuker (TU Wien, Austria)

11:14 *Phase Error Estimation for Automotive SAR*

Masoud Farhadi and Reinhard Feger (Johannes Kepler University Linz, Austria); Johannes Fink (Robert Bosch GmbH, Germany); Thomas Wagner (Johannes Kepler University Linz, Austria); Markus Gonser and Juergen Hasch (Robert Bosch GmbH, Germany); Andreas Stelzer (Johannes Kepler University Linz, Austria)

Phase error estimation and correction plays an essential role in high-quality synthetic aperture radar (SAR) image formation. Especially in automotive applications, because of the highly non-linear driving paths, it is required to alleviate uncompensated motion errors. In this work, we use the general version of phase gradient autofocus (PGA) which is compatible with time-domain image formation algorithms. The adapted method overcomes the typical problems of conventional approaches and shows remarkable robustness against a large range of simulated errors. Furthermore, the proposed approach is evaluated on real radar data acquired by mounting a 77-GHz radar system on a bumper of a car. It is demonstrated that the implemented algorithm removes phase errors and improves the quality of automotive SAR image formation.

11:21 *Moving objects elimination towards enhanced dynamic SLAM fusing LiDAR and mmw-radar*

Xiangwei Dang (University of Chinese Academy of Sciences, China); Xingdong Liang (National Key Laboratory of Microwave Imaging Technology, Institute of Electronics, Chinese Academy o, China); Yanlei Li (Institute of Electronics, Chinese Academy of Sciences, China); Zheng Rong (Institute of Automation, Chinese Academy of Sciences, China)

Robust and accurate localization and mapping are essential for autonomous driving. The traditional SLAM methods generally work under the assumption that the environment is static, while in dynamic environment performance will be degenerate. In this paper, we propose an efficient and effective method to eliminate the influence of dynamic environment on SLAM by fusing LiDAR and mmw-radar, which significantly improve the robustness and accuracy of localization and mapping. The method fully utilizes the advantages of different measurement characteristics of two sensors, efficient moving object detection based on Doppler effect by radar and accurate object segmentation and localization by LiDAR, to remove the moving objects and use the resulting purified point cloud as the input of SLAM towards enhanced performance. The proposed approach is evaluated through experiments in various real world scenarios, and the results demonstrate the effectiveness of the method to improve the robustness and accuracy of SLAM in dynamic environments.

11:28 *Machine Learning Applied to Blockage Classification in Automotive Radar*

Matthew R Fetterman (Veoneer, USA)

Detection of radar blockage is a critical safety function for automotive radar. In this paper, we report on a machine-learning approach to classify the blockage condition in automotive radar, using detection data. We consider logistic regression, tree-bagging, and neural network approaches. We used pruning to reduce the size of the neural network to make it a viable option for embedded processors with limited memory. The results show that the classifiers, especially the neural network, can achieve high accuracy with a low false-alarm rate.

11:35 *Sub-mm Resolution Indoor THz Range and SAR Imaging of Concealed Object*

Aman Batra (University of Duisburg-Essen, Germany); Vu Viet Thuy (Blekinge Institute of Technology, Sweden); Yamen Zantah and Michael Wiemeler (Universität Duisburg-Essen, Germany); Mats I. Pettersson (Blekinge Institute of Technology, Sweden); Diana Goehringer (Technische Universität Dresden, Germany); Thomas Kaiser (Universität Duisburg-Essen, Germany)

In radar systems, the frequency range is being extended to high frequencies such as THz for sub-mm resolution. The spectrum offers high resolution due to available large bandwidth but on the contrary, propagation distance and penetration depth are limited because of smaller wavelength. The THz region suffers from higher atmospheric absorption in comparison to sub-GHz systems. In comparison to optical technology, the radar technique majorly benefits with respect to the penetration property such as cloud/smoke cover penetration and detection of concealed objects. However, the THz range and synthetic aperture radar (SAR) imaging of concealed objects are not very well established. Therefore, this paper examines this property at THz. A testbed has been set up with a bandwidth of 110 GHz at a carrier frequency of 275 GHz. The imaging of a very small metal object is performed. Firstly, the sub-mm resolution is validated with the experiment after that the range and SAR imaging are performed in which this object is covered with different types of materials. The backscattered data is processed with the image reconstruction algorithms and the results are presented in this paper with respect to sub-mm resolution and detection.

11:42 *Cognitive Pilot - Synthetic Aperture Radar*

Andrey Geltser (Cognitive Robotics LTD, Russia); Elena Velikanova and Zhargal Erdyneev (Cognitive Pilot, Russia)

This work investigates synthetic aperture radar (SAR) to automotive applications using experimental data from vehicle-mounted Frequency Modulation Continuous Wave (FMCW) radar. SAR approach for automotive radar has great attention from many research groups. But at first, most of these investigations are either based on computer simulations or measurements were obtained from special equipment (for example linear rails). Secondly, most real experiments carry out on slow car velocity (about 8 km/h) and in side-looking mode only. Not enough attention to forward-looking mode. Thirdly, the main objects for investigation are: non-moving cars, buildings, i.e. objects with large RCS. But it is interesting to analyze image with moving humans. In this work we present experimental research of automotive SAR in real city conditions, both in side-looking and forward-looking mode, with medium own velocity value (up to 50 km/h) and in the presence of moving people. The main research tasks are: * Which algorithm is preferable for SAR data processing in automotive radar? * How to improve range resolution in SAR if signal bandwidth is small? * Can we see moving human on SAR radar image? * How to operate in forward-looking SAR?

11:49 *Exploiting Compressive Sensing Basis Selection to Improve 2 x 2 MIMO Radar Image*

Neda Rojhani (University of Florence, Italy); Marco Passafiume (University of Florence & Studio MP, Italy); Matteo Lucarelli (Università di Firenze, Italy); Giovanni Collodi (Università degli Studi di Firenze, Italy); Alessandro Cidronali (University of Florence, Italy)

This paper presents a novel technique suitable to build a basis matrix for image recovery in Compressive Sensing Multiple-Input Multiple-Output (CS-MIMO) radar. The proposed technique selects the best sparsifying basis matrix through the use of Gaussian noise, achieving the R^N orthonormal space base with the sparsest structure. A comparison is made between the performance of this optimized basis matrix with both the Fast Fourier Transformation (FFT) and the Haar wavelet. Improvement with respect to optimum Nyquist criterion is quantitatively evaluated by using the effective Target peak to Secondary peak Ratio (TSR). Experimental data on a MIMO radar show that this basic matrix maintains the Field of View (FOV) while improving the angular resolution with respect to the prior sparsity matrix.

Monday, November 23 11:56 - 12:00

Short Break

Monday, November 23 12:00 - 12:35

Passive Devices

Chair: Christoph F Mecklenbräuker (TU Wien, Austria)

12:00 ***BAW Filters for 5G: Lead Geometry Impact on Current Distribution in Resonators***

Michael Fattinger and Susanne Kreuzer (Qorvo, USA)

Thermal performance and power handling of BAW filters in modern 5G capable handsets is an ever-increasing challenge. Higher integration densities (more communication bands, other functionality) and smaller form factor PCBs (slim phones, larger batteries) dictate the trend for smaller BAW filter modules [1]. The higher frequency bands included in 5G (f>3GHz) intensify this challenge due to smaller resonators inherent to the BAW technology at these frequencies. Further increasing the power density in Tx filters, which is unfavorable for power handling and thermal management. Thus, a better understanding of the heat generating mechanism in BAW resonators is of utmost importance to be able to create filter designs that are up to the task. In this paper we will focus on the electrode currents and their distribution caused by the acoustic motion of the resonators and the connecting lead geometry, which can drive unwanted localization of joule heating. The data is not generated by EM FEM simulations, but rather calculated from real world measurements of the surface motion of BAW resonators by means of interferometry.

12:07 ***BAW multiplexers for 5G: Visualizing the source of perturbed nonlinear cancellation by interferometry***

Susanne Kreuzer (Qorvo, USA)

Nonlinear (NL) performance requirements on BAW filters and modules highly increased in the past years. Next generation 5G BAW modules will serve many new frequency bands, where superior NL performance of BAW filters is indispensable. Whereas the prediction accuracy on the purely electromagnetic (EM) contributions of BAW simulation reached an impressive level, there is still a lack of predicting all acoustic phenomena that can impact the final response of a real device precisely. Regarding harmonics specifications of a filter, this manifests in acoustic spurious modes showing up as pronounced ripples for example in the H2 response. In this article the main contributions to imperfect cancellation in a real BAW device are summarized and a novel way to visualize harmonics cancellation using interferometry is presented. This new approach allows for an indirect detection of the strains present in the resonator's piezo layer over frequency and thus makes it possible to analyze and gain a deeper understanding of the final electrical nonlinear performance.

12:14 ***Potentialities of Air-Filled Substrate Integrated Waveguides based on Carbon Nanotubes in E-band***

Phi Long Doan (Grenoble INP & RFIC-Lab, France); Emmanuel Pistono (University Grenoble Alpes, CNRS, IMEP-LAHC, France); Philippe Coquet (CINTRA UMI 3288 CNRS/NTU/THALES, Singapore); Jianxiong Wang (CINTRA, CNRS/NTU/THALES, Singapore); Florence Podevin (IMEP-LAHC Grenoble, France); Dominique Baillargeat (University of Limoges, CNRS, XLIM, France); Joseph de Saxcé (University of Limoges/CNRS, XLIM, France); Stéphane Bila (XLIM UMR 7252 Université de Limoges/CNRS, France)

This paper describes a classic architecture of a 4 × 4 Butler matrix in an innovative air-filled waveguide technology based on carbon nanotubes for beam pointing or beam tracking activities for 5G applications. The working frequencies concern particularly the E-band (71-86 GHz). The model used to simulate the waveguides, couplers and crossovers needed for the Butler matrix is presented as well as the expected results in terms of S parameters. The expected insertion loss is extremely low thanks to the considered technology, 0.02 dB/mm in E-band, making the carbon nanotubes very attractive in this context. The transitions that allow connecting the waveguides to planar transmission lines have also been developed and are introduced in this paper. Their maximum insertion losses are 0.6 dB for a matching better than 17 dB over the entire E-band

12:21 ***Miniaturization of Transmission Lines: Meandered Slow-wave CPWs***

Marc Margalef-Rovira (University of Grenoble & TIMA/RFIC-Lab, France); Tadeu Mota-Frutuoso and Abdelhalim Saadi (University of Grenoble, France); Loic Vincent (University Grenoble Alpes, CIME Nanotech, France); Christophe Gaquiere (IEMN, University of Lille, France); Manuel Barragan (University of Grenoble, France); Philippe Ferrari and Emmanuel Pistono (University Grenoble Alpes, CNRS, IMEP-LAHC, France)

This work presents novel transmission line structures based on Meandered Slow-wave CoPlanar Waveguides (MS-CPWs), aiming to achieve high miniaturization. As a proof-of-concept, these two kinds of transmission lines were designed and fabricated in the AMS 0.35 µm CMOS technology together with classical straight and meandered microstrip lines. Measurement results from 70 kHz to 100 GHz of the fabricated transmission lines are presented. At 80 GHz, all the considered transmission lines present similar quality factors, ranging between 10 and 14. On the other hand, at this frequency, one of the developed MS-CPW presents an effective dielectric constant of 88, while the meandered microstrip exhibits an equivalent effective dielectric constant of 51, thus leading to higher compactness for the MS-CPW.

12:28 *Filtenna Design for 5.8 GHz DSRC and 5.9 GHz WAVE Coexistence*

Alessandro Cidronali (University of Florence, Italy); Giovanni Collodi (Università degli Studi di Firenze, Italy); Matteo Lucarelli (Università di Firenze, Italy); Stefano Maddio and Giuseppe Pelosi (University of Florence, Italy)

In this manuscript a filtenna designed for automotive applications in ITS system environment is presented. The proposed device is a compact circularly polarized patch antenna characterized by high gain. The latter is enabled by the use of a parasite coupling mechanism. The antenna itself is integrated with a compact filter, realized etching out properly designed spirals from the feeding line. The resulting structure is a low profile filtenna, suitable for transmitting DSRC signals at 5.8 GHz while at the same time blocking the WAVE protocol data allocated at 5.9 GHz. This implementation is extremely compact, scalable and suitable for On-Board Units deployment.

Monday, November 23 12:35 - 13:26

Lunch Break

Monday, November 23 13:26 - 13:47

Communication and Interference

Chairs: Martin Kunert (Robert Bosch GmbH, Germany), Holger Meinel (Daimler (retired), Germany)

13:26 *Time-Frequency Shift Modulation for Chirp Sequence based Radar Communications*

Mohamad Basim Alabd, Lucas Giroto de Oliveira, Benjamin Nuss and Werner Wiesbeck (Karlsruhe Institute of Technology, Germany); Thomas Zwick (Karlsruhe Institute of Technology (KIT), Germany)

Combining radar and communication systems plays a vital role in designing future wireless systems due to its ability to decrease the number of spectrum overcrowding. In this paper, measurements in an anechoic chamber and simulations are presented to verify the adaptation on the typical fast chirp radar signal structure for enabling a communication feature. Moreover, a correction method is suggested to preserve the use of 2D-FFT for radar signal processing, which can be easily implemented using the current radar sensors. The measurement setups have been implemented using software-defined radios (SDRs), and symbol error rate curves (SER) are shown related to the investigated measurement and simulation scenarios, which support the revamping of the conventional chirp waveform.

13:33 *Slow-Time Mitigation of Mutual Interference in Chirp Sequence Radar*

Mate Toth (Infineon Technologies & Graz University of Technology, Austria); Paul Meissner and Alexander Melzer (Infineon Technologies, Austria); Klaus Witrisal (Graz University of Technology, Austria)

Automotive radars are increasingly used for safety-critical advanced driver assistance systems (ADAS) and autonomous driving applications. Due to unregulated waveforms in the automotive frequency bands, mutual interference between radar-equipped vehicles is becoming a key issue, as it can lead to significant losses of sensor performance. In this work, a novel mutual interference model and a subsequent mitigation method are introduced for chirp sequence radars. The method integrates well into the conventional range-Doppler processing chain, and enables control over the inherent trade-off between interference suppression and signal distortion. Its properties are discussed using extensive simulations within a statistical performance analysis framework. In the investigated scenarios, the method achieved an improvement in detection performance without introducing false alarms.

13:40 *Combining Radar and Communication at 77 GHz Using a CDMA Technique*

Maximilian Lübke (Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany); Jonas Fuchs (Friedrich-Alexander University Erlangen-Nuremberg, Germany); Victor Shatov and Anand Dubey (Friedrich-Alexander University Erlangen-Nürnberg, Germany); Robert Weigel (Friedrich-Alexander Universität Erlangen-Nürnberg, Germany); Fabian Lurz (Hamburg University of Technology, Germany)

In the paper, a system that combines radar sensing and a new communication approach, using Direct-Sequence-Spread-Spectrum-signals, is presented. Those signals benefit from their attributes, regarding the reduced interference between multiple transmitters. This interference is caused by the fact that in modern vehicles more and more radar sensors are integrated to reach an 360 degree view of the vehicles' surroundings. To gain more knowledge of the surrounding, the idea is to get further information by connecting vehicles and establishing a communication between them. Therefore, radar signals at 77 GHz are modulated to exchange i. e. security information of the incoming surroundings between cars. In consequence, both parts are integrated into one platform, which reduces both costs as well as occupied place. A system, which is capable of this design approach, is presented in MATLAB/Simulink environment. The propagation parameters are simulated by an electromagnetic field simulator WinProp and fed back into the Simulink simulation. This workflow provides a promising simulation tool for joint sensing-communications. The final proof of concept of the sensing and communication part is presented for a typical traffic situation.

Monday, November 23 13:47 - 14:22

Systems

Chairs: Martin Kunert (Robert Bosch GmbH, Germany), Holger Meinel (Daimler (retired), Germany)

13:47 ***A Road-Side Unit Architecture Suitable for Concurrent Multi-Lane Vehicular Communications***

Marco Passafiume, Matteo Lucarelli and Giovanni Collodi (Department of Information Engineering, University of Florence, Italy); Alessandro Cidronali (University of Florence, Italy)

This work presents a novel approach for concurrent synchronous multi-lane communications between Road Side Units (RSUs) and On-Board Units (OBUs), based on the flexibility of software defined radio receivers. By exploiting frequency multiplexing, the proposed technique guarantees the concurrent communications of two RSUs with the same OBU across the road, without any need for additional selective filtering. The technique applies to the electronic toll collecting systems operating under the ETSI ES200674 communication standard, in which it enables the free-flow application. Experimental validations show a behavior backing the suggested technique, and field tests demonstrate a communication area compatible with the real-case scenario usage.

13:54 ***76 GHz OFDM Radar Demonstrator with Real-Time Processing for Automotive Applications***

Benjamin Nuss and Axel Diewald (Karlsruhe Institute of Technology, Germany); Jan Schoepfel (Ruhr-University Bochum, Germany); Daniel Martini (IMST GmbH, Germany); Nils Pohl (Ruhr-University Bochum & Fraunhofer FHR, Germany); Thomas Zwick (Karlsruhe Institute of Technology (KIT), Germany)

In recent years orthogonal frequency-division multiplexing (OFDM) has attracted lots of attention in research as a possible modulation scheme for future radars. Due to increasing hardware capabilities the focus of OFDM development has been broadened even by automotive applications despite its challenging requirements on sampling rates and processing power. This paper presents a demonstrator dealing with these demands by using a baseband unit with broadband digital-to-analog and analog-to-digital converters, a field programmable gate array for real-time signal processing and monolithic microwave integrated circuits designed particularly for digital modulation schemes like OFDM. The setup can operate in the automotive radar band between 76 and 81 GHz and provides two quadrature transmit and receive channels in a multiple-input multiple-output configuration.

14:01 ***A MIMO UHF-RFID SAR 3D Locating System for Autonomous Inventory Robots***

Matthias Gareis (Friedrich-Alexander University, Germany); Christian Carlowitz (University of Erlangen-Nuremberg, Germany); Martin Vossiek (LHFT, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany)

As ultrahigh frequency (UHF) radio-frequency identification (RFID) is a cost-efficient, reliable technology, its use for Internet of Things applications is very attractive. The goal of three-dimensional (3D) product maps for smart warehouses is very challenging, but can be achieved with UHF-RFID. Therefore, we equipped a mobile robot platform with a commercial RFID reader and added a switching matrix to integrate a multiple input-multiple output (MIMO) synthetic aperture radar based localization concept (SARFID) with the use of eight antennas. The mobile robot platform and the MIMO localization technique together demonstrate good tag localization results. We evaluate both single-dimensional and two-dimensional synthetic aperture radar (SAR) trajectories. Their shapes are the main contributor to the achievable accuracy. The robot position is acquired by the robot's odometry data. Despite the substantial error in the robot position, we generate 3D product maps with tags labeled on objects and achieve a 3D root mean square error (RMSE) of 3.8 cm.

14:08 ***ASGARD1: A Novel Frequency-based Automotive Radar Target Simulator***

Fahimeh Rafieinia and Kasra Haghighi (Uniquesec AB, Sweden)

Creating realistic, rich and dynamic environment for testing automotive radars is highly demanded for different applications from early-stage radar development to functions development, verification and validation for driver assistance or autonomous driving. This requires a radar target simulator (RTS) capable of generating many point targets with arbitrary trajectories. This paper introduces a fundamentally different RTS approach compared with the existing delay-line based methods. In this approach, the perception of a moving target is created in the spectrum domain. The result is a flexible and affordable RTS. It has some advantages desirable for automotive industry such as the possibility to simulate close-to-zero minimum distances and multiple targets. Since there is no processing delay, this method is suitable for safety-critical tests in over-the-air hardware-in-the-loop setups.

14:15 ***ATRIUM: Test Environment for Automotive Radars***

Stefan O. Wald, Torsten Mathy, Sreejith Nair, Carlos Moreno and Thomas Dallmann (Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany)

In the automotive sector, the importance of autonomous driving will continue to increase in the future, in addition to further development in the areas of vehicle safety and driving comfort. In order to be able to develop the systems required for this, the automotive industry is dependent on appropriate sensor technology that is able to reliably detect the vehicle's environment in real time and provide the system with additional relevant information. Radar, Lidar and camera systems are among the environmental sensors used in a modern vehicle. These sensors will play a decisive role in the future development of driver assistance systems and autonomous driving. For the development and testing of radar systems, a suitable test environment is needed to verify the reliable function of radar sensors. In this publication a new method developed at Fraunhofer FHR (Fraunhofer Institute for High Frequency Physics and Radar Techniques) , is presented, which was implemented with the 1D radar target simulator ATRIUM.

Monday, November 23 14:22 - 14:50

MMICs/Active Devices

Chairs: Martin Kunert (Robert Bosch GmbH, Germany), Holger Meinel (Daimler (retired), Germany)

14:22 *A 79GHz 4RX-2TX SiGe-Integrated Sequential Sampling Pulse Radar*

Alexander Leibetseder (Infineon Technologies Linz GmbH & Co. KG, Austria); Christoph Wagner (Danube Integrated Circuit Engineering (DICE), Linz, Austria); Andreas Stelzer (Johannes Kepler University Linz, Austria)

A 79 GHz, SiGe-integrated, multiple-input multiple-output (MIMO) sequential sampling pulse radar is presented. The radar sensor is equipped with two transmit channels and four coherent receive channels and is manufactured in a 250-GHz-fT SiGe BiCMOS technology. The fabricated chip is tested by in-system measurements using a uniform patch antenna array, which is fabricated on a RF PCB.

14:29 *240-GHz System on Chip FMCW Radar for Short Range Applications*

Alexander Kaineder (Johannes Kepler Universität, Austria); Christoph Mangiavillano (Johannes Kepler University, Austria); Faisal Ahmed (Infineon Technologies AG & DICE GmbH & Co KG, Austria); Muhammad Furqan (DICE GmbH & Co KG - Danube Integrated Circuit Engineering, Austria); Andreas Stelzer (Johannes Kepler University Linz, Austria)

A 240-GHz system on chip (SoC) frequency-modulated continuous-wave (FMCW) radar for short range applications is presented in this paper. The SoC is attached to a carrier printed circuit board (PCB) which in turn is mounted on a radio frequency (RF) frontend using an interposer. Through the use of on-chip antennas, a small form factor is achieved for the SoC, only requiring bond wires for voltage supplies, intermediate frequency (IF) outputs and a 20-GHz local oscillator (LO) input. Measurements reveal a peak effective isotropic radiated power (EIRP) of around 7 dBm at 233 GHz with a power consumption of 1.3 W using 1.8 V and 3.3 V supply voltages. A clear detection of corner cubes at distances of 1.5 m and 2.5 m was possible using this radar demonstrator.

14:36 *A Fully-Integrated High-Isolation Transfer Switch for G-band in-situ Reflectometer applications*

Walid Aouimeur (TiHive Technologies, France); Daniel Gloria (STMicroelectronics, France); Marc Margalef-Rovira (University of Grenoble & TIMA/RFIC-Lab, France); Christophe Gaquiere (IEMN, University of Lille, France); Issa Alaji (Université de Lille, IEMN, France); Estelle Lauga-Larroze (Université Grenoble Alpes, RFIC-Lab, France); Jean-Daniel Arnould (IMEP-LAHC Laboratory, France)

This paper describes two fully-integrated transfer switches designed for in-situ reflectometers and Built-In Self-Test applications (BIST) in the 140 to 220 GHz band (Gband). The proposed switches were designed in the STMicroelectronics 55-nm BiCMOS technology using the Single-Shunt and the Double-Shunt topology, respectively. In the 140 to 195 GHz frequency range, the Double-Shunt Transfer Switch shows an isolation between 27 and 46 dB, and an insertion loss between 5 and 7 dB. Compared to the Single- Shunt Transfer Switch, the double shunt switch presents a much better isolation while having a quite comparable insertion loss and area overhead. To the best of our knowledge, the proposed switches are the first fully integrated transfer switches in BiCMOS or CMOS technologies.

14:43 *A Non-Closed-Form Mathematical Model for Uniform and Non-Uniform Distributed Amplifiers*

Mohamad EL Chaar (Université Grenoble Alpes & RFIC Lab, France); Florence Podevin and Sylvain Bourdel (Université Grenoble Alpes, Grenoble INP, RFIC-Lab, France); Antonio Lisboa de Souza (Federal University of Paraiba, Brazil); Manuel Barragan (University of Grenoble, France)

A non-closed-form general mathematical model for CMOS distributed amplifier (DA) for broadband applications is presented. Contrary to the artificial transmission line (TL) assumption made in the conventional analytical models, the proposed model treats the DA as a discrete set of cells connected together, and hence considers propagation and mismatch between inter-cells. This approach provides designers with a much more accurate first sizing of the DA compared to conventional ways and, as a result, leads to a reduced design time and complexity. The model enables both quantitative and qualitative analysis of a DA, for the purpose of aiding the designers in predicting the relations between DA performance and its multi-design parameters, especially in the context of non-uniform designs. In addition, it is well suited to Computer-Automated Design (CAutoD), to help in achieving designs having a given set of performance goals. The validation of the model is demonstrated on two designs, by a comparison with simulations done in Keysight's ADS tool and using STMicroelectronics' 55-nm SiGe BiCMOS design kit. First design is inspired from an already published non-uniform DA design while second one proposes a 100-GHz bandwidth CMOS uniform DA with 8 dB of power gain, after using it in a CAutoD process.

Monday, November 23 14:50 - 14:54

Short Break

Monday, November 23 14:54 - 15:22

Antenna Arrays

Chairs: Martin Kunert (Robert Bosch GmbH, Germany), Holger Meinel (Daimler (retired), Germany)

14:54 ***A 77-GHz FMCW MIMO Radar Employing a Non-Uniform 2D Antenna Array and Substrate Integrated Waveguides***

Simon P Hehenberger (DLR- German Aerospace Center, Germany); Alexander Yarovoy (TU Delft, The Netherlands); Andreas Stelzer (Johannes Kepler University Linz, Austria)

In state-of-the-art frequency-modulated-continuous-wave (FMCW) multiple-input-multiple-output (MIMO) radar systems, antennas are usually designed with microstrip technology and are arranged in uniform arrays such that the synthesized virtual array maximizes the angular resolution. This paper presents the design of a 77-GHz FMCW MIMO radar frontend with antennas and feed structures based on Substrate Integrated Waveguides (SIW) and non-uniform planar arrays optimized for sidelobe suppression. A design procedure for MIMO arrays with particular emphasis on sidelobe level suppression based on convex optimization is presented, and a novel transition from differential microstrip line to SIW is utilized to feed the transmit antennas. Measurements show the successful SIW and antenna design, as well as a sidelobe level of -40 dB within the field of view of the radar system.

15:01 ***Grating Lobes Suppression of Patch Antenna Arrays Using Parasitic Monopoles***

Wasim Alshrafi (RWTH-Aachen University, Germany); Dirk Heberling (RWTH Aachen University, Germany)

This work presents a technique to suppress the grating lobes of the antenna arrays that consists of large separated patch elements. The solution is based on modifying the patch radiation pattern using a parasitic monopole to suppress the grating lobes of the antenna array. The analysis of the combined structure is presented. The presence of the monopole modified the patch radiation pattern due to the coupling between them. This coupling as well as the induced current on the monopole are analytically calculated. The study provides the behaviour of the coupling for different separation distances and monopole dimensions. Then it is used to calculate the total radiation pattern of the single antenna element as well as the antenna array. Finally, the results are verified by the full-wave simulation.

15:08 ***Performance Analysis of Beam-Switching using One-dimensional Antenna Arrays***

Manuel Lobinger and Kevin Niederwanger (TU Wien, Austria); Stefan Schwarz (TU Wien & CD-Lab Society in Motion, Austria)

Adaptive beamforming (BF) is a well known application of active BF but comes with the cost of high-complexity and computational effort in terms of angle and channel estimation. In order to find a low-complexity alternative of adaptive BF we investigate the performance of a beam-switching method considering a uniform linear antenna array (ULA), one dimensional BF and two-wave with diffuse power (TWDP) fading. Therefore we compare adaptive BF with beam-switching using horizontally and vertically arranged ULAs in terms of signal-to-noise ratio (SNR) and achievable rate by means of Monte Carlo simulations.

15:15 ***Massive MIMO Radar based Burden Surface Imaging: How mm-Wave Integrated Circuits Enable Optimization of Blast Furnace Charging***

Stefan Schuster (Voestalpine Stahl Gmbh & Institute for Communications and Information Engineering, Austria); Dominik Zankl, Stefan Scheiblhofer and Christoph Feilmayr (Voestalpine Stahl GmbH, Austria); Johann Reisinger (Voestalpine Stahl Gmbh, Austria); Reinhard Feger and Andreas Stelzer (Johannes Kepler University Linz, Austria); Christian M. Schmid (Infineon Technologies, Austria)

In the last decade there was enormous progress in integrated mm-wave integrated circuit design, targeting primarily mobility applications like automated driving [1], [2]. It is shown in this paper how this progress, paired with advanced signal processing and the enormous increase of available processing power, enables successful implementation of completely different, yet spectacular, applications. The evolution of designs of massive multiple-input multiple-output imaging radars in combination with the associated real-time signal processing and in-line autocalibration for analyzing the burden surface in blast furnaces, the BLASTDAR system, is presented. BLASTDAR systems now operate in all five voestalpine blast furnaces for several years.

Monday, November 23 15:22 - 16:04

Localization and Sensor Networks

Chairs: Martin Kunert (Robert Bosch GmbH, Germany), Holger Meinel (Daimler (retired), Germany)

15:22 ***Range Association and Fusion in a Network of Single-Channel Monostatic OFDM Radars***

Lucas Giroto de Oliveira, Mohamad Basim Alabd and Benjamin Nuss (Karlsruhe Institute of Technology, Germany); Thomas Zwick (Karlsruhe Institute of Technology (KIT), Germany)

This study introduces a framework for positioning with a network of single-channel monostatic radars with decentralized detection. In this context, a multitarget-multisensor data association procedure for estimating the number of point targets and assigned reflections from the radar stations to each supposed target is described. Next, a data fusion stage for each of these supposed targets as well as remarks on the achievable accuracy are discussed. Based on achieved results for a network of orthogonal frequency-division multiplexing (OFDM) radars, it is concluded that the introduced framework yields appropriate estimates on both number of targets and their positions if range measurement errors are small, being also robust against false alarms.

15:29 ***WSN Implementation of Cooperative Localization***

Bernhard Etzlinger (Johannes Kepler University Linz, Austria); Andreas Ganhör (Johannes Kepler University, Linz, Austria); Julian Karoliny (Silicon Austria Labs GmbH & Johannes Kepler University, Linz, Austria); Richard Hüttner (Johannes Kepler University, Linz, Austria); Andreas Springer (Johannes Kepler University Linz, Austria)

Cooperative localization increases the accuracy of location estimates especially in networks with sparse anchor deployment. In this work, its implementation in low-cost low-power wireless sensor networks is presented. A WSN hardware platform with ultra-wideband ranging and communication is shown and the application of a belief propagation based cooperative localization algorithm discussed. With a simple channel access scheme and a standard ranging method, the main sources of error are discussed and indoor evaluations of the system are conducted.

15:36 ***Recursive Phase Extraction for Holographic Localization of Incoherent FMCW Beacons***

Melanie Lipka (LHFT, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany); Erik Sippel (Friedrich-Alexander Universiät Erlangen-Nürnberg, Germany); Stefan Brückner (LHFT, Freidrich-Alexander-Universität Erlangen-Nürnberg, Germany); Martin Vossiek (LHFT, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany)

Radio-based localization systems are a vibrant field of scientific research with various use-cases in indoor environments. Particularly, the live tracking of freely moving objects offers significant value; however, such tracking requires high update rates and precise localization. An advanced approach with low computational effort is the holographic extended Kalman filter (HEKF) presented in [1], which has already achieved accuracy in the cm-range even with a moderate bandwidth. Hereby, the phase value is extracted from the peak of the spectrum. Thus, the computational effort can be reduced further by replacing this maximum-search. In this paper, a recursive method for the phase extraction for HEKFs in secondary radar systems with an incoherent beacon is presented and evaluated using a 24 GHz frequency-modulated-continuous-wave system. Index Terms-FMCW radar, radar signal processing, position

15:43 ***Geometry-Aided BLE-Based Smartphone Positioning for Indoor Location-Based Services***

Branislav Rudic (Linz Center of Mechatronics GmbH, Austria); Maria Klaffenböck (LCM GmbH, Austria); Markus Pichler-Scheder (LCM, Austria); Dmitry Efrosinin (Peoples' Friendship University of Russia, Russia & Johannes Kepler University Linz, Austria); Christian Kastl (Linz Center of Mechatronics GmbH, Austria)

Self-positioning of smartphones in indoor environments offers a wide variety of applications. Anyway, in harsh environments, the achievable accuracies using received signal strength indicator measurement data are comparably low. However, restrictions due to geometry allow more accurate estimates of smartphone positions and trajectories. Based on received signal strength data from Bluetooth low energy beacons and Gaussian assumptions, an application of a discrete-state hidden Markov model -- taking the geometry into account -- in combination with dynamic model parameter estimation, leads to a significant improvement of error statistics.

15:50 ***Augmenting the Accuracy of EPTS and Smartwatches Using Multiband RTK GNSS Module and UWB Positioning System***

Adnan Waqar (Edith Cowan University & ECU, Australia); Rohit Kumar, Iftekhar Ahmad, Daryoush Habibi and Quoc Viet Phung (Edith Cowan University, Australia)

With recent advances in navigation and communication, physical activity monitoring smartwatches have experienced rapid growth. Similar to activity tracking smartwatches, Electronic Performance Tracking Systems (EPTS) can be used specifically by professional sportspeople to track athletes during matches. By increasing the positioning accuracy of these tracking devices, more meaningful data can be generated which will further increase the demand for these devices. EPTS or fitness tracking smartwatches should be lightweight, compact, and have low power consumption so that they do not create any hindrance to physical movement. With these limitations, certain high accuracy positioning techniques that are deployed in robotics, construction, and navigation, cannot be used in these devices. However, using the latest positioning solutions, it is now possible to increase the accuracy of these devices up to a few centimeters. In this paper, we present two solutions. First, to increase the positioning accuracy of present EPTS from meters to centimeters and enabling them to track an athlete's movements indoor. Second, directing correction data from a source to a GNSS receiver via mobile phone using a Bluetooth module we present a solution that can sharply increase the accuracy of fitness tracking smartwatches.

15:57 ***Location-based Trustworthiness of Wireless Sensor Nodes using Optical Localization***

Leander B. Hörmann (Linz Center of Mechatronics GmbH, Austria); Markus Pichler-Scheder (LCM, Austria); Christian Kastl (Linz Center of Mechatronics GmbH, Austria); Hans-Peter Bernhard (Johannes Kepler University Linz, Austria); Peter Priller

(AVL List GmbH, Austria); Andreas Springer (Johannes Kepler University Linz, Austria)
A continually growing number of sensors is required for monitoring industrial processes and for continuous data acquisition from industrial plants and devices. The cabling of sensors represent a considerable effort and potential source of error, which can be avoided by using wireless sensor nodes. These wireless sensor nodes form a wireless sensor network (WSN) to efficiently transmit data to the destination. For the acceptance of WSNs in industry, it is important to build up networks with high trustworthiness. The trustworthiness of the WSN depends not only on a secure wireless communication but also on the ability to detect modifications at the wireless sensor nodes itself. This paper presents the enhancement of the WSN's trustworthiness using an optical localization system. It can be used for the preparation phase of the WSN and also during operation to track the positions of the wireless sensor nodes and detect spacial modification. The location information of the sensor nodes can also be used to rate their trustworthiness.

Monday, November 23 16:04 - 16:10

Short Break

Monday, November 23 16:10 - 17:10

Uhnder The Radar: Digital Code Modulation

Keynote

Manju Hegde

Chairs: Martin Kunert (Robert Bosch GmbH, Germany), Holger Meinel (Daimler (retired), Germany)