Program Overview Monday, March 25, 2019

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<tr><td>15:10 - 15:40</td><td>Coffee break</td><td rowspan="3">Poster session PS1</td><td></td><td></td><td></td><td></td></tr>
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Program Overview Tuesday, March 26, 2019

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<tr><td>09:00 - 10:10</td><td></td><td rowspan="4">Poster-session PS2</td><td rowspan="3">Phased-array front-end concepts</td></tr>
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<tr><td>10.20 - 10:30</td><td rowspan="3">Coffee break</td><td></td><td rowspan="2">DFG info meeting</td></tr>
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<tr><td>15:40 - 16:00</td><td></td><td></td><td rowspan="3">Planar cir-cuits, trans-mission lines, and antennas</td><td rowspan="3">Short-range radar and FMCW radar</td></tr>
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<tr><td>17.45 - 23:00</td><td colspan="6">Conference Dinner at "Reithalle Stuttgart"</td></tr>
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Program Overview Wednesday, March 27, 2019

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<tr><td>08:30 - 09:50</td><td colspan="3"></td><td>Waveguide compo-nents and filters</td><td>Millimeter-wave integrated circuits</td><td></td></tr>
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<tr><td>10:20 - 11:40</td><td colspan="3"></td><td>Hybrid am-plifiers and oscillators</td><td>Characteri-zation and modeling of integra-ted-circuit compo-nents</td></tr>
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<tr><td>11:50 - 13:10</td><td colspan="3"></td><td>Closing session & Keynote 5</td><td></td><td></td></tr>
<tr><td>13:10 - 13:40</td><td>Lunch break</td><td colspan="2"></td><td></td><td rowspan="4">Workshop "Electro-magnetic sensors for life sciences" (ESSENCE)</td><td rowspan="2">Workshop "New radar technolo-gies for au-tonomous driving" (ELEVATE)</td></tr>
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Keynote Speeches

Monday – Opening Session (13:10-15:10, Room: Schiller-Saal)

Conference Opening
Jan Hesselbarth

Welcome Adress
Prof. Dr.-Ing. Hansgeorg Binz,
University of Stuttgart, Vice Rector for Teaching and Continuing Education

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Cicero Vaucher
NXP, Netherlands

The evolving landscape in automotive radars: waveform, system implementation, and IC technologies

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Advanced driving assistance systems (ADAS) will have a steep penetration in automotive segments over the next years. This is partly due to increased affordability, but most of all due to legislation demanding autonomous emergency braking and pedestrian protection systems. For easy adoption and adaptation into a wide range of vehicles, small size, low cost and low power are of prime importance, due to reduced sensor sizes and difficult operational conditions. In this talk, we review the latest signaling waveforms, system implementation aspects, and IC technology options for next-generation car-radar products. We then discuss key circuits and present measurement results of a fully-integrated radar front-end in 40nm CMOS silicon technology. The radar IC covers the 76-81 GHz band for higher range resolution, and has built-in features to easily implement radar MIMO techniques, for increased angular resolution with a relatively small number of physical RX channels.

Cicero S. Vaucher received the Ph.D. degree in Electrical Engineering from the University of Twente in 2001. He was with Philips Research Laboratories Eindhoven from 1990 to 2006, when he joined NXP Semiconductors as Philips Semiconductors became an independent company. He is presently with the Infotainement and Driver Assistance (IDA) Business Line, working as an Automotive radar product architect. He is also a part-time professor at TU Delft.
His research activities and interests include micro-wave and mm-Wave transceiver architectures, radar system implementation and signal processing, and implementation of circuit building blocks. He is the author of Architectures for RF Frequency Synthesizers (Boston, MA: Kluwer, 2002) and is a co-author of Circuit Design for RF Transceivers (Boston, MA: Kluwer, 2001). He is an (co-) inventor of 28 unique patent families. Dr. Vaucher is acting on the IEEE-MTT Wireless-Enabled Automotive and Vehicular Applications Technical Committee 27. He is a Senior Member of the IEEE and a NXP Technical Fellow.

Ruonan Han
MIT, United States

**Chip-Scale Wave-Matter Interactions:
New Frontier for RF-to-THz Integrated Sensors in Silicon**

Since the invention of radar in early 1900s, innovations in RF sensing have lasted for an entire century; now, a complete radar system can be implemented inside a single silicon chip. So what is the next frontier for integrated RF-to-THz sensors? Essentially, radars and millimeter-wave imagers remotely detect large-scale objects that are insensitive to wave frequencies. In this talk, we show that new opportunities are opened up (1) when we use high-precision, frequency-selective waves to direct interact with the quantum behaviors of microscopic particles and (2) when we confine such operations at chip scale.
To showcase this idea, we introduce a few sensor chip prototypes in silicon, which utilize various modalities of wave-matter interactions in RF-to-THz domains. Targeting at the rotational modes of gas molecules at low-THz, we present a dual-frequency-comb CMOS spectrometer, which performs high-parallelism spectral sensing and ultra-high-selectivity molecular detection in 220~320GHz. Using the same rotational mode, we also built a CMOS molecular clock, which locks its 80-MHz output to the 231.061-GHz transition line of carbonyl sulfide (OCS) gas confined in a small volume. The clock consumes only 66 mW, while delivering a long-term frequency stability at 10-10 level (and potentially below 10-11). Next, towards a fully-electronic probing of the vibrational modes in large bio-molecules, we report a SiGe radiator array which delivers 0.1-mW

total radiated power at 1 THz. Lastly, we also present emerging sensing techniques in microwave frequencies. In specific, a room-temperature, CMOS quantum magnetometer is demonstrated with vector-field sensing capability. Different from Hall sensors, this electro-optical chip probes the Zeeman splitting of nitrogen-vacancy (NV) centers in a diamond attached to the chip surface, and delivers nT/Hz1/2 level sensitivity. This new category of low-cost and compact RF-to-THz sensors are expected to greatly advance the capabilities of chemical analysis, bio-medical diagnosis/research, navigation, networking, security and so on.

Professor **Ruonan Han** received his Ph.D. degree in electrical and computer engineering from Cornell University in 2014. Prior to that, he received his B.Sc. degree in microelectronics from Fudan University in 2007 and M.Sc. degree in electrical engineering from the University of Florida in 2009. He is currently an associate professor with the Department of Electrical Engineering and Computer Science at Massachusetts Institute of Technology. started his career as a circuit designer for mmW circuits on GaAs technologies at Fraunhofer IAF in Freiburg in 1994, where he was working on the design of the first 77GHz MMICs for ACC systems. Afterwards he worked in various R&D management positions for RF communication products at TriQuint Semiconductors (now Qorvo) and Infineon Technologies, respectively.

The research of Prof. Han has focused on millimeter-wave and terahertz integrated circuits and microsystems for emerging sensing and communication technologies. He was the recipient of the IEEE Solid-State Circuits Society (SSCS) Pre-Doctoral Achievement Award, the IEEE Microwave Theory and Tech. Society (MTT-S) Graduate Fellowship Award, the Best Student Paper Award of two IEEE RFIC symposia (2012 and 2017), and the Director's Best Thesis Award at Cornell University. He is the associate editor of IEEE Transactions on Very-Large-Scale-Integration (VLSI) Systems, and also serves on the technical program committee of IEEE RFIC symposium and the steering committee of IEEE Intl. Microwave Symposium (IMS). He held the MIT E. E. Landsman (1958) Career Development Chair Professorship in 2014~2017, and is the winner of the National Science Foundation (NSF) CAREER Award in 2017.

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Tuesday – Plenary Session (11:00-12:30, Room: Schiller-Saal)

Ho-Jin Song
POSTECH, Korea

Terahertz Communications at 300 GHz: Devices, Packages and System

Recent progress in semiconductor devices on compound semiconductor or silicon substrates has made it possible to produce more power and receive a signal with less noise at THz frequencies. Various integrated circuits for the THz radio front-end functional blocks, including power and low-noise amplifiers, modulators and demodulators, and oscillators, have been demonstrated in the last decade. In the first experimental demonstration conducted in 2004, bulky instruments originally developed for THz spectroscopy were used to transmit pulsed THz signals carrying a 7-kHz bandwidth audio signal across a short free space. However, recently, there have been several successful demonstrations of multi-Gbps data transmissions at THz frequencies with state-of-the art devices and components. In this talk, the first prototype of a THz wireless communications system designed under the 'touch-and-go' scenario will be presented. I clarify the concept of the KIOSK data downloading system, cover some considerations in this work, and present a brief link-budget plan. We will then overview technologies for implementing THz components operating at 300 GHz and their performance, followed by preliminary investigation of the channel responses and the experimental demonstration results. At the end of the presentation, we will discuss several issues that need to be addressed for the future of the THz communications systems, in terms of system architectures, packaging and potential applications.

Ho-Jin Song received the B. S. degree in electronics engineering from Kyungpook National University, Daegu, Korea in 1999, and the M.S. and Ph.D. degree in electrical engineering from Gwangju Institute of Science and Technology (GIST), Gwangju, Korea, in 2001 and 2005, respectively. Since he joined Nippon Telegraph and Telephone, Japan, in 2006, which is the third largest telecommunication company in the world, he had engaged in the development of sub-millimeter and terahertz wave devices, circuits and systems for communication, remote sensing and imaging applications. In 2015, he was named to a distinguished research scientist of NTT Labs. Since 2016, Dr. Song has been with the department of Electrical Engineering, Pohang University of Science and Technology

(POSTECH), Pohang, Gyeongbuk, Korea. His current research interest includes mm-wave and terahertz circuits, antenna, packages and test-bed systems, particularly for wireless communication, connectivity and radar applications. Dr. Song was a recipient of GIST Best Thesis Award (2005), NTT Microsystem Labs Research of the Year Award (2009 and 2014), Young Scientist Award of Spectroscopical Society of Japan (2010), IEEE Microwave and Wireless Component Letters Tatsuo Itoh Best Paper Award (2014) and Best Industrial Paper Award at IEEE MTTs-IMS 2016 (2016). He is a senior IEEE member and an IEEE distinguished microwave lecturer for the 2019-2021 term.

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Christophe Fumeaux
University of Adelaide, Australia

Dielectric Resonator Antennas: A Journey through the Spectrum

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Dielectric resonator antennas have been proposed in the 1980's as alternatives to conventional low-gain printed-circuit antennas. They are typically composed of a low-loss dielectric block mounted on a ground plane. Their operation exploits the high "radiation losses" of open dielectric resonators operating in their low-order modes. Dielectric resonator antennas are characterized by a small size, wide bandwidth, simple feeding and design versatility. Their most decisive advantage however may be their ability to work in various resonant modes (including magnetic-dipole modes) and their high radiation efficiency when realised with low-loss dielectric materials. This last property becomes most relevant as the frequency is increased into the millimetre-wave range and above, where conductor losses become significant in conventional metallic resonant antennas.

The presentation will provide a perspective on the development of dielectric resonator antennas, as a journey through the spectrum. This journey will progress through five orders of magnitude in frequency, starting in the microwave range with wideband geometries, advanced feeding methods, and multi-mode designs. It will continue with examples of high-efficiency millimetre-wave antennas, before extending the considerations into the terahertz range, with demonstration of reflectarrays and antennas based on dielectric resonators. We will then reach the optical regime with descriptions

of dielectric resonant nano-structures configured in reflect-/transmit-arrays operating at infrared and visible light, towards flat optical components with unusual properties.

Christophe Fumeaux received the Diploma and Ph.D. degrees in physics from the ETH Zurich, Switzerland, in 1992 and 1997, respectively. From 1998 to 2000, he was a Postdoctoral Researcher at the University of Central Florida. In 2000, he joined the Swiss Federal Office of Metrology as a Scientific Staff Member. From 2001 to 2008, he was a Research Associate and lecturer with the Laboratory for Electromagnetic Fields and Microwave Electronics at ETH Zurich. Since 2008, he has been with The University of Adelaide, where he is currently a Professor with the School of Electrical and Electronic Engineering. His current main research interests concern antenna engineering, THz technology and the application of RF design principles to optical micro/nano-structures.

Prof. Fumeaux was the recipient of the ETH Medal for his doctoral dissertation. From 2011 to 2015, he was a Future Fellow of the Australian Research Council. He was the recipient of the 2018 Edward E. Altshuler Prize, the 2014 IEEE Sensors Journal and the 2004 ACES Journal best paper awards. He served as an Associate Editor for the IEEE Transactions on Microwave Theory and Techniques from 2010 to 2013. From 2013 to 2016 he served as Senior Associate Editor and later Associate Editor-in-Chief for the IEEE Transactions on Antennas and Propagation. Since March 2017, he is serving as Editor-in-Chief for the IEEE Antennas and Wireless Propagation Letters.

Wednesday – Closing Session (11:50-13:10, Room: Schiller-Saal)

Heike Riel
IBM, Switzerland

titel to be defined

Awards Presentation and Closing Remark
Jan Hesselbarth
Handover to GeMiC 2020 in Cottbus

Sessions

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Mo2a: Non-planar antenna techniques
Chairs: Stefan Lindenmeier (Universität der Bundeswehr, Germany), Holger Maune (Technische Universität Darmstadt, Germany)
Room: Schiller-Saal 11:00-12:20

11:00 Evaluation of Advantageous LTE MIMO Nefer Antennas in Real Test Drives and in a New Reproducible Half Virtual Test Drive

Mahmoud Almarashli; Sertan Hastürkoglu; Stefan Lindenmeier
Universität der Bundeswehr München, Germany

A reproducible virtual test drive for LTE MIMO automotive application is investigated in comparison with real field test measurements by way of examples for different LTE-antennas. Both test drives, the virtual and the real one cover the same test route in Munich city for 2x2-MIMO data transmission. Special focus is given on a flat Nefer antenna, showing a high performance in laboratory measurements as well as via its throughput values in the test drives. The antenna covers all LTE-frequency bands as well as the WLAN frequency up to 6 GHz.

11:20 High RCS Passive Tag based on Dielectric Resonator - 2D Lens Combination

Ali Al-haj Abbas[1]; Mohammed El-Absi[1]; Ashraf Abuelhaija[2]; Klaus Solbach[3]; Thomas Kaiser[1]
[1]Duisburg-Essen University, Germany; [2]Applied Science Private University, Jordan; [3]UDE, Germany

In this paper, a Lens-Dielectric Resonator combination is proposed to improve RCS of dielectric resonator tags to be used in a self-localization system where high RCS is essential to combat clutter signals. As a proof of concept, a cylindrical dielectric resonator is located in the focal area of a 200 mm diameter (3.5 lambda at 5.2 GHz) 2D Luneburg Lens sandwiched between two tapered metal plates. Two approaches of realizing the continuous variation of the Luneburg lens dielectric permittivity are implemented, fabricated, and tested: by using stepped cylindrical layers of dielectric material (fabricated by machining process) and by using effective medium theory in which the lens is constructed from a group of cells made of various cuboids sizes connected to trapezoidal rods (fabricated by 3D printing technology using PP). A good compatibility between DR and lens is observed. The improvement in RCS is found to vary depending on DR resonance mode. For the HE11 mode, a 20 dB improvement is achieved.

11:40 Millimeter-Wave Leaky-Wave Antennas Based on Polymer Rod with Periodic Annular Metal Strips

Utpal Dey; Julian Tonn; Jan Hesselbarth
University of Stuttgart, Germany

Leaky-wave antennas based on a polymer rod, operating at Ka-frequency band, are presented. A periodic pattern of 50 annular metal rings is applied to the polymer rod, resulting in a radiation pattern scanning with frequency. The antennas are operating either in the fundamental HE11 mode or in the rotationally symmetric TM01 mode, the latter resulting in omnidirectional radiation pattern. The antennas are fed via transitions to rectangular waveguide and coaxial waveguide, respectively. The designs are verified by measurements. Operating in HE11 mode, a gain between 12 dBi and 18 dBi is measured at frequencies from 27 GHz to 40 GHz, while scanning over 55 degrees angle in direction. The peak frequency scanning resolution amounts to 8.3 degrees per GHz. Operating in TM01 mode, a gain between 12 dBi and 16 dBi is measured at frequencies from 33 GHz to 40 GHz, while scanning over 34 degrees angle in direction. The peak frequency scanning resolution is 6.5 degrees per GHz.

12:00 Fully Dielectric Rod Antenna Arrays with High Permittivity Materials

Roland Reese; Henning Tesmer; Ersin Polat; Matthias Jost; Matthias Nickel; Rolf Jakoby; Holger Maune
Technische Universität Darmstadt, Germany;

In this work, we investigate the effect of high permittivity materials for a fully dielectric 1×4 antenna array based on a multimode interference power divider. Designed at W-band, from 95 to 105 GHz, two plastic/ceramic composites L300 and L440 from Premix are used with "r = 3 and "r = 4.4, respectively. The results are compared to our published design made out of Rexolite with "r = 2.53. Compared to Rexolite, the antenna array can be already scaled down to 52% of the sectional area using L440. The input reflection is below -15 dB over the whole frequency range for both arrays. Measurement and simulation of the antenna patterns are in good agreement, with measured antenna gains between 14 to 16 dBi.

MO2b: Electromagnetic sensing and material characterization (SFB MARIE)
Chairs: Andreas Rennings (University of Duisburg-Essen, Germany), Ilona Rolfes (Ruhr-Universität Bochum, Germany)
Room: Silcher-Saal 11:00-12:20

11:00 Triple-Barrier Resonant-Tunnelling Diode THz Detectors with on-chip antenna

Khaled Arzi[1]; Simone Clochiatti[1]; Safumi Suzuki[2]; Andreas Rennings[1], Daniel Erni[1]; Nils Weimann[1]; Masahiro Asada[2]; Werner Prost[1]
[1]University of Duisburg-Essen, Germany; [2]Tokyo Institute of Technology, Japan

Signal detection at (sub-)mm-wave frequencies via a single chip size component is discussed. The monolithic integration consists of high current density InP-based Triple Barrier Resonant Tunneling Diode into an on-chip antenna. The asymmetrical current voltage characteristic of the Triple Barrier Resonant Tunneling Diode enables signal detection at zero bias. A very high responsivity above 250 GHz is experimentally demonstrated. The on-chip antenna integration is based on impedance matching and the challenge towards broad-band implementations are discussed.

11:20 Resonant Antenna Periodically Loaded with Series Capacitances for Enhanced Radiation Efficiency

Benedikt Sievert, Daniel Erni and Andreas Rennings
University of Duisburg-Essen, Germany

A periodic series-capacitance loaded patch antenna for increased radiation efficiency at 250 GHz in on-chip environment is presented. The antenna is described as a periodic high pass transmission line. An exemplary candidate with increased efficiency is compared to a conventional patch antenna for broadside radiation. An essential part of this paper is an equivalent circuit model explaining the increased efficiency as well as the decreased bandwidth of the structure. A dispersion diagram analysis is motivated for the design process as well as for physical insight.

11:40 A Feed-Forward Control Based Method to Reduce the Settling Time of Phase-Locked Loops for Frequency Ramp Synthesis

Lukas Polzin; Marcel van Delden; Thomas Musch
Ruhr-Universität Bochum, Germany

Phase-locked loops (PLLs) are used as ultrawideband and precise frequency synthesizers for frequency modulated continuous wave signals. A considerable problem is the settling time, in which the output frequency of a PLL does not follow a frequency change instantly. For frequency ramps, this reduces the usable bandwidth of the sys-

tem or the maximal possible measuring rate. To improve the settling time we present a feed-forward control (FFC) based method, which adapts the modulation of either the reference frequency or the division ratio of the frequency divider. The method is applied to two noise-optimized microwave PLLs. The obtained simulation and measurement results are compared and demonstrate the effectiveness. For an X-band PLL, the settling time is reduced by a factor of 15.44 to 306 ns and for a V-band PLL by a factor of 2.2 to 228 ns.

12:00 Investigation on Optical Methods for Multi Scale Electromagnetic Simulations

Steffen Vogt; Jochen Jebramcik; Orell Garten; Jan Barowski; Ilona Rolfes
Ruhr-Universität-Bochum, Germany

In this paper a ray tracer based on a shooting and bouncing ray (SBR) technique is presented using an optimization algorithm for precise phase calculation of the channel impulse response, which is mandatory for multi scale simulations. The radiation pattern of the antenna is computed by a full wave simulation in order to calculate the propagating wavefront. The complex open circuit voltage of the antenna is used for modelling the channel impulse response to get the accurate interference phenomena of the received waves. The algorithm is verified by comparison with a commercial full wave simulator. It is also shown that the optimization approach does not only offer high precision, but also enables fast ray tracing, which allows accurate and fast multi scale electromagnetic simulations.

PS1: Poster session 1
Chair: Ning Yan Zhu (University of Stuttgart, Germany)
Room: Foyer 15:10-17:10

Antenna Selection Performance of Distributed Antenna Systems in Full-Duplex Indoor Base Station

Nidal Zarifeh; Mai Alissa; Theo Kreul; Thomas Kaiser
University of Duisburg-Essen, Germany

The work in this paper is trying to answer the question: In a full-duplex indoor base station with antenna selection, what are the benefits of using distributed antennas instead of co-located antennas? In other words, how much the use of distributed antennas would contribute in mitigating the self-interference in the full-duplex system. A ray-tracing tool is used to characterize the indoor multi-path channel environment. Subsequently, a baseband analysis is done to evaluate the performance of the full-

duplex system. The distributed antenna system slightly outperforms the co-located system in the studied scenario.

Dual Band Metamaterial Power Divider with Improved Relative Bandwidth for LTE Applications

Iulia Mocanu[1]; Laura Manoliu[2]
[1]Politechnica University Bucharest, Romania; [2]University of Stuttgart, Germany

A dual band power divider for Long Term Evolution (LTE) standard is implemented using metamaterial transmission lines. First, a study regarding the influence of symmetry and number of cells over the performances is carried on. The behaviour of the power divider is then, analysed in the frequency domain and great agreement between theory and simulation is achieved. The novelty of this paper is the usage of Dual Composite Right Left Handed (D-CRLH) transmission lines, which are optimized both from the performances' point of view and the technological constrains, to design a dual band power divider with good results for both frequencies. Measurements confirm the dual band behaviour of the power divider.

Comparison of Hybrid Beamforming Systems Using Phase Shifters and Switches

Joerg Eisenbeis; Yueheng Li; Pablo Ramos López; Jan Fischer; Thomas Zwick
Karlsruhe Institute of Technology (KIT), Germany

Hybrid beamforming systems represent a promising architectural approach for massive multiple-input multiple-output (MIMO) systems operating at millimetre wave frequency. The hybrid beamforming approach splits the beamforming process into an analogue beamforming network and a digital beamforming of reduced size. Recent research reveals the benefit of using a combination of phase shifters and switches to further increase energy efficiency. A switch-off functionality of an arbitrary number of antenna chains is moreover interesting in times of low mobile communication cell utilisation. Within this work, we compare different hybrid beamforming architectures using phase shifters and switches. To enable a fair comparison between the different architectures RF losses within the analogue beamforming network are taken into account.

Figure of Merit for Beam-Steering Antennas

Julio Gonzalez Marin; Jan Hesselbarth
University of Stuttgart, Germany

A new concept for a figure of merit for beam-steering antennas is proposed. The new figure of merit quantifies how efficiently an antenna with beam-steering capability can make use of its aperture size to radiate beams into a wide geometrical sector. The new figure of merit takes into account beam degradation when steering, maximum

steering angle and antenna aperture size. Measured data of a large number of beam-steering antennas presented in the literature are analyzed and their performances are compared using the new figure of merit.

A High Precision Reconfigureable Bistatic Interferometric Radar with Integrated Six-port Receiver at 60 GHz

Matthias Voelkel; Sebastian Mann; Martin Frank; Robert Weigel; Amelie Hagelauer
Friedrich-Alexander University Erlangen-Nuremberg, Germany

In this paper a 60 GHz bistatic reconfigureable sixport radar for high precision measuring is presented. The frontend is designed in a substrate-integrated waveguide technology including coupler, attenuator and transmission lines. The core of the front-end is a integrated six-port receiver MMIC including the passive six-port structure, a LNA and four detectors. It has been designed using a 0.13µm SiGe BiCMOS process. A BGT60, stabilized by a PLL-circuit, generates the transmit signal for vivaldi antennas. The system includes also a baseband circuit with adjustable differential amplifier, 24 bit@52kSa/s ADC converter for signal sampling and DAC converter for gain and attenuation tuning. Furthermore, the stacked system is directly connected to a FPGA board. A full NIOS2 system is set up to control the radar and send the collected data via ethernet to the PC. C++ software is written to configure the system in an easy comfortable way and to visualize the measured data. Measurements show, that the radar works in a range up to five meter. The maximum distance deviation at 1m is 30µm and the standard deviation is 12.6 µm.

A Compact Low-Loss Multilayer SIW Diplexer at K/Ka-Band

Anton Sieganschin; Thomas Jaschke; Hans Mitto; Nadja J Lamann; Jan Waldhelm; Arne F Jacob
Hamburg University of Technology, Germany

This contribution deals with a compact substrate integrated waveguide (SIW) diplexer for terminal array antennas at K-/Ka-band. The diplexer connects the transmit (Tx) and the receive (Rx) frontend with an antenna element. It is comprised of a bifurcation and two second order bandpass filters with low insertion loss. The Rx-filter has additionally two transmission zeros in the Tx-band. The structure is implemented in multilayer printed circuit board (PCB) technology. This yields a compact design which can be integrated in an array with half-wave element spacing. The simulated diplexer performance is validated by measurements. The insertion loss in the Rx-band is below 0.7 dB and the Tx-/Rx-isolation exceeds 40 dB in the Tx-band.

MO4a: Wireless communication systems
Chairs: Rolf Jakoby (Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany), Thomas Zwick (Karlsruhe Institute of Technology (KIT), Germany)
Room: Schiller-Saal 15:40-17:40

15:40 Numerical Investigation of the Impact of Array Orientations on Orbital Angular Momentum (OAM) Based Communication Using a Mixed-Mode Matrix

Lei Wang[1]; Woocheon Park[2]; Heinz-D. Brüns[1]; Christian Schuster[1]; Dong Gun Kam[2]
[1]Hamburg University of Technology, Germany; [2]Ajou University, Korea

Wireless communication of radio waves carrying orbital angular momentum is investigated in this paper, to explore the impact of the orientations of transmitting and receiving arrays. As an example, two circular arrays, each containing eight dipoles, are taken as a transmitter and a receiver of radio waves carrying different OAM modes. A mixed-mode matrix, taking consideration of all possible OAM modes, is used to interpret the communication performance. Thanks to the advantage of the mixed-mode matrix, the received power of an OAM mode is a combination of all generated OAM modes at the transmitter. The orientations of the transmitter and receiver are studied using the method of moment (MoM) to reveal their dependencies of OAM-based communication. Based on the results, a general guideline with regard to array orientations for the optimization of OAM-based communication is derived.

16:00 A Novel Scheduling Technique for NOMA in 5G Wireless Communication Systems

Yasser Naguib
Cairo University, Egypt

This paper investigates the problem of user selection in multiuser multiple-input single-output (MU-MISO) cellular systems employing non-orthogonal multiple access (NOMA). In order to strike a balance between complexity and performance, a scheduling algorithm is proposed for selecting the two users supported by each transmit beam. The proposed algorithm is shown to outperform other methods presented in literature in terms of sum throughput, and achieved rate by the user whose channel exhibit non-favorable large-scale fading conditions.

16:20 E-band simplex wireless data transmission and bandwidth-dependent performance analysis based on OFDM signals

Seyyid Dilek; Eswara Rao Bammidi; Ingmar Kallfass
University of Stuttgart, Germany

In this paper the bandwidth dependent performance analysis of a transceiver system in E-band (71-76~GHz) frequency range is presented. The performance analysis includes the influence of baseband signal power variation and bandwidth variation on the error vector magnitude. Orthogonal frequency-division multiplexing modulation technique is used for the wireless data transmission. The difference of the EVM degradation between different modulation schemes in OFDM signals is less than 0.4 dB above 3.5 GHz RF bandwidth, whereas below 3.5 GHz RF bandwidth, the difference of EVM degradation is approximately 1 dB. Maximum achieved data rate of 5 GHz RF bandwidth for 32-QAM OFDM modulation is 15.625 Gbps.

16:40 FPGA based 24 GHz radar communication system

Andreas Wanjek; Serdal Ayhan; Zhidong Hua; Thomas Schäfer
SEW-Eurodrive GmbH & Co KG, Germany

This paper presents an approach of combining radar object detection with additional data transfer. The concept is based on a 24 GHz FMCW (frequency modulated continuous wave) radar sensor that is controlled by a FPGA (field programmable gate array). For object detection a simple CFAR (constant false alarm rate) principle is used that allows sufficient object extraction. For communication a FSK (frequency shift keying) modulation and a correlation based demodulation approach is realized. A master-slave concept extended by a time division duplex approach is employed to synchronize two independent radar sensors with divergent carrier frequency. The developed system enables multiple object detection and data transfer in real time with data rates up to 100 kBit/s and low error rate.

17:00 Compact and Wireless 2.5-5 GHz Frequency Doubler for Harmonic RFID Applications

Paula Palacios and Mohamed Saeed Elsayed; Ahmed Ghareeb; Renato Negra
RWTH Aachen University, Germany

This paper presents a harmonic RFID tag with possible medical applications. The proposed topology consists on a wireless 2.5 to 5GHz frequency doubler. It occupies only 32mm×16mm and is based on a Schottky diode together with two printed Planar Inverted-F Antennae (PIFA). The design, fabrication and characterization are presented, where the experimental measurements prove a successful behaviour with a measured conversion gain up to −30 dB when the tag is present.

17:20 A Multi-Beam Direction- and Polarization-Agile mm-Wave Front-End for 5G Communications

Steffen Spira; Reiner S. Thomä; Matthias Hein
Ilmenau University of Technology, Germany

A millimeter wave multi-beam direction- and polarization-agile front-end for 5th generation of wireless communications is presented. Active voltage summing was used for the lossless electronic rotation of polarization, thus enhancing the envisaged flexibility of 5G air interfaces. The front-end core comprises a low-temperature co-fired ceramic multilayer module, hybrid-integrated monolithic microwave integrated circuits, and an incorporated dual-polarized array antenna, altogether at a compact size of 74 mm × 74 mm. Antenna feed phases and polarization angles and states are electronically controllable. The front-end, completed by control circuit boards and a heatsink, exhibits an over-the-air gain of 50 dB and a noise figure of 4.1 dB. Measurement results comprising the polarization control and beamformer blocks are presented.

MO4b: Radar signal processing

Chairs: Mario Pauli (Karlsruhe Institute of Technology, Germany), Christian Waldschmidt (University of Ulm, Germany)
Room: Silcher-Saal 15:40-17:40

15:40 Typical architectures of a generic radar front-end for the application in automotive sensors (Invited)

Ernst Weissbrodt
Valeo, Germany

The variety of applications of radar sensors in automotive requires a multiplicity of hardware architectures. The scope of application ranges from multiple simple sensors for passenger detection inside a very confined area, classical long range sensors in a front radar, "cocoon radar" for surround surveillance of the car, to high resolution radar with virtual arrays. Also, legislation demands the protection of vulnerable road users, as described in Euro NCAP. Obviously, this requires very different system architectures and hence radar hardware to realize cost efficient solutions for the mass market. In today's industrial radar hardware, the classical separation between an analog front-end and the digital back-end for signal processing doesn't exist anymore. With the clear trend towards CMOS radar chipsets with a competitive RF performance, today's MMICs can include ADCs, micro controllers and memory. But the higher the integration of the MMIC, the less flexibility is possible in terms of system architecture (e.g. number of channels) and more compromises need to be accepted (e.g. processing power/memory). This talk will give an overview of today's typical applications of radar sensors in the

automotive industry, present established approaches like analog beamforming with delay lines or phase shifters, MIMO with simultaneous coded transmission, and elevation measurements. Thereby, the requirements for radar chipsets and the RF front-end in general will be discussed and its implications for the radar signal processing outlined.

16:00 Compressed Sensing based Single Snapshot DoA Estimation for Sparse MIMO Radar Arrays

Fabian Roos[1,]; Philipp Hügler[1]; Lizette Tovar Torres[1]; Christina Knill[1]; Johannes Schlichenmaier[1]; Claudia Vasanelli[1,]; Nils Appenrodt[2]; Juergen Dickmann[2]; Christian Waldschmidt[1]
[1]University of Ulm, Germany; [2]Daimler AG, Germany

The angular resolution of a radar system is enhanced with an increasing antenna aperture. Instead of using more antenna elements, the distances in the aperture can be increased with a sparse array. To mitigate the high side lobes originating from the sparse array, the missing antenna elements can be reconstructed by means of compressed sensing. In this paper, a sparse antenna array with a low side lobe level is determined with a genetic algorithm and a cost function. An investigation is performed what difference in the radar cross section of two targets in the same range-Doppler cell can be achieved. Additionally, instead of considering point targets only, a target vehicle is measured with a 77 GHz MIMO radar.

16:20 Extraction of Scattering Centers Using a 77 GHz FMCW Radar

Sevda Abadpour; Axel Diewald; Mario Pauli; Thomas Zwick
Karlsruhe Institute of Technology (KIT), Germany

This paper investigates monostatic RCS measurement results of a typical car as a complex object using an FMCW automotive radar to determine the backscattering behavior of the target. The backscattering behavior can be modeled by identifying the scattering centers of the target. In a subsequent step, the extracted scattering centers can be used for the simulation of the millimeter wave automotive radar channel in realistic scenarios. These scenarios can be simulated by a comprehensive system simulation environment according to asymptotic ray-based methods. The used ray-tracing tool showed a good estimation of communication channels, however for radar channels, that relies primarily on backscattering effects, its accuracy is strongly dependent on the scattering behavior of the targets. The integration of highly resolved CAD models into the ray-tracing software results in a high computational effort. In many cases, the exact CAD model of a car or other traffic participants is not even available. So, one solution for minimizing the computational effort is to determine the scattering centers of complex objects and to identify the most significant ones. Based on these relevant scattering centers a simplified model can be created. For this purpose, some measure-

ment campaigns have been performed in a realistic stationary environment to investigate the spatially resolved scattering behavior of a car.

16:40 Predictive Quantization for Staggered Synthetic Aperture Radar

Nicola Gollin; Michele Martone; Michelangelo Villano; Paola Rizzoli; Gerhard Krieger
German Aerospace Center (DLR), Germany

For present and future spaceborne SAR missions, an increasing amount of onboard data is going to be required, due to the employment of large bandwidths, multiple polarizations, and large swath widths, which lead to hard requirements in terms of onboard memory and downlink capacity. In this context, SAR raw data quantization represents an essential aspect, since it affects both the amount of data to be stored and transmitted to the ground and the quality of the resulting SAR products. In this paper, a data reduction approach based on predictive quantization is investigated in the context of Tandem-L, a DLR proposal for a highly innovative bistatic L-band radar satellite mission, aimed at monitoring the dynamic processes of the Earth. The proposed technique takes advantage of the time-variant autocorrelation properties of the non-uniform azimuth raw data stream in order to reduce the amount of data through a novel quantization method, named Predictive-Block Adaptive Quantization. Different prediction orders are investigated by considering the trade-off between achievable performance and complexity. Simulations for different target scenarios show that a data reduction of about 10-15% can be achieved with the proposed technique with a modest increase of the system complexity. Moreover, having a priori information on the gaps position in staggered SAR, a technique for their reconstruction based on dynamic bit allocation has been successfully implemented as well, showing no significant loss of information.

17:00 Novel 4D 79 GHz Radar Concept for Object Detection and Active Safety Applications

Gang Li; Yoke Leen Sit; Christian Sturm; Urs Lübbert; Alicja Ossowska; Sarath Manchala; Tobias Kettner; Kevin Krupinski
Valeo Schalter und Sensoren GmbH, Germany

A novel 4D automotive radar capable of estimating the range, azimuth and elevation angles, and velocity is presented in this work. The radar operates at 79 GHz with a 1.6 GHz bandwidth and uses the ubiquitous fast chirp FMCW. To achieve the elevation information, the MIMO technique and a BPSK- based coding [1] is used on the transmit signals for a simultaneous transmission covering a wide angular field-of-view without any time blind spot. A real-time signal processing and 3D mapping of the environment is made possible by the physical antenna arrangement and simplified digital beamforming processing. Three measured use cases i.e. curb stone height estimation, drain cover detection and parking lot detection; to determine height of the obstacles and

the quality of the height estimation are shown in this work. The performance of this 4D radar is good and promising for the active safety applications within the definitions of the Euro NCAP.

17:20 Cooperative Target Detection in a Network of Single-Channel Radar Sensors

Maximilian Steiner; Karim Sherif Osman; Christian Waldschmidt
University of Ulm, Germany

In automotive sensor networks the spatial distribution of the radar sensors allows to unveil additional information about the target objects. For example, the different angles to a target provide an increased robustness and the wide sensor distances allow for a single snapshot motion estimation. This is even possible with single-channel radar sensors, but the reliability of the output highly depends on the condition that single scattering points are jointly detected. This paper presents an algorithm which associates single detections of a target over multiple sensors by utilizing the ego-motion of the vehicle. Further, it is shown how all target detections can be assessed and how reliable detections can be identified to improve subsequent processing steps like the target localization. The proposed processing is validated by radar measurements at 77GHz.

Sessions

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TU1a: Mixed-signal IC and microwave integrated oscillators
Chairs: Manfred Berroth (University of Stuttgart, Germany), Friedel Gerfers (Technical University Berlin, Germany)
Room: Schiller-Saal 08:30-10:20

08:30 A Compact Resistive Quadrature Low Noise Ka-Band VCO SiGe HBT MMIC

Aleksey Dyskin[1]; Sandrine Wagner[2]; Ingmar Kallfass[3]
[1]Technion - Israel Institute of Technology, Israel; [2]Fraunhofer IAF, Germany; [3]University of Stuttgart, Germany

A compact resistive I/Q low noise Ka-band voltage-controlled oscillator is reported in this paper. The oscillator consists of two emitter-coupled logic based high-frequency inverters and a voltage-to-current converter for the oscillation frequency control. The oscillator provides differential I/Q outputs for future integration with a sub-harmonic down-conversion mixer. The oscillator demonstrates a gain of 4.31 GHz/V with a phase noise of -75 dBc/MHz at 1 MHz offset over the oscillation bandwidth. The oscillator consumes between 117 to 148 mW from a 4V supply for different tuning voltages. The oscillator was designed using a high-frequency design methodology and was then optimized for a low-noise operation.

08:50 An Integrated VCO with Frequency Tripler in SiGe BiCMOS with a 1-dB Bandwidth from 22GHz to 32GHz for Multiband 5G Wireless Networks

Frank Herzel; Goran Panic; J. Borngräber; Dietmar Kissinger
IHP, Germany

We present a 9GHz wideband voltage-controlled oscillator (VCO) integrated with a frequency tripler on a single chip. The circuit can generate frequencies from 21.3GHz to 32.1GHz with a phase noise between -122 and -114dBc/Hz at 10MHz offset from the carrier. The 1-dB bandwidth is from 22GHz to 32GHz with an output power between -13dBm and -12dBm. Using a direct-conversion or a sliding-IF transceiver frontend architecture, various 5G frequency bands between 24GHz and 40GHz can be addressed. The chip occupies an area of 1.5mm2 and dissipates 95mA from a 3.3V supply.

09:10 An Ultra-Wideband 3-23 GHz VCO Array with high continuous tuning range for FMCW Radar application

Tom Drechsel; Frank Ellinger; Niko Joram
Technical University of Dresden, Germany

This paper presents a ultra-wideband (UWB) signal source which features an array of

three wideband voltage controlled oscillators (VCO) and is tunable from 3.2 GHz to 22.7 GHz with a relative tuning range of 150 %. The maximal continuous tuning range is 10 GHz and the phase noise is between -106 dBc/Hz and -126 dBc/Hz at 1 MHz offset to the carrier. The system can operate as a small and low cost frequency synthesizer which generates frequency chirps with a very high chirp bandwidth for FMCW primary radar application with high range resolution. The ASIC was fabricated using a 130 nm SiGe technology and has a prescaler for frequency synthesizer operation, a differential amplifier, a totem-pole power amplifier for single ended high power output, is fully self-biased, has a typical power consumption of 300 mW and a size of 1.8 mm^2.

09:30 A 0.2-18 GHz Schmitt Trigger with up to 13%-85% Duty-Cycle Tuning in 130nm SiGe BiCMOS

Hatem Ghaleb; Yu Zhu; Corrado Carta; Frank Ellinger
Technical University of Dresden, Germany

This paper reports on the design of a Schmitt trigger for the generation of high-speed switching signals with pulse-width modulation capability. The circuit is implemented using HBT transistors in a 130nm SiGe BiCMOS process, and shows broadband operation from 200 MHz up to 18 GHz. It has a single-ended output voltage swing of 400 mV, and rise/fall times of 10 ps and 13 ps at 10 GHz. The output-waveform duty cycle is tuned by varying the circuit's threshold levels for the switching transitions, resulting in a continuous tuning range between 13% and 85% at 1 GHz. A push-pull Totem-Pole output buffer is designed to enable measurements with 50 Ω measurement equipment. The trigger circuit has 24.6 mW power consumption, in addition to 20.8 mW for the output buffer at the 50% duty cycle setting. The circuit implementation is very compact, requiring only 0.02 mm2 of active area. To the best knowledge of the authors, this is by far the fastest reported Schmitt trigger to date.

09:50 A 44fs RMS Jitter 6GHz Limiting Amplifier in 22nm CMOS FDSOI

Marcel Runge; Philipp Scholz; Friedel Gerfers
Technical University Berlin, Germany

This paper presents a low-power, low-noise limiting amplifier for ultra low-noise wide-band clock regeneration. The proposed limiting amplifier was fabricated in 22nm CMOS FDSOI and reveals an outstanding measured 44fs RMS clock jitter performance at 6GHz signal frequency consuming only 9.6mW power at 0.9V supply voltage and an area of 0.0021mm2. Given a 48dB open loop gain as well as a unity gain bandwidth of 35GHz of the limiting amplifier, a small differential sine-wave with signal level of -9.5dBm (300mVppd) is sufficient to generate clock signals with < 50fs RMS clock jitter. Given the superior noise performance of the proposed amplifier in conjunction with 22nm CMOS FDSOI, the ultra-low noise clock generation as well as the data converter can be integrated in a single-chip solution incorporating compact, low-cost > 1GS/s

high-resolution data converter systems with a jitter induced signal-to-noise ratio of >60dB (10bit ENOB). Thus, 22nm CMOS FDSOI is a promising vehicle for high bandwidth, high-resolution data converters with on-chip clock generation.

10:10 Non-Linear PAM-4 VCSEL Equalization and 22nm SOI CMOS DAC for 112 Gbit/s Data Transmission

Urs Hecht[1]; Nikolay Ledentsov Jr[2]; Philipp Scholz[1]; Mikel Agustin[2]; Patrick Schulz[1]; Nikolai Ledentsov[2]; Friedel Gerfers[1]
[1]Technical University Berlin, Germany; [2]VI Systems GmbH, Germany

The non-linear behavior of 850nm VCSELs is analyzed. 80Gbit/s unequalized optical PAM-4 signal is demonstrated for the first time. The proposed non-linear TX equalization enables 112Gbit/s PAM-4 data transmission with significant linearity and SNR improvements. A 7bit segmented DAC driver is proposed for the 56Gbaud transmitter. It is Implemented in a 22nm SOI CMOS process providing a differential signal swing of 950mVppd as well as a SNR and SFDR of 43dB and 53dBc respectively.

TU1b: Phased-array front-end concepts

Chairs: Alexander Koelpin (BTU & Chair for Electronics and Sensor Systems, Germany), Dirk Plettemeier (Dresden University of Technology, Germany)
Room: Silcher-Saal 09:00-10:30

09:00 Conformal Antennas for a Wide View Angle in Automotive Radar

Jonathan Mayer; Lukas Matter; Benjamin Nuss; Jerzy Kowalewski; Thomas Zwick
Karlsruhe Institute of Technology (KIT), Germany

The autonomous driving needs a round view of the environment. To enlarge the angular view of a single radar sensor, it is possible to use conformal antenna arrays. The advantages of these systems and the number of necessary channels are investigated in this work. Therefore, different setups were designed and tested at 24 GHz considering different criteria like view angle, unambiguous range and gain over the whole field of view. Beneath pattern measurements, radar similar tests were done in an antenna measurement chamber. The work shows that conformal antennas can widen the view angle of a radar. However, enough transmit and receive channels are necessary to cover a suitable view angle.

09:20 Low-cost Transmitarray Antenna Designs with +/-70° Beam Steering Range in V-Band

Martin Frank[1]; Fabian Lurz[1]; Robert Weigel[1]; Alexander Koelpin[2]
[1]Friedrich-Alexander University Erlangen-Nuremberg, Germany; [2]BTU & Chair for Electronics and Sensor Systems, Germany

This paper presents the design and characterization of linearly polarized low-cost transmitarray antennas with +/-70° beamforming range in V-band. The antennas are composed of 13 x 13 planar unit-cells. The unit-cells consist of two layers RO4350B laminate. The unit-cells provide a one bit phase resolution. The desired unit-cell behavior has been validated by simulations and measurements. Eight transmitarrays with different phase distributions have been designed and fabricated to realize different beam steering angles. The experimental characterization of the radiation patterns shows the desired performance in the frequency range from 59 GHz to 63 GHz.

09:40 MIMO Antenna Array System with Integrated 16x16 Butler Matrix and Power Amplifiers for 28GHz Wireless Communication

Xiaozhou Wang[1]; Martin Laabs[1]; Dirk Plettemeier[1]; Keishi Kosaka[2]; Yasuhiko Matsunaga[2]
[1]Dresden University of Technology, Germany; [2]NEC Corporation, Japan

This paper proposes, for the first time, a MIMO antenna array system composing of 1x16 Quasi-Yagi antenna array, 16x16 high-dimension Butler matrix and 16 chains of power amplifiers for the 5G wireless communication system operating at 28GHz. Due to the integration of the power amplifiers between the radiation part (1x16 Quasi-Yagi antenna array) and the beamforming network (16x16 Butler Matrix), 18dB additional power gain is experimentally achieved at 28GHz. A beam pattern comparison based on the measured results of MIMO antenna array systems are processed to investigate the influences from the integration of power amplifiers, which could occur the phase and amplitude deviation errors at the inputs of the antenna array. A flexible system of PCBs is implemented to separately characterize power amplifiers inside and outside the MIMO antenna array system. Furthermore, the performance of the interconnections of the PCBs by bonding wires is evaluated and discussed based on the simulated and measured results.

10:00 Class-G Supply Modulation for MIMO and Radar with Phased Array Antennas

Nikolai Wolff[1]; Wolfgang Heinrich[2]; Olof Bengtsson[2]
[1]Wenglor Sensoric GmbH, Germany; [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany

Class-G supply modulation, i.e., discrete level supply modulation, is a powerful efficiency enhancement technique. It allows wideband modulated operation of RF power

amplifiers and high output power. For massive multiple-input multiple-output functionality in 5G systems, phased array antennas can be used to implement dynamic beamforming, similar to radar systems. Different configurations for driving the phased array antennas are possible. The configuration under investigation consists of a single baseband source that is distributed to antennas driven by dedicated power amplifiers with controllable input delay lines. This complexity-reduced topology where the power amplifiers are discretely supply modulated with the same supply waveform has only minor impact on the efficiency improvement. Instead the linearity is limited by a trade-off that depends on the relative modulation bandwidth, the electrical antenna size and the beam angle. It is shown that planar phased array antennas with 2x2 or 4x4 elements can be efficiently driven with this topology and an efficiency improvement of 10%-points can be achieved. Even 8x8 phased arrays are supported by this topology at reduced bandwidth and beam angles.

PS2: Poster session 2
Chair: Ning Yan Zhu (University of Stuttgart, Germany)
Room: Foyer 09:00-11:00

Design and Optimization of Mixers Using Load-Pull Analysis of Higher Order Intermodulation Products
Laura Manoliu; Christopher Grötsch; Ingmar Kallfass
University of Stuttgart, Germany

This work proposes an innovative approach to improve the design of frequency-converting circuits. The novelty is the determination of the precise optimal impedance at each harmonic and inter-modulation frequency that will improve the performance of the mixer cell. The method takes into account the effect of the load impedances at inter-modulation frequencies on the conversion gain of the circuit. The proposed method can be applied to the optimization of any figure of merit. The optimal performance is found by varying load impedances, along with frequency, separately controlled using an ideal filter network at one or several mixer ports. The proposed load-pull analysis is applied to the optimization of a resistive mixer as a millimeter-wave monolithic integrated circuit, having a local oscillator frequency of 300 GHz and radio frequency bandwidth of 88 GHz. It is shown that by filtering the harmonics and presenting specific impedances, the conversion gain increases by more than 2.5 dB, while the radio frequency 3 dB-bandwidth has doubled. With the help of this analysis, the output matching network can be optimized.

Millimeter wave spectroscopy system for blood coagulation measurements
Giacomo Ulisse; Sebastian Harder; Viktor Krozer
Goethe University of Frankfurt am Main, Germany

Blood coagulation tests are extremely important to discover bleeding disorders and cardiovascular diseases. Nowadays blood coagulation tests require large and expensive instruments. Furthermore, the tests require high formed personnel. It is fundamental for this kind of measurements to reduce the costs and the complexity of the procedures. In this paper, we report a millimeter wave spectroscopy system that permits to measure the characteristics of blood varying during the time and consequently the possibility to estimate the coagulation time. The system permits to perform measurements in an easy way without the need of expensive consumables giving the opportunity in the future to have a portable device that anyone can use.

Design and Numerical Analysis of a Ka-Band Patch Antenna for Structural Health Monitoring Applications
Hai Duy Nguyen[1]; Gernot Zimmer[2]; Jochen Moll[1]; Viktor Krozer[1]
[1]Goethe University of Frankfurt am Main, Germany;[2]Frankfurt University of Applied Sciences, Germany

This paper presents a design of Ka-Band microstrip patch antenna for structural health monitoring (SHM) applications. Following a successful SHM system for wind turbine blades, the antenna is developed for the frequency bands of 33.4GHz-36GHz. Horn antennas in the current system could be replaced with microstrip patch array for better integrity, and reduced weight. The array is constructed from 4x4 radiating elements, fed by capacitance probes, and packed in cavities. In consequence, simulation results show relative impedance bandwidth (return loss better than 15dB) of 12.8%, at resonance frequency fo = 35GHz. Directivity is about 18dBi, and side-lobe levels (SLL) are better than -15dB on both E-planes.

Numerical Analysis of Two-Dimensional Waveguide Patches for Surface Damage Detection
Jochen Moll
Goethe University of Frankfurt am Main, Germany

A novel method for damage detection in metallic structures has been introduced recently based on the concept of jointed electromagnetic waveguides. Here, the electromagnetic waveguide is formed by an open waveguide placed on top of the host structure to be inspected. Electromagnetic waves propagating in the waveguide interact sensitively with a structural damage leading to changes in the scattering parameters. The main goal of the present paper is the numerical analysis of two-dimensional waveguide patches in the frequency band from 2GHz to 8GHz. A parametric numerical

analysis has been performed for through holes at different positions and for holes with different diameters.

Novel Passive Calibration Method for Fully Polarimetric Near Field MIMO Imaging Radars

Georg Körner; Daniel Oppelt; Julian Adametz; Martin Vossiek
Friedrich-Alexander University Erlangen-Nuremberg, Germany

In this paper a novel method for calibration of multiple-input multiple-output (MIMO), fully polarimetric near field radar systems is presented. The developed approach allows for the first time for a practical and effective calibration, i.e. the correction / equalization of the frequency transfer function of all polarimetric radar channels even in a near field scenario where the target distance is not large compared to the MIMO antenna array dimension. In a first step, the mutual coupling between all channels is corrected by an empty space measurement. The polarimetric calibration is based on measurements with two simple, passive calibration standards. An offset short calibration of the co-polarized channels is conducted by using a mirroring reflection of a plane metal plate. A dihedral reflector is employed for the calibration of the cross-polarized channels. Since the dihedral reflection is distinctly directive and due to the close range acquisition condition, only channels with adjacent antenna elements can contribute to the calibration process. However, it is shown in this paper, that the sparse calibration data obtained from these few antenna combinations are sufficient for a successive calibration of all cross-polarized channels. This way, the novel method allows for a simple but yet effective calibration of fully polarimetric high resolution near field imaging MIMO radars based on two cost-efficient passive standards and with very low adjustment efforts during the calibration.

TU3a: Application of optical components in microwave systems

Chairs: Joerg Schoebel (Technische Universität Braunschweig & SF Microwave GmbH, Germany), Andreas Stöhr (University of Duisburg-Essen, Germany)
Room: Schiller-Saal 13:10-15:10

13:10 Microwave Photonics (Invited)

Thomas Schneider
TU Braunschweig, Germany

Due to the increasing demands of applications in fields like radar, wireless and optical communications and signal processing, the generation and processing of microwave signals with large bandwidth and flexible tunability up to several tens of GHz is re-

quired. It is hard to fulfill these requirements by conventional methods like electronic circuits. Photonics instead can easily handle very broad bandwidths, can transmit broadband signals with almost no loss over lengths of several kilometers and is immune against electromagnetic interference. Microwave photonic filters based on the nonlinear effect of stimulated Brillouin scattering (SBS) have shown flat-top response, high selectivity, programmable bandwidth, filter shape and tunability, for instance, properties completely impossible with classical microwave filters. However, in the past microwave photonic systems have been built with kilometers of optical fibers, not very attractive for many applications. Very recently, the success in photon-phonon coupling in subwavelength waveguides has paved the way to integrated microwave-photonic devices combining the positive aspects of both worlds.

13:30 Optical Signal Generation and Distribution for Large Aperture Radar in Autonomous Driving

Stefan Preussler[1]; Fabian Schwartau[1]; Joerg Schoebel[1,2]; Thomas Schneider[1]
[1]Technische Universität Braunschweig, Germany; [2]SF Microwave GmbH, Germany

Fully autonomous driving, even under bad weather conditions, requires use of multiple sensor systems including radar imaging. Here a new concept for the optical generation and distribution of radar signals, comprising low complexity transmitter and receiver chips and a complex central station will be introduced. Within a proof-of-concept radar experiment an angular resolution of 1.1° was achieved.

13:50 2D mm-Wave Beam Steering via Optical True-Time Delay and Leaky-Wave Antennas

Matthias Steeg; Peng Lu; Jonas Tebart; Andreas Stöhr
University of Duisburg-Essen, Germany

In this paper we outline a concept to provide 2-dimensional photonic-assisted beam steering at mm-wave frequencies by utilizing leaky-wave antennas and integrated optical beam forming networks. Thereby, heterodyne detection is employed to tune the RF for leaky-wave antenna (LWA) beam scanning by remotely changing the optical frequency of a tunable laser. Beam steering in the other dimension is provided via an optical true time delay (TTD) beam forming network, which is compatible to the LWA beam scanning even for multiple GHz of bandwidth. Through wavelength-division multiplexing and optical filters, multiple beams can be generated even at the same RF. To prove the concept a system based on discrete components is set up and used to demonstrate 2D beam steering of a 1 Gbit/s data signal in the 60 GHz band over 1.5 m wireless distance.

14:10 Fully-Hermetic 71-86 GHz WR12 Coherent Photonic Mixer Providing an RF Output Power up to +15 dBm

Besher Khani[1]; Sumer Makhlouf[1]; Jörg Lackmann[1]; Andreas Gerhard Steffan[2]; Jörg Honecker[2]; Andreas Stöhr[1]
[1]University of Duisburg-Essen, Germany; [2]Finisar Berlin, Germany

Novel compact fully-hermetic E-band (71-86 GHz) coherent photonic mixer (CPX), featuring a rectangular waveguide WR12 output and providing an RF output power up to +15 dBm, is reported in this work. According to our knowledge, this is the highest reported output power level radiated directly form a photonic mixer module in the E-band frequency range. The fabricated WR12-CPX allows direct optical-to-wireless conversion of optical baseband or IF-band signals, e.g. for radio-over-fiber (RoF) front-hauling in mobile communications. The module comprises an InP-based balanced-PD (BPD) chip, a GaAs HEMT MMIC medium power amplifier, and a laminate-based grounded coplanar waveguide to rectangular waveguide (GCPW-WR12) transition. The transition couples the optically generated, e.g. via heterodyning, millimeter-wave signal from the output of the BPD chip to the WR12. It is based on a double-slot antenna structure and developed on a Rogers RT/duroid 5880 laminate with a thickness of 127 µm. The presented GCPW-WR12 transition enables the development of fully-hermetic photonic packages, which is required to improve the durability of the BPD chip. The transition design is optimized by utilizing a 3D electromagnetic simulation software (ANSYS HFSS) for achieving a wide operational bandwidth with an average insertion loss (IL) of about 1.6 dB and a return loss (RL) higher than 15 dB in the frequency range of 71-86 GHz. Finally, the RF responsivity of the WR12-CPX module and the hermeticity of the transition are experimentally characterized.

14:30 Precise, High-Bandwidth Digital-to-Analog Conversion by Optical Sinc-Pulse Sequences

Janosch Meier; Thomas Schneider
Technische Universität Braunschweig, Germany

A concept for a precise digital-to-analog conversion based on optically generated sinc-pulse sequences is proposed. Since only standard elements of optical telecommunications are required, the concept has the potential to be integrated on a silicon photonics platform. The achievable analog bandwidth and corresponding sampling rate can be three to four times the bandwidth of the incorporated photonic and electronic components. Since experimental results for the integrated digital-to-analog converter (DAC) are not yet available, besides simulations, we present proof-of-concept experimental results for the generation of precise sinc-pulse sequences and the analog-to-digital conversion (ADC) with these pulse sequences.

14:50 Sinc-shaped, Nyquist Channel Demultiplexing with Silicon Photonics
Arijit Misra[1]; Dvir Munk[2]; Moshe Katzman[2]; Stefan Preussler[1]; Avi Zadok[2]; Thomas Schneider[1]
[1]Technische Universität Braunschweig, Germany;[2]Bar-Ilan University, Israel

Sinc-shaped Nyquist pulses have a rectangular spectrum. In the spectral domain, adjacent Nyquist wavelength division multiplexed (WDM) channels can be multiplexed without any guard band. Theoretically, they can be used to transmit the maximum possible symbol and data rate. The demultiplexing of WDM channels requires filters with transfer functions that are as close as possible to rectangular shapes. Here we present the successful demultiplexing of rectangular-shaped optical Nyquist WDM channels, modulated with an advanced modulation format, with an eight-channel integrated silicon photonics device.

TU3b: Implementation aspects of 5G systems (Industrial Focus Session)
Chairs: Jan Hesselbarth (University of Stuttgart, Germany), Wolfgang Templ (Nokia Bell Labs, Germany)
Room: Silcher-Saal 13:10-15:10

13:10 Future cell massive MIMO research system for future 5G applications (Invited)
D. Wiegner; W. Templ; T. Bohn; C. Haase; G. Kaltbeitzel; S. Wörner; P. Klose; S. Merk; J. Scherzinger; H. Schlesinger; S. Wesemann, et. al.
Nokia Bell Labs, Germany

With the world projected to hold 41 mega-cities by 2030, over 60% of the world's population will live in cities, requiring a massive increase in communication network density and capacity to serve the ever-increasing demand for higher data traffic triggered by future broad band communication and networked devices (IoT, M2M). However, there is as well an evident need for supplying the suburban and rural areas with equivalent communication capacity, not at last to prevent a disparate world divided into a digital utopia and a digital desert. The task of providing cost- and energy-efficient solutions for a rapid deployment and dense coverage with high performing wireless communication infrastructure is at the heart of these scenarios. Massive MIMO systems are promising potential solutions facing the future challenge on drastically increasing data rates applicable for different applications like fronthauling and direct user access. Against this background, the talk gives an overview on our award-winning Future Cell 2.1 GHz FDD massive MIMO small-cell fronthauling research system, enabling cableless and thus much more flexible small cell deployment, not only providing line-of-

sight but also none-line-of-sight connectivity. Furthermore, our significantly more compact follow-up 3.6 GHz TDD massive MIMO research system currently realized at Nokia Bell Labs will be presented. Both systems comprise up to 64 antennas being individually controlled by the digital RF frontend. A focus of the presentation will be on the system design, on the modular and scalable RF frontend concept as well as on the hardware implementation, which are both massive MIMO systems commonly underlaying.

13:50 Co-simulating mm-wave 5G phased array antennas together with beamforming ICs for optimum system performance (Invited)

R. Giacometti
Keysight, Germany

Phased array antenna system performance analysis requires accurate modeling at different levels and the use of different simulation technologies. The radiating elements need to be characterized individually and also with their mutual interactions. The antenna feed structure needs to be included in the analysis, with its coupling and impedance matching effects. The amplitude and phase control circuitry adds nonlinearities, noise and impedance mismatches. All of these elements should finally be analyzed and optimized together to achieve optimum system performance.

14:30 5G technology, new challenges and solutions for millimetre wave 'over the air' testing (Invited)

J. Borrill
Anritsu Corporation

5G networks are being developed and deployed currently, with focus to higher data rates and new use cases for low latency and ultra reliability. Part of the 5G network solution is to use millimetre wave frequency bands, to access wider bandwidths for high data rates. This has lead to the research and development of new test methods and solutions for 'over the air' testing, as direct cable connection to large millimetre wave arrays, or to embedded millimetre wave antennas, is not possible. This presentation will look at the use cases for testing, the key technical challenges to overcome, and the solutions now being provided. This will include the use cases in 5G for near field versus far field measurement, and the requirements for test tolerance and measurement uncertainty in different 5G use cases.

TU4a: Planar circuits, transmission lines, and antennas
Chairs: Wolfgang Heinrich (Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany), Arne F Jacob (Technische Universität Hamburg, Germany)
Room: Schiller-Saal 15:40-17:20

15:40 Wideband Out-of-phase Power Divider with Large Power Division Ratios

Seyed-Ali Malakooti[1]; Marzieh SalarRahimi[2]; Christophe Fumeaux[1]
[1]The University of Adelaide, Australia; [2]KU Leuven, Belgium

An out-of-phase power divider with large power division ratios and broadband response is realized in this paper based on the double-sided parallel-strip lines with an inserted conductor as a virtual ground. The wideband performance is achieved through sacrificing the perfect isolation and return loss at the main frequency by modifying the impedance of only two transmission lines. Using a third order approximation based on the least squares fitting method, the need for optimization of the two targeted transmission lines producing wideband response is ruled out. To substantiate the design method and equations, a circuit with 25:1 power division ratio in conjunction with 80% operational bandwidth referring to 15 dB return loss and isolation is developed. The measured results show the maximum 0.8 dB amplitude deviation from the specified power division ratio with a phase difference between the output ports of 180+-5 degrees.

16:00 Crosstalk Effects of Differential Thin-Film Microstrip Lines in Multilayer Motherboards

Gia Ngoc Phung[1]; Franz Josef Schmückle[1]; Ralf Doerner[1]; Thomas Fritzsch[2]; Steffen Schulz[1]; Wolfgang Heinrich[1]
[1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany; [2]Fraunhofer Institut für Zuverlässigkeit und Mikrointegration, Germany

With increasing demand for miniaturization the requirements for packaging and system integration are more challenging especially when more and more components are to be integrated into a compact module. In such a situation, crosstalk effects and signal degradation due to dense layouts may become critical. The focus of this paper is on the influence of neighboring elements, discontinuities and ground layer modifications in coupled thin-film microstrip lines in differential operation. Moreover, design guidelines how to mitigate these effects are provided.

16:20 L-Band Antenna Array for Next Generation DLR Airborne SAR Sensor

Diego Lorente; Markus Limbach; Bernd Gabler
German Aerospace Center (DLR), Germany

The Microwaves and Radar Institute at the German Aerospace Center (DLR) operates an airborne multi-frequency SAR sensor (F-SAR). Due to the interesting applications of remote-sensing imaging for low frequencies, a new dual polarized L-Band antenna system for the next generation sensor is presented in this paper. Despite the restricted size of the used aircraft, the new antenna optimizes the available space in the antenna carrier by providing more antenna elements, in comparison with the current L-Band sensor, without increasing the inter-element mutual coupling and thereby enhancing the radiation properties of the antenna.

16:40 Optically Transparent Patch Antennas at 77 GHz Using Meshed Aluminum

Philipp Hügler; Mohamad Zaky; Michael Roos; Steffen Strehle; Christian Waldschmidt
University of Ulm, Germany

A process to realize optically transparent patch antennas with double-sided aluminum metalization of meshed structures on fused silica is presented in this paper. For cost-saving manufacturing, aluminum is used as metalization and wire-bonding is chosen as an industry standard RF interconnection technique. Despite the fact that aluminum has a lower conductivity compared to silver or gold, 64 % and 81 % transparent antennas at 77 GHz with 4.4 dBi and 3.7 dBi gain respectively were realized.

17:00 76GHz band Rat-Race Circuit Utilizing Composite Right-/Left-Handed Transmission Line without Chip Elements

Ryoto Nakano; Tadashi Kawai; Akira Enokihara
University of Hyogo, Japan

Screen printing technology using silver nanoparticle ink with high conductivity attracts attention as a technology for fabricating low-loss transmission lines in high frequency band such as millimetre-wave band. Its effectiveness has been confirmed in millimetre-wave band exceeding 100GHz [1]. This paper describes a 180-degree rat-race circuit utilizing composite a right-/left-handed transmission line (CRLH-TL) composed of lumped elements at 76GHz band in order to confirm the reliability of circuit components by utilizing screen printing technology. The proposed rat-race circuit consists of three right-handed transmission lines (RH-TLs) and a CRLH-TL. The CRLH-TL consists of two left-handed (LH) unit cells composed two series capacitances and a shunt inductance, and two distributed RH-TLs connected on both side of the LH-TL section. Conventionally, it has also been the mainstream to use chip elements for these lumped elements, but the proposed circuit consists of only transmission lines without them. For 76GHz band, the designed -10dB rat-race circuit with the CRLH-TL can realize compact size and practical characteristics. Effectiveness of the design method was confirmed by using a commercially electromagnetic field simulator (ANSYS HFSS).

TU4b: Short-range radar and FMCW radar
Chairs: Martin Vossiek (LHFT, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany), Thomas Walter (University of Applied Sciences Ulm, Germany)
Room: Silcher-Saal 15:40-17:20

15:40 Modular Wideband High Angular Resolution 79 GHz Radar System
Fabian Schwartau[1]; Stefan Preussler[1]; Markus Krueckemeier[1]; Florian Pfeiffer[2]; Hannes Stuelzebach[2]; Thomas Schneider[1]; Joerg Schoebel[1,3]
[1]Technische Universität Braunschweig, Germany; [2]Perisens GmbH, Germany; [3]SF Microwave GmbH, Germany

This paper demonstrates a modular 79 GHz radar system based on the Texas Instruments AWR1243 radar chip. The modules are synchronized with a radio-over-fiber link to allow the combination of many modules and thus large apertures. A large aperture results in a high angular resolution, which is the key requirement for object classification at long ranges. We describe the coherent synchronization, the chosen antenna pattern, a genetic algorithm to optimize antenna weights and the overall system design. Finally, we demonstrate the capabilities of the system with measurements of a test set up.

16:00 A Radar Target Simulator Concept for Close-Range Targets with Micro-Doppler Signatures
Johannes Iberle[1]; Marc A. Mutschler[1,2]; Philipp A. Scharf[1]; Thomas Walter[1]
[1]Ulm University of Applied Sciences, Germany; [2]University of Ulm, Germany

In this publication a concept of a radar target simulator is presented, designed to simulate micro-Doppler signatures at short distances. The progress of the project is still at the beginning of the development process, but nevertheless the motivation and first partial results will be presented. In the first part, the requirements of the radar target simulator are derived from measurements of vulnerable road users, which will demonstrate the possibilities and advantages of such a system. The second part deals with the system design and the first measurements of the system.

16:20 Simulation method for multiple reflections in near-field applications
Mark Eberspächer
Balluff GmbH Neuhausen, Germany

A field simulation procedure for structures where multiple reflections occur is presented. The basic objective is the computation of each particular reflection contributing significantly to the steady state reflection coefficient of a problem. The method is based on plane-wave field expansion including evanescent waves in order to account for

near-field effects. As an example, an arrangement similar to a Fabry-Perot resonator is analyzed and the results are compared to that of a commercial field solver.

16:40 Parametric Study of Time-Reversal Imaging for the Detection of Tumors in MRI-derived Breast Phantoms

Elham Norouzzadeh[1]; Jochen Moll[2]; Somayyeh Chamaani[1]
[1]K. N. Toosi University of Technology, Iran; [2]Goethe University Frankfurt am Main, Germany

In this paper, the performances of two time-reversal (TR) based algorithms namely time-reversal multiple signal classification (TR-MUSIC) and decomposition of time reversal operator (DORT under its French acronym) for detecting breast cancer through UWB microwave imaging, are assessed. These assessments are carried out by changing the location of a hypothetical spherical tumor in an MRI-based numerical breast phantom through simulations in CST microwave studio environment. The recorded data is processed by the two TR-based procedures which result in the final images of cancerous breast tissues. In all cases, data acquisition has been conducted in 2 steps with and without a tumor inside the breast. During each step, UWB pulses within the wideband frequency range of 2-5 GHz are transmitted by 16-element antenna array which also receives backscattered signals from the breast tissue. In this work, we show that the implemented method can locate tumors with high precision, whether the tumor is located in the middle of the breast phantom, near to the skin or even close to the muscle wall which possesses a high reflectivity.

17:00 A broadband UAV-Based FMCW GPR and the Influence of Vegetation

Ralf Burr[1]; Markus Schartel[2]; Winfried Mayer[3]; Thomas Walter[1]; Christian Waldschmidt[2]
[1]Ulm University of Applied Sciences, Germany; [2]University of Ulm, Germany; [3]Endress + Hauser GmbH & Co. KG, Germany

Ground penetrating radar (GPR) is one of the tools supporting mine detection. In this contribution a wide-band frequency-modulated-continuous wave (FMCW) GPR operating in the frequency band from 0.6 GHz to 4.6 GHz in a bistatic configuration is presented. The frequency synthesis is realized using a broadband voltage controlled oscillator (VCO) in a higher frequency band and mixed down to the desired frequency band. The radar including antennas is integrated on a unmanned aerial vehicle (UAV). In measurements the effect of vegetation and the frequency dependence is investigated.

Sessions

Wednesday, March 27, 2019						
	Foyer			Schiller-Saal	Silcher-Saal	Tagungsraum 4.3.11-13
08:00 - 08:30	Registration opens 08:00					
08:30 - 09:50				Waveguide components and filters	Millimeter-wave integrated circuits	
09:50 - 10:00	Coffee break					
10.00 - 10:20						Workshop (Keysight)
10:20 - 11:40				Hybrid amplifiers and oscillators	Characterization and modeling of integrated-circuit components	
11:40 - 11:50						
11:50 - 13:10				Closing session & Keynote 5		
13:10 - 13:40	Lunch break				Workshop "Electromagnetic sensors for life sciences" (ESSENCE)	Workshop "New radar technologies for autonomous driving" (ELEVATE)
13:40 - 16:40						
16:40 - 16:50						
16:50 - 17:30						ELEVATE cluster meeting

WE1a: Waveguide components and filters
Chairs: Martin Schneider (University of Bremen, Germany), Klaus Solbach (UDE, Germany)
Room: Schiller-Saal 08:30-09:50

08:30 Realization of Folded W-Band Waveguide Filters with Additional Asymmetric Resonant Transmission Zeros

Daniel Miek; Michael Höft
Kiel University, Germany

In this paper the realization of asymmetric filter responses in folded W-band waveguide filters is discussed. Two third order filter set-ups with three as well as up to seven transmission zeros realized by means of resonant cross-coupling are presented. Filter design and realization is discussed and the measurement results are compared with simulation. Design charts for proper positioning of the physical resonant cross-coupling inverters are derived to avoid cumbersome simulations in the filter design process. Finally, a discrete equivalent circuit containing a resonant cross-coupling inverter is proposed and the S-parameters are compared with data from full-wave simulation.

08:50 Low-Dispersive Transition from Circular Metallic to Circular Dielectric Waveguides at W-Band Frequencies

Andre Meyer; Kristina Krüger; Joshua Obermeyer; Martin Schneider
University of Bremen, Germany

At mm- and sub-mm-wave frequencies dielectric waveguides (DWGs) are an interesting alternative to commonly used metallic waveguides. DWGs have lower losses, lower weight and increased flexibility. In addition, dielectric waveguides can be designed for minimal waveguide dispersion over a wide frequency range. For instance, a short section of a metallic waveguide might be more dispersive than several meters of a dispersion-minimized dielectric waveguide. To replace metallic waveguides by DWGs a transition between both waveguide types is needed. In order to benefit from the low dispersion and low losses of DWGs, in this paper a low-dispersive, low-loss transition from circular metallic waveguide to circular dielectric waveguide is presented. The circular feeding waveguide allows dual or circular polarized wave propagation along the DWG.

09:10 Additive Manufacturing Developments for Satellite Antenna Applications from C- to Ka-Band

Philipp Kohl; Michael Kilian; Andreas Schinagl-Weiß; Christian Hartwanger
Airbus Defence and Space GmbH, Germany

In this paper, Airbus shows the latest satellite antenna developments made by additive layer manufacturing (ALM). To investigate the performance of ALM manufactured components for satellite antenna applications, four different components were built. Important antenna key performance parameters such as return loss, isolation and radiation behavior were measured.

09:30 Automated Generation of High-Order Modes for Tests of Quasi-Optical Systems of Gyrotrons for W7-X Stellarator

Tobias Ruess[1]; Konstantinos Avramidis[1]; Gerd Gantenbein[1]; Zisis Ioannidis[1,2]; Stefan Illy[1]; Jianbo Jin[1]; Felix Lutz[1]; Alexander Marek[1]; Sebastian Ruess[1]; Tomasz Rzesnicki[1]; Jörg Weggen[1]; Manfred Thumm[1]; Dietmar Wagner[3] ; John Jelonnek[1]
[1]Karlsruhe Institute of Technology (KIT), Germany; [2]Technological Educational Institute of Piraeus, Greece; [3] IPP Garching, Germany

A test system for the verification of the quasi-optical converter system is vital in the gyrotron development. For this reason, an automated measurement setup has been developed and is benchmarked with the TE28,8 mode operating in the cavities of the gyrotrons of W7-X with a high purity of about 95 % and a counter-rotating amount of about 0.3 %. The time duration for the mode generator adjustment has been reduced to two days for this mode. After a successful mode excitation, the quasi-optical mode converter, consisting of a launcher and three mirrors, is measured having a vectorial Gaussian mode content of 97 %.

WE1b: Millimeter-wave integrated circuits

Chairs: Michael Schlechtweg (Fraunhofer IAF, Germany), Herbert Zirath (Chalmers University of Technology, Sweden)
Room: Silcher-Saal 08:30-09:50

08:30 60-GHz SiGe-BiCMOS Power Amplifier With 14.7 dBm Output Power and 18 dB Power Gain

Ali Ferchichi; Sami Rehman; Corrado Carta; Frank Ellinger
Technical University of Dresden, Germany

In this paper, a power amplifier (PA) operating in the 60 GHz ISM band is presented. A single-stage cascode architecture has been used. The circuit has been fabricated in a 130-nm SiGe BiCMOS technology with a total chip area of 0.3 mm2. The measured amplifier reaches a power gain of 18 dB and a saturated output power (PSAT) of 14.7 dBm, which corresponds to a peak power added efficiency (PAE) of 11%. The PA exhibits a

1-dB compression point (P1dB) of 12 dBm. Regarding the small-signal performance, the PA achieves a small-signal power gain of 17.6 dB and a 3-dB bandwidth of 12 GHz, from 54 GHz to 66 GHz, covering the whole 60-GHz ISM band. To the authors' best knowledge, the presented amplifier demonstrates the highest PSAT among the reported single-stage single-ended PAs and requires the lowest chip area.

08:50 260 GHz Broadband Power Amplifier MMIC

Benjamin Schoch[1]; Axel Tessmann[2]; Arnulf Leuther[2]; Sandrine Wagner[2]; Ingmar Kallfass[1]
[1]University of Stuttgart, Germany; [2]Fraunhofer Institute for Applied Solid State Physics, Germany

This paper presents a broadband H-Band (220 - 325 GHz) power amplifier (PA) in a 35 nm InGaAs based metamorphic high electron mobility transistor technology. The amplifier is realized as a submillimeter-wave monolithic integrated circuit (S-MMIC) and is designed to drive a high power amplifier in a communication system. A five-stage amplifier S-MMIC based on common source gain cells was realized and measured on-wafer with a maximum gain of 14.7 dB at 245 dB. The 3-dB-bandwidth is from 238 to 292 GHz with a gain variation of around 2 dB. The amplifier has four parallel transistors in the last two stages and provide a linear power up to -11 dBm of input power, where the P1dB,in is placed. A saturated output power of 6.7 dBm at 280 GHz could be measured.

09:10 An Active Gate-Pumped Transconductance Upconverter for Terahertz Frequencies

Christopher Grötsch[1]; Ingmar Kallfass[1]; Sandrine Wagner[2]
[1]University of Stuttgart, Germany; [2]Fraunhofer Institute for Applied Solid State Physics, Germany

A single-ended active frequency upconverter for H-band applications is presented. The mixer is designed for a LO frequency at 300 GHz and shows a flat conversion curve over a large bandwidth from 270 to 313 GHz with a conversion gain of -7 dB at a very low LO input power of -3 dBm. In saturation a simulated conversion gain of 0 dB is reached. The MMIC was realized in a 35 nm gate-length InGaAs-based metamorphic HEMT technology.

09:30 Continuous 360° Vector Modulator with Passive Phase Generation for 140 GHz to 200 GHz G-Band

Paul Stärke; Vincent Rieß; Corrado Carta; Frank Ellinger
Technical University of Dresden, Germany

This work presents an integrated broadband vector modulator for mm-wave applications operating between 140 GHz to 200 GHz (G-band). At 170 GHz, it achieves a continuous gain of 3.5 dB over a full 360° phase shift and a peak gain of 10 dB. The circuit

core consists of an input buffer, a passive four-quadrant power splitter for the phase generation and an active variable gain combiner. A broadband 90° hybrid and two 180° coupled- line baluns, both with low amplitude and phase imbalance, are implemented for the phase splitter. The design is optimized for constant phase shifts, with a group delay variation below 5ps and a power consumption of less than 28 mW. The final chip occupies a total area of 0.79 mm^2 , with 0.26 mm^2 for the active core and is manufactured in a 130 nm SiGe BiCMOS process.

WE2a: Hybrid amplifiers and oscillators

Chairs: Renato Negra (RWTH Aachen University, Germany), Rüdiger Quay (Fraunhofer IAF, Germany)

Room: Schiller-Saal 10:20-11:40

10:20 AlGaN/GaN High Electron-mobility Varactors on Silicon Substrate

Raul Amirpour[1]; Dirk Schwantuschke[1]; Peter Brückner[1]; Rüdiger Quay[1]; Oliver Ambacher[2]

[1]Fraunhofer Institute for Applied Solid State Physics IAF, Germany; [2]University of Freiburg, Germany

This paper gives a first presentation of an AlGaN/GaN high electron-mobility varactor grown on a high resistivity silicon substrate. The technology is compared to a GaN on silicon carbide technology and the devices are characterized by fitting a large-signal model. Compared to GaN on SiC varactors a similar performance is achieved. Only slightly increased losses due to higher sheet and contact resistance lower the Q-factor of the GaN on Si varactor.

10:40 A Broadband and High-Efficiency Push-Pull Power Amplifier with Dual-Input and Planar Output Balun

Carsten Zang; Felix Auer; Michael Kamper

Fraunhofer Institute for Integrated Circuits IIS

A broadband push-pull RF power amplifier is designed and measured. The PA yields high efficiency from 0.8 to 3.7GHz with a peak drain efficiency of 68% at 1.6GHz. The output power is greater or equal to 40dBm over the entire band with a minimum power gain of 10dB. Two 6W packaged GaN devices are used to design the PA. The PA features individual RF inputs to optimize peak and backoff efficiency; phase shift between the inputs and its influence on the overall performance is investigated through simulation and measurement. A planar balun is used at the output. No additional output matching is utilized.

11:00 A 1 kW 13.56 MHz Class D^(-1) Power Stage with 90 % Drain Efficiency

Zihui Zhang[1]; Xuan Anh Nghiem[2]; Renato Negra[3]; Georg Boeck[2]
[1]Berlin Institute of Technology, Germany; [2]Glomic GmbH, Germany; [3]RWTH Aachen University, Germany

This work describes the design and implementation of a highly efficient, low-cost 13.56 MHz, 1 kW RF solidstate power stage for RF plasma application and heating. The prototype achieves more than 1 kW RF output power with a drain efficiency of 90%.

11:20 Design approach for compact rotary travelling-wave oscillator based on lumped phase shift networks

Bhaskar Shivanna[1]; Ahmed Ghareeb[2]; Mohamed Saeed Elsayed[2]; Suramate Chalermwisutkul[3]; Renato Negra[2]
[1]Robert Bosch GmbH, Germany; [2]RWTH Aachen University, Germany; [3]King Mongkut's University of Technology North Bangkok & The Sirindhorn International Thai-German Graduate School of Engineering, Thailand

This paper introduces a design approach for Rotary Travelling-Wave Oscillator (RTWO) circuit utilizing lumped phase shift networks to enable compact implementation at low frequencies. In addition, the design trade-offs between the physical length, oscillation frequency, and bandwidth of the phase shift networks are studied. Using off-the-shelf components, a prototype RTWO circuit is designed, fabricated, and characterised at 150 MHz showing a successful proof-of-concept.

WE2b: Characterization and modeling of integrated-circuit components

Chairs: Markus Groezing (University of Stuttgart, Germany), Matthias Rudolph (Brandenburg University of Technology, Germany)
Room: Silcher-Saal 10:20-11:20

10:20 RF-Noise Model Extraction Procedure for Distributed Multiport Models

Felix Heinz[1]; Dirk Schwantuschke[1]; Matthias Ohlrogge[2]; Arnulf Leuther[1]; Oliver Ambacher[1,3]
[1]Fraunhofer Institute for Applied Solid State Physics IAF, Germany; [2]Testo Industrial Services GmbH, Germany; [3]IMTEK, University Freiburg, Germany

A parameter extraction procedure for noise models in distributed multiport topology is presented. This model topology is able to describe the small-signal behavior of high electron mobility transistors (HEMTs) even in the sub millimeter-wave regime while providing full model-scalability. The method introduces an efficient way to extract

both the active, intrinsic transistor parameters and the noise properties for distributed multiport models. A fully scalable small-signal and noise-model of a 50 nm metamorphic HEMT technology in the distributed multiport approach is presented.

10:40 On the Variation in Short-Open de-embedded S-parameter measurement of SiGe HBT upto 500 GHz

Thomas Zimmer[1]; Chandan Yadav[2]; Sebastien Fregonese[2]; Marina Deng[2]; Marco Cabbia[2];Magali De Matos[2]
[1]IMS, France; [2]University of Bordeaux, France

In this paper, we present possible variability issues in TRL calibrated Short-Open de-embedded S-parameters of SiGe HBT upto 500 GHz. The effect of the variability in S-parameters is also investigated and presented for the HBT characteristics. The reason behind variability in de-embedded S-parameter of HBT is discussed and is attributed to TRL calibrated S-parameters of de-embedding test structures. In addition, we present two different analysis methods to select most suitable test structures combination in TRL calibration during transistors' de-embedding with Short-Open method. The selection methods are based on the TRL calibration carried on de-embedding structures and electric field distribution in test-structures through electromagnetic simulation.

11:00 Three-Port S-Parameter based characterization of integrated bridged-T-Coils

Oner Hanay; Jule Hulsman; Renato Negra
RWTH Aachen University, Germany

This paper introduces a bridged-t-coil characterisation tool based on several levels of equivalent circuits and input impedance measurements gathered from S-parameter analysis. The input impedances of the models for different circuitry, termination and frequencies are calculated based on symbolic variables and equated to the simulated input impedances of the bridged-t-coil for the same test set-up resulting in a linear equation system. By calculating the values of the components of the equivalent circuits it becomes possible to analyse and design an integrated bridged-t-coil in a systematic manner. Therefore, the proposed models allow an acceleration of the design flow as critical parameters can be extracted so that the layout can be tuned and optimized regarding the gained information. As a proof-of-concept an integrated bridged-t-coil is designed in a 65nm CMOS technology and the S-parameters of the proposed models are compared to the S-parameters of the EM-simulated three-port. The models deviation of the three-port S-parameters in the considered frequency band lies below 3%.
keynote.

Workshops

Monday, March 25, 2019

WS1: Robert Bosch GmbH Workshop
Challenges of future radar systems for autonomous driving
Room: Tagungsraum 4.3.11 - 13 10:50-12:10

Günter Vogel
Robert Bosch GmbH

The workshop covers innovations in system and circuit design for automotive radar with three contributions:

Automotive radars on the move – achievements and future challenges
(Martin Kunert, Bosch)
The automotive industry is currently facing its biggest changes ever since the invention of the powered vehicle more than 100 years ago. Automotive radar systems will contribute significantly to the (r)evolution of perception systems that are needed to make the transition to autonomous vehicles a reality.
This presentation will show important milestones and achievements already reached in the vehicular radar development history and the challenges that are still lying ahead on the roadmap to radar-supported autonomous driving. Both technical and operational/regulatory topics will be addressed and explained.

The next step towards digital automotive radar – stepped-carrier OFDM
(Daniel Schindler, Bosch)
FMCW based radar is very efficient and has relatively low hardware requirements. However, its performance is limited for MIMO and multi-user multiplexing. Digital modulations have interesting features to overcome these limitations but usually require complex hardware, which is not feasible for automotive applications. The stepped-carrier OFDM approach is a compromise between digital signal generation and reduced hardware efforts to overcome FMCW's limitations while still being suitable for automotive requirements.

Millimeter wave circuits in ultra deep submicron CMOS technology for automotive radar SOCs
(Gregor Tretter, Bosch)
Most of today's automotive radar sensor ICs are manufactured in SiGe technology, utilizing conventional chirp generation. With modern ultra deep submicron CMOS tech-

nologies, these systems can benefit from a higher integration level in order to improve system flexibility, power consumption, area efficiency and cost.
This presentation will show millimeter wave design aspects and implementations for a CMOS radar system on chip (SoC), which combines mmWave, analog and digital circuitry into a single chip.

WS2: Keysight Workshop
Simulate and Measure 5G NR beamforming transceivers
Room: Tagungsraum 4.3.11 - 13 15:40-17:20

Keysight Technologies Deutschland GmbH

While the expectations for 5G seem to be growing in the news every month, Keysight is actively working to help 5G developers several challenging technical issues that span the entire product development cycle, from early architecture exploration, to baseband algorithm development, RF system and circuit design and finish with prototype measurements and production testing.
In the design phase, Keysight's SystemVue integrated simulation environment allows users to investigate, implement and verify their communications PHY signal processing designs with dynamic link-level scenarios, that also include both classical and phased-array antennas. SystemVue's 5G Baseband Verification Library supports several multi-antenna system architectures, including digital, RF, and hybrid beamforming, as well as advanced high-order MIMO signal processing. Consisting of signal processing building blocks, subsystems, reference multi-antenna system modeling examples, and infrastructure components, the library allows system architects to execute realistic technical research and easily migrate from one 5G communication system design concept to another.
Once system design has been finalized and prototypes of the main building blocks become available, the component, subsystem, and system performance needs to be verified. There are many questions to answer here: are my components correctly applying the phase and gain adjustments as they are being directed to? Is my antenna able to accurately control and steer a beam in both transmit and receive mode? How do different MIMO configurations impact the overall beamforming performance? What can I test and learn about my device early in the workflow, to make testing easier later in the workflow – and vice versa? Keysight provides a wide range of measurement solutions to help answer these questions and many others. With tools that can be used across the workflow, time can be saved and design and implementation accelerated.

Tuesday, March 26, 2019

WS3: ANSYS Germany GmbH Workshop
Radar based ADAS scenario simulation using advanced electromagnetic and asymptotic methods

Room: Tagungsraum 4.3.11 - 13 08:30-10:10

Markus Laudien (Lead Application Engineer RF)
ANSYS Germany GmbH

The development of sensitive and reliable mmWave radar modules for ADAS application requires accurate and fast-as-possible electromagnetic simulation techniques. In the past years the requirement for simulation has moved away from an entirely component based approach like for PCB antenna arrays within a radome towards parametric placement studies near a bumper or even traffic scenario analysis with multiple scatterers and multiple target localization. Due to the complexity and electromagnetic size any simulation approach is challenged to find a good compromise between accuracy and simulation time, which generally can only be addressed by hybrid methods and partial automatization.
This workshop gives an overview about the methods and the common design flow: Some first applications of module design will be discussed and the approach for embedded radiation pattern and phase distortion analysis will be presented and shown in examples. Based on the embedded radiation pattern an approach for traffic scenarios for Range/Doppler analysis will be shown. As todays requests move towards real-time or faster-than-real-time analysis an outlook will be given how reduced order models (ROMs) can be used for fast analysis of traffic scenarios.
In order to give the attendees some impression about the handling of the tools this workshop will show in partial live-demos how the different steps can be set up and solved like: initial simulation of antenna array on PCB , Radar module placement behind the bumper, setup of Doppler-scenario with different vehicles and fixed objects, Range Profile, Doppler Postprocessing and more.
A summary and question and answer session will close the workshop.

WS4: Dassault Systèmes Workshop
Advances in the simulation of electromagnetic fields
Room: Tagungsraum 4.3.11 - 13 13:40-15:20

Dassault Systèmes Deutschland GmbH (former CST GmbH)

This workshop aims to demonstrate the unison of different tools and techniques recently combined in the SIMULIA brand. From classical high frequency applications like 5G antenna design to automotive radar applications as well as filter design solutions the tooling must be combined to generate new designs as fast and accurate as possible.
During the workshop we will hear three talks:

- 5G mm-Wave Antenna Design for Mobile Phones and Connected Vehicles
- Synthesis, Tuning and Multi-physics Analysis of MW Filters
- Simulation and Optimization of Automotive Radar

Wednesday, March 14, 2018

WS5: Keysight Workshop
Challenges and Solutions of Advanced Automotive Radar Design and Test Lifecyle
Room: Tagungsraum 4.3.11 - 13 10:00-11:40

Keysight Technologies Deutschland GmbH

From blind spot detection and parking assistance to adaptive cruise control and automatic emergency braking system, automotive radar is now an indispensable part of Advanced Driver Assistance Systems (ADAS) and autonomous driving systems. The growing demands for advanced automotive radar technologies such as using the 77 and 79GHz frequency bands with up to 4GHz modulation bandwidth and micro-Doppler to detect and protect pedestrians have also led to new design and test challenges to the developers and the engineers in automotive industry.
This workshop will review advanced automotive radar design and test challenges including verification of unique radar waveform designs, Angle of Arrival (AoA), micro Doppler effect, transmit and receive antenna channel number, weather impacts, generation and analysis of ultra-wideband mm-Wave radar signals, and more. The workshop will also provide insights in to how Keysight automotive solutions can help you overcome these design and test lifecycle challenges from simulation through Research & Development (R&D) and manufacturing.

- Automotive radar technologies behind ADAS and autonomous driving systems
- System level simulation solutions for advanced approaches to automotive radar design
- Implications of testing at millimeter wave frequency bands (77 / 79 GHz) with ultra-wide bandwidths (up to 4 GHz)
- Keysight solutions to help overcome your design and test lifecycle challenges, from early design simulation, to R&D, then to manufacturing.

WS6: ELEVATE Workshop
New Radar Technologies for Autonomous Driving - Sensors, Algorithms, Testing
Room: Tagungsraum 4.3.11 - 13 13:40-16:40

Prof. Thomas Zwick
KIT Karlsruhe, Germany, Thomas.Zwick@kit.edu

Workshop within the ELEVATE program (research initiative of the Federal Ministry of Education and Research (BMBF) of Germany

- mmWave Radar Technologies and Circuits for Future Autonomous Driving - Klaus Aufinger (Infineon Technologies AG), Nils Pohl (Ruhr-Universität Bochum)
- Advanced Packaging & System-Integration for Automotive RF Applications - Karl-Friedrich Becker (Fraunhofer IZM)
- Future PCB Based Packaging Technologies for Automotive Radars – Manuel Martina (Schweizer Electronic AG), Thomas Zwick (KIT)
- Digital Modulations for Automotive Radar – Benedikt Schweizer, Simon Stephany (University of Ulm)

Break

- Cooperative Sensor Networks - Thomas Binzer (Robert Bosch GmbH)
- Sparse Array Design for high-resolution angular estimation with Compressive Sensing - Maria A. Gonzalez-Huici (Fraunhofer FHR)
- Test concepts for vulnerable road users – Prof. Walter (Hochschule Ulm)
- Installed-performance evaluation of automotive radar systems over-the-air - Matthias Hein (TU Ilmenau), Florian Baumgärtner (Daimler AG)

WS7: ELEVATE cluster meeting
Room: Tagungsraum 4.3.11 - 13 16:50-17:30

Prof. Thomas Zwick
KIT Karlsruhe, Germany, Thomas.Zwick@kit.edu

WS8: Kick-off workshop "ESSENCE – Second Phase"
Room: Silcher-Saal 13:40-17:25

Rolf Jakoby and Martin Schüßler
Technische Universität Darmstadt, Germany,
essence@imp.tu-darmstadt.de

In this Kickoff-Workshop "ESSENCE – Second Phase", there will be three presentations of distinct topics within the framework of ESSENCE of well-recognized scientists from different disciplines.
The Priority Program "Electromagnetic Sensors for Life Sciences: New sensor concepts and technologies for biomedical analysis and diagnostics, process- and environmental monitoring" ("ESSENCE", SPP1857) has been established in 2014 by the German Research Foundation (DFG) promoting scientific projects involving researchers from different disciplines such as electrical engineering, physics, biology and medicine. The central idea of the Priority Program ESSENCE is to foster interdisciplinary research in the field of electromagnetic sensors, whose principle of sensing or measurement is based on the interaction between the electromagnetic fields of the sensor and the matter to be detected or analyzed with a special focus on biomolecules, cells, tissues or other relevant substances in life sciences. Practical applications are in the fields of medicine, biology, pharmacology and environmental analysis/monitoring, which reach from clinical through point-of-care applications to laboratory- and on-site diagnostics. Beyond that, it might enable new forms of treatments as well. Multidisciplinary research is focused on new principles, concepts and technologies of electromagnetic sensors and sensor arrays, partly in combination with new dedicated surface functionalization for electromagnetic transducers.

13:40 : Welcome and Introduction (R. Jakoby)
13:55 : Single-chip in-cell ESR and online reaction monitoring using VCO-based detectors (J. Anders, R. Bittl, J. Korvink)
14:40 : Ultra-fast bio-molecule detection based on radio-frequency nano-pore and nano-channel circuits (R. Blick)
15:25 : Lab-in-a-tube: non-linear dielectric spectroscopy for multiparametric bio-analysis (D. Karnaushenko, M. Medina Sánchez)
16:10 : Coffee break
16:40 : Planning ESSENCE 2019 – 2022 (R. Jakoby)
17:10 : Chancengleichheitsmassnahmen in ESSENCE (C. Hessinger)
17:25 : End

Please note: All delegates have free admission to all workshops.

Conference Venue

Welcome to Stuttgart!

Fascinating and beautiful, cosmopolitan and charming, traditional and future-oriented: the diversity of the Stuttgart region makes it worth visiting. Its economy and its culture are equally thriving – whereby the one is often interlinked with the other, as in the case of the world-famous automobile brands whose names and museums are synonymous with Stuttgart.
Brilliant achievements and an outstanding inventive spirit are typical of the Stuttgart Region and are evident at every turn: castles and palaces bear witness to a great past – and bold, futuristic architecture to an equally great present. The fine arts have always been given ample room to flourish, and many visitors are astonished at the wealth of outstanding gems which the Stuttgart Region has to offer. International sporting events, merry festivals, colourful markets, world-class shopping facilities, traditional cuisine and a countryside defined by a long tradition of viniculture and the River Neckar offer a wide range of leisure activities in the Stuttgart Region.

Kultur- & Kongresszentrum Liederhalle

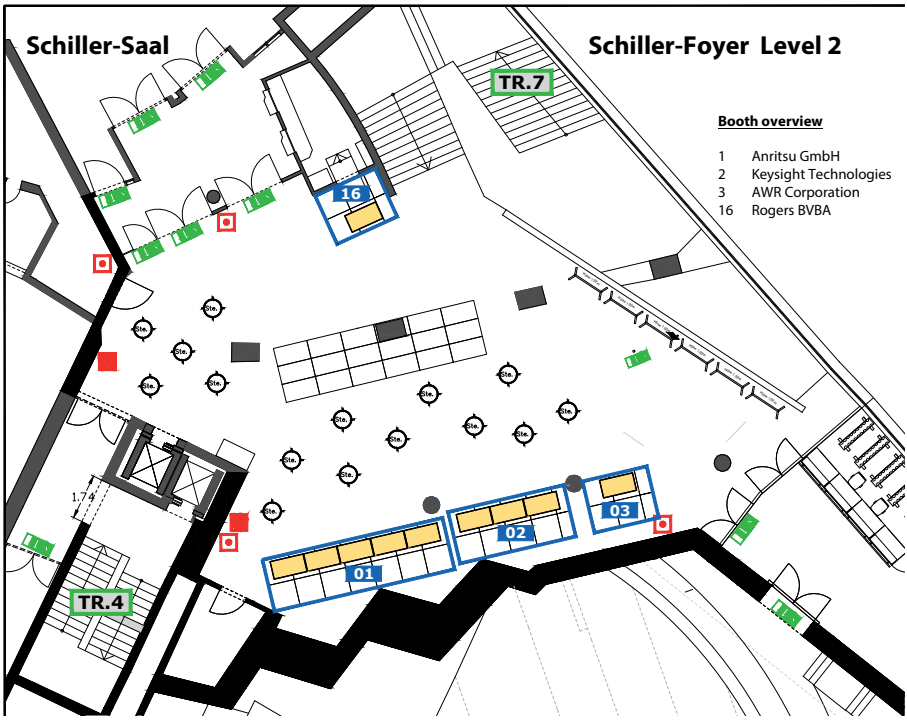
The Liederhalle was built in 1864 as a rehearsal and performance venue for the Stuttgart Liederkranz choir. The building was destroyed by firebombs in 1934. In 1956, however, Stuttgart rebuilt their Liederhalle on the same site. This architectural work of art was constructed in 1956 by Rolf Gutbrod and Adolf Abel and was extended by Wolfgang Henning's addition of a convention annex in 1991.

The Liederhalle is ideally connected with the public transport system. Take Tram-Line U14 (Mühlhausen) or U29 (Vogelsang) from mainstation to Berliner Platz (Liederhalle)

If you arrive by car, please use the underground car park ("Liederhalle - Bosch Areal").

Room layout of Liederhalle

The sessions take place in three different rooms: Schiller-Saal, Silcher-Saal and Room 4.3.11 - 13. The exhibition and poster sessions are located in the Schiller-Foyer (level 1 and 2).



© KKL Liederhalle

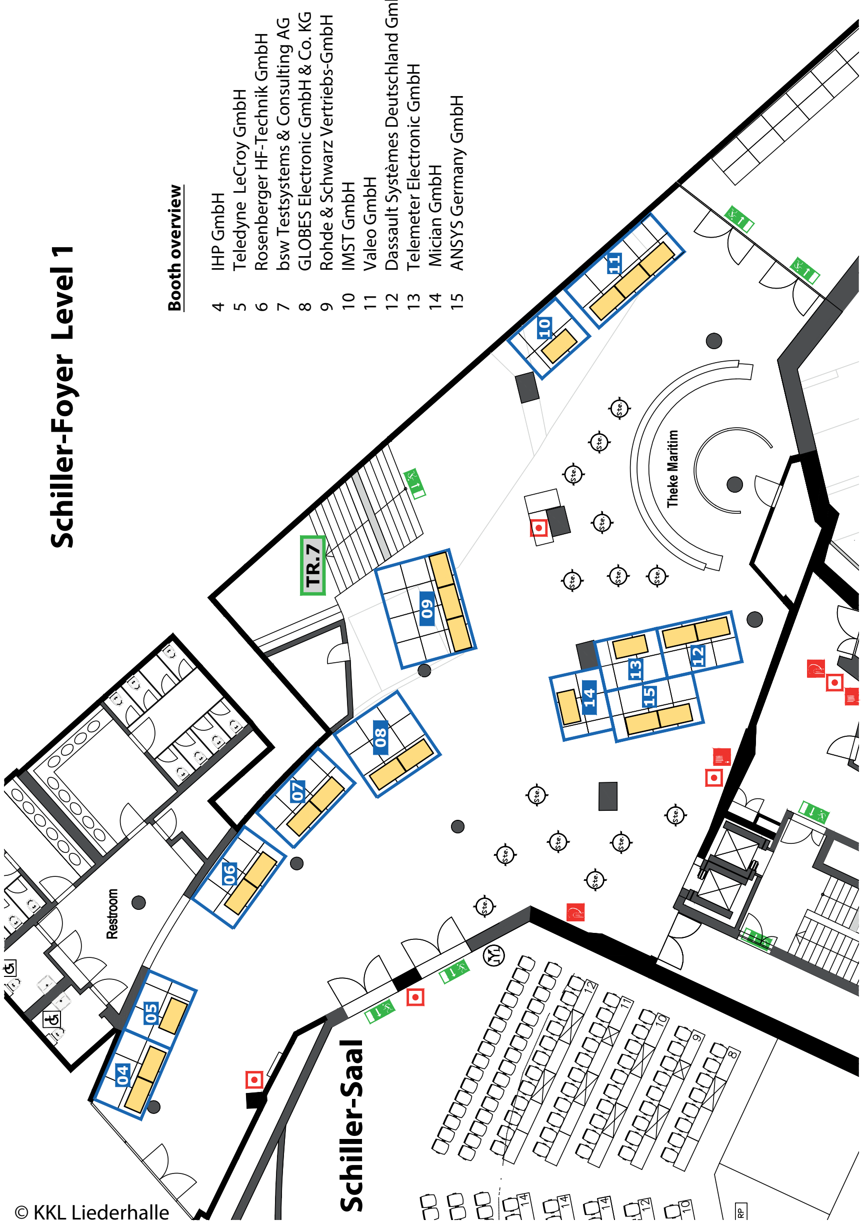
Industry-Sponsored Welcome Reception

All conference participants are cordially invited to attend the get-together on Monday evening from 6 to 8 p.m.! The welcome reception takes place in the Schiller-Foyer.
Enjoy the opportunity to meet colleagues and to share ideas and experiences in a convenient atmosphere.

Schiller-Foyer Level 1

Booth overview

4	IHP GmbH
5	Teledyne LeCroy GmbH
6	Rosenberger HF-Technik GmbH
7	bsw Testsystems & Consulting AG
8	GLOBES Electronic GmbH & Co. KG
9	Rohde & Schwarz Vertriebs-GmbH
10	IMST GmbH
11	Valeo GmbH
12	Dassault Systèmes Deutschland GmbH
13	Telemeter Electronic GmbH
14	Mician GmbH
15	ANSYS Germany GmbH



Conference Dinner

© Maritim Hotel Stuttgart

Join us for a relaxing evening among friends and colleagues! The conference dinner is catered by Maritim Hotel and takes place at the **Alte Stuttgarter Reithalle**, built in 1885 with glass and steel in the style of the Italian Renaissance. As one of the last remaining buildings of this kind it is a protected monument.
All GeMIC deleguates enjoy complimentary entrance. Additional dinner tickets for partners can be purchased during the conference.

Address	Maritim Hotel Stuttgart Seidenstraße 34 70174 Stuttgart
Date:	Tuesday, March 26
Starting at:	17:40

Location map: