

SMARAD

Centre of Excellence in Smart Radios and Wireless Research

Activity Report 2011-2013

Antti Räsänen (editor)

Aalto University publication series

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Wireless Research

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Aalto University
School of Electrical Engineering
Department of Radio Science and Engineering

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ABSTRACT

Centre of Excellence in Smart Radios and Wireless Research (SMARAD), originally established with the name Smart and Novel Radios Research Unit, is aiming at world-class research and education in Future radio and antenna systems, Cognitive radio, Millimetre wave and THz techniques, Sensors, and Materials and energy, using its expertise in RF, microwave and millimetre wave engineering, in integrated circuit design for multi-standard radios as well as in wireless communications.

SMARAD has the Centre of Excellence in Research status from the Academy of Finland since 2002 (2002-2007 and 2008-2013). Currently SMARAD consists of five research groups from three departments, namely the Department of Radio Science and Engineering, Department of Micro and Nanosciences, and Department of Signal Processing and Acoustics, all within the Aalto University School of Electrical Engineering. The total number of employees within the research unit is about 100 including 8 professors, about 30 senior scientists and about 40 graduate students and several undergraduate students working on their Master thesis.

The relevance of SMARAD to the Finnish society is very high considering the high national income from exports of telecommunications and electronics products. The unit conducts basic research but at the same time maintains close co-operation with industry. Novel ideas are applied in design of new communication circuits and platforms, transmission techniques and antenna structures. SMARAD has a well-established network of co-operating partners in industry, research institutes and academia worldwide. It coordinates a few EU projects. The funding sources of SMARAD are diverse including the Academy of Finland, EU, ESA, Tekes, and Finnish and foreign telecommunications and semiconductor industry. As a by-product of this research SMARAD provides highest-level education and supervision to graduate students in the areas of radio engineering, circuit design and communications through Aalto University and Finnish graduate schools.

During years 2011 – 2013, 18 doctor degrees were awarded to the students of SMARAD. In the same period, the SMARAD researchers published 197 refereed journal articles and 360 conference papers.

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1. Introduction to SMARAD

Centre of Excellence in Smart Radios and Wireless Research (SMARAD)

In 2001 the Academy of Finland appointed SMARAD with the name “Smart and Novel Radios Research Unit” as one of the centres of excellence in research for the period 2002–2007. In 2006 the Academy announced its decision that the renewed SMARAD (“Centre of Excellence in Smart Radios and Wireless Research”) was appointed a Centre of Excellence for years 2008–2013, see <http://smarad.aalto.fi/en/>.

According to the Academy: “Centres of excellence are research units or researcher training units which comprise one or more high-level research teams that are at or near the international cutting edge of research in their field. They will also share a common set of objectives and work under the same management. Funding for centres of excellence comes not only from the Academy, but also from the host organisations of the units concerned, and possibly from other funding bodies, such as Tekes, business enterprises and foundations. A centre of excellence may be a unit of research teams working at both universities and research institutes.”

Currently the number of Centres of Excellence is decreasing: the Academy Board appointed 18 centres of excellence for the national CoE programme for 2008–2013, 15 centres for 2012–2017, and 14 centres for the years 2014–2019. Unfortunately, SMARAD is not among the 14 centres appointed for 2014–2019.

SMARAD was originally formed by in 2006 by the Radio Laboratory and the Signal Processing Laboratory of the Department of Electrical and Communications Engineering, Helsinki University of Technology (TKK). In 2006, the Electronic Circuit Design Laboratory of TKK joined SMARAD. After the restructuring of the TKK organization, the current SMARAD involves research groups from three departments, namely the Department of Radio Science and Engineering, Department of Micro and Nanosciences, and Department of Signal Processing and Acoustics, all within the Aalto University School of Electrical Engineering.

SMARAD provides world-class research and education in RF, microwave and millimetre wave engineering, in integrated circuit design for multi-standard radios as well as in wireless communications. In microwave and millimetre wave engineering it is also the only research unit in Finland. SMARAD is a contributor to MilliLab, ESA External Laboratory (a joint institute between VTT and Aalto University School of Electrical Engineering), see <http://virtual.vtt.fi/virtual/millilab/>. The total number of employees within the research unit is about 90 including 25–30 senior scientists and 40–45 doctoral students and several students working on their Master thesis. The unit conducts basic research but at the same time maintains close co-operation with industry. Novel ideas are applied in design of new communication circuits and platforms, transmission techniques and antenna structures resulting also in patents and invention reports. ‘Smart’ in SMARAD’s name refers to adaptability of antennas, radio devices, or materials to RF signals or fields.

SMARAD has a well-established network of co-operating partners in industry, research institutes and academia worldwide. It has coordinated a few EU projects. The funding sources of SMARAD are also diverse including the Academy of Finland, Tekes, and the Finnish and foreign telecommunications and semiconductor industry. As a by-product of this research SMARAD provides highest-level education and supervision to graduate students in the areas of radio engineering, circuit design and communications through Aalto University and Finnish graduate schools and networks.

SMARAD Principal Investigators are (2013):

Prof. Antti Räsänen, chair: Millimetre wave and THz techniques

Academy prof. Visa Koivunen, vice-chair: Communications and statistical signal processing

Prof. Kari Halonen: Electronic circuit design

Prof. Sergei Tretyakov: Advanced artificial electromagnetic materials and smart structures
Prof. Katsuyuki Haneda: RF applications in mobile communications and non-destructive testing

Members of the Scientific Advisory Board of SMARAD (2013):

Prof. Danielle Vanhoenacker-Janvier, Université Catholique de Louvain (UCL), Belgium

Prof. Björn Ottersten, Royal Institute of Technology Stockholm (KTH), Sweden

Professor Heli Jantunen, Oulu University

Professor, Vice-Rector Ilkka Niemelä, Aalto University

Dr Ritva Dammert, Aalto University

Dr Kati Sulonen, Academy of Finland

Dr Hannu Kauppinen, Nokia Research Center

Dr Jani Ollikainen, Nokia Research Center

2. Research teams in the end of 2013

1. **Millimetre wave and THz techniques.** The research group is led by Prof. Antti Räisänen. There are 3 other senior researchers with a doctoral degree and 9 researchers working towards their doctoral degree.
2. **Advanced artificial electromagnetic materials and smart structures.** This research group is led by Prof. Sergei Tretyakov. Prof. Constantin Simovski works in this group. The research group includes 2 other senior researchers, and 7 researchers working towards their doctoral degree.
3. **RF applications in mobile communications and non-destructive testing.** This research group is led by Prof. Katsuyuki Haneda. There are 4 other senior researchers with a doctoral degree and 8 researchers working towards their doctoral degree. Prof. Pertti Vainikainen led this group until June 2012.
4. **Communications and statistical signal processing.** The research group is led by Academy prof. Visa Koivunen. Prof. Risto Wichman works full time in this research group. In addition, there are 4 other senior researchers with a doctoral degree in the group. There are 13 researchers working towards their doctoral degree.
5. **Electronic circuit design.** The research group is led by Prof. Kari Halonen. Prof. Jussi Ryyänen works full time in this research group. The group includes 2 other senior researchers with a doctoral degree and 11 researchers working towards their doctoral degree.

3. Highlights of SMARAD research in 2013

The Centre of Excellence in Smart Radios and Wireless Research, SMARAD, specialises in research into RF, microwave and millimetre wave techniques, integrated circuit design for multi-standard radios as well as wireless communications. Areas of special interest include RF techniques for wireless data communications, radio channel modelling and measurement, new and smart materials and structures, smart (adaptive) antennas, integrated circuit design for multi-standard radios, receiver structures and architectures and the signal processing algorithms they require. The results will have practical application especially in future wireless communication systems. In the following the SMARAD research in 2013 is described under the following titles: Future radio and antenna systems, Cognitive radio, Millimetre wave and THz techniques, Sensors, and Materials and energy.

3.1 Future Radio and Antenna Systems

Future wireless systems demand ever higher data rates and wider bandwidths. Meeting these demands continues to be a challenging and wide research topic ranging from antennas and propagation to system concepts. The future of wireless communications is strongly heterogeneous, where different systems coexist in the same bands requiring highly flexible and reconfigurable transceivers. Moreover, interference management is a major issue since cell sizes are getting smaller, networks may be single frequency networks and network planning may not be feasible in some deployments (e.g. pico-cell and femto-cell deployments, ad-hoc networks) where cell sizes are shrinking. Spectral efficiencies should be improved simultaneously giving rise to different multiple antenna techniques including cooperative MIMO, closed-loop MIMO, multiuser MIMO, as well as diversity transmission schemes.

In addition, future wireless systems require new network topologies characterized by flexible spectrum use and cooperative techniques. So far wireless cellular systems have been optimized for wide area coverage, while WLAN has targeted short-range communications and it lacks mechanisms to support, e.g., mobility, necessary to wide area systems. System architecture for local area communications combining the mobility and services of cellular systems and high data rates and self-organization and autoconfigurability of WLAN would be highly desirable.

Relays in wireless communication systems. Relays that receive and retransmit the signals between network nodes can be used to increase throughput or extend coverage of networks and facilitate novel network topologies. Relays can be classified into amplify-and-forward (AF) relays and decode-and-forward (DF) relays. The former ones retransmit the signal without decoding DF relays decode the received signal, encode the signal again, and transmit.

From signal processing point of view AF relays offer interesting challenges in terms of cooperation between multiple relays, channel estimation and equalization and utilization of channel state information in multihop networks. Spectral shaping of the transmitted signal requires advanced techniques for digital filter design. DF relays, for one, offer various possibilities to optimize the resource sharing between transmit and receive slots and develop joint encoding and decoding techniques in multiple access systems. Our research develops concepts and analysis for relay enhanced wireless networks.

Full-duplex communications. Relays like other wireless transceivers may operate in half-duplex mode, i.e. they do not transmit and receive simultaneously in the same frequency band, or in (in-band) full-duplex mode. The latter operation typically requires a spatial separation between transmit and receive antennas to reduce loop-back interference from the transmit antennas to the receive antennas. Implementation costs of full-duplex transceivers are higher than those of half-duplex ones and their operation range is limited determined by transmit and receive powers and interference levels. On the other hand full-duplex relays may improve system throughput when the transceivers do not require two separate channel resources for reception and transmission. Gains, however, depend on several system parameters, e.g. the symmetry of the traffic between the network nodes.

Full-duplex MIMO transceivers inevitably require adaptive loop interference cancellation techniques in RF domain and digital baseband, the latter being outlined in Fig. 1. The transceiver may optimize spatial transmit and receive filters to mitigate loop interference based on different amount of side information on the channels (left), or subtract the estimated interference (right), or combine these two approaches. In addition to algorithm design, the effect of loop interference must be incorporated into analytical performance studies as well.

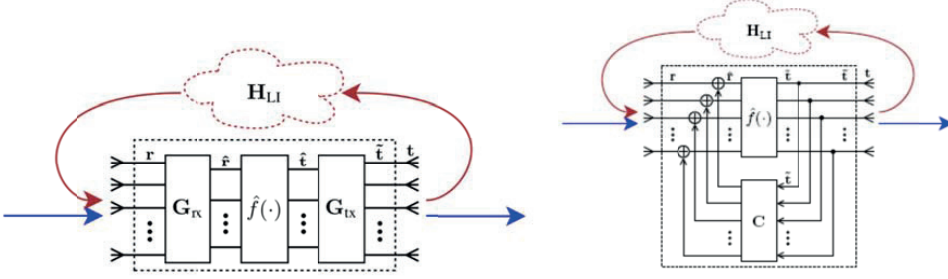


Fig. 1. Loop interference cancellation in spatial domain or subtraction of estimated loop interference.

Our research benchmarks and develops concepts and analysis for wireless communication systems consisting of full-duplex network nodes.

Dirty RF. Building flexible, compact, high-quality, and yet low-cost radio equipment for future wireless systems, is not straightforward. On one hand, re-configurable architecture is required given the heterogeneous radio environment and flexible spectrum use. On the other hand, wide bandwidths together with high data rates would rather require dedicated hardware solutions. We focus on developing deep understanding, how the most essential analog RF impairments, power amplifier nonlinearities, oscillator phase noise, mirror frequency interference due to IQ imbalance, nonidealities in A/D converters, effect the performance of wideband multi-antenna transceivers. The emphasis is on the analytical work to characterize the resulting distortion and their effect on system performance in closed-form, and to develop digital signal processing algorithms for the mitigation of RF impairments.

Multiantenna systems. The goal is to derive transceivers and transmission schemes that exploit all the degrees of freedom in radio channels to achieve high spectral efficiency, high system throughput, extended range as well as powerful interference cancellation capability. In general, practical multi-antenna systems require some channel state information in the transmitter, because otherwise interference between different data streams and users becomes too large in the receiver. The main research problem is then to optimize the tradeoff between the system performance and the required feedback information from receivers to transmitters.

In case of cooperative and multipoint MIMO techniques, multiple transmitters simultaneously transmit to a user, which is especially advantageous when the user is located on the edge of the coverage area. With multiuser MIMO techniques the same channel resource is shared with multiple network nodes aiming to further improve the throughput of network. Concerning heterogeneous wireless systems and spectrum sharing, cooperative and multiuser MIMO algorithms should operate in decentralized manner assuming that network nodes possess only limited information on the state of the system. These kind of distributed techniques are further elaborated within wireless sensor networks.

Distributed and resource efficient parameter estimation in wireless sensor networks. The objective is to develop distributed detection and estimation schemes for detecting an event and estimating and tracking an unknown common parameter, e.g., state of the power grid, temperature, level of water contaminants, or a target position, using multiple displaced sensors. Nodes are linked to each other and cooperate by exchanging information to perform decentralized real-time information processing and optimization. Consequently, the nodes are able to adapt to changing statistics of the data and topographical conditions of the network. In the particular case of sensor networks, the bandwidth and power requirements are closely linked to whether the acquired data is

processed in a centralized or decentralized manner, see Fig. 2. In the former approach, signals from all sensor nodes are processed jointly in one centralized fusion center, thus, facilitating the use of battery operated and low-cost sensors. For a large network, the excessive amount of data can make central processing computationally prohibitive, and may require communications over longer range which leads to reduced battery life. Comparing to the centralized estimation approach, decentralized (or distributed) detection and estimation reduces the amount of data that each estimator needs to process by introducing collaboration between neighboring nodes in the network. Collaboration improves algorithm robustness, e.g., in case of sensor failures; however, it increases bandwidth and power requirements.

As an alternative to classical approaches, this research project aims to develop distributed estimation algorithms with sensors that can make discerning use of received data, thereby providing more informative estimates and thriftier use of resources like power and bandwidth. Thus the nodes should update the parameter estimates only when needed and cooperate only when such an action improves awareness. The amount of data transmitted in a sensor network can be effectively reduced via censoring where data is transmitted only if it is informative. Such algorithms will lead to improved performance, battery savings, prolonged lifetime for the sensor nodes, and improved reliability of the entire network.

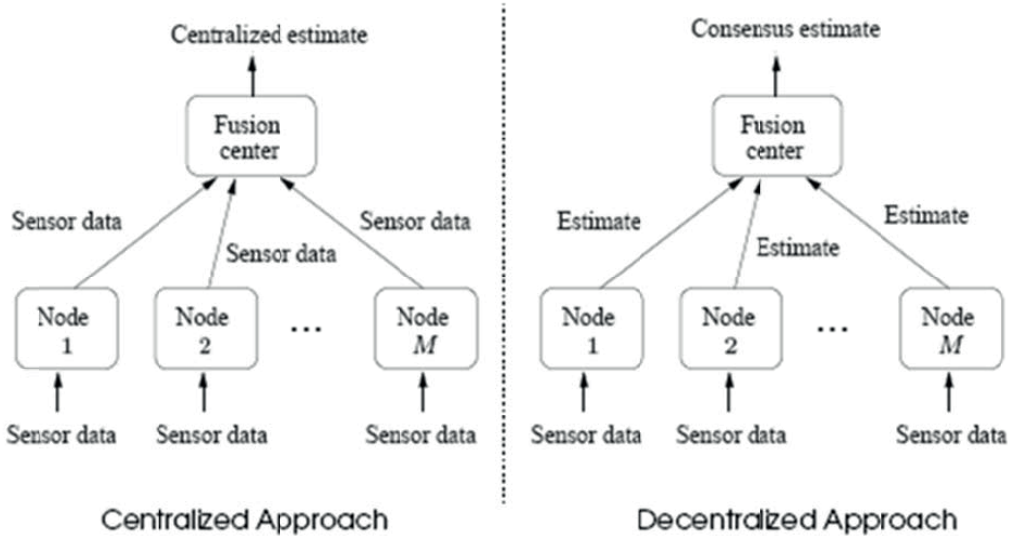


Fig. 2. Centralized and decentralized estimation in a network with M nodes.

Optimal signal processing for arbitrary array configurations. In this work signal processing techniques for sensor arrays of arbitrary geometry are developed. Signals are processed in azimuth, elevation and polarimetric domains. Optimal, robust and high-resolution techniques are derived and their statistical properties are established. Typical applications include beamforming, interference cancellation, source localization, and wavefield parameter estimation. The methods can deal with array nonidealities by incorporating the array calibration data and wavefield modeling in an elegant manner. Conformal arrays and azimuth, elevation and polarimetric data processing can be handled. In fact, this work has solved the problem of deriving optimal array processing algorithms for conformal arrays and real-world arrays with nonidealities. Hence, the developed methods are applicable in most arrays and applications of practical interest.

Multiantenna systems are becoming seminal part of future communication terminals, navigation receivers, wireless and sensor networks. There are many design constraints, especially in handheld

devices such as mobile internet terminals and handheld TV-receivers, and it is rarely possible to build array configurations with nice uniform geometry. Moreover, array elements suffer from nonidealities and mutual coupling. Consequently, there is a need for array processing techniques that allow applying advanced smart antenna algorithms such as optimal beamforming and direction finding, to real-world arrays with arbitrary configuration and array nonidealities. For example, in small handheld devices there are so many design constraints that no regular array geometry can be used.

Novel optimal and robust procedures for array processing using arbitrary array configurations are developed in this work. Analytical performance studies are completed with practical implementations using real world arrays in hand-held terminals. The prototype depicted in Fig. 3 has been implemented in cooperation with Nokia Research center. There is a high performance prototype system for tracking other users carrying RF tags or mobile phones. It has been demonstrated in a good number of international wireless events. Similar principles may be used to develop conformal arrays of arbitrary geometry for beamforming and high resolution direction finding applications in azimuth, elevation and polarimetric domains.

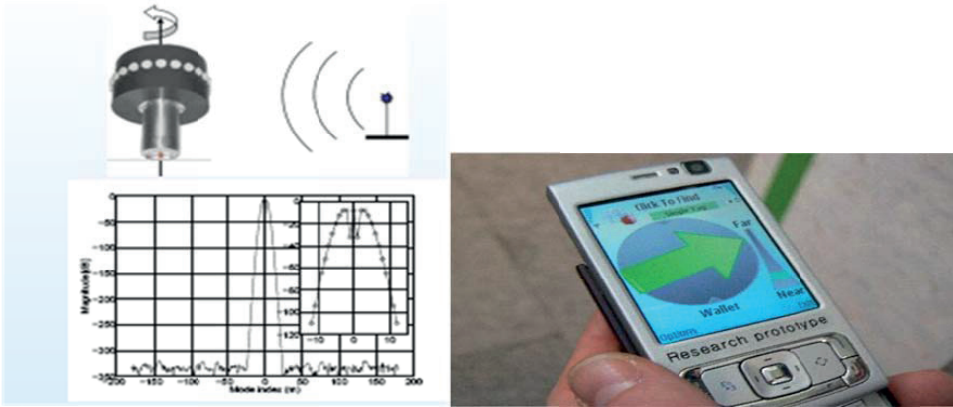


Fig. 3. Optimal and computationally efficient array processing techniques may be generalize to arbitrary array configurations by using Fourier transform of the array calibration data and non-trivial manipulation of input-output matrix model for the array data. Practical application of our method: implementation of 2-D antenna array of arbitrary geometry in a mobile terminal and application in direction finding and ranging (Right).

MIMO radar and novel radar concepts. Another interesting line of research followed in this research is MIMO (Multiple-Input Multiple-Output) radars and waveform diversity. MIMO radars are multistatic radar configurations that provide significant performance gains over classical radar systems. Antennas may be co-located as in traditional phased array systems or they may be widely distributed. Multiple different waveforms are commonly used simultaneously which provides an additional degree of freedom in resolving more targets. Similarly to MIMO communications, spatial diversity (induced by radar cross section) may be exploited. Novel techniques for target detection, high resolution localization and tracking, parameter estimation and accurate time synchronization for distributed MIMO radar are developed. There is special emphasis in optimizing the radar transmitter which is a shift of paradigm compared to classical radar research. In co-located MIMO radars, different waveforms may be launched from each antenna, see Fig. 4. The possibility of using different probing signals in each antenna provides many benefits in target identification and interference cancellation, for example. Novel methods for parameter estimation, resource allocation and adaptive and optimal waveform design are developed and their performances are analyzed.

Additional radar related topics include waveform agile multicarrier techniques for radar, passive radars, and wireless ranging and radar and detection of vital signs using radar.

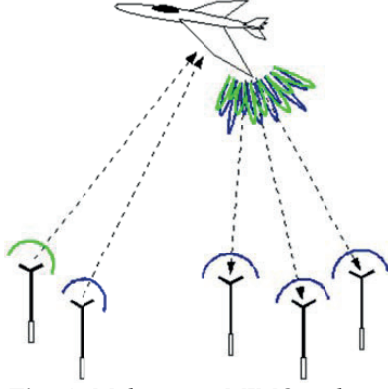


Fig. 4. Multistatic, MIMO radar configuration using waveform diversity. Virtual aperture may be created using signal processing for designing and optimizing the waveforms launched from each antenna.

Reducing the interaction between user and mobile terminal antenna based on antenna shielding. A new shielding concept of a mobile terminal antenna having a reduced user absorption and an improved hand and head SAR performance has been investigated and verified by simulations and measurements. The operational principle of the shielded structure is such that one antenna element is active at a time and the other is passive acting as a shield when connected to the ground as shown in Fig. 5 (b) and (c). The results can be used to design antenna structures having reduced user effect. The obtained results show that the shielding structure can increase the total efficiency with the hand and head by 5.0 dB at 900 MHz and by 2.1 dB at 2000 MHz compared to the traditional single element structure. Also, a significant improvement in the hand and head SARs can be obtained compared to the reference structure. For instance, the shielding structure can decrease the SAR in the hand by 45% at 900 MHz. Moreover, the head SAR can be decreased by 81% at 900 MHz and by 43% at 2000 MHz, when both the hand and head are present. It is also shown that the shielded top-located antenna structures outperform the traditional bottom-located antennas with a significant margin.

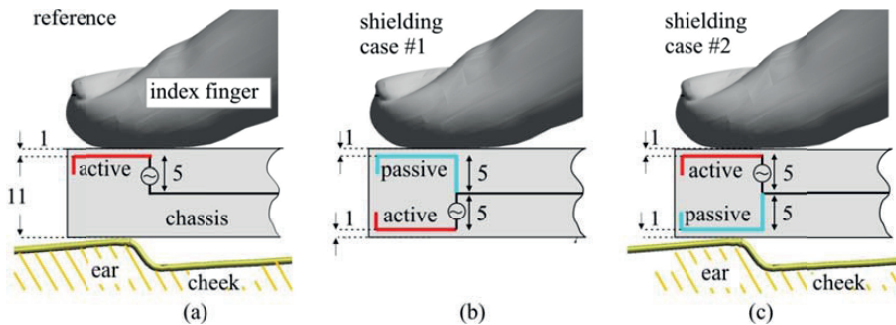


Fig. 5. Antenna structure having active and passive antenna elements. (a) reference structure, (b) shielding case #1, and (c) shielding case #2. Dimensions in millimetres.

Impedance matching circuitry to prevent antenna frequency detuning due to user interaction in mobile handsets. An experimental study on inherently non-resonant capacitive coupling element

antennas was made. It shows that the user-induced input impedance detuning of a mobile terminal antenna can be avoided by taking the user effects into account proactively in the design of the antenna matching circuit. The multi-band matching circuit used in this study was designed by predicting the impedance detuning effect of a talking grip hand in advance. This resulted in improved impedance matching with the hand compared to a free space case as illustrated in Fig. 6(a). On the other hand, it was shown that different hand grips affect the antenna impedance in different ways. Single-band matching was shown to be more sensitive on impedance detuning than multi-band matching as shown in Fig. 6(b). Narrowband matching in a mobile terminal antenna should be made adaptively tunable in order to mitigate the detuning, provided that tuning improves the total efficiency.

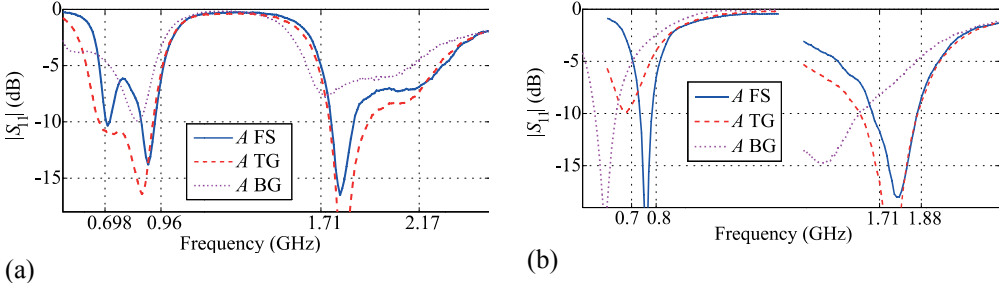


Fig. 6. Measured impedance matching of a tested antenna with (a) multi-band and (b) single-band matching circuits in free space, with a talking grip hand (TG) and with a tight browsing grip (BG) hand.

Influence of the user's hand on mutual coupling of dual-antenna structures on mobile terminal. This research focuses on the influence of the user's hand on the mutual coupling of dual-antenna structures on a mobile terminal. The terminal consists of two planar inverted-F antennas (PIFA) on a typical 100 x 40 mm² mobile terminal chassis operating at 900 MHz, 2000 MHz, 3500 MHz and 5300 MHz bands. The hand was placed at different positions while the index finger touched different locations (see Fig. 7(a-d)), and the variation of the mutual coupling was investigated. From Fig. 7(e-h), it is shown that the dual-antenna structures exhibited up to 10 dB variations in mutual coupling, depending on the hand and index finger locations. The Poynting vector characteristics of the mobile terminal and free space electric field distributions can be used as tools for understanding the behavior of the mutual coupling in the dual-antenna structures in the presence of a user's hand.

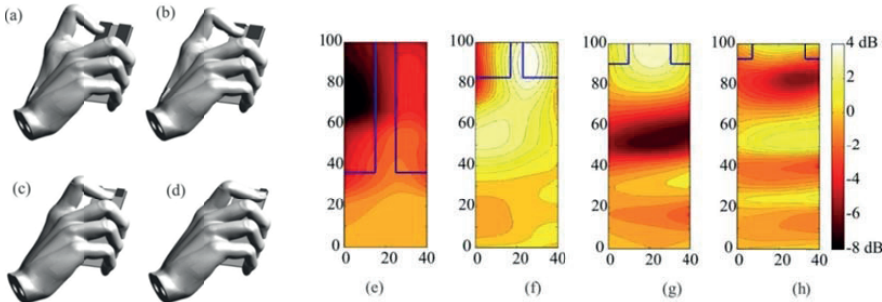


Fig. 7. (a)-(d) Four different index finger locations and the hand phantoms were vertically shifted down. Mutual coupling (relative to the case without hand) as a function of index locations at (e) 900 MHz, (f) 2000 MHz, (g) 3500 MHz and (h) 5300 MHz. The solid lines represent top view of the dual-antenna geometry. All dimensions are in millimetres.

Spatial degrees-of-freedom of multipath propagation channels. A method of estimating spatial degrees of freedom (SDoF) in measured multipath propagation channels was established. The SDoF is the maximum number of eigenchannels for spatial diversity and multiplexing and is affected by the antenna aperture size and propagation channel conditions. The SDoF is derived by means of the spherical-wave expansion of electromagnetic fields radiated from an antenna array having a certain aperture size. The SDoF estimates are independent of particular realization of antenna elements on the aperture. Therefore, the SDoF provides the number of antenna elements on the aperture for efficient improvement of the system performance by utilizing the spatial transmission, e.g., diversity and multiplexing. Figure 8(a) shows the SDoF for various multipath channel conditions in measured indoor scenarios. The legends “D1” to “D3” correspond to line-of-sight (LOS) conditions with varying transmit-receive antenna distances, while the legends “A” to “C” and “E” represent obstructed-LOS (OLOS) conditions. The legend “F” is under a non-LOS (NLOS) case. The results reveal that the SDoF does not depend significantly on conventional classification of LOS, OLOS, NLOS conditions. Noticeable trend of the SDoF is observed only when the transmit-receive distance is extremely short in “D1”, and when the LOS is totally blocked in “F”, which lead to the lowest and highest SDoF, respectively. When calculating the SDoF per unit electrical antenna aperture size, it is possible to discuss the efficiency of spatial communications. Figure 8(b) shows the result for various radio frequencies, indicating that lowest frequency tested in our measurement, 2.4 GHz, has the best potential for channel capacity improvement by means of spatial communications since there are more SDoF attainable per unit electrical antenna aperture size.

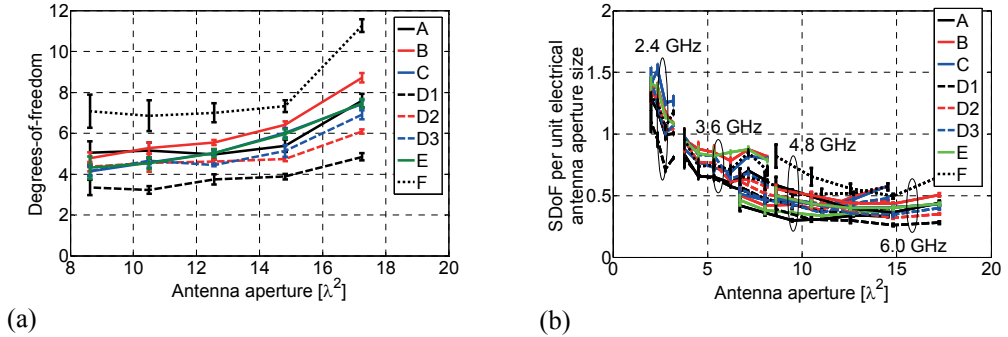


Fig. 8. (a) Dependence of the SDoF on the electrical aperture size of an antenna array at 6GHz radio frequency for various measured indoor channels. (b) SDoF per unit electrical antenna aperture size, plotted for different radio frequencies.

Wideband RFICs and antennas with interface impedance optimization. The interface for a 0.7 to 2.7 GHz mixer-first receiver and compact-size capacitive coupling element (CCE) antenna was implemented first in 2011. A realization of the system is illustrated in Fig. 9 together with a block diagram of the antenna RFIC interface implementation. The optimization of the RF interface allows for optimal noise and blocker performance while simultaneously achieving narrowband instantaneous matching to the antenna. The system integration and measurements were performed during 2012. The measurements included both the characterization measurements of the antenna and the RFIC and over-the-air measurements of the full system. Figure 9 (right) shows the micrograph of the implemented receiver and the PCB configuration around the IC. Additionally, a synthesizer making use of the digital-period synthesis (DPS) has been implemented during 2011-2012 which is able to support the operation frequency range of this work.

The joint measurements of the 0.7 to 2.7 GHz mixer-first receiver and compact-size capacitive coupling element (CCE) antenna were finalized in 2013. A photograph of the measurement setup is illustrated in Fig. 10 together with an implementation picture of demonstration board. The

optimization of the RF interface allows for optimal noise and blocker performance while simultaneously achieving narrowband instantaneous matching to the antenna. The complete system performance in Table I is state-of-art in RFIC design. In addition, this demonstrator was the first published mixer-first receiver including the antenna. During 2013 the RFIC development continued to enable interference detection throughout the operation frequencies. The purpose of the detector is to locate harmful blockers and based on its decision the main receiver could be adjusted to suppress blockers. The chip including mixer first receiver and detector was submitted to process in 2013 and the measurements of this will take place in 2014.

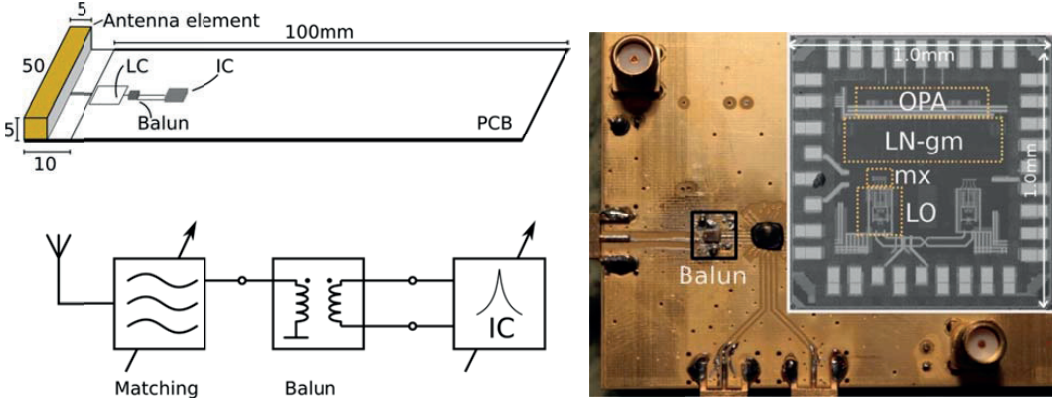


Fig. 9. The physical implementation of the RFIC together with the CCE antenna element and conceptual block diagram of the antenna RFIC interface employing a balun. The photograph presents characterization PCB showing the RF signaling and in the inset a micrograph of the implemented mixer-first receiver RFIC.

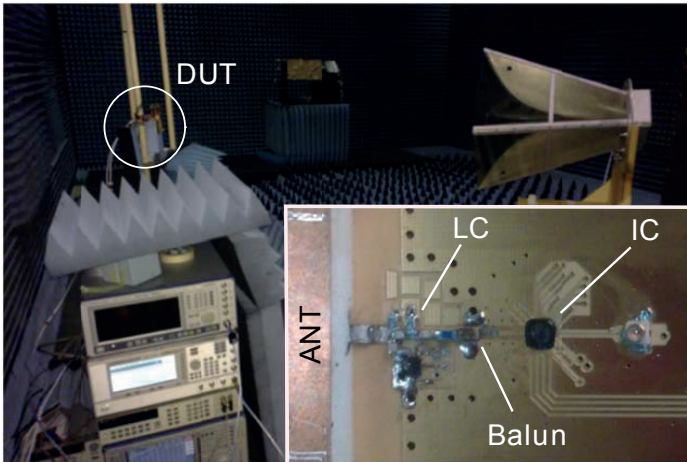


Fig 10. Measuremnt setup of the combined RFIC-CCE antenna receiver.

Table I. Measured performance of the RFIC and antenna

Parameter	IC alone	IC + antenna
Band (GHz)	0.7-3	0.8-2.6
RF Gain (dB)	40-43	36-41
Gain variation (dB)	3	5
Antenna efficiency (dB)	-	-2...-3.5
NF (dB)	4-6*	9 (1GHz)**
IIP3 (dBm)	+17	+17

Direct delta-sigma receiver. The direct delta-sigma receiver (DDSR) was introduced in 2010 and combines a delta-sigma A/D converter and a direct-conversion receiver into one functional whole. The first stages of the A/D converter are brought to RF, which is an important step towards the realization of RF-to-digital receivers that have analog RF inputs and digital bit-stream outputs. Aalto University in co-operation with ST-Ericsson (now Ericsson) carried out theoretical and experimental work on the new DDSR concept. This included successful IC implementations of a narrowband 2.5-GHz and a wideband 0.7–2.7-GHz in 40-nm CMOS, shown in Figure 11. The wideband DDSR was reported in February at the International Solid-State Circuits Conference (ISSCC), which is the foremost worldwide forum for advances in microelectronics.

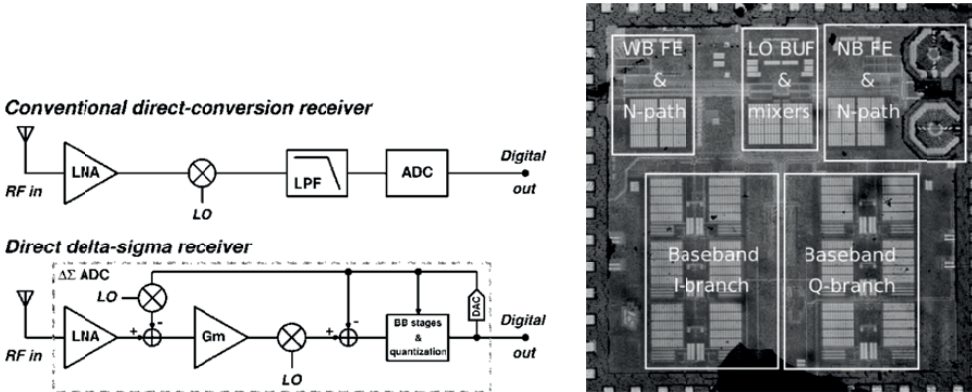


Fig. 11. Block diagram and chip micrograph of DDSR.

Bi-anisotropic metasurfaces for arbitrary wave control. In a series of papers, we have introduced and implemented the concept of magnetoelectric (bi-anisotropic) sheets designed to transform electromagnetic waves in arbitrary ways, both in reflection and transmission. In particular, we have established the general theory of reflection and transmission of waves through arbitrary bianisotropic metasurfaces and found what parameters of the surface are responsible for particular effects (like polarization transformation or matching). Several potential applications have been targeted, such as ultimately thin perfect absorbers, isolators, polarization transformers, lenses. Required conditions for electromagnetic properties of bi-anisotropic particles necessary for the

desired operations have been identified in the most general case of uniaxial reciprocal and nonreciprocal particles. For example, it has been found that it is possible to realize single-layer grids which exhibit the total absorption property when illuminated from one side but are totally transparent when illuminated from the other side (an ultimately thin isolator).

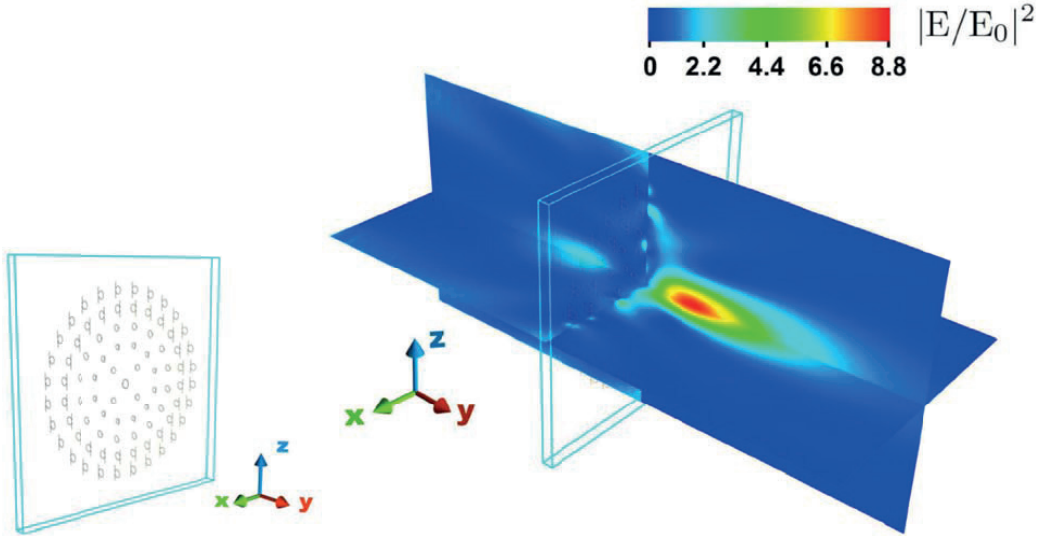


Fig. 12. An example of a bi-anisotropic metasurface acting as a focusing reflector (metamirror, which is transparent when the frequency is far from the resonance of the inclusions). The normally incident plane wave (incidence from the right) is focused in reflection. The transmitted field is negligibly small.

Fig. 12 illustrates the performance of a single layer of resonant particles designed to operate as a metamirror, focusing the incident plane waves into a point. Note that the focal length of this device is only 0.6 of the free-space wavelength. As far as we know, this is the record value for refractive power of any known lens.

Balanced and optimal bianisotropic particles: maximizing power extracted from electromagnetic fields. We have introduced the concept of “optimal particles” for strong interactions with electromagnetic fields. We have found that for different kinds of excitation waves different particles are needed. Four classes of general uniaxial bianisotropic particles (chiral, omega, moving, and Tellegen particles) were studied as candidates to extract as much energy as possible from coming linear/circular polarized propagating/evanescent waves. Optimal shapes and dimensions for optimal reciprocal particles have been found. We have shown that in key cases the optimal reciprocal particles have all the polarizabilities equal (or they differ only by sign). We call such sets of polarizabilities “balanced”. It is expected that the use of balanced and optimal particles especially in the design of artificial electromagnetic materials will allow optimization of electromagnetic performance of various devices, where the material or layer is interacting with various types of electromagnetic waves (antennas, absorbers, sensors, lenses, and so on). Furthermore, we have studied the ultimate upper limits of power which can be scattered by an arbitrary electrically small (dipolar) particle or antenna.

Development of moments model interpreting cloaking and absorption mechanism. We have developed a simple model of a cloaked PEC cylinder (left Fig. 13), of noninfinitesimal electrical

size, replacing it by an omnidirectional electric-line scatterer and a bipolar magnetic one. Accordingly, the far field is determined in a compact closed form. The analysis of the results shows that the optimal cloaking regime corresponds to the frequency point where the total electric moment is drastically mitigated and thus the radiation pattern of the device resembles that of a magnetic-dipole line (right Fig. 13). In this way, the radiation patterns of the device are directly controllable through the material parameters of the configuration, a feature that is useful in practical applications.

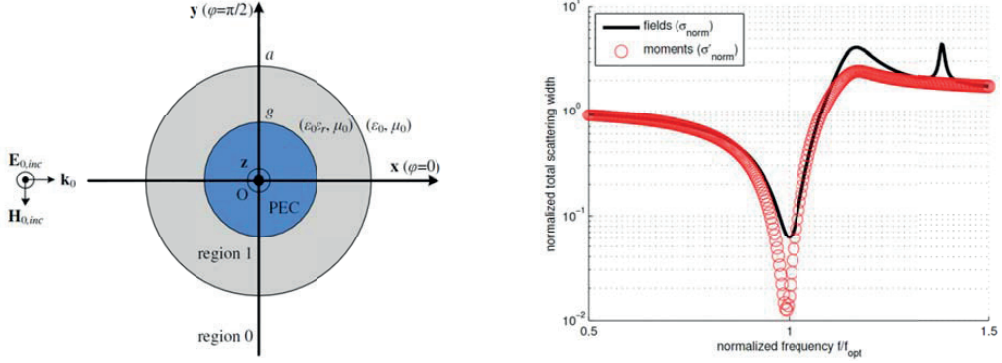


Fig. 13. (left) The simple physical configuration of the structure comprised of a PEC core covered by an ordinary dielectric cladding. (right) The normalized total scattering width as function of the oscillation frequency, computed with the rigorous field formulas and our approximate moments model.

Furthermore, we have used the knowledge of the physical mechanism of cloaking conductive cylinders to introduce a very simple one-layer absorber which equally effectively absorbs power incident on the two opposite sides of the layer (nearly all known symmetric absorbers are multi-layer structures with a metal ground plane inside). This new absorber consists of metal cylinders covered by lossy dielectric shells. Thanks to the design of balanced structure, which is equally strongly excited electrically and magnetically, reflection can be brought to zero. Choosing the proper level of losses, all the power can be absorbed in the lossy dielectric.

Scattering from small particles. Typically, in a scattering scenario incident electric field induces the electric dipole moment while the incident magnetic field induces the magnetic dipole moment. However, electrically small particles can also exhibit bi-anisotropic magneto-electric coupling so that the electric moment of the particle is generated by both electric and magnetic incident fields (likewise, the magnetic moment is induced by both fields). We considered the case of the most general uniaxial bi-anisotropic particles, characterized by four dyadic polarizabilities, illuminated by a linearly polarized plane wave. Conditions for zero backward and forward scattering were found for a general uniaxial bi-anisotropic particle as well as for all fundamental classes of bi-anisotropic particles: omega, “moving”, chiral, and Tellegen particles. Possibility for zero total scattering was also discussed for aforementioned cases. The scattering pattern and polarization of the scattered wave were also determined for each particle class. In particular, we analyzed the interplay between different scattering mechanisms and showed that in some cases it is possible to compensate scattering from a polarizable particle by appropriate magneto-electric coupling. Examples of particles providing zero backscattering and zero forward scattering were also presented and studied numerically. This study is relevant to the design of absorbers, where the goal is to minimize reflection and/or transmission and to the design of cloaks and low-scattering small sensors, where the goal is to minimize the total scattering.).

Low-reflection inhomogeneous microwave lens based on loaded transmission lines. A new implementation of a low-reflection microwave lens based on loaded transmission lines (TLs) has been proposed. The lens has a flat profile with well-matched interfaces and inhomogeneous refractive index in the direction orthogonal to the optical axis which is achieved by loading the transmission lines comprising the lens with different inductive elements. The incident wave is coupled to the TLs using a linear metallic taper, a so called transition layer. The basic operation of the lens is demonstrated in Fig. 14(a). The operation of the lens was studied numerically and using a semi-analytical approach. The electric field behind the lens calculated using a semi-analytical approach is shown in Fig. 14(b). The main benefits of the new lens design, as compared to traditional homogeneous dielectric lenses or the previously studied TL lenses, are simple and cheap manufacturing, good coupling with free space, and simple reconfigurability of the refractive index (via change of loading inductances). In 2013, we have designed, manufactured, and measured a prototype of such new microwave lens.

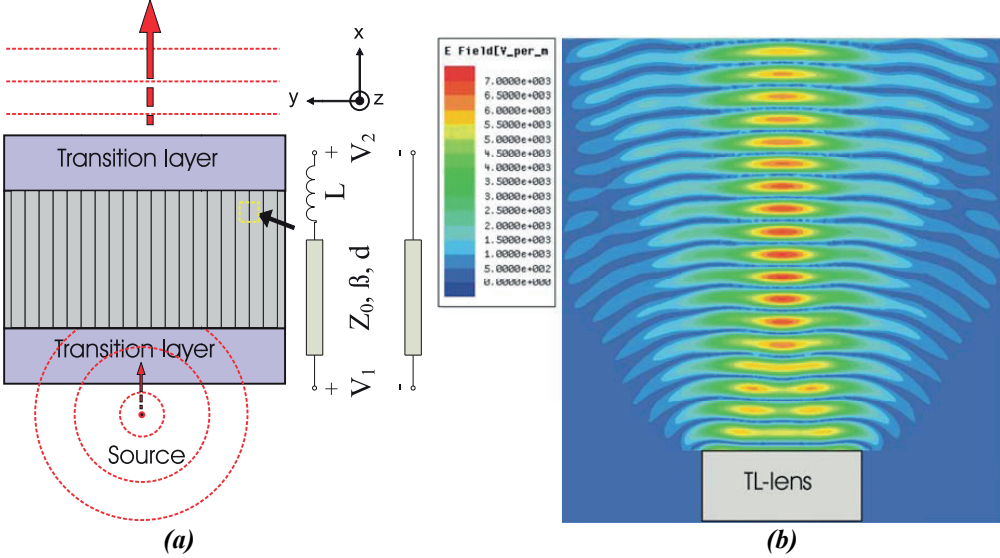


Fig. 14. Basic idea of the lens structure (a); Electric field behind the lens calculated using a semi-analytical approach (b).

Development of semi-analytical techniques in treating waveguiding structures. Several advanced topics on waveguide devices have been examined. Given the genuine significance of integral equation techniques, the Green's functions, used as kernels into the corresponding formulations, play an equally important role. We obtain the Green's function into a bent, metallic waveguide (left Fig. 15) when the singular source is located in the vicinity of the formulated corner. The singular term is separated and the overall quantity possesses a common, uniform expression regardless of the position of the observation point. In another waveguide configuration (in optical frequencies), two consecutive dielectric layers with specific permittivity combination and certain size ratio are found to exhibit good performance as a low-pass filter in the visible and at the nano-scale (right Fig. 15).

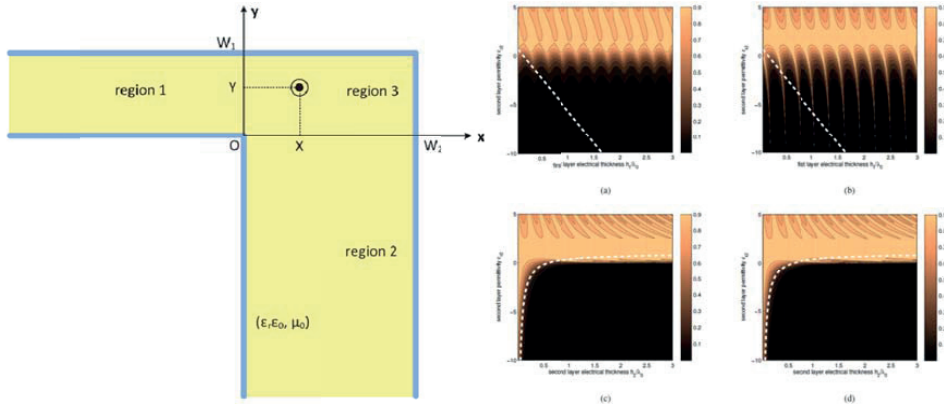


Fig. 15. (left) The configuration of a bent waveguide excited by a point source in the vicinity of the corner. (right) Contour plots of the transfer function of a double-layered optical filter with respect to its material and dimension characteristics.

Full-wave characterization of indoor office environment for accurate coverage analysis. The growing complexity of wireless networks and their massive deployment in composite indoor environments impules a precise propagation prediction, especially, for promising areas such as cognitive radios in television white spaces (TVWS) and femto-cells. This research work deals with a full-wave characterization of an indoor office environment at wireless local area network (WLAN) and worldwide interoperability for microwave access (WIMAX) frequencies using finite-difference time-domain (FDTD) numerical technique. Full-wave time domain electromagnetic analysis based on FDTD method is becoming highly attractive for large scale propagation studies as it provides better accuracy than ray models but at the expense of high computational resources. However, the recent development in parallel processing computer architectures such as graphical processing units (GPUs) has enabled the evaluation of huge computational problems by FDTD method.

The aim is to demonstrate the applicability of accurate full wave oriented approach for large scale propagation prediction in contrast to conventional approximate ray models. Numerical simulation were carried out using a 3D full-wave electromagnetic solver SEMCAD-X for an indoor office room shown in Fig. 16(a) to evaluate pathloss and small scale fading characteristics which were then validated through multiple-input multiple-output (MIMO) channel measurements. The simulated and measured results are found to be in close proximity of each other with a constant difference of 5.5 dB on average for which a correction factor could be applied for accurate results. This substantiates the feasibility of FDTD for propagation studies. Fig. 16(b) illustrates the electric field cartography obtained at 3.1 GHz in x-y plane for the office room environment.

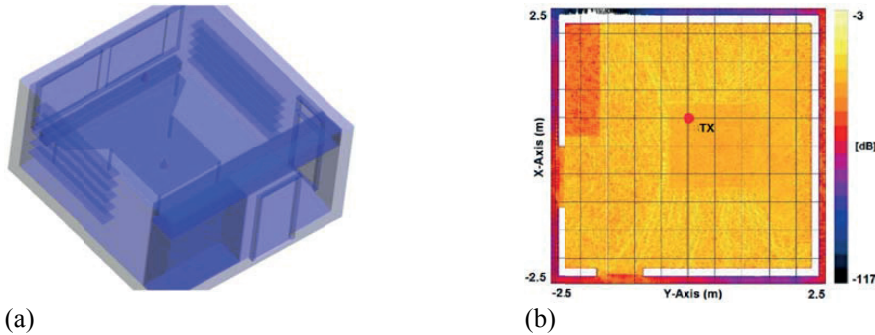
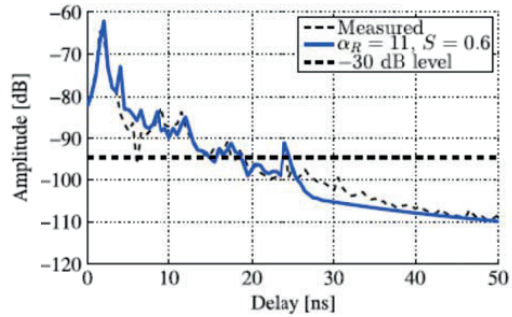
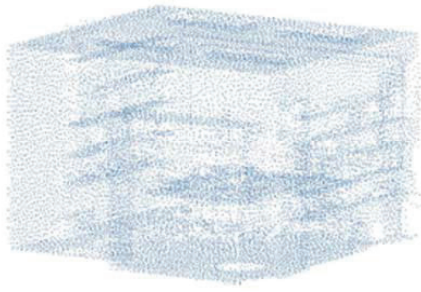


Fig. 16. (a) 3D office room simulation model. (b) Simulated electric field cartography at 3.1 GHz.

60 GHz indoor radio wave propagation prediction method based on full scattering model. In radio system deployment, the main focus is on assuring sufficient coverage, which can be estimated with path loss models for specific scenarios. When more detailed performance metrics such as peak throughput are studied, the environment has to be modeled accurately in order to estimate multipath behavior. By means of laser scanning we can acquire very accurate data of indoor environments, but the format of the scanning data, a point cloud (Fig. 17(a)), cannot be used directly in available deterministic propagation prediction tools. Therefore, we propose to use a single-lobe directive model, which calculates the electromagnetic field scattering from a small surface and is applicable to the point cloud, and describe the overall field as fully diffuse backscattering from the point cloud. The focus of this paper is to validate the point cloud-based full diffuse propagation prediction method at 60 GHz. The performance is evaluated by comparing characteristics of measured and predicted power delay profiles in a small office room as shown in Fig. 17(b). Also directional characteristics are investigated. It is shown that by considering single-bounce scattering only, the mean delay can be estimated with an average error of 2.6% and the RMS delay spread with an average error of 8.2%. The errors when calculating the azimuth and elevation spreads are 2.6° and 0.6° , respectively. Furthermore, the results demonstrate the applicability of a single parameter set to characterize the propagation channel in all transmit and receive antenna locations in the tested scenarios.



(a)

(b)

Fig. 17. (a) A point cloud of a small office, and (b) measured and predicted power delay profiles compared.

Indoor short-range radio propagation measurements at 60 and 70 GHz. Millimeter-wave radios operating at unlicensed 60 GHz and licensed 70 GHz bands are attractive solutions to realize short-range backhaul links for future flexible network deployment. In this work, we report directional radio channel sounding performed at 60 and 70 GHz in large indoor short-range scenarios such as offices, a shopping mall, and a railway station. Initial channel characterization is reported through propagation path detection and analyses on diffuse scattering power and delay spread. The characterization reveals that specular mechanisms represented by propagation paths dominate over diffuse scattering in the measured scenarios because of the large area size of physical environments. Typical examples of power delay profiles with the detected specular peaks are presented in Fig. 18. The results furthermore show that the delay spread does not change much between 60 and 70 GHz, suggesting that the same channel model framework can be used for modeling the radio channels at the two frequencies.

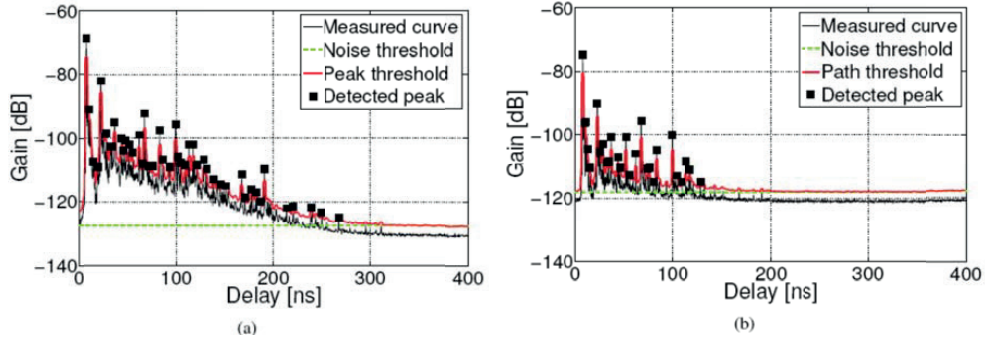


Fig. 18. Exemplary PDPs in the office in use: (a) 60 and (b) 70 GHz. The PDPs were measured at the same Tx and Rx location. Threshold functions for noise and peak detection, and detected peaks are overlaid.

60 GHz spatial radio transmissions: multiplexing or beamforming? Channel capacity gain of the spatial multiplexing and beamforming techniques is compared for 60 GHz multi-carrier radio systems such as orthogonal frequency division multiplexing. The term beamforming refers to the conventional gain focusing, for the strongest propagation path, by narrow antenna beams, while the spatial multiplexing realizes parallel data streams through appropriate pre- and post-coding weights to utilize the spatial degrees-of-freedom of the radio channel. We derive a channel capacity that depends only on the multipath richness of the propagation channel and the antenna aperture size, but otherwise is independent of the realization of antenna elements on the aperture. We evaluate the capacity for a single-polarized 60 GHz radio channels measured in a conference room environment. The capacity with -10 dBm transmit power and 2 GHz bandwidth in line-of-sight scenarios is illustrated in Fig. 19. The figure (a) shows the capacity with $1\lambda^2$ antenna aperture size while the figure (b) is with $9\lambda^2$ aperture size. The results with $1\lambda^2$ aperture size does not show superiority of the spatial multiplexing to the beamforming because of the limited receive signal-to-noise ratio to utilize the available spatial degrees-of-freedom of the radio channel. In contract, the results with $9\lambda^2$ antenna aperture size shows the superiority because of the improvement of the receive signal-to-noise ratio. It is worth noting that there are multiple spatial degrees-of-freedom available in the measured millimeter-wave line-of-sight channels.

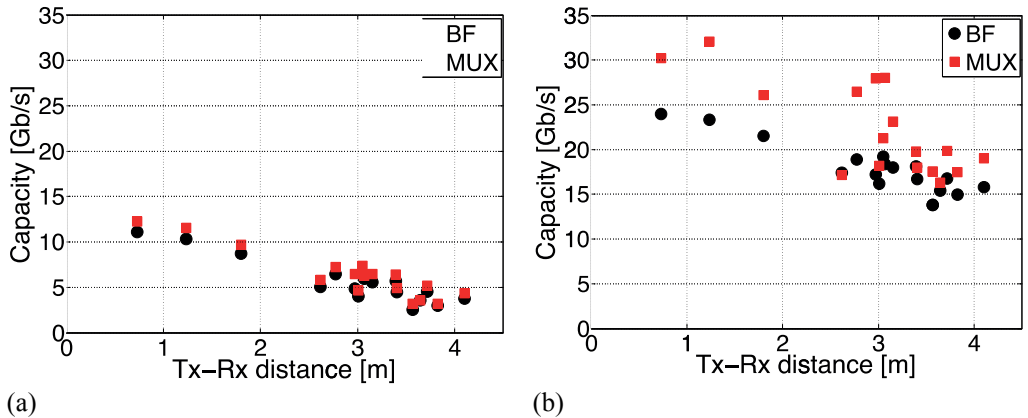


Fig. 19. Comparison of the ergodic channel capacity for beamforming (BF) and spatial multiplexing (MUX) in a line-of-sight millimeter-wave channel. Transmit and receive antenna aperture size is (a) $1\lambda^2$ and (b) $9\lambda^2$, respectively.

Isolation improvement in compact relay terminals using loops. In-band full-duplex systems provide a radical improvement in spectral efficiency over half-duplex systems, especially in relaying applications, where the frequencies can be reused. The main bottleneck in designing such in-band full duplex systems is the self-interference (SI) at the receiver caused by its own transmission. In order to mitigate the SI, cancellation must be done at the antenna, radiofrequency (RF), and digital domains. In order to improve the antenna isolation for a back-to-back relay operating at 2.6 GHz as shown in Fig. 20(a), loops are used to partially cancel the reactive near field. The concept of using loops stems from Faraday's law of electromagnetic induction and Lenz's law. The induced currents in the loops create magnetic fields which oppose the change in the flux producing it, thereby partially cancelling the local reactive magnetic fields produced by the antenna. At the operating frequency of 2.6 GHz, we have an improvement of 6 dB in the worst case isolation shown by the black circles in Fig. 20(b), indicating a minimum isolation of 55 dB between the transmit and receive antennas. The isolation can be further improved by combining different techniques for practical deployment of full-duplex relays.

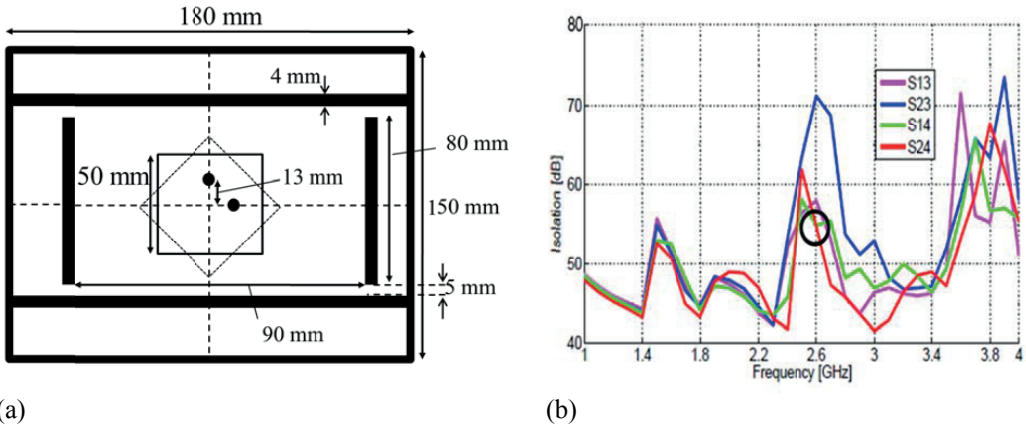


Fig. 20. (a) Top view of compact relay design with loops at 2.6 GHz. (b) Isolation between the antenna ports on either side of the compact relay with loops for reactive near field cancellation.

Uncertainties in MIMO over-the-air multi-probe test systems. MIMO over-the-air (OTA) measurements and simulations for network and mobile terminal performance evaluation and prediction are receiving strong interest due to the urgent need to develop test standards for fourth generation systems and beyond. The multi-probe based anechoic chamber and fading emulator method has been an important candidate for MIMO OTA testing. We have investigated uncertainties and limitations related to the use of such multi-probe system for synthesizing the desired fields inside the test zone. The topics related to the uncertainties include investigation of the required number of probes, optimum probe locations and the influence of the probe polarization. The investigation has done against the equivalent reflectivity level of the field synthesis using 2D multi-probe system where probes are placed on the horizontal plane on a circle around the test zone. Computer simulation has performed for several different cases by varying the radius of probe circle, by introducing the probe positioning error at the probe locations and by varying the probe polarization. Two different probe configurations were analyzed, case 1: where probes are dual polarized (vertically and horizontally polarized) at each location and case 2: where half of the probes are vertically polarized and half are horizontally polarized. Taking the maximum acceptable reflectivity level as, e.g., -15dB , it was shown that the selected multipath environment can be accurately synthesized inside the test zone with radius $r_0 = 0.15\text{m}$ in a 2D MIMO OTA test system where 32 probes are placed on a circle with radius $r \geq 1.5\text{m}$ at $f = 1850\text{ MHz}$ using both probe

configurations. Example results by varying the radius of the probe circle with probe positioning error are presented in Fig. 21.

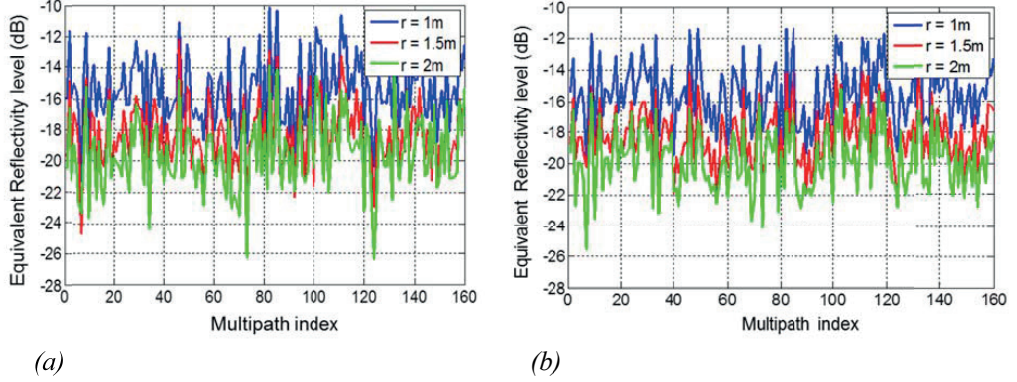


Fig. 21. Equivalent reflectivity level by varying the radius of the probe circle as $r=1 \dots 2$ m with 32 probes, $r_0=0.15$ m at $f=1850$ MHz for a selected multipath scenario. (a) case 1 and (b) case 2.

Multi-element Antennas for LTE MIMO mobile handsets operating around 3500 MHz. The design of multi-element antennas for mobile handset remains challenging also at higher frequencies despite smaller antenna dimensions and an electrically larger element separation than at traditional cellular frequency bands, especially than below 1 GHz. Antenna elements specifically for multi-element antennas operating at 3400-3600 MHz were designed and their optimal locations and orientations on the handset chassis were investigated. An isotropic radiation pattern can be obtained by combining the radiation patterns of multiple antenna elements, where the novel idea was that each antenna element produces a confined chassis current distribution (Fig. 22 a-c) which improves mutual isolation between the elements. Multi-element antenna configurations with two- and eight-element antennas were designed (Fig. 22 d-e) and evaluated experimentally in indoor propagation environments. The MIMO channel capacity was larger compared to the multi-element designs using traditional PIFA antenna elements, i.e. with no optimally confined chassis current distribution. This behavior was still observed in the presence of the user's hand.

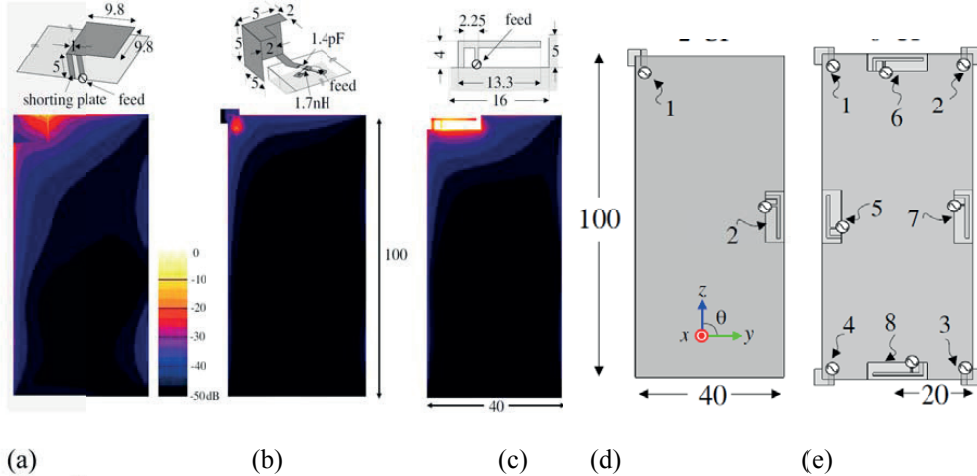


Fig. 22. Antenna element geometries and corresponding normalized magnitude of current distributions for (a) PIFA, (b) CCE and (c) IFA. Proposed combination of CCE and IFA as antenna elements in a (d) two-element structure and a (e) eight-element structure. All dimensions are in millimeters.

Capacitive coupling element antennas for multi-standard mobile handsets. Antenna solutions based on a simple capacitive coupling element (CCE) on a compact smartphone chassis were developed. The CCE is a versatile antenna structure, whose operational frequency range is easily modifiable with circuit design. Wideband solutions as well as a tunable narrow-band solution were developed for the LTE-A frequency bands. For the wideband solution, it could be shown with experimental data how the same CCE can be implemented with single-feed and dual-feed interface towards the transceiver front-end (Fig. 23). Both antennas operate at the LTE-A frequencies 698–960 MHz and 1710–2690 MHz with good efficiency, owing to a novel dual-branch impedance matching circuit which utilizes the properties of the CCE and the chassis in a proficient way (patent pending). The single-feed wideband antenna was combined with a novel passive-mixer-first receiver prototype that achieves a 0.7–2.7-GHz reception band. A tunable antenna solution based on the same CCE was designed for a software defined radio receiver. This frequency-tunable antenna operates at 750–2500 MHz with acceptable efficiency (Fig. 24). In future, expected improvements in tuning technologies will lead to even wider tuning ranges with improved efficiency.

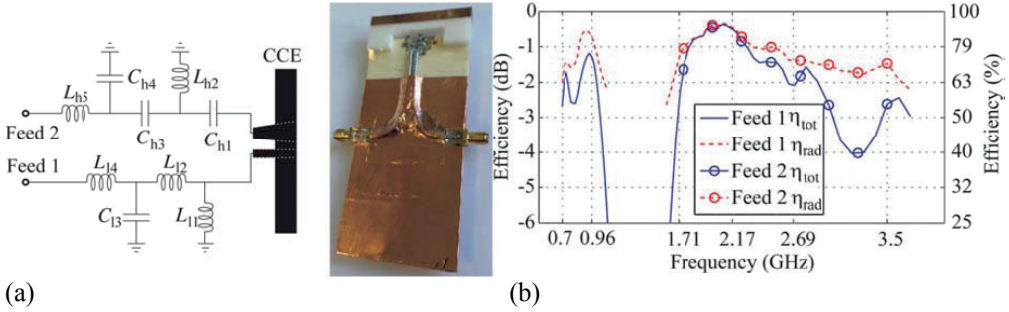


Fig. 23. (a) Circuit schematic and photo of the dual-feed CCE with dual branch matching circuit. (b) Measured total and radiation efficiency of the dual-feed CCE.

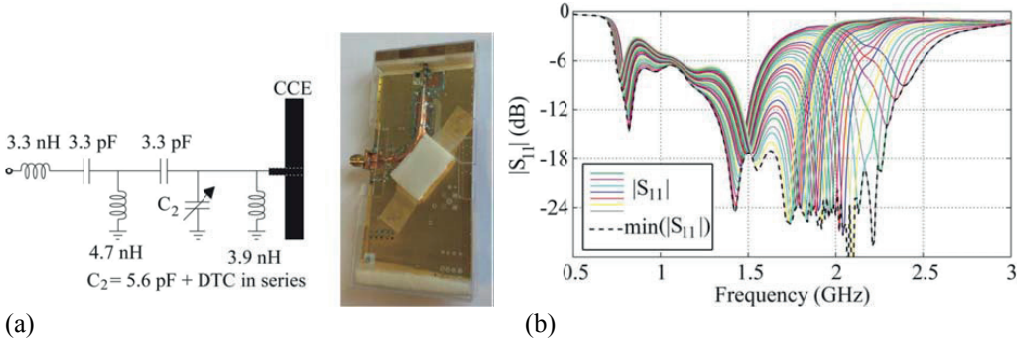


Fig. 24. (a) Circuit schematic and photo of the tunable CCE antenna. (b) Measured impedance matching of the tunable CCE antenna.

Optimal dual-antenna design in a small terminal multi-antenna system. A novel 2.6-GHz multiple-input and multiple-output (MIMO) antenna system for mobile terminals was designed. The antenna structures consist of a broadband main antenna covering most of the LTE-A bands (Fig. 25 (a) left), and a narrowband second antenna operating at the 2.6 GHz band (Fig. 25 (a) right). The main antenna is a traditional monopole-type capacitive coupling element (CCE) placed on the short edge of the terminal. The second antenna consists of two - out-of-phase fed inductive coupling elements (ICE) placed on the long edges of the chassis. The main purpose of the design is to

demonstrate that this kind of antenna system offers good performance in terms of electromagnetic (EM) isolation and envelope correlation between the antennas. This has been experimentally verified and is originated on the fact that both antennas excite effectively different orthogonal wavemodes (see Fig. 25 (b)), which is studied with the help of the theory of characteristic wavemodes.

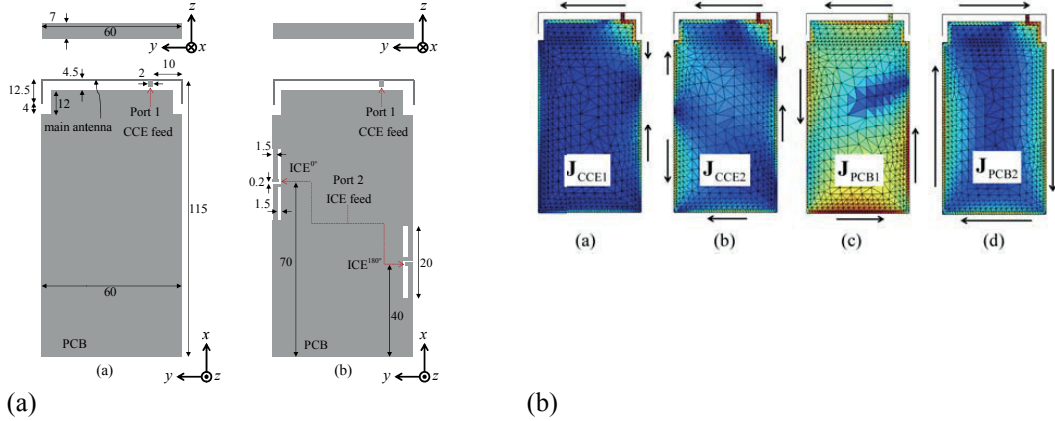


Fig. 25. (a) Simplified small terminal with only the main antenna (left) and with the secondary antenna (right). Dimensions are in millimeters. (b) Normalized current distributions with maxima (arrows) and nulls (blue) at the edges of the characteristic wavemodes at 2.6 GHz.

Design strategy for 4G handset antennas and a multiband hybrid antenna. A novel design strategy for multi-standard mobile handset antennas is presented and verified with experimental results. A prototype antenna was simulated and fabricated as shown in Fig. 26. The results show that the presented antenna operates with better than 3 dB (50 %) efficiency across the frequencies of 698–2900 MHz and 3250–3600 MHz, thus having state-of-the-art performance. The antenna is shown to have a robust performance with a user, and it can fulfill the specific absorption rate (SAR) and hearing aid compatibility (HAC) requirements. In addition, it is demonstrated how the multi-antenna functionality can be included within the antenna structure, simultaneously achieving a small antenna volume of 750 mm³. The diversity gain and isolation are better than 10 dB at the frequency band 2110–3600 MHz. Hence, the proposed antenna is well suited for future LTE-A mobile handsets.

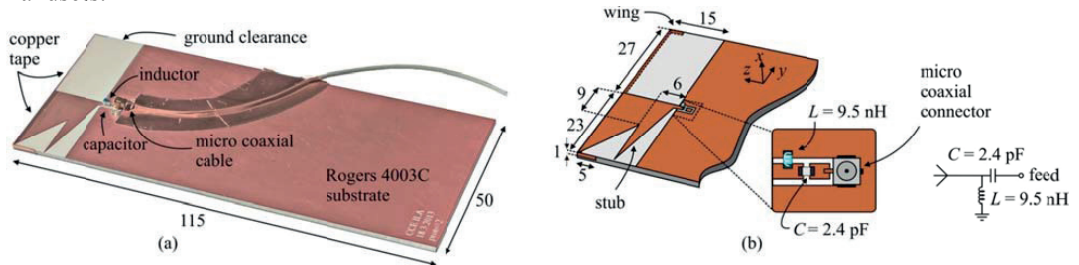


Fig. 26. (a) Fabricated antenna prototype. (b) Schematic view of the antenna structure. Dimensions are in mm.

3.2 Cognitive Radio

This research concentrates on enabling technologies for flexible spectrum use and cognitive radios. Cognition indicates that the radio is capable of learning from the radio environment and adjust its transmission parameters including frequency, waveforms and power. The radio has situation

awareness in a sense that it has knowledge of its own capabilities, status of the spectrum in the neighborhood and maybe even the network. Cognitive radio takes an opportunistic view in agile usage of underutilized parts of radio spectrum. Secondary (unlicensed) users need to ensure that no harmful interference is caused to primary, incumbent users of the frequency band. Free spectrum is a resource that varies depending on the time, frequency band and location. The primary user may not need the spectrum all the time in all the places. Hence, one could utilize the spectrum much more efficiently by finding idle spectrum and exploiting it for data transmission while controlling the level of interference caused to other users, see Fig. 27. It is also important to develop power efficient and high fidelity implementations for cognitive radios so that battery operated devices can operate for a long time without compromising their performance.

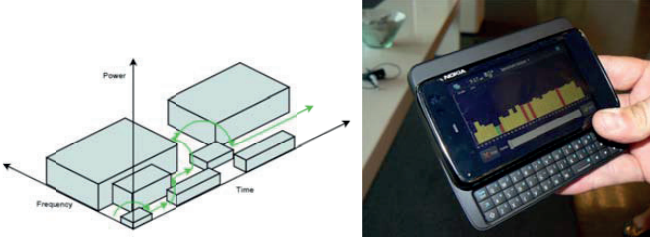


Fig. 27. Flexible use of time-frequency-location varying underutilized spectrum and related spectrum sensor prototype used for finding idle spectrum.

Spectrum exploration and exploitation. Research in spectrum exploration and exploitation has focused on optimizing identification and exploitation of unused spectrum in a cooperative and distributed manner. In practice, this means that finding and accessing idle spectrum are optimized jointly. Distributed detectors in finding idle spectrum provide diversity gain since they can mitigate shadowing and fading effects. Moreover, user cooperation facilitates fast multiband sensing and improves performance while using simple individual detector structures, and consequently power efficiency. Distributed and sequential detection methods for finding unoccupied spectrum and changes in the state of the spectrum with minimum average delay are developed and their statistical properties analyzed. The concrete research problems in spectrum exploration and exploitation addressed in this work are dealing with identifying idle spectrum by a group of cooperating sensors, jointly optimal sensing and access policies by multiple radios over multiple potentially scattered subbands. Optimization is based on trading off between the exploration and exploitation of the spectrum such that sensing and accessing is focused on subbands where high quality spectrum is idle persistently. As a result, the system learns the dynamic behavior of the spectrum and can maximally exploit identified idle spectrum. Joint optimization and accessing of idle bands is modeled as a restless multiarm bandit (RMAB) problem. We have shown that such policies is optimal in a sense that it experiences logarithmic regret, see Fig. 28. We have also developed reinforcement learning based ϵ -greedy algorithms for finding idle spectrum. The utility function rewards high achieved data rates from identified idle spectrum. These learning methods stem from statistical inference, machine learning and stochastic optimization. Policies for exploring and accessing the spectrum can be optimized jointly. In addition, we have developed methods for modeling and managing interference as well as flexible spectrum usage in device to device communications. This work has been done in cooperation with Princeton University and Nokia Research Center.

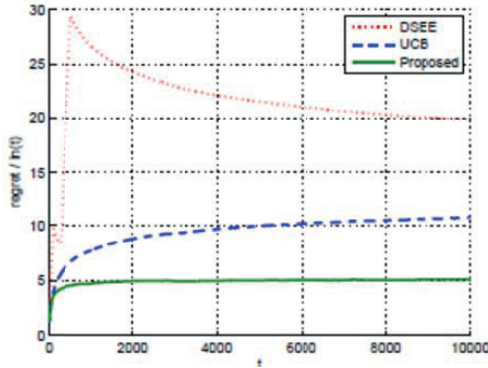


Fig. 28. *Logarithmic regret of proposed RMAB sensing and access policy. The method learns and exploits persistent spectral recourses efficiently. The developed method is optimal in a sense that the regret is logarithmic.*

White spaces. Secondary usage of TV white-spaces is an emerging application of cognitive radio techniques, where unutilized or underutilized spectrum reserved for digital terrestrial television is allocated to wireless communications. Spectrum sensing can be used to determine the level of TV signals in a specific location, but sensing alone is not able to provide information on the frequency planning of the network, i.e., it is not possible to know whether a particular TV frequency is planned to use in the measured location. Thus, sensing must be complemented with a geo-location database. We develop techniques to improve the secondary usage of TV white spaces by combining the information from geo-location database and radio propagation modeling with measurements from white-space devices. An extensive measurement campaign where a good number of the spectrum sensors developed in SMARAD are used to find idle spectrum on digital TV bands in a distributed manner has been completed.

Heterogeneous networks. Cognitive radio techniques are useful when several different networks operate in the same frequency band and geographical area without centralized control, which is a typical scenario in case of heterogeneous networks. We investigate the design and optimization of dynamic resource allocation and interference management strategies for spectrally efficient wireless heterogeneous networks with multiple levels of coverage and services. Such networks and coverage provide service to tier subscribers of different priorities and quality needs. Our research focuses on developing distributed and effective mechanisms for resource allocation and interference management to facilitate simpler and decentralized network operation in heterogeneous environments. The idea is to fully exploit various levels of network's radio link control signaling and feedback information. Such information is available in most practical wireless systems and can facilitate better cooperation in heterogeneous wireless coverage. As a result, our lower-tier user links can respond to varying interference conditions from higher-tier user transmission. Utilizing such information facilitates heterogeneous network coverage through distributed cooperation. It provides practical and efficient way of achieving spectrum sharing, better data rate and QoS, and multiple levels of network cooperation.

Spectrum sensing hardware. On the area of the cognitive radio hardware research, the detector hardware was further improved by optimization of different HW parameters. However, the main focus in 2013 was to make extensive field measurements with the existing HW. The field tests, illustrated in Fig. 29, have been carried out in order to enable the demonstration of co-operative sensing. The main part of the field tests happened in Helsinki area and the results of these measurement

campaigns are openly available in the web. In addition, the visualization of the results in an interactive map was developed during 2013. The sensing data was collected from several sensing nodes operating simultaneously.

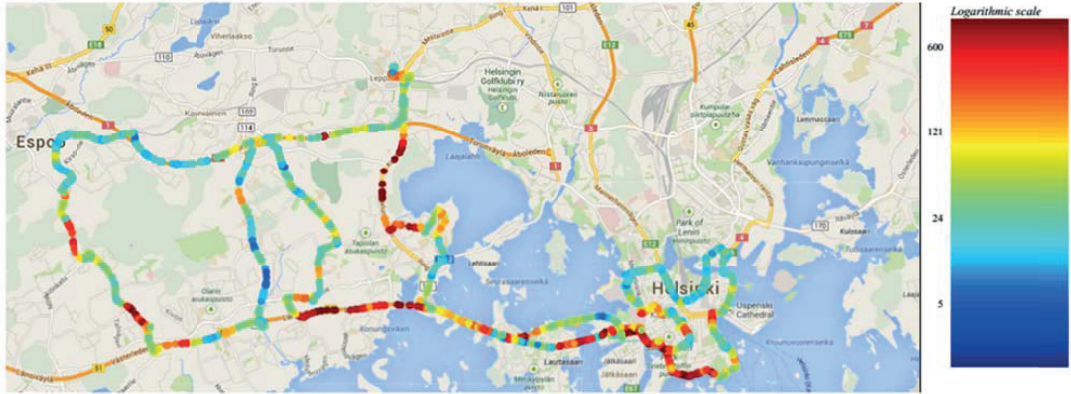


Fig. 29. Spectrum measurements in Espoo region.

3.3 Millimetre Wave and THz Techniques

As stated in Section 3.1, future wireless systems demand ever higher data rates and wider bandwidths. These demands plus capability of forming narrow antenna beams call for millimetre wave and THz techniques.

Characterisation, modelling, and applications of nonlinear 2-terminal millimetre wave devices. ESA-sponsored SMARAD and MilliLab activities for the characterisation of Schottky devices for space and other THz applications have been continued.

Universal fundamental and subharmonic test jigs have been developed for mixer-based characterisation of THz single-anode and antiparallel Schottky diodes under comparable conditions. A diode-independent substrate is used in a mixer block with integrated adjustable waveguide tuners placed very close to the diode in order to minimize losses. In this way different diodes can be tested and compared in mixer operation, under conditions optimized for each diode, but using the same mixer block and the same substrate. Most recently the subharmonic mixer jig (see Fig. 30 lhs) has been developed and demonstrated in testing of antiparallel diodes at 183 GHz. Analysis of results shows that a comprehensive characterisation of Schottky diodes can be performed using the mixer-based characterisation in addition to traditional characterisation based on I-V, C-V and S-parameter measurements.

The transient current method developed for THz Schottky diode thermal characterization enables the extraction of thermal resistances, time constants, and peak junction temperatures from the cool-down response of a diode (see Fig. 30 rhs) after a heating current pulse. The method has been validated with measurements of varactor diodes and also a measurement setup accuracy verification routine has been developed. Characterization results have been compared against the results of, e.g., two commercial 3D thermal simulators. For example, the total thermal resistance result for a diode with an anode area of $9 \mu\text{m}^2$ is within $\pm 10\%$ of the average value of 4020 K/W from different methods. An application of the developed method is in providing data for the reliability evaluation of devices for space operational missions. For example in frequency multipliers the peak junction temperature of a diode is a critical parameter.

On-wafer S-parameter measurements with a vector network analyser are a significant part of millimeter wave and THz device testing and modelling. For achieving appropriate measurement results an accurate calibration is needed. The calibration method and the error model determine the accuracy of the calibration but also the calibration standards need to be defined accurately. A novel method to define the line-reflect-reflect-match (LRRM) calibration standards in measurement configuration affected by leakage has been developed. The Line standard and the resistance of the Match standard need to be known and the reactances of the reflection standards (typically Open and Short) and Match standard are calculated from the raw S-parameter data of the calibration standards' measurement. The 16-term error model can be calibrated using the LRRM standards with the previously developed calibration method based on the reciprocity conditions.

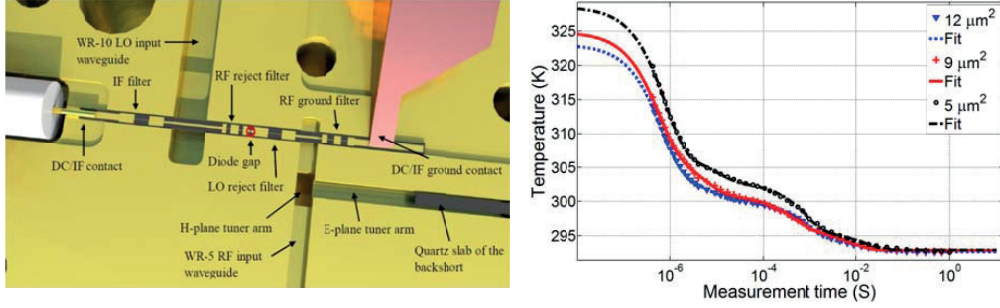


Fig. 30. 3D-illustration of the lower waveguide block of the subharmonic mixer test jig (lhs). Transient current measurement method thermal response for diodes of different anode areas (rhs).

Integrated lens antennas for beam steering. An integrated lens antenna provides the means for beam-steering with high directivity. The conventional lens designs suffer from strong internal reflections that cause severe deterioration of the beam-steering properties. We have developed a simple lens design that allows minimising the internal reflections. It is shown that with any permittivity and with any feed directivity it is possible to design the lens shape in such a way that the reflection loss is low, for moderate beam-steering angles, without resorting to a complicated matching layer. A ray-tracing illustration of the developed lens design and an example of a comparison of simulation and measurement results are presented in Fig. 31. Also, an integrated lens antenna design for beam-steering with small scan loss is developed. This lens design is based on a well-known extended hemispherical lens. By placing the feed elements on a spherical bottom surface of the lens, instead of a conventional planar one, all of the feed antennas are oriented towards the collimating part of the lens. The presented lens design enables beam-steering with low side-lobes and nearly identical beam shape for all beams. Measurement results show good beam shape and low scan loss up to 30° beam-steering angles with a low permittivity Teflon lens.

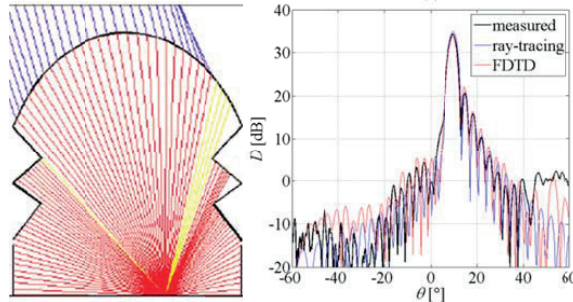


Fig. 31. Ray-tracing illustration of the developed method for reduction of the harmful internal reflections in a integrated lens antennas (lhs). Comparison of measured, ray-tracing simulation result, and a full-wave FDTD simulation result (rhs).

Near-field measurements of reflectarray elements. Reflectarray antennas are typically characterized via beam pattern measurements. However, it is often desirable to get more accurate information on the performance of the individual elements than can be observed directly from the measured beam patterns. Therefore, a near-field probing measurement range was developed in order to extract the reflection coefficients of individual elements and study their phase shifting properties. The studied reflectarray consists of coplanar patch antennas with four-state fixed phase shifting realized with coplanar stubs. Fig. 32 a) shows the reflectarray and an open-ended waveguide probe used in the measurements. Very dense sub-wavelength sampling is used and considerable amount of data points is averaged in the neighborhood of the element center point to obtain a single data point for a single element. Fig. 32 b) shows the averaging scheme for each element. The phase-shifting of each element is estimated by comparing the element data with the reflection from the ground plane at the same distance.

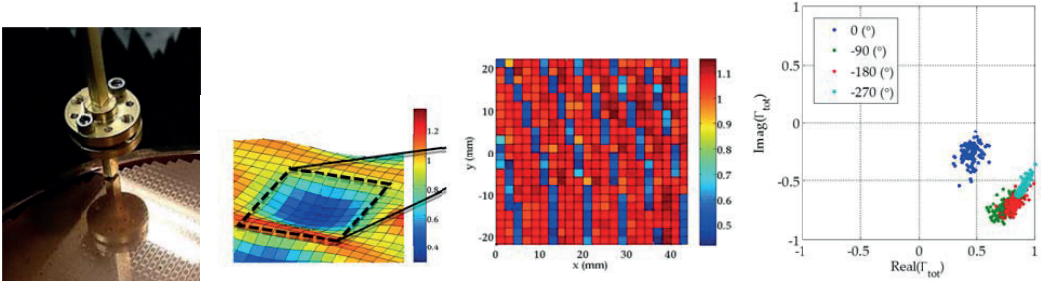


Fig. 32. a) Reflectarray near-field probing measurement range with the open-ended probe at 1-mm distance from the reflectarray surface. b) Averaging scheme to obtain single data point corresponding to a single element and averaged amplitudes of the reflection coefficient in a part of the reflectarray. c) Extracted complex reflection coefficients of four different phase shifting elements.

Wide-band dielectric rod waveguide antennas. Dielectric rod waveguides (DRW) are very promising transmission lines, when low loss dielectric materials are used. They can be combined with semiconductor devices (oscillators, detectors, mixers, etc.) in the hybrid and/or monolithic integrated circuits and also used as antennas. Simulations show that the single DRW antenna can operate in a wide range of frequencies from 75 GHz to 1 THz. The antenna geometry is presented in Fig. 33. The maximum cross-section of the antenna is 1.0 mm × 0.5 mm and it can be matched with different rectangular metal waveguides as it schematically shown in Fig. 33 (left). The antenna performance was experimentally verified over frequency range of 75 GHz to 325 GHz. The upper limit is due to our limited manufacturing capability to produce sharp antenna tips. The return loss of the antenna is better than 17 dB over the whole frequency range. The simulated and measured radiation patterns in E plane at 280 GHz and 310 GHz are shown in Fig. 33 (right). The antenna gain of 10 dB and half power beamwidth of 55° are constant over the whole frequency band.

Ultra-wideband lens-based DRW antennas for optoelectronic THz power generation. The breakthrough targeted by this work is the achievement of a long-needed cost-affordable THz source that features high power, large tuneability, high reliability, and integration to the antenna arrays for beam steering application. A photomixer-based THz emitter is driven by a dual-optical-frequency semiconductor-based laser source that provides down to Hz-level linewidths of the THz beat frequency. Because of the high dielectric constant of the semiconductor substrates only a small amount of terahertz power is radiated. For increasing the radiated power a DRW is used. Due to the substrate-antenna junction many higher-order modes are excited into the antenna for higher enough

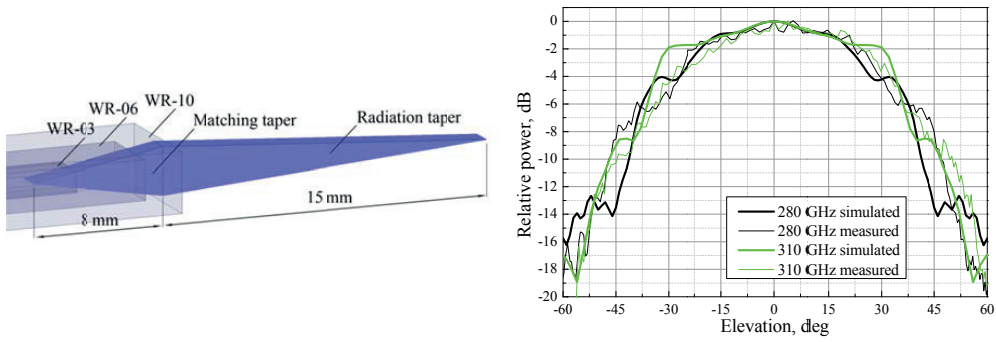


Fig. 33. Geometry of the antenna (left) and the radiation patterns of the antenna (right).

frequencies. This leads to the existence of nulls in the desired radiation direction at many frequencies, which is undesirable for most of applications. For avoiding such a bandwidth limitation, a planar hyper-hemispherical lens is embedded into the dielectric rod (see Fig. 34 a)). It is implemented by reducing the relative permittivity ϵ_2 around its shape either by using different materials or by doing electrically small holes (see Fig. 34 b)). Lens permittivity ϵ_1 is kept the same as the wafer. Figs. 34 c) and d) shows how a single-mode regime is achieved in an electrically large DRW antenna using embedded lens. Rod length is chosen to be 17 mm and width 2.2 mm. As it can be seen, it keeps a single-mode working regimen up to 400 GHz.

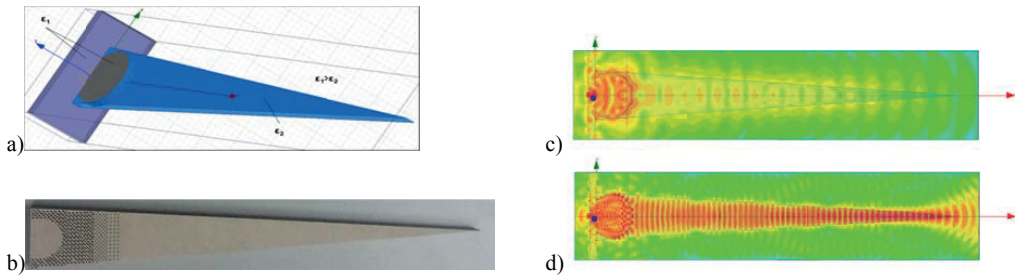


Fig. 34. Hyper-hemispherical lens embedded in a DRW antenna of permittivity ϵ_2 lower than the substrate (a). Elliptical dielectric lens defined by drilling holes around its shape (b). This proof-of-concept has been manufactured at Carlos III university of Madrid. Simulated E-field [$\log(V/m)$] distribution on XZ plane at 150 GHz (c) and 400 GHz (d).

Experimental verification of systematic design method for composite right-left handed (CRLH) periodic transmission lines. The design method developed and reported in the SMARAD report 2012 was experimentally verified during 2013. The method is proved to provide a versatile tool for the design of a number of applications based on CRLH periodic transmission line (PTL). Especially the design of CRLH leaky-wave antennas is benefitting since they are usually based on a cascade of many CRLH cells. Three main principles of the method include precise characterization of the loading elements, compensation of their parasitic components, and compensation of the inter-cell coupling through the scaling of the loading elements using the inductive and capacitive coupling coefficients. Numerical verification was done at 26 and 77 GHz. Experimental verification was done at 26 GHz by manufacturing and measuring the scattering parameters and radiation properties of a leaky-wave structure. Comparison of dispersion, attenuation constant, directive patterns, and maximum gain measurement results to the simulated results shows good agreement with the expected performance (see Fig. 35). Moderate accuracy, ease of use, and speed favor the systematic method over other methods available.

Characterization of nanomaterials. Novel nanomaterials like carbon nanotubes (CNTs), graphene, and silver nanowires (AgNWs) are promising for millimeter wave and terahertz integrated circuits. The characterization of the propagation constant of CNT layers on polyethylene terephthalate (PET) substrate, graphene on SiC substrate, and AgNWs in the frequency range of 75 to 110 GHz was carried out in RAD. A DRW platform was successfully used for measurements of high frequency properties of CNTs, AgNWs and graphene layers (see Fig. 36 a)). DRW made with the low loss

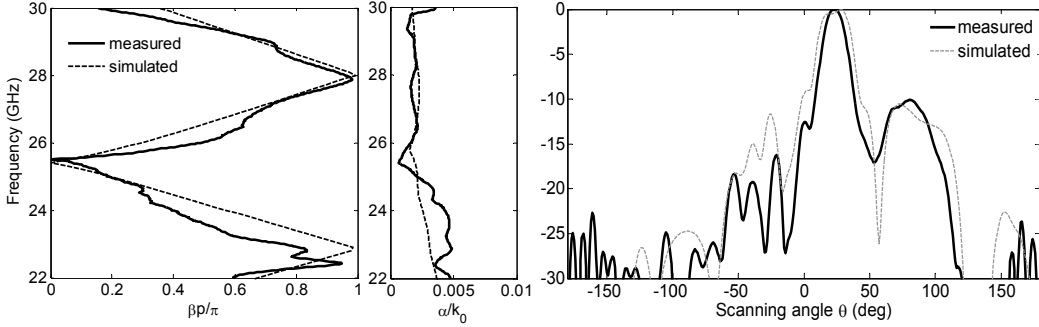


Fig. 35. Measured and simulated dispersion and attenuation constant for 10 cell structure, and Comparison of radiation pattern of a 20 cell structure at 28 GHz.

dielectric material is an open transmission line which can be coupled well with the standard metal waveguides. If one or more walls are covered with a layer of nanomaterial, the surface impedance will change, which will result in the change of the propagation constant. The losses introduced by AgNWs were about 4 dB per 60 mm and caused by the reflection properties of metallic material. The losses due to deposited CNT layers were about -35 dB in average, the decreasing of propagation losses vs. frequency was observed. Our simulation model indicates that such losses originated from the high absorption of the material. Losses due to graphene layers were about 2.5 dB. The attenuation constant α can be calculated from experiments. The attenuation due to graphene and AgNWs is almost negligible for the whole frequency band, meanwhile CNT layers are observed to be highly attenuating material but attenuation decreases with frequency (see Fig. 36 b)).

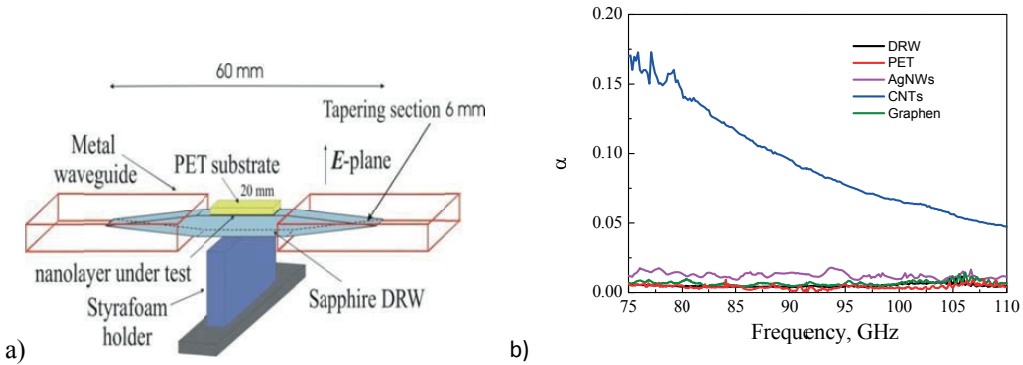


Fig. 36. a) Measurement setup and b) measured attenuation constants of nanomaterials.

Rapid and dynamic optoelectronic beam steering for terahertz frequency applications. THz technology utilization continues to grow at exceptional rates, due to the vast potentials offered to many application areas. Within this research effort we aim to develop a novel dynamic lens solution which will enable reconfigurable optics for a range of imaging platforms, enabling real-time or complex imaging paradigms. Initial designs have included the generation of a binary Fresnel lens, or zone plate, within an optically excited semiconductor substrate. Changes to the optical projections

result in a corresponding change of the THz beam properties. Fig. 37 a) highlights the generation of a directive beam using such photonic lenses; increased optical excitation yields increasingly directive THz beams using the reconfigurable lens. The reconfigurable lens was then tested using a 3D-FMCW radar front end with a bespoke back end processor in order to control the lens and generate the image from gathered data. Fig. 37 b) illustrates an example 3D image (collapsed to 2D) of some point targets spread throughout a scene. The image was generated using no moving parts at 15 pixels per second. Current research efforts are seeking to optimize the design, whilst also investigating potential alternative designs for significant speed boosts and reduced form factors.

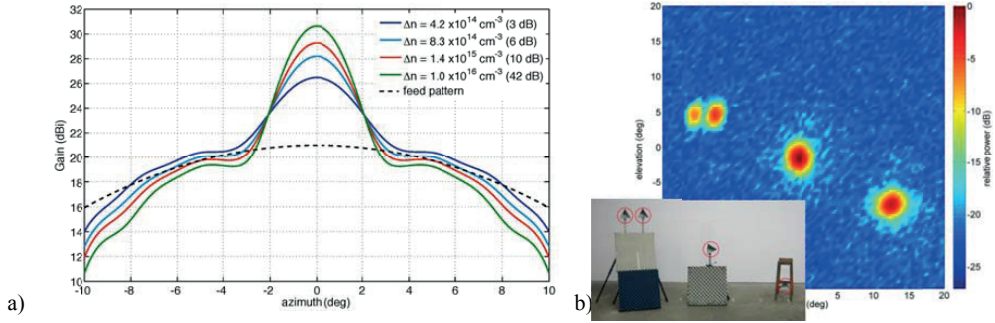


Fig. 37. a) Simulated semiconductor free-carrier density requirement for THz beam formation; b) Example imagery using THz radar image platform to images scene of distributed point targets with no moving parts.

Realization of wideband hologram compact antenna test range (CATR). A method for wideband operation of the hologram CATR has been studied. The needed adjustment of the feed location is linearly related to the working frequency, and the beam of the desired plane wave is steered in the quiet zone. The wideband method for generating the plane wave has been presented, and verified (see Fig. 38). A large focal ratio is needed for the wideband application, and the recommended value is larger than 4. The effectiveness of the wideband operation has been verified by the measured results at W and D bands for the hologram aperture diameter of 350 mm. The measured quiet-zone quality of the hologram is better than the typical requirements (peak-to-peak variation less than 2 dB in amplitude and 20 degrees in phase) from 95 GHz to 170 GHz.

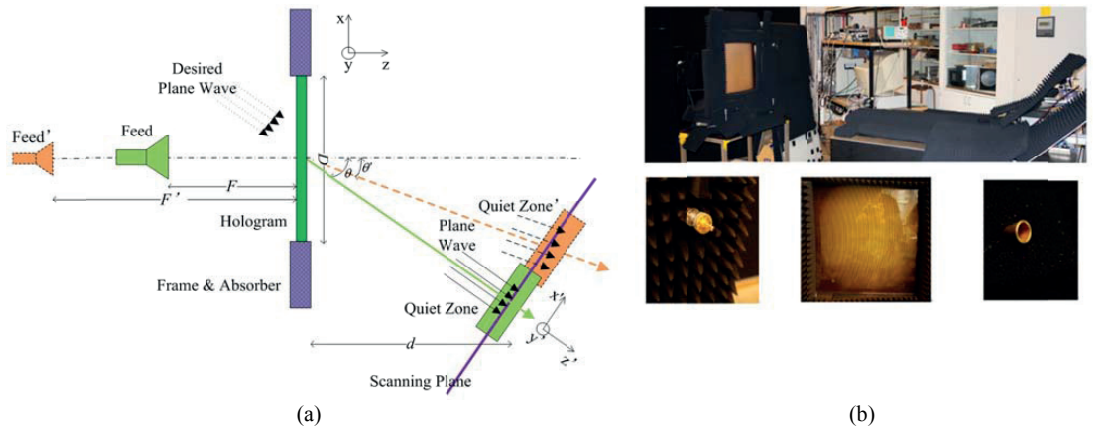


Fig. 38. The wideband application of hologram CATR: a) conceptual layout, and b) setup for the measurements

Antenna radiation pattern retrieval from the reflection coefficient measurements. A novel and rapid antenna pattern retrieval method has been developed. In the proposed technique, a reflective surface with known reflective properties is placed in the vicinity of the aperture of AUT and the antenna reflection coefficient is measured. The measurement is repeated many times with different reflective surfaces. The antenna properties are solved from the measured reflection coefficients. The advantages of the method are that there are no flexing cables needed and the setup can be compact. In addition, the antenna near-field distribution does not need to be separable and the radiation pattern can be solved in 2D. The method could be feasible for characterizing antennas even in a probe station, for which the conventional methods are based on spherical measurement requiring complex mechanical arms for the probe antenna movements around the AUT. We derive and verify the analytical foundations for the new method, and demonstrate the method both by simulations and experimentally for a pyramidal horn antenna at 30 GHz. Fig. 39 shows the schematic design of the proposed antenna pattern retrieval technique and the comparison of the reconstructed, simulated and measured normalized radiation patterns at 30 GHz. The results are in good agreement between $-25^\circ \dots +25^\circ$ which is the calculated valid angular region with the physical dimensions of the current setup. The reconstructed pattern with measured S_{11} deviates less than 0.5 dB from the pattern measured in far-field range at -16 dB level.

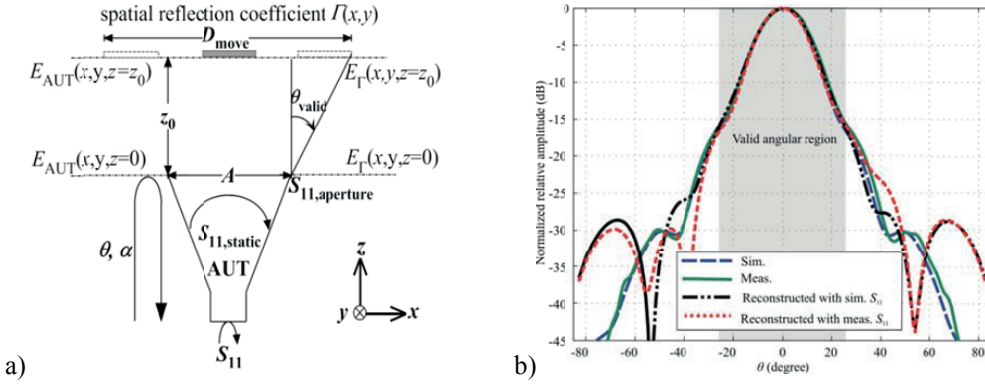


Fig. 39. a) Schematic design of the proposed antenna pattern measurement technique and b) normalized far-field patterns at 30 GHz.

Inkjet printed and reconfigurable antennas. Printed inkjet monopole antennas are characterized on different platforms. It was found out that antenna disposal on the painted substrate with silver paint can lead to the gain amplification. Also, we have studied the concept of the fluidic antennas at 5.8 GHz. Single patch antenna and 3 element antenna array were developed and characterized. Mechanically tunable antennas can adapt to the changes in the system requirements and the shape of the radiating element can change accordingly to these variations. The same antenna structures can be scaled to mm-wave frequencies. Also, a 4x4 patch antenna array operating at 60 GHz frequency band was developed. The radiation properties for the planar and different conformal cases were studied by simulations. In a conformal installation the enlargement of the main beam was observed (see Fig. 40). This kind of structures can be used in applications where large angular coverage and high gain values are required.

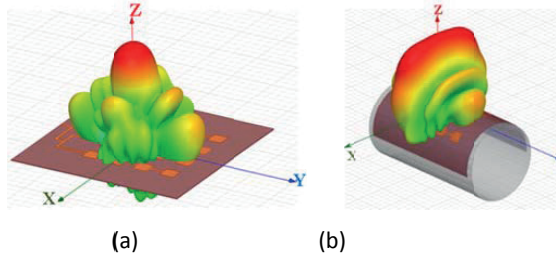


Fig. 40. Simulated 3D realized gain radiation patterns at 60 GHz and antenna array orientation for (a) planar case (b) conformal case.

Propagation channel modeling. Scattering patterns of built surfaces were empirically characterized. The scattering patterns of the brick and glass walls have been measured in the 69-74 GHz frequency range. The wideband channel measurement system has been used to record channel transfer functions and after post-processing the reflected paths have been identified from the measured averaged power delay profiles. The results of this work can be utilized, e.g., in geometry-based stochastic channel model. Propagation channel model for the estimation of optimum antenna configuration for indoor scenarios was developed with ray tracing: Fig. 41 shows the used ray tracing model for an office room. The effect of the human body shadowing on the system performance was studied. When the line-of-sight connection was blocked by the human being, beam steering technique can be used to reconfigure the antennas and point the main beam towards the strongest multipath component. By performing these simulations an optimum antenna configuration, i.e., necessary gain, half-power beam width, and angular coverage can be defined.

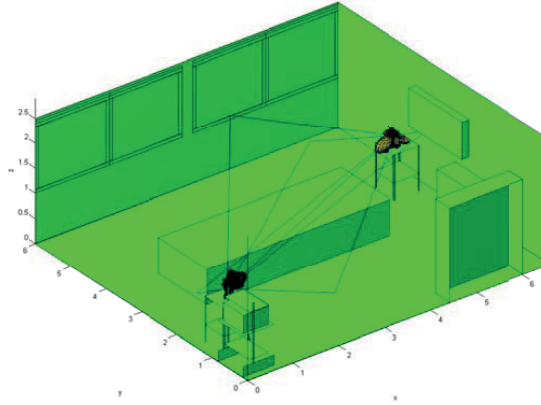


Fig. 41. Ray tracing model for the office room scenario.

Millimetre wave integrated circuits. A W-band differential phase shifter with active switches in 28-nm CMOS technology has been designed and measured. In order to reduce the substrate loss, the slow-wave structure has been used in the phase shifter design procedure. Moreover, use of a unique approach enables the design of the branch-line coupler in a very compact chip-area 75% smaller compared to a conventional branch-line coupler. The measurement results show maximum 19.6° phase deviation, 12.85 dB average signal loss, and 0.8 dB output imbalance at 100 GHz. Considering the 1-dB maximum output imbalance, the phase shifter bandwidth is from 97 to 106 GHz. Also the input and output matching within this bandwidth are better than -10 dB. In order to mitigate the signal loss, a new version has been designed and submitted for fabrication in November

2013. New design includes buffer amplifiers both at the input and output of the phase shifter shown in Fig. 42. The simulation results show around 11 GHz bandwidth and 9.1 dB gain. The microchip shown in Fig. 1 includes also 320 GHz amplifier, 300 GHz power amplifier, and appropriate test structures for characterizing the millimeter-wave behaviour of active and passive components. To design the amplifiers, we have implemented inductive feedback between gate and drain of the transistor to achieve maximum gain. The inductive feedback is realized by transmission line. The three-stage 320 GHz amplifier has simulated gain of 10-dB around 320 GHz. To realize 300 GHz power amplifier we have implemented conventional power combining technique. The simulation results show 8 dB gain around 300 GHz.

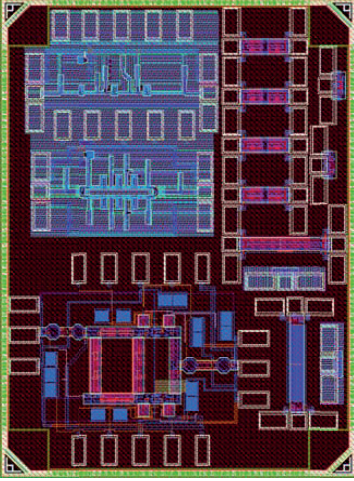


Fig. 42. Layout of the microchip including radio-front-end blocks for a *W*-band differential phase shifter, 320 GHz amplifier, 300 GHz power amplifier, and test structures.

We collaborated with NASA Jet Propulsion Laboratory, Pasadena, California for developing InP HEMT Amplifiers for astrophysics and Earth remote sensing applications. A noise temperature of 120 K at 258 GHz was measured when the LNA module was cryogenically cooled to 20 K. At the same 20 K condition, the noise temperature is less than 145 K between 234-268 GHz. To our knowledge, these results are the lowest LNA noise temperatures at these frequencies reported to date.

3.4 Sensors

Microwave visualization of buried objects in the ground. The method of both detection and recognition of buried objects based on reconstruction of the phase profile of the radar signal has been developed. Formerly, this method had been formulated for the frequency-domain data. Recently, it had been modified for the case of impulse radar that is motivated by the fact that the most commercial georadars utilize impulse technology.

The method is based on extraction of phase information related to reflection of the signal of impulse radar from the object. To this end, transient response of the object of interest is localized in the A-scan data by time gating, shifted to zero distance and then transformed to the frequency domain. The average phase of obtained frequency response depends on the contrast between medium and embedded object and thus can be used for differentiating objects by their material properties. In case there are several signal peaks in the A-scan produced by other targets, those are processed further in

a similar way. Finally, two separate A-scans by amplitude and phase are built from the initial transient A-scan. These A-scans are used to build corresponding B-scans that are combined further in a common image using the following rule: amplitude governs intensity of the pixel while phase governs its color.

Performance of this method has been tested using radar data provided by the commercial radar Malå CX11. Results are shown in Fig. 43.

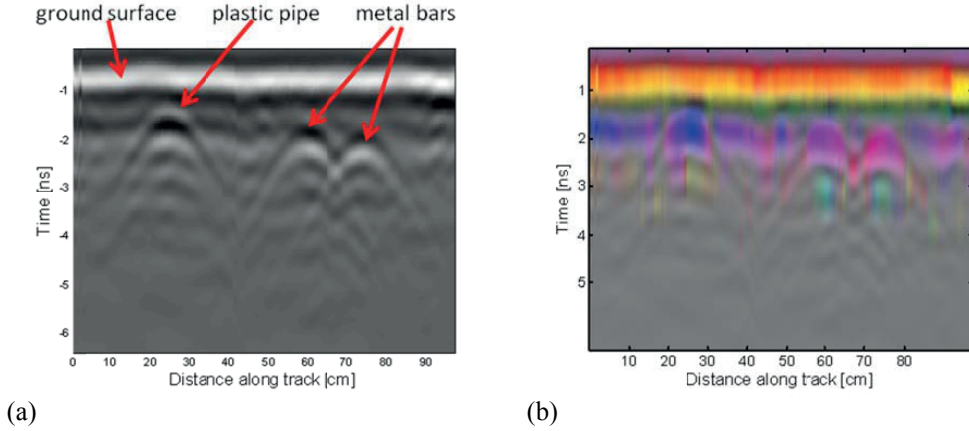
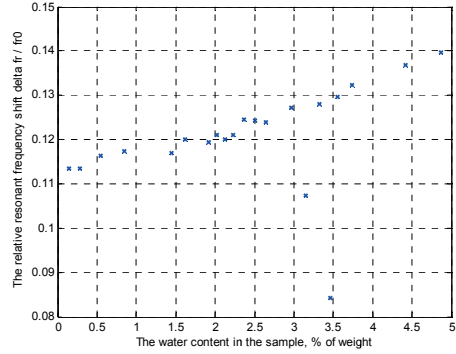
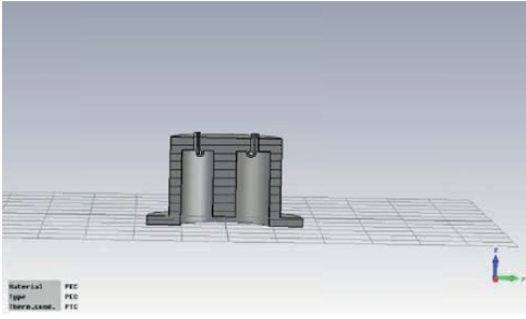


Fig. 43. Subsurface images obtained by a commercial georadar Malå CX11. (a) – image of the radar operating in a normal mode; b – image built using modified signal processing with phase profiling.

As seen in Fig. 43(a), the commercial georadar in normal mode is suitable only for the detection of subsurface objects. Novel signal processing technique applied to the same data set allows also discriminating them. So, plastic pipe can be easily distinguished from metal bars using Fig. 43(b). Such discrimination can be hardly done by observing Fig. 43(a) obtained in normal mode.

RF moisture measurement of concrete with a resonator sensor. A feasibility study of moisture measurement of concrete with the RF resonator sensor method has been carried out. The resonator method is based on the resonant frequency shift when the permittivity of the material under test (MUT) increases with growing water content. A simulation model of the used resonator sensor was built in the electromagnetic simulator CST Microwave Studio, as shown in Fig. 44(a). The diameter of the sensor is 4 cm. The couplings are on the top side of the resonator. In the measurements of the resonant frequency, which is denoted by f_r , the resonator sensor is placed in close proximity on the concrete surface. The sample, a concrete pavement tile, is first measured when it is completely dry after oven-drying. After that, the sample is made completely saturated with tap water and the measurement is repeated at 21 water saturation levels until a completely dry state. The dependency between the resonant frequency shift and the moisture content is shown in Fig. 44(b). The resonant frequency shift is presented in relation to f_{r0} , which is the resonant frequency of the sensor without the material under test. The result shows an almost linear dependence between the relative resonant frequency shift and the water content. The resonant frequency shift increases when the moisture content increases, which is to be expected. It was also verified that such resonance method is sensitive enough for the moisture measurement of concrete with any saturation level of moisture.

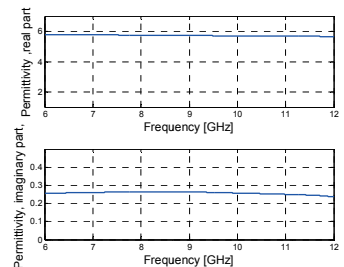
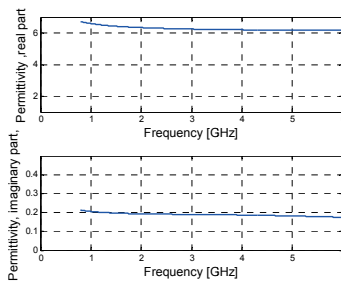


(a)

(b)

Fig. 44. (a) The cutting plane of the resonator sensor. (b) The result: the relative resonant frequency shift as a function of the water content (%) in the sample.

Complex permittivity of concrete in the frequency range 0.8 to 12 GHz. The complex permittivity of a concrete tile is determined in the frequency range 0.8 to 12 GHz. The measurement is made as a transmission measurement. Fig. 45a) shows the front side of the sample with the transmitting antenna. Two planar Vivaldi antenna pairs are used to cover the frequency range from 0.8 GHz to 6 GHz and 6 GHz to 12 GHz. The presented measurement method allows the defining of the complex permittivity of any kind of concrete, even when the material composition is not known. The permittivity is derived from measured transmission coefficients. The data undergo signal processing in Matlab by which the multiple reflections inside the sample and between the antennas and sample interfaces are excluded. The signal processing is done by time-gating with a windowing function, e.g. Gaussian. Thereafter, the data contain only the reflection caused by the air-concrete interface and the permittivity can be calculated. The permittivity is presented in Figs. 45b) and c), from 0.8 GHz to 6 GHz and from 6 to 12 GHz, respectively.



(a)

(b)

(c)

Fig. 45. (a) The transmission measurement setup viewed from the other side of the concrete sample. Real and imaginary part of the permittivity for a concrete sample, measured from (b) 0.8 GHz to 6 GHz and (c) 6 GHz to 12 GHz.

Accelerometer interface. A charge-balancing accelerometer was designed and tested as the second part of the project. A hybrid interface topology was utilised to achieve high resolution, high linearity and low power supply sensitivity. The accelerometer consisted of a micromechanical sensor element, self-balancing bridge (SBB) open-loop readout, AC force feedback and ADC. The ratiometric output of the SBB is converted to the digital domain by the ADC. In order to achieve

high resolution, a micromechanical sensor element with a high quality factor, Q , was utilised. The AC force feedback was used for damping the high Q to get a low settling time.

The sensor interface was fabricated using a standard $0.35\ \mu\text{m}$ AMS CMOS process. The chip micrograph of the accelerometer interface is shown in Fig. 46. The fabricated chip had an area of $6.66\ \text{mm}^2$ and consumed $1\ \text{mA}$ current at a nominal supply voltage of $3.6\ \text{V}$. The sensor had a maximum DC non-linearity of 1.3% over the commercial temperature range, from $-40\ ^\circ\text{C}$ to $+85\ ^\circ\text{C}$, with an input range of $1.15\ \text{g}$. The noise floor of the sensor was around $2\ \mu\text{g}/\sqrt{\text{Hz}}$ and the signal bandwidth was $200\ \text{Hz}$. The bias instability was $13\ \mu\text{g}$ and the sensor gain variation was less than 5% in the $3\text{--}3.6\ \text{V}$ supply range.

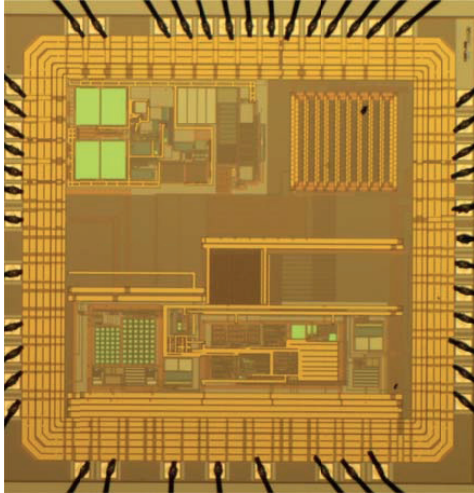


Fig. 46. Chip micrograph of the accelerometer interface.

Inclination sensor interface. In this project the goal was to design an integrated 2-axis inclination sensor interface circuit with a calibration circuit to reduce the effect of those non-idealities in capacitive MEMS inclinometer elements that inflict inaccuracy when sensing is done with a low clock frequency. Two such non-idealities, for example, are the built-in bias voltage in the MEMS sensor element and the leakage current between the sensor nodes.

An analog sensor interface was implemented with a mixed-signal calibration circuit to mitigate the effect of the non-idealities. A voltage regulation system consisting of a charge pump and a low-dropout regulator was designed to provide a stable on-chip supply voltage with external supply voltages ranging from $3.0\ \text{V}$ to $3.6\ \text{V}$ and $4.5\ \text{V}$ to $5.5\ \text{V}$. An analog-to-digital converter, a digital filter and an SPI interface were designed to enable a digital output and writing and reading of calibration bits.

The designed IC was processed using a standard $0.35\ \mu\text{m}$ AMS CMOS process. Supply voltage was $3.3\ \text{V}$. Area of the core blocks was $5.3\ \text{mm}^2$. Detection range of the system was $\pm 15^\circ$ and measured non-linearity was 0.25% for X-axis and 0.52% for Y-axis.

MEMS frequency source. The research work related to MEMS frequency sources was mostly focused on characterization of the integrated interface electronics developed by the end of the previous year and system-level measurements. The micrograph of the developed system, a temperature compensated Real Time Clock based on a MEMS resonator is shown in Fig. 47. The interface circuit consists of a low power oscillator, a DSP block and a Sigma-Delta analog to digital converter described together with the temperature sensor in more detail in the following section.

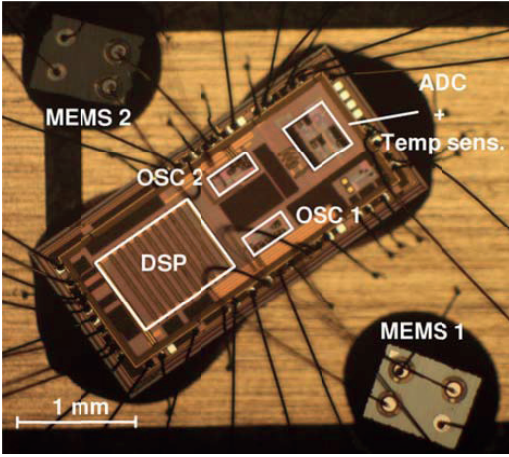


Fig. 47. Chip micrograph of the low-power temperature-compensated Real Time Clock.

The oscillator core utilizes a novel amplitude limiting circuitry. MEMS resonators require the drive signal to be within certain, design specific limits. Too high amplitude results in the device operating in the non-linear regime, which could result in heavy distortion in the output signal or lead to mechanical failure of the micro-resonator. This feature requires careful design of an amplitude control or limiting circuitry. The implemented solution utilizes a synchronous amplitude limiter that allows maintaining a safe operation area for the silicon resonator. The novelty of this architecture is that it does not require any external control signals and guarantees proper system functionality across the process corners and standard industrial temperature range -40°C to 85°C .

A drawback of silicon-based MEMS resonators is their high Temperature Coefficient of Frequency (TCF), on the order of $-30\text{ppm}/^{\circ}\text{C}$. In order to implement a precision frequency source, this issue needs to be addressed. In the system of Fig. 47 the compensation is performed using electronic circuitry. The temperature of the die is measured by the on-chip temperature sensor and converted to digital data with the analog to digital converter. This information, together with the resonator frequency vs. temperature characteristics is used to determine the compensation coefficients and generate a temperature-compensated 1Hz output signal.

The system has been implemented using a $0.18\text{ }\mu\text{m}$ standard CMOS process with the active area consumption of 1.14 mm^2 . The worst-case timekeeping accuracy is $\pm 4\text{ppm}$ across the specified temperature range, as shown in Fig. 48. The entire system draws on the order of $2\text{ }\mu\text{A}$ of current at room temperature and runs off a 1.8V supply, which makes it feasible for use in low power applications.

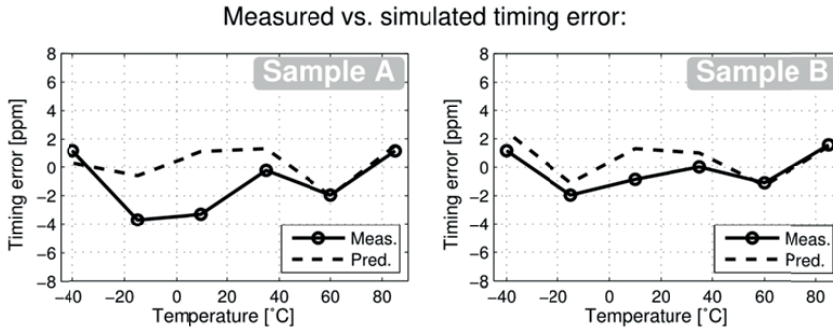


Fig. 48. Timekeeping accuracy of the low-power temperature-compensated Real Time Clock.

Low-power temperature sensor. As a part of the MEMS frequency source project, a low-power temperature sensor was designed and fabricated. The sensor is designed to have few tens of nanowatts power consumption at an update rate of 2 samples/min. The sensor core is based on bipolar transistor present in CMOS technology. The analog PTAT voltage of the sensor core is converted to digital with an incremental $\Delta\Sigma$ ADC. A stream of bits from ADC is fed to a digital on-chip integrator, which converts 1-bit ADC output to 16-bit signed output. The sensor has been implemented using 0.18 μm CMOS process from AMS with a nominal supply voltage of 1.8 V. The micrograph of the fabricated temperature sensor is shown in Fig. 49.

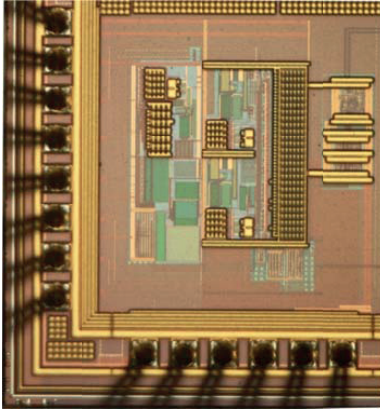


Fig. 49. Micrograph of the temperature sensor.

Universal power management for energy harvesters. The second process run of the power management system IC was completed. The system includes two voltage regulators for DC energy inputs of two adjacent input voltage ranges, an active rectifier for RF energy inputs, a power-in reset for detecting input voltage range, a voltage reference and a large on-chip capacitor for filtering and stability. The functionality of all the blocks, except for the voltage reference, has been verified through measurements.

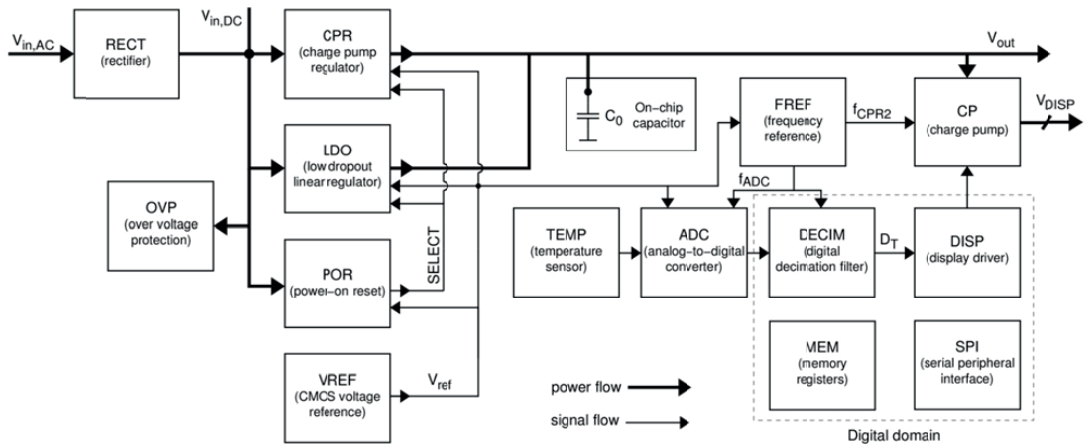


Fig. 50. Block diagram of the universal power management for energy harvester.

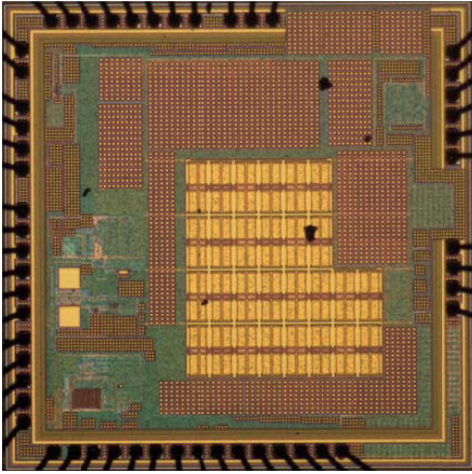


Fig. 51. *Chip micrograph of the universal power management for energy harvester.*

The third design of the power management system has been prepared, and is submitted for fabrication in May 2014. In addition to the blocks in the previous design, it includes a temperature sensor, a frequency reference for accurate clock generation, an ADC for converting analog sensor signals to digital domain, a charge pump for driving an electrophoretic display, an overvoltage protection circuit and another type of voltage reference. It will also include a digital block for SPI communication, DSP, trimming, driving a display, and system control.

The system is able to interface different energy harvester types with ultra-low power devices and different sensors, and print data on an electrophoretic display. The system uses a supercapacitor for filtering and energy storage. Collaboration with Tampere University of Technology is done for obtaining energy harvesters and supercapacitors, both realized in flexible printed electronics technology.

In further designs, the target is to include a radio circuit for wireless communication and extend the demonstratable energy harvester types to at least photovoltaic, thermal, RF radiation, kinetic and fuel cell harvester.

CMOS components for RF Energy Harvesting. This work is aimed to design various essential components required to build an RF energy harvesting system. Various standard and proposed prototypes of single ended RF-to-DC converters and new architectures of voltage reference circuits were developed in the process- run held in March-2013. In RF to DC converter design we used the dynamic threshold control and internal threshold cancellation mechanism. The proposed RF to DC architectures exhibits good agreement between simulations and measurement. The maximum power conversion efficiency obtained from RF to DC converters is in the range of 20 to 22% with the received power-strength of -10dBm for the resistive load of 10 k Ω . We have designed two reference voltage generator circuits. These circuits are capable of working from -40 °C to +85 °C for the supply voltage range of 1.25V to 2V. The proposed voltage reference circuits offer the measured temperature coefficient of 17.43 ppm/ °C and 19.302 ppm/ °C with a few nanowatts of power consumption in the reference generating core. The targeted application of these reference cores is to provide a reference voltage for a low dropout regulator used in a power management block of the RF energy harvester. In continuation of the first, the second design is submitted in Feb-2014. The second chip contains the novel architectures of differential RF to DC converters, and other essential components like frequency reference circuit, current reference circuits, power on reset circuits and LDO.

Low-power temperature sensors. The chip also contains various designs of nano-watt temperature to digital converters (TDC). These TDCs are capable of working on a supply voltage of 1V with simulated temperature inaccuracy of $\pm 3^\circ\text{C}$ without any calibration. Two different, reasonably accurate temperature sensors capable of working with a few microwatt power consumptions were also designed and fabricated in a March-2013 process run. The targeted applications of these temperature sensors were on-chip thermal monitoring and environmental temperature monitoring where moderate temperature accuracy is desirable. In the first sensor, the temperature sensing core consists of two nano-power MOS-based circuit elements namely PTAT and CTAT sensors. These circuit elements generate proportional and complementary voltage signal corresponding to the temperature. The temperature inaccuracy of PTAT sensor element is $\pm 0.35^\circ\text{C}$ and for NTAT sensor element it is $\pm 1^\circ\text{C}$. The difference of these two voltages was converted into duty cycle by using PWM with a temperature inaccuracy of $\pm 1.5^\circ\text{C}$. Whereas in the second design, the temperature sensor utilizes the dependency of the rising time of the output pulse of an inverter, on drain current when triggered by a fixed frequency square wave. The temperature information in this architecture is also in terms of duty cycle of the output pulse with the temperature inaccuracy of $\pm 1.25^\circ\text{C}$. These sensors were implemented using a standard 0.18 μm CMOS technology from AMS with a nominal supply voltage of 1.8V, Fig. 52.

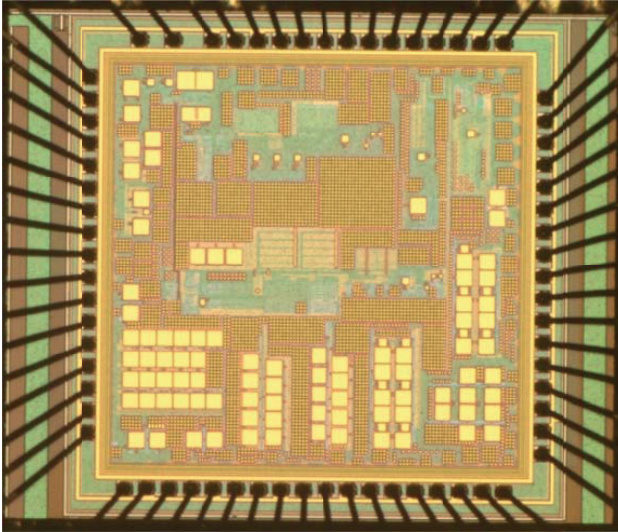


Fig. 52. Chip micrograph of CMOS components for RF to DC converter and low power temperature sensors.

3.5 Materials and Energy

Circuit theory model of radiative thermal transfer and thermal radiation. We have developed a theory of radiative heat transfer in multilayer structures based on an equivalent electrical network representation for material slabs in an arbitrary multilayered environment with an arbitrary distribution of temperatures and electromagnetic properties among the layers, Fig. 53. Our approach is fully equivalent to the known theories operating with the fluctuating current density, while being significantly simpler in the analysis and applications. The method allows optimization of heat transport by proper selection of material properties of intermediate layers. A practical example of the near-infrared heat transfer through the micron gap filled with an indefinite metamaterial has

been considered using the suggested method. Giant enhancement of the transferred heat compared to the case of the empty gap has been theoretically demonstrated.

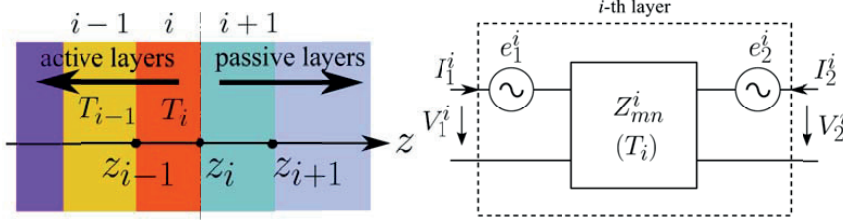


Fig. 53. Multi-layered structure of layers with different electromagnetic properties and at different temperatures and the equivalent four-pole network of a material layer under temperature $T = T_i$.

Highly-directive thermal emission from an indefinite medium slab. We have shown that slabs filled with asymmetric hyperbolic media (ASHM) with the anisotropy axis, tilted with respect to the interfaces, can produce thermal radiation with high spatial coherence, Fig. 54. This effect is caused by enhanced level of spontaneous emission inside hyperbolic medium and ability of modes with a very high density to be emitted from ASHM without total internal reflection.

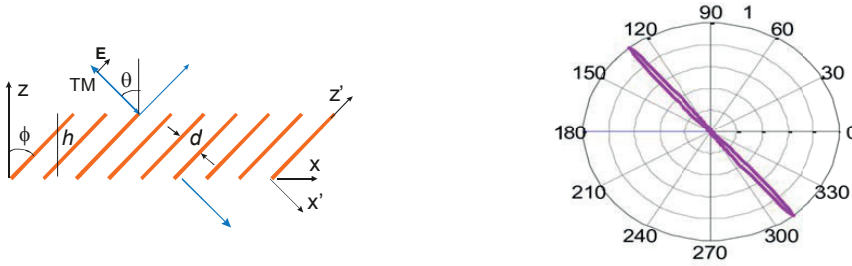


Fig. 54. Left: Schematic view of the ASHM slab. Yellow lines show direction of the optical axis. Blue arrows show directions of the thermal radiation lobes. Right: Emissivity diagram in polar coordinates for ASHM, made of silver nanowire composite, calculated using the Maxwell equations and fluctuation-dissipation theorem.

Effect of spatial dispersion in thermal radiative heat transfer via wire media. We have investigated the influence of spatial dispersion on thermal radiative heat transfer between two hot bodies via metallic wire media (WM) slabs, see Fig. 55. Two kinds of WM have been studied: made of tungsten and gold. In contrast to carbon nanotube arrays, where the effects of the spatial dispersion can be neglected, we took into account two waves excited at interfaces with wire media, the quasi-TEM wave, which has no cutoff, and the TM waves which are evanescent ones. We have found, that the spatial dispersion and excitation of the evanescent TM wave reduces thermal radiative power flow by 50-80 percent.

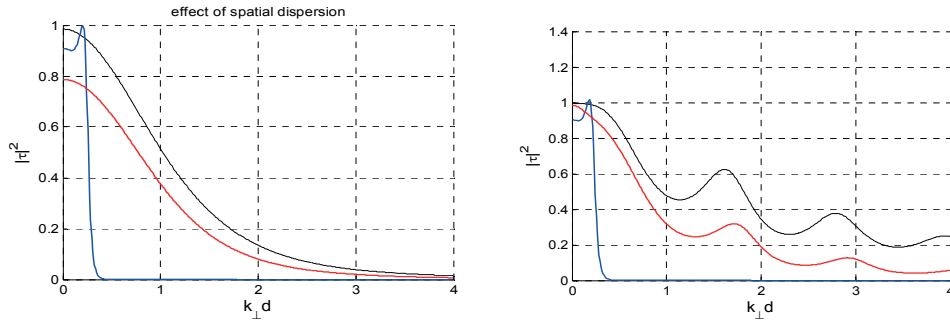


Fig. 55. Illustration of the effects of spatial dispersion (SD) on the thermal radiation heat transfer through wire media. Both TM and quasi-TEM waves and additional boundary conditions are taken into account. Black curve shows transmission coefficient versus the normalized transverse component of the wave vector. Red curve – if the SD is taken into account. Blue curve illustrates propagation through a vacuum gap. The width of the gap is 100 nm. Note that the transferred heat power is proportional to $|\tau|^2$. Left: tungsten WM. Right: gold WM.

Light-trapping in thin-film solar cells enhanced by nanoantennas. We have theoretically optimized the novel type of light-trapping structures based on arrays of nanoantennas excited far from plasmonic resonances, which we proposed earlier. We have demonstrated that such grids can enhance substantially the photo-voltaic absorption not only in in Cuprum Indium Gallium Selenide nanolayers which were studied a year ago, but also in nanolayers of GaAs, polycrystalline and amorphous silicon. In all these design solution the geometry of the nanoantenna array keeps the same, only the sizes of the elements vary. In all cases under study the predicted value for the short-circuit photo-current in the presence of the optimized light-trapping structures was simulated larger than that obtained in the presence of the optimal anti-reflecting coating. Our Russian partner has learned how to fabricate these nanoantennas with high quality (resolution 10-15 nm) in large-area panels on top of a passivation silica layer covering amorphous, polycrystalline and crystalline silicon, Fig. 56.

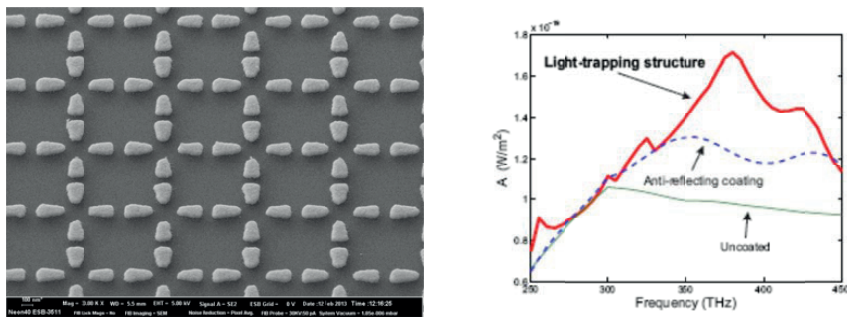


Fig. 56. SEM picture of the array of nanoantennas (left) and the spectrum of the photovoltaic absorption simulated for a CIGS-based solar cell with 100-nm thick photo-absorbing layer using software packages CST Microwave Studio and Ansoft HFSS (results fully coincide visually).

Huge local field enhancement in perfect plasmonic absorbers. We have theoretically revealed a new effect of huge local field enhancement in a so-called perfect plasmonic absorber performed of silver nanospheres a host material with permittivity dispersion-less over the visible range and equal

to 1.9 above a silicon substrate. First, we have studied the absorption of light power in a planar grid modelled as an effective sheet with zero optical thickness. The key prerequisite of the total absorption is the simultaneous presence of both resonant electric and magnetic modes in the structure. We show that the needed level of the magnetic mode is achievable using the effect of substrate-induced bianisotropy. On the microscopic level this bianisotropy is a factor which results in huge local field enhancement at the same wavelength where the maximal absorption holds.

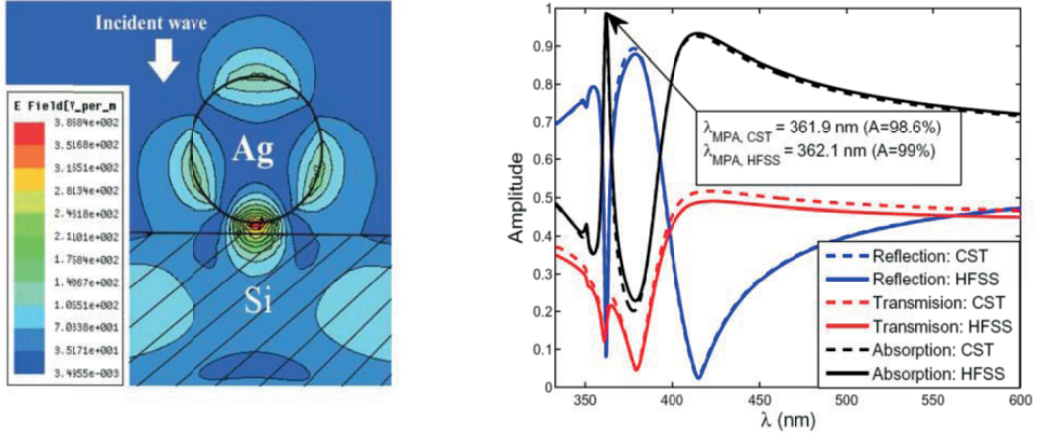


Fig. 57. (a) – Color map of the local field amplitude normalized to that of the incident wave at the wavelength of maximal power absorption. (b) – Coefficients of reflection (amplitude), transmission (amplitude), and absorption (power) of the normally incident plane wave in the proposed plasmonic structure (HFSS vs CST).

Optimization of radiative thermal transfer in macron-gap TPV systems. We have shown the possibility to engineer in a prospective micron-gap thermophotovoltaic system the strongly super-Planckian flux of radiative energy within the prescribed frequency band, whereas the harmful transfer of radiative heat beyond this band is suppressed. This regime is highly favorable for the conversion of heat into electricity and theoretically allows a combination of huge (much more than the black body) thermal emission with high efficiency of the photovoltaic conversion. As a result both Planckian and Shockley-Queisser limit are beaten and the electric output of thermophotovoltaic system will be surprisingly high. Fig. 58 illustrates the structure and the result obtained for radiative heat transfer. Giant enhancement of the transferred heat compared to the case of the empty gap is shown in the right panel.

Light-trapping in thin-film solar cells enhanced by dielectric nanolenses. We have proposed the enhancement of the photovoltaic absorption in thin-film solar cells using densely packed arrays (not obviously regular) of non-absorbing submicron or micron-sized dielectric spheres located on top of the cell. The spheres can decrease reflection forming an effective blooming layer. Simultaneously, they can suppress the transmission through the photovoltaic layer transforming the incident radiation into a set of collimated beams. The focusing of the light inside the photovoltaic layer allows an enhanced absorption in it leading to the increase of the photovoltaic current. Every sphere focuses the incident wave separately—this mechanism does not require collective effects or resonances and therefore takes place in a wide spectral range. Since the fabrication of such the coating is easy, our light-trapping structure may be cheaper than previously known light-trapping ones and perhaps even than flat anti-reflecting coatings.

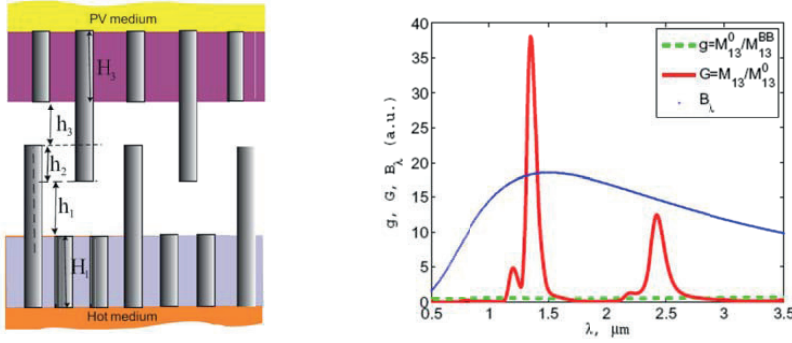


Fig. 58. Multi-layered nanotextured structure with free-standing nanowires of tungsten (left panel) which allows the frequency-selective strongly super-Planckian radiative heat transfer (right). Red curve – radiative heat transfer in presence of nanowires normalized to that in absence of nanowires. Green dashed curve - radiative heat transfer in absence of nanowires normalized to that between two black bodies (nearly uniform and equal 0.65). Blue curve – in arbitrary units – shows the radiative heat transfer between two black bodies. Photovoltaic medium at the left is Ge, hot medium is polycrystalline SiC. Host media for wire media are anodic aluminium oxide (violet - at the cold side of the TPV system) and amorphous silicon (blue - at the hot side). The temperature of the hot side is assumed to be 1300°C, at the cold side – room temperature.

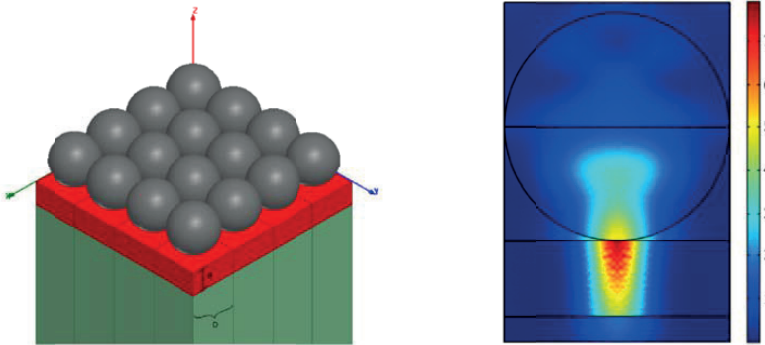


Fig. 59. Left panel – the light-trapping structure of silica nanospheres. Red- thin PV layer(doped a-Si), green – substrate of anodic zinc oxide serving the bottom electrode. The top electrode (not shown) maybe performed as a mesh of metal microstrips. Then light-trapping nanospheres fill in the area between these microstrips. Right panel – a color map of field intensity - illustrates the effect of light trapping at a certain wavelength (500 nm). The so-called photonic nanojet is formed at the point where the nanosphere and the semiconductor touch on another. The effect is not resonant and therefore very broadband.

Absorption in asymmetric hyperbolic media. We have developed a novel concept of applications of hyperbolic metamaterials (AHMM) and demonstrated that broad-band absorption can be achieved in an optically ultrathin layer of AHMM (see Fig. 60). Asymmetry in properties of waves, propagating upward and downward to media interfaces, appears if the optical axis of the hyperbolic metamaterial is tilted with respect to interfaces and it causes unusual electromagnetic properties of

AHMMs. AHMMs can be made of any plasmonic materials, such as noble metals, doped silicon, arrays of metallic carbon nanotubes, graphene, etc.

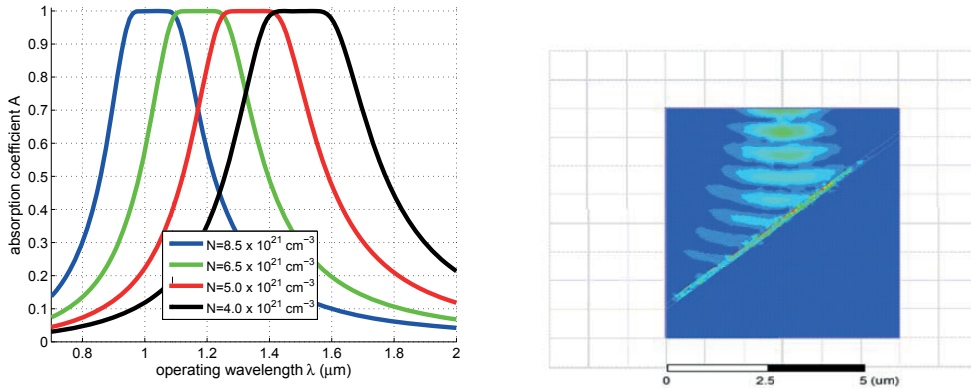


Fig. 60. (Left) Absorption in the layer of AHMM, made of Si nanowires, calculated for different concentrations of charge carriers in doped Si. (Right) HFSS simulation of the Gaussian beam, incident onto the layer of AHMM and totally absorbed in it. Thickness the layer is taken to be $\lambda/10$.

4. Participation in European projects

TUMESA

SMARAD (Aalto University Department of Radio Science and Engineering) was the coordinator of project TUMESA (*MEMS Tuneable Metamaterials for Smart Wireless Applications*), which was funded by the European Community within Seventh Framework Programme, Information and Communication Technologies theme. Prof. Antti Räisänen was the Chairman of the Governing Board and Dr. Dmitry Chicherin was the Project Manager until April 2011, and during the remaining time Dr. Juha Ala-Laurinaho was the Project Manager. In addition to Aalto University, the project partners were KTH - Royal Institute of Technology, University of Rennes I, Autocruise S.A. and MicroComp Nordic AB. The objective of the project was to develop components and sub-systems based on microelectromechanical systems (MEMS) in order to provide a cost-efficient and high-performance technology platform for millimetre-wave automotive and industrial radar and future high-capacity communication systems. More precisely, the main goals of the project were: to develop novel on-chip phase shifting and beam-steering devices based on MEMS tuneable high-impedance surfaces; to integrate developed phase shifting components in novel space-efficient antenna arrays on a single chip; to elaborate novel concepts of implementation the beam-steering devices and antenna arrays in cost-efficient radar sensor and future high-capacity wireless communication systems and evaluate fabricated prototypes at a system level. Most of the projects goals were achieved. Duration of the project was 3 years and 4 months, from 1 June 2008 to 30 September 2011. The project website is <http://radio.tkk.fi/tumesa>.

METACHEM

From September 2009 to September 2013, SMARAD was active in the FP7 Research Project METACHEM, Nano-chemistry and self-assembly routes to metamaterials for visible light. Prof. Simovski was responsible for the theoretical part of WP1 of this project and represented the contribution of Aalto into it. WP1 is considered as a step towards a 3D-isotropic metamaterial, operating in the visible range and demonstrating epsilon-near-zero, mu-near-zero, and negative

refraction properties without strong spatial dispersion. The final project report (November 2013) was approved by the European commission (January 2014).

METIS

Since 2012, SMARAD has been active in the FP7 IP ICT – 317669 METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society). The METIS-project aims at laying foundations for the next generation – so called fifth-generation – cellular wireless communications. One of the important technological elements that constitute the fifth-generation cellular network is millimeter-wave radio communications, for which the SMARAD is contributing by developing a radio propagation channel model.

COST IC1004

SMARAD has been participating in the COST Action IC1004 “Cooperative radio communications for green smart environments”. The action involves 135 institutions from 35 countries including participation from Asia and Americas. The action concerns Smart Wireless Environments, like the human body, energy efficient buildings, vehicular or urban environments, where many devices are connected to wireless networks. The radio channel is central to the design of smart wireless environments, and the SMARAD contributes to the radio channel modeling aspects for diverse types of environments.

COST IC1102

SMARAD contributes to the COST Action IC1102 “Versatile, Integrated, and Signal-aware Technologies for Antennas (VISTA)”. The action involves over 100 institutions from 32 countries including participation from North America, Africa, and Oceania. Main focus of the action is design of resilient, energy-efficient, and adaptive antenna systems that can work in varying wireless environments. SMARAD has been active in the action with respect to adaptive small antenna design and measurement methodology, especially for mobile devices including smart phones.

ARTEMOS

From April 2010, SMARAD has been active in ENIAC research project ARTEMOS (Agile RF Transceivers and Front-Ends for Future Smart Multi-Standard Communications Applications). This project aims at developing architecture and technologies for implementing agile radio frequency (RF) transceiver capacities in future radio communication products. These new architecture and technologies will be able to manage multi-standard (multi-band, multi-data-rate, and multi-waveform) operation with high modularity, low-power consumption, high reliability, high integration, low costs, low PCB area, and low bill of material (BOM). Prof. Jussi Ryyänen, is responsible of developing direct delta-sigma receiver in WP4 of this project.

RODIN

From October 2010 to September 2013, SMARAD has been active in the FP7 Research Project RODIN (Suspended Graphene Nanostructures). The RODIN-project is organized around the concept of suspended single-and few-layer graphene nanostructures and annealed diamond-like carbon films. In particular project focuses on engineering and measuring the mechanical and electromechanical properties. Prof. Jussi Ryyänen, is responsible of evaluating electrical performance of developed mechanical resonators.

5. SMARAD funding in 2011–2013

2011:

	RAD	SA	MNT	Total
Univ. budget (incl. extra funding for CoE)	1.216.000	404.000	511.000	2.131.000
External (competitive) funding	1.940.000	965.000	1.613.000	4.518.000
Total	3.156.000	1.369.000	2.124.000	6.649.000

External funding from the following sources:

- Academy of Finland (CoE)	351.000	136.000	79.000	566.000
- Academy of Finland	519.000	481.000	421.000	1.421.000
- TEKES	418.000	68.000	309.000	795.000
- GETA	83.000	25.000	67.000	175.000
- ESA	40.000	-	-	40.000
- EU	305.000	1.000	98.000	404.000
- Finnish industry and other domestic	224.000	254.000	639.000	1.117.000

2012:

	RAD	SA	MNT	Total
Univ. budget (incl. extra funding for CoE)	1.343.000	733.000	405.000	2.481.000
External (competitive) funding	1.924.000	1.130.000	1.586.000	4.640.000
Total	3.267.000	1.864.000	1.990.000	7.121.000

External funding from the following sources:

- Academy of Finland (CoE)	500.000	157.000	87.000	744.000
- Academy of Finland	435.000	621.000	337.000	1.393.000
- TEKES	411.000	110.000	425.000	946.000
- GETA	124.000	71.000	89.000	284.000
- ESA	57.000	-	20.000	77.000
- EU	216.000	-	59.000	275.000
- Finnish industry and other sources	181.000	171.000	569.000	921.000

2013:

	RAD	SA	MNT	Total
Univ. budget (incl. extra funding for CoE)	1.392.000	672.900	542.700	2.607.600
External (competitive) funding	1.307.000	1.296.300	1.376.100	3.979.400
Total	2.699.000	1.969.200	1.918.800	6.587.000

External funding from the following sources:

- Academy of Finland (CoE)	441.000	141.200	341.235	923.435
- Academy of Finland	239.000	656.800	241.765	1.137.565
- TEKES	209.000	138.200	410.700	757.900
- National doctoral school	0	0	0	0
- ESA	116.000	0	0	116.000
- EU	53.000	0	72.400	125.400
- Finnish industry and other sources	249.000	360.100	310.000	919.100

6. SMARAD personnel during 2011–2013

In the Department of Radio Science and Engineering:

Ala-Laurinaho, Juha, D.Sc.(Tech.)	Senior scientist
Albooyeh, Mohammad, M.Sc.	Doctoral student
Alitalo, Pekka, D.Sc.(Tech.)	Post-doctoral researcher
Amin, Ameer, B.Sc.	Research assistant
Asadchy, Viktor, M.Sc.	Research assistant, Doctoral student
Bin Abdullah Al-Hadi, Azremi, M.Sc.	Doctoral student
Chicherin, Dmitry, Lic.Sc. (Tech.)	Doctoral student
Dahlberg, Krista, Lic.Sc.(Tech.).	Doctoral student
Du, Zhou, M.Sc.	Doctoral student
Enayati, Amin, M.Sc.	Visiting doctoral student
Ermolov, Kirill, Mr.	Research assistant
Flood, Matthew, Mr.	IAESTE trainee
Gallacher, Thomas, PhD	Post-doctoral researcher
Generalov, Andrey, M.Sc.	Doctoral student
Geng, Suiyan, Lic.Sc. (Tech.)	Doctoral student
Haapiainen-Laine, Sari, BBA	Financial assistant
Haimakainen, Johannes, Mr.	Research assistant
Haneda, Katsuyuki, D.Sc.	Post-doctoral researcher, Assistant Professor
Hashemi, Seyedmohammade, M.Sc.	Stipendiate
Heino, Mikko, Mr.	Research assistant
Hernandez Zamora, Bruno, B.Sc.	Erasmus stipendiate
Holopainen, Jari, D.Sc.(Tech.)	University teacher
Huang, Yi, B.Sc.	Research assistant
Icheln, Clemens, D.Sc.(Tech.)	University teacher
Ilvonen, Janne, M.Sc.(Tech.)	Doctoral student
Islam, Md. Mazidul, B.Sc.	Research assistant
Järveläinen, Jan, M.Sc.(Tech.)	Doctoral student
Kari, Henri, Mr.	Research assistant
Karilainen, Antti, M.Sc. (Tech.)	Doctoral student
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Khanal, Subash, M.Sc.(Tech.)	Doctoral student
Khatun, Afroza Mst, M.Sc.	Doctoral student
Kiuru, Tero, M.Sc. (Tech.)	Doctoral student
Kivekäs, Outi, D.Sc. (Tech.)	Post-doctoral researcher
Kolmonen, Veli-Matti, D.Sc. (Tech.)	Post-doctoral researcher
Kurvinen, Joni, Mr.	Research assistant
Kyrö, Mikko, D.Sc.(Tech.)	Post-doctoral researcher
Laitinen Tommi, D.Sc. (Tech.)	Senior scientist
Laurila, Pekka, Mr.	Research assistant
Lindberg, Stina, B.Sc.(Econ.)	HR Secretary
Lioubtchenko, Dmitri, Ph.D.	Academy research fellow
Luukkonen, Olli, D.Sc. (Tech.)	Post-doctoral researcher
Maksimovitch, Yelena, Dr.	Researcher
Mallat, Juha, D.Sc.(Tech.)	Senior University Lecturer
Medina Acosta, Gerardo, B.Sc.	Erasmus stipendiate
Meriläinen Mikko, Mr.	Research assistant
Miah, Md. Suzan, B.Sc.	Research assistant

Mikhnev, Valeri, Dr.	Senior scientist
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Molina Hurtado, Daniel, B.Sc.	Research assistant
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Mylläri, Tuula, Ms.	Secretary
Mäkelä, Sampo, B.Sc.	Research assistant
Nefedov, Igor, Dr.Sc.	Senior scientist
Nefedova, Irina, M.Sc.	Research assistant, Doctoral student
Niemi, Teemu, B.Sc. (Tech.).	Research assistant
Olkkonen, Martta-Kaisa, M.Sc.(Tech.)	Doctoral student
Parveg, Dristy, M.Sc.	Doctoral student
Piiroinen, Kalle, Mr.	Research assistant
Planman, Irma, Ms.	HR Secretary
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Pusa, Jehki, Mr.	Research assistant
Radi, Younes, M.Sc.	Doctoral student
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Salo, Sampo, Mr.	Research assistant
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Simovski, Constantin, Dr.Sc.	Professor
Song, Jinsong, B.Sc.	Research assistant
Takizawa, Kenichi, Dr.	Visiting researcher
Tamminen, Aleksi, D.Sc.(Tech.)	Doctoral student, Post-doctoral researcher
Tretyakov, Sergei, Dr.Sc.	Professor
Törmänen, Olli, Mr.	Research assistant
Vahdati, Ali, M.Sc.(Tech.)	Doctoral student
Vainikainen, Pertti, D.Sc. (Tech.)	Professor
Valagiannopoulos, Costas, Dr.	Post-doc researcher
Valkonen, Risto, D.Sc.(Tech.)	Doctoral student, Post-doctoral researcher
Vehmas, Joni, M.Sc.(Tech.)	Research assistant, Doctoral student
Venkatasubramanian, Sathya, M.Sc.	Research assistant, Doctoral student
Viikari, Ville, D.Sc.(Tech.)	Assistant Professor
Virk, Usman, M.Sc. (Tech.)	Research assistant, Doctoral student
Zvolensky, Tomas, M.Sc.	Doctoral student

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Bica, Marian, B.Sc.	Research assistant
Bysany D., Satish, B.Sc.	Research assistant
Chaudhari, Sachin, M.Sc.	Doctoral student, Post-doctoral researcher

Chis, Adriana, M.Sc.	Visiting researcher, Doctoral student
Cierny, Michal, M.Sc.	Doctoral student
Dhamala, Ujjwal, B.Sc.	Research assistant
Eriksson, Jan, D.Sc. (Tech.)	Senior scientist
Haghparast, Azadeh, M.Sc.	Doctoral student
Hietala, Markku, Mr.	Project secretary
Hynninen, Jussi, M.Sc.(Tech.)	Computer administrator
Jacob Mathecken, Pramod, M.Sc.	Doctoral student
Jänis, Pekka, M.Sc.(Tech.)	Doctoral student
Jäntti, Joonas, Mr.	Research assistant
Kashyap, Neelabh, M.Sc.	Research assistant, Doctoral student
Kim-Ollila, Hyon-Jung, Ph.D.	Visiting Scholar
Koivisto, Tommi, M.Sc.(Tech.)	Doctoral student
Koivunen, Visa, D.Sc.(Tech.)	Academy professor
Lairila, Jenni, Ms.	Research assistant
Le, Vieth-Anh, M.Sc.	Doctoral student
Lemetyinen, Mirja, Ms.	HR secretary
Lundén, Jarmo, D.Sc.(Tech.)	Post-doctoral researcher
Naseri, Hassan, B.Sc.	Research assistant
Oborina, Alexandra, M.Sc.	Doctoral student, Post-doctoral researcher
Ojaniemi, Jaakko, M.Sc.	Doctoral student
Oksanen, Jan, M.Sc.	Doctoral student
Ollila, Esa, D.Sc. (Tech.)	Academy fellow
Pereira Da Costa, Mario, M.Sc.	Doctoral student
Pölönen, Keijo, M.Sc.(Tech.)	Doctoral student
Rajamäki, Robin, Mr.	Research assistant
Rajasekharan, Jayaprakash, M.Sc.	Doctoral student
Rautiainen, Terhi, D.Sc.(Tech.)	Post-doctoral researcher
Razavi, Seyed Alireza, D.Sc.(Tech.)	Post-doctoral researcher
Richter, Andreas, D.Sc.	Professor
Saeed, Umar, B.Sc.	Research assistant
Riihonen, Taneli, M.Sc.(Tech.)	Doctoral student
Saeed, Umar, B.Sc.	Research assistant
Salmi, Jussi, D.Sc.(Tech.)	Post-doctoral researcher
Schober, Karol, M.Sc.	Doctoral student
Sikander, Ulla, Ms.	Project secretary
Simonen, Tarmo, M.Sc.(Tech.)	Computer administrator
Vehkaperä, Mikko, PhD	Post-doctoral researcher
Werner, Stefan, D.Sc.(Tech.)	Academy fellow
Wichman, Risto, D.Sc.(Tech.)	Professor

In the Department of Micro and Nanosciences:

Aaltonen, Lasse, Lic.Sc. (Tech.)	Doctoral student
Chouhan Shailesh M.Sc. (Eng)	Doctoral student
Gronicz Jakub, M.Sc.(Eng.)	Doctoral student
Halonen, Kari, D.Sc.(Tech.)	Professor, Head of the department
Jamalizavareh Shiva, B.Sc.	Research assistant
Kalanti, Antti, M.Sc. (Tech.)	Doctoral student
Kaltioikallio, Mikko, M.Sc.(Tech.)	Doctoral student
Koskinen Lauri, D.Sc.(Tech.)	Post-doctoral researcher

Kärkkäinen, Mikko, Lic.Sc.(Tech.)	Doctoral student
Laulainen, Erkkka, Mr.	Research assistant
Lemberg, Jerry, B.Sc.(Tech)	Research assistant
Nieminen, Tero, M.Sc.(Tech.)	Doctoral student
Olabode Olaitan, B.Sc.	Research assistant
Parveg Dristy M.Sc. (Eng)	Doctoral student
Pulkkinen, Mika, B.Sc.	Research assistant
Rapinoja, Tapio, M.Sc.(Tech.)	Doctoral student
Ryynänen, Jussi, D.Sc.(Tech.)	Professor
Saari, Ville, Lic.Sc. (Tech.)	Doctoral student
Salomaa, Jarmo, M.Sc.(Tech.)	Doctoral student
Stadius, Kari, D.Sc.(Tech.)	Senior researcher
Söderman, Lea, Ms.	Secretary
Tikka, Tero, M.Sc.(Tech.)	Doctoral student
Turunen, Vesa, M.Sc.(Tech.)	Doctoral student
Vahdati, Ali, M.Sc.(Tech.)	Doctoral student
Varonen, Mikko, D.Sc.(Tech.)	Post-doctoral researcher
Viitala, Olli, M.Sc.(Tech.)	Doctoral student
Xu, Liangge, M.Sc. (Tech.)	Doctoral student
Yucetas, Mikail, M.Sc.(Tech.)	Doctoral student

7. Visitors to SMARAD in 2011–2013

Visiting Professors:

2011:

- Prof. Takahiro Aoyagi, Tokyo Institute of Technology, Japan, 1 week
- Prof. Olga Glukhova, Saratov State University, Russia, 2 weeks
- Prof. Gregorio Fernando, Universidad Nacional del Sur, Argentina, 2 weeks
- Prof. Marcello de Campos, Universidad Federal do Rio de Janeiro, Brazil, 1 week
- Prof. Sergiy Vorobyov, University of Alberta, Kanada, 1 week
- Prof. Sumit Roy, University of Washington, USA, 1 week
- Prof. Vincent H. Poor, Princeton University, USA, 1 week

2012:

- Prof. Silvio Hrabar, University of Zagreb, Croatia, 1 week
- Prof. Christophe Menzel, University of Jena, Saksa, 2 weeks

2013:

- Prof. Santos Venkatesh, University of Pennsylvania, 1 month
- Prof. Dave Tyler, Rutgers, The State University of New Jersey, 1 month

Visiting Researchers:

2011:

- B.Sc. Bruno Hernandez Zamora, Universidad Autonoma de Madrid, Spain, 4 months
- B.Eng. Soichi Saito, Tokyo Denki University, Japan, 2 months
- M.Eng. Daisuke Sugizaki, Tokyo Denki University, Japan, 1 month

- B.Eng. Kenshiro Tsutsuki, Tokyo Denki University, Japan, 1 month
- M.Sc. Seyedmohammad Hashemi, Iran University of Science and Technology, Iran, 3 months
- Dr Constantinos Valagiannopoulos, University of Athens, Greece, 12 months
- M.Sc. Amin Enayati, IMEC, Katholieke Universiteit Leuven, Belgium, 7 months
- Dr Yelena Maksimovich, Institute of Applied Physics, Minsk, Belorussia, 2 months
- Dr Kenichi Takizawa, National Institute of Information and Communications Technology, Japan, 5 months
- M.Sc. Inigo Liberal, Public University of Navarra, 4 months

2012:

- M.Sc. Jaakko Marttila, Tampere University of Technology, Finland 1 month
- B.Sc. Irina Nefedova, Saratov University, Russia, 8 months
- M.Sc. Emilio Antonio Rodriguez, University of Vigo, Spain, 3 months
- Dr Reza Arablouei, University of South Australia, 2 months
- B.Sc. Ugus Umut, Bogazici University, Turkey, 5 months
- B.Sc. Jugé Thibault, Grenoble Institute of Technology, France, 6 months
- B.Sc. Victar Asadchy, Gomel University, Belorussia, 6 months
- Dr Yelena Maksimovich, Institute of Applied Physics, Minsk, Belorussia, 1 month
- Dr Kenichi Takizawa, National Institute of Information and Communications Technology, Japan, 6 months
- M.Sc. Junichi Naganawa, Tokyo Institute of Technology, 1 month
- B.Sc. Mikhail Davidovich, Saratov State University, 1 month
- M.Sc. Zhu Meifang, Lund University, 1 week
- Dr. Marcello de Campos, Universidad Federal do Rio de Janeiro, Brazil, 1 week
- Dr. Jose Apolinario, Universidad Federal do Rio de Janeiro, Brazil, 1 week

2013:

- B.Sc. Ana Cardenas, Universidad Politecnica de Madrid, Spain, 2.5 months
- M.Sc. Alejandro Rivera-Lavado, Universidad Carlos III de Madrid, Spain, 4 months
- Dr Thomas Gallacher, University of St. Andrews, UK, 11 months
- Dr Zhiping Li, Beihang University, China, 13 months

8. Visits from SMARAD to foreign institutes in 2011–2013

2011:

- Dr Pekka Alitalo, German Aerospace Center, Wessling, Germany, 2 months
- Dr Katsuyuki Haneda, University of Southern California, Los Angeles, USA, 2 weeks
- Dr Katsuyuki Haneda, Tokyo Denki University, Japan, 2 weeks
- Prof. Constantin Simovski, ITMO, St. Petersburg, 2 weeks
- M.Sc. Tomas Zvolensky, Queen's University, Belfast, UK, 1 month
- Dr Marko Kosunen, University of California, Berkeley, USA 3 months
- Dr Mikko Varonen, JPL California Institute of Technology, USA, 11 months
- Academy prof. Visa Koivunen, Princeton University, USA, 2 months
- Dr Jarmo Lunden, Princeton University, USA, 8 months
- M.Sc. (Tech.) Jan Oksanen, Princeton University, USA, 2 months
- Dr Esa Ollila, Princeton University, USA, 8 months
- Dr Jussi Salmi, University of Southern California, USA, 1 month

2012:

- Dr Marko Kosunen, University of California, Berkeley, USA 3 months
- M.Sc. Mikko Kaltiokallio, University of Nice, France, 1 week
- Prof. Antti Räisänen, Universidad Politécnica de Catalunya Barcelona, Spain, 1 week
- Prof. Antti Räisänen, Universidad Politécnica de Madrid, Spain, 1 week
- Prof. Sergei Tretiakov, Friedrich-Schiller-Universität Jena, Germany, 1 month
- Dr Katsuyuki Haneda, Tokyo Denki University, Japan, 2 weeks
- D.Sc.(Tech.) Jari Holopainen, Rheinisch-Westfälische Technische Hochschule, Aachen, Germany, 1 month
- M.Sc. Vasilii Semkin, Université Nice Sophia Antipolis, 1 month
- M.Sc.(Tech.) Jan Järveläinen, Tokyo Institute of Technology, Japan, 2 weeks
- M.Sc.(Tech.) Jan Järveläinen, National Institute of Information and Communications Technology, Japan, 2 weeks
- Prof. Visa Koivunen, Princeton University, USA, 2 months
- M.Sc.(Tech.) Jan Oksanen, Princeton University, USA, 11 months
- Prof. Risto Wichman, University of California, Davis, San Francisco, USA, 1 week
- M.Sc.(Tech.) Michal Cierny, University of California, Davis, San Francisco, USA, 1 week
- Prof. Visa Koivunen, Princeton University, USA, 2 weeks
- Prof. Visa Koivunen, University of Pennsylvania, USA, 1 week
- D.Sc (Tech.) Esa Ollila, Princeton University, USA, 1 week
- D.Sc.(Tech.) Esa Ollila, Supélec, France, 1 week

2013:

- Prof. Antti Räisänen, Universidad Carlos III de Madrid, Spain, 3 months
- Dr Marko Kosunen, Berkeley Wireless Research Center, USA, 3 months
- Dr Lauri Koskinen, Berkeley Wireless Research Center, USA, 1 month
- Prof. Sergei Tretiakov, Technical University of Denmark, Denmark, 3 months
- Dr Jari Holopainen, Christian-Albrechts-Universität zu Kiel, Germany, 3 months
- M.Sc. Vasilii Semkin, TU Braunschweig, Germany, 1 month
- Academy prof. Visa Koivunen, Princeton University, USA, 6 months
- M.Sc(Tech) Sathya Venkatasubramanian, Kyoto University, Japan, 1 month
- Dr Mikko Varonen, Jet Propulsion Laboratory and Californian Institute of Technology, USA, 5 months

9. Post-graduate degrees in 2011–2013**Doctor of Science (Technology) degrees:****2011:**

- | | |
|-----------------|---|
| Jari Holopainen | Compact UHF-band antennas for mobile terminals: focus on modelling, implementation, and user interaction
Thesis defence: 29 April 2011
Opponents: Prof. Dirk Manteuffel, Christian-Albrechts-Universität, Kiel, Germany, and Dr Kevin Boyle, EPCOS, UK Ltd, U.K.
Preliminary examiners: Prof. Ph.D. Koichi Ito, Chiba University, Japan, and |
|-----------------|---|

- Dr Ping Hui, Nokia Corporation, Canada
 Supervisor: Prof. Pertti Vainikainen
 Ville Saari Continuous-time low-pass filters for integrated wideband radio receivers
 Thesis defence: 29 April 2011
 Opponent: Prof. Mohammed Ismail, The Ohio State University, USA
 Preliminary examiners: Assoc. Prof. Andrea Baschirotto, University of Milano-Bicocca, Italy, and Dr Kimmo Koli, ST-Ericsson, Finland
 Supervisor: Prof. Jussi Ryyänen
- Juho Poutanen Geometry-based radio channel modelling: Propagation analysis and concept development
 Thesis defence: 13 May 2011
 Opponents: Dr Jonas Medbo, Ericsson Research, Sweden, and Prof. Martine Lienard, University of Lille, France
 Preliminary examiners: Prof. Mir Ghorashi, Tokyo Institute of Technology, Japan, and Dr Tricia Willink, Communication Research Centre, Canada
 Supervisor: Prof. Pertti Vainikainen
- Suiyan Geng Millimeter wave and UWB propagation for high throughput indoor communications
 Thesis defence: 2 November 2011
 Opponent: Fredrik Tufvesson, Lund University, Sweden
 Preliminary examiners: Dr Chia-Chin Chong, NTT Dokomo Labs, Palo Alto, USA, and Prof. Hirokazu Sawada, Tohoku University, Sendai, Japan
 Supervisor: Prof. Pertti Vainikainen
- Tero Kiuru Characterization, modelling, and design for applications of waveguide impedance tuners and Schottky diodes at millimeter wave lengths
 Thesis defence: 12 December 2011
 Opponent: Prof. Jan Stake, Chalmers University of Technology, Gothenburg, Sweden
 Preliminary examiners: Dr Thomas Crowe, Virginia Diodes Inc., Charlottesville, USA, and Dr Imran Mehdi, Jet Propulsion Laboratory, Pasadena, USA
 Supervisor: Prof. Antti Räsänen
- Dmitri Chicherin Studies on microelectromechanically tuneable high-impedance surface for millimetre wave beam steering
 Thesis defence: 2 December 2011
 Opponent: Prof. Didier Lippens, Université des Sciences et Technologie de Lille, France
 Preliminary examiners: Prof. Wolfgang Menzel, University of Ulm, Germany, and Dr Tauno Vähä-Heikkilä, VTT Technical Research Centre of Finland
 Supervisor: Prof. Antti Räsänen
- 2012:**
- Antti Karilainen Magnetic materials and responses in antenna applications
 Thesis defence: 10 August 2012
 Thesis supervisor: Prof. Sergei Tretiakov
 Opponent: Prof. Richard Ziolkowski, University of Arizona, Tucson, USA
 Preliminary examiners: Prof. Andrea Alù, University of Texas, Houston, USA and Prof. Martin Ferran, Universitat Autònoma de Barcelona, Spain

- Sachin Chaudhari Spectrum sensing for cognitive radios: algorithms, performance, and limitations
 Thesis defence: 23 October 2012
 Thesis supervisor: Academy Prof. Visa Koivunen
 Opponents: Dr. Ananthram Swami, Army Research Laboratory, MD, USA and Prof. Marco Lops, University of Cassiano, Italy
 Preliminary examiners: Dr. Ananthram Swami, Army Research Laboratory, MD, USA and Prof. Sergio Barbarossa, University of Rome 'La Sapienza', Italy
- Alexandra Oborina Analyzing performance of mobile MIMO-OFDM wireless systems: tools and results
 Thesis defence: 21 September 2012
 Thesis supervisor: Academy Prof. Visa Koivunen
 Opponents: Prof. Tapani Ristaniemi, University of Jyväskylä, Finland, and Assoc. Prof. Kimmo Kansanen, NTNU, Norway
 Preliminary examiners: Prof. Tapani Ristaniemi, University of Jyväskylä, Finland, and Dr Samuli Visuri, Nokia, Finland
- Eduardo Zacarias B. Limited feedback MIMO techniques for temporally correlated channels and linear receivers
 Thesis defence: 3 February 2012
 Thesis supervisor: Prof. Risto Wichman
 Opponents: Assistant Prof. Joakim Jaldén, KTH Royal Institute of Technology, Sweden, and Prof. Marcos Katz, CWC Oulun yliopisto, Finland
 Preliminary examiners: Assistant Prof. Joakim Jaldén, KTH Royal Institute of Technology, Sweden, and Dr.-Ing. Patrick March, Technische Universität Dresden, Germany
- 2013:**
- Mikko Kyrö Radio wave propagation and antennas for millimeter-wave communication
 Thesis defence: 4 January 2013
 Thesis supervisor: Prof. Antti Räsänen
 Opponent: Prof. Thomas Kuerner, Technical University of Braunschweig
 Preliminary examiners: Prof. Theodore (Ted) S. Rappaport, New York University (NYU-Poly), USA, and Dr. Alexis Paolo Garcia Ariza, MEDAV GmbH, Uttenreuth, Germany
- Risto Valkonen Impedance matching and tuning of non-resonant mobile terminal antennas
 Thesis defence: 15 March 2013
 Thesis supervisor: Prof. Antti Räsänen
 Opponent: Prof. Anja Skrivervik, Ecole Polytechnique Federale de Lausanne, Switzerland, Switzerland
 Preliminary examiners: Dr. Marta Martínez Vázquez, IMST GmbH, Kamp-Lintfort, Germany, and Assoc. Prof. Buon Kiong Lau, Lund University (LTH), Sweden
- Mikail Yüçetas Capacitive accelerometer interfaces utilising high-Q micromechanical sensor elements

Thesis defence: 27 June 2013
 Thesis supervisor: Prof. Kari Halonen
 Opponent: Prof. Michael Kraft, Fraunhofer Institute for Microelectronic Circuits and Systems, Germany
 Preliminary examiners: Prof. L. Richard Carley, Carnegie Mellon University, Pittsburgh, PA, USA, and Dr. Marc Pastre, Ecole Polytechnique Federale de Lausanne, Switzerland

Pekka Jänis: Interference management techniques for cellular wireless communication Systems
 Thesis defence: 5 July 2013
 Thesis Advisor: Academy prof. Visa Koivunen
 Opponents: Prof. Gerald Matz, TU Wien, Austria and prof. Constantinos Papadias, Athens Information Technology, Greece.
 Preliminary examiners: Prof. Petar Popovski, Aalborg University, Denmark, and Dr. Timo Roman, Renesas Mobile Europe, Finland

Aki Karttunen Millimetre and submillimetre wave antenna design using ray tracing
 Thesis defence: 10 September 2013
 Thesis supervisor: Prof. Antti Räisänen
 Opponent: Prof. Andrea Neto, Technical University of Delft, The Netherlands
 Preliminary examiners: Assistant Prof. Nuria Llombart, Technical University of Delft, The Netherlands, and Dr Artem Boriskin, University of Rennes 1, France

Aleksi Tamminen Developments in imaging at millimeter and submillimeter wavelengths
 Thesis defence: 24 September 2013
 Thesis supervisor: Prof. Antti Räisänen
 Opponent: Dr Duncan A. Robertson, University of St Andrews, UK
 Preliminary examiners: Assoc. Professor Sergey Pivnenko, Technical University of Denmark, Lyngby, Denmark, and Assistant Prof. Yuri Alvarez, University of Oviedo, Spain

Mário Jorge Pereira da Costa: Wavefield modeling and signal processing for sensor arrays of arbitrary geometry
 Thesis defence: 3 November 2013
 Thesis advisor: Academy prof. Visa Koivunen
 Opponents: Prof. Lee Swindlehurst, UC Irvine, USA and Prof. Marius Pesavento, TU Darmstadt, Germany
 Preliminary examiners: Prof. Marius Pesavento, TU Darmstadt, Germany, and Assoc. Prof. Mats Bengtsson, KTH, Stockholm, Sweden

Azremi Abdullah Al-Hadi: Multi-element antennas for mobile communication systems: Design, evaluation and user interactions
 Thesis defence: 8 November 2013
 Thesis supervisor: Prof. Ville Viikari
 Opponent: Prof. Gert F. Pedersen, Aalborg University, Denmark

Preliminary examiners: Prof. Cyril Luxey, University of Nice Sophia-Antipolis, France, and Dr. Tim Brown, University of Surrey, UK

Licentiate of Science (Technology) degrees:

2011:

- | | |
|-----------------|---|
| Krista Dahlberg | Mixer test jig for millimeter wave Schottky diodes
Graduation date: 7 February 2011
Supervisor: Prof. Antti Räisänen
External examiner: Dr. Jyrki Louhi, Nokia Siemens Networks |
| Aleksi Tamminen | On developments in submillimeter-wavelength imaging
Graduation date: 6 October 2011
Supervisor: Prof. Antti Räisänen
External examiner: Dr Ville Viikari, VTT Technical Research Centre of Finland |

2012:

- | | |
|---------------|---|
| Afroza Khatun | Advanced scanning techniques for field synthesis and near-field antenna measurements
Graduation date: June 18, 2012
Supervisor: Prof. Pertti Vainikainen
External examiner: Professor Manuel Sierra Castañer, Universidad Politécnica de Madrid (UPM), Spain |
| Janne Ilvonen | Environment insensitive mobile terminal antennas
Graduation date: June 18, 2012
Supervisor: Prof. Pertti Vainikainen
External examiner: D.Sc.(Tech.) Pekka Ikonen, TDK-EPC Corporation |
| Tero Nieminen | Integration of Low-Voltage CMOS Analogue-to-Digital Converters
Graduation date: May 28, 2012
Supervisor: Prof. Kari Halonen
External examiner: Prof. Markku Åberg, VTT |

10. Awards, honors, and prizes in 2011–2013

2011:

- Best Student Paper Award for paper: S. Kiminki, V. Saari, A. Pärssinen, V. Hirvisalo, A. Immonen, J. Ryyänänen, T. Zetterman, “Design and Performance Trade-offs in Parallelized RF SDR Architecture,” in Proc. Int. Conf. Cognitive Radio Oriented Wireless Networks and Communications, Osaka, Japan, Jun. 2011
- Second Student Paper Award, Metamaterials Congress 2011: Awarded to Antti Karilainen for the paper “Zero-backscattering self-dual object from two chiral particles”, Metamaterials 2011, Barcelona, Spain, 10-15 October 2011

2012:

- The International Academy, Research, and Industry Association (IARIA) has granted a Best Paper Award to a paper written within SMARAD in cooperation between the research groups of Professor Jussi Ryyänen and Professor Visa Koivunen, titled “Dual-Lag Correlation-Based Feature Detection of OFDM Signals with Cyclic Phase Compensation”, authored by Vesa Turunen, Marko Kosunen, Visa Koivunen and Jussi Ryyänen. The paper was presented at The Second International Conference on Advances in Cognitive Radio CORORA 2012 in France in spring 2012.
- Janne Ilvonen received the SEMCAD X Student Research Award 2011, 3rd Prize, for his article “Mobile Terminal Antenna Performance with the User's Hand: Effect of Antenna Dimensioning and Location”

2013:

- University Carlos III of Madrid awarded “Catedra de Excellencia” to Antti Räisänen for 6 months starting September 27th, 2013
- Katsuyuki Haneda, Best paper award in antennas and propagation track, VTC2013-Spring. Paper title: “Spatial degrees-of-freedom of 60 GHz multiple-antenna channels”
- Katsuyuki Haneda, Best propagation paper award, EuCAP2013. Paper title: “Dynamics of spatial degrees-of-freedom in MIMO mobile channels”
- Tero Kiuru received the Young Engineer's award at the XXXIII URSI National Convention on Radio Science on April 25, 2013 with his presentation “Thermal characterisation as a part of reliability testing of THz Schottky diodes” by T. Kiuru, S. Khanal, J. Mallat, A.V. Räisänen, and T. Närhi
- Finntesting Society has selected the M.Sc. thesis “Pulsed and transient characterization of THz Schottky diodes” by Subash Khanal for a thesis of the year 2012

11. Publications 2011

11.1 Articles in scientific journals with peer-review

1. M. Albooyeh, D. Morits, and C. Simovski, “Electromagnetic characterization of substrated metasurfaces,” *Metamaterials*, vol. 5, no. 3, pp. 93–111, 2011.
2. M. Albooyeh and C. Simovski, “Substrate-induced bianisotropy in plasmonic grids,” *Journal of Optics A*, vol. 13, no. 2, p. 105102, 2011.
3. P. Alitalo, A. O. Karilainen, T. Niemi, C. R. Simovski, and S.A. Tretyakov, “Design and realisation of an electrically small Huygens source for circular polarization,” *IET Microwaves, Antennas & Propagation*, vol. 5, no. 7, pp. 783–789, 2011.
4. P. Alitalo and S. Tretyakov, “Broadband electromagnetic cloaking realized with transmission-line and waveguiding structures (invited paper),” *Proceedings of the IEEE*, vol. 99, no. 10, pp. 1646–1659, 2011.
5. D. Baranov, A. Vinogradov, C. Simovski, I. Nefedov, and S. Tretyakov, “On the electrodynamics of an absorptive uniaxial non-positively definite (indefinite) medium,” *Journal of Experimental and Theoretical Physics*, vol. 141, no. 9, pp. 1–9, 2011.
6. L. Bergamin, P. Alitalo, and S. Tretyakov, “Nonlinear transformation optics and engineering of the Kerr effect,” *Physical Review B*, p. 205103, 2011.
7. A. Bin Abdullah Al-Hadi, J. Ilvonen, R. Valkonen, J. Holopainen, O. Kivekäs, C. Icheln, and P. Vainikainen, “Coupling element –based dual-antenna structures with hand effects,” *Int. J. of Wireless Information Networks*, vol. 18, no. 3, pp. 146–157, 2011.

8. A. Bin Abdullah Al-Hadi, V. Papamichael, and P. Vainikainen, "Multi-antenna mobile terminal diversity performance in proximity to human hands under different propagation environment conditions," *Electronics Letters*, vol. 47, pp. 1214–1215, 2011.
9. D. Chicherin, M. Sterner, D. Lioubtchenko, J. Oberhammer, and A.V. Räisänen, "Analog-type millimeter-wave phase shifters based on MEMS tunable high-impedance surface and dielectric rod waveguide," *Int. J. of Microwave and Wireless Technologies*, vol. 3, no. 5, pp. 533–538, 2011.
10. F. Costa, O. Luukkonen, C. Simovski, A. Monorchio, S. Tretyakov, and P. de Maagt, "TE surface wave resonances on high-impedance surface based antennas: Analysis and modeling," *IEEE Trans. on Antennas and Propagation*, vol. 59, no. 10, pp. 3588–3596, 2011.
11. J. Holopainen, O. Kivekäs, J. Ilvonen, R. Valkonen, C. Icheln, and P. Vainikainen, "Effect of the user's hands on the operation of lower UHF-band mobile terminal antennas: Focus on digital television receiver," *IEEE Trans. on Electromagnetic Compatibility*, vol. 53, no. 3, pp. 831–841, 2011.
12. J. Ilvonen, O. Kivekäs, J. Holopainen, R. Valkonen, K. Rasilainen, and P. Vainikainen, "Mobile terminal antenna performance with the user's hand: Effect of antenna dimensioning and location," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 772–775, 2011.
13. J. Ilvonen, R. Valkonen, O. Kivekäs, P. Li, and P. Vainikainen, "Antenna shielding method reducing the interaction between user and mobile terminal antenna," *Electronics Letters*, vol. 47, no. 16, pp. 896–897, 2011.
14. A.O. Karilainen, P.M.T. Ikonen, C.R. Simovski, S.A. Tretyakov, A.N. Lagarkov, S.A. Maklakov, K.N. Rozanov, and S.N. Starostenko, "Experimental studies on antenna miniaturisation using magneto-dielectric and dielectric materials," *IET Microwaves, Antennas & Propagation*, vol. 5, no. 4, pp. 495–502, 2011.
15. A.O. Karilainen, P.M.T. Ikonen, C.R. Simovski, and S.A. Tretyakov, "Choosing dielectric or magnetic material to optimize the bandwidth of miniaturized resonant antennas," *IEEE Trans. on Antennas and Propagation*, vol. 59, no. 11, pp. 3991–3998, 2011.
16. A.O. Karilainen, J. Vehmas, O. Luukkonen, and S.A. Tretyakov, "High-impedance-surface-based antenna with two orthogonal radiating modes," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 247–250, 2011.
17. T. Kiuru, J. Mallat, A.V. Räisänen, and T. Närhi, "Schottky diode series resistance and thermal resistance extraction from S-parameter and temperature controlled I–V measurements," *IEEE Trans. on Microwave Theory and Techniques*, vol. 59, no. 8, pp. 2108–2116, 2011.
18. O. Kozina, I. Nefedov, L. Melnikov, and A. Karilainen, "Plasmonic coaxial waveguides with complex shapes of cross-sections," *Materials*, vol. 4, pp. 104–116, 2011.
19. O.N. Kozina, L.A. Melnikov, and I.S. Nefedov, "Strong field localization in subwavelength metal-dielectric optical waveguides," *Optics and Spectroscopy*, vol. 111, no. 2, pp. 241–247, 2011.
20. M. Kyrö, K. Haneda, J. Simola, K. Nakai, K.-i. Takizawa, H. Hagiwara, and P. Vainikainen, "Measurement based path loss and delay spread modeling in hospital environments at 60 GHz," *IEEE Trans. on Wireless Communications*, vol. 10, no. 8, pp. 2423–2427, 2011.
21. I. Liberal, I. S. Nefedov, I. Ederra, R. Gonzalo, and S.A. Tretyakov, "Electromagnetic response and homogenization of grids of ferromagnetic microwires," *J. of Applied Physics*, vol. 110, no. 6, p. 064909, 2011.
22. I. Liberal, I. Nefedov, I. Ederra, R. Gonzalo, and S. Tretyakov, "On the effective permittivity of arrays of ferromagnetic wires," *J. of Applied Physics*, vol. 110, p. 104902, 2011.
23. O. Luukkonen, S.I. Maslovski, and S.A. Tretyakov, "A stepwise Nicolson-Ross-Weir -based material parameter extraction method," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1295–1298, 2011.

24. A. Miroschnichenko, I. Maksymov, A. Davoyan, C. Simovski, P. Belov, and Y. Kivshar, "An arrayed nanoantenna for broadband light emission and detection," *Physica Status Solidi - Rapid Research. Letters*, vol. 3, no. 3, pp. 347–349, 2011.
25. D. Morits and C. Simovski, "Isotropic negative effective permeability in the visible range produced by clusters of plasmonic triangular nanoprisms," *Metamaterials*, vol. 5, no. 4, pp. 162–168, 2011.
26. S. Myllymäki, R. Valkonen, J. Holopainen, A. Huttunen, V.K. Palukuru, M. Berg, H. Jantunen, and E. Salonen, "Capacitive-sensor-induced losses in 900-, 1800-, and 1900-MHz antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 330–333, 2011.
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77. M. Kallio, R. Valkonen, K. Stadius, and J. Ryyänen, "Towards a general-purpose radio interface: CCE antennas and blocker-tolerant RFICs," *XXXIII Finnish URSI Convention on Radio Science and SMARAD Seminar*, April 24-25, 2013, Finland, pp. 31-34.
78. T. Rapinaja, L. Xu, K. Stadius, and J. Ryyänen, "Digital-intensive wideband RF frequency synthesis," *XXXIII Finnish URSI Convention on Radio Science and SMARAD Seminar*, April 24-25, 2013, Finland, pp. 83-86.
79. J. Anteroine, K. Wonjae, K. Stadius, and J. Ryyänen, "Towards high-frequency graphene electronics," *XXXIII Finnish URSI Convention on Radio Science and SMARAD Seminar*, April 24-25, 2013, Finland, pp. 169-172.
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81. E. Roverato, M. Kosunen, J. Lemberg, K. Stadius, J. Ryyänen, P. Eloranta, R. Kaunisto, and A. Pärssinen, "A programmable DSP front-end for all-digital 4G transmitters," *IEEE 11th International New Circuits and Systems Conference (NEWCAS)*, June 16-19, 2013, France, pp. 1-4.

82. D. Parveg, M. Varonen, M. Kärkkäinen, and K. Halonen, "Design of mixers for a 130-GHz transceiver in 28-nm CMOS," *9th Conference on Ph. D. Research in Microelectronics and Electronics*, June 24-27, 2013, Austria, pp. 77-80.
83. D. Parveg, M. Varonen, M. Kärkkäinen, A. Vahdati, and K. Halonen, "Design of 28-nm CMOS mixers for a 130-GHz transceiver," *XXXIII Finnish URSI Convention on Radio Science and SMARAD Seminar*, April 24-25, 2013, Finland, pp. 177-180.
84. A. Vahdati, M. Varonen, M. Kärkkäinen, and K. Halonen, "Design of a W-band 2-bit differential CMOS phase shifter," *9th Conference on PhD. Research in Microelectronics and Electronics*, June 24-27, 2013, Austria, pp. 97-100.
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86. M. Kärkkäinen, M. Kantanen, S. Caujolle-Bert, M. Varonen, R. Weber, A. Leuther, M. Seelmann-Eggebert, T. Närhi, and K. Halonen, "MHEMT G-band low-noise amplifiers," *IEEE MTT-S International Microwave Symposium Digest*, Seattle, WA, 2013
87. T. Rapinaja, K. Stadius, and J. Ryyänen, "A 0.3-to-8.5GHz frequency synthesizer based on digital period synthesis," *39th European Solid-State Circuit Conference*, September 16-20, 2013, Romania, pp. 237-240.
88. J. Gronicz, N. Chekurov, L. Aaltonen, and K. Halonen, "A MEMS-based oscillator with synchronous amplitude control," *9th Conference on PhD. Research in Microelectronics and Electronics*, June 24-27, 2013, Austria, pp. 117-120.
89. J. Gronicz, L. Aaltonen, N. Chekurov, M. Kosunen, and K. Halonen, "A 1.8 MHz MEMS-based oscillator with synchronous amplitude limiter," *21st European Conference on Circuit Theory and Design*, 2013, Dresden, Germany, 4p.
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91. E. Roverato, M. Kosunen, J. Lemberg, T. Nieminen, K. Stadius, J. Ryyänen, P. Eloranta, R. Kaunisto, and A. Pärssinen, "A configurable sampling rate converter for all-digital 4G transmitters," *European Conference on Circuit Theory and Design (ECCTD)*, September 8-12, 2013, Germany, 4p.
92. S. Chouhan and K. Halonen, "A modified cross coupled rectifier based charge pump for energy harvesting using RF to DC conversion," *European Conference on Circuit Theory and Design (ECCTD)*, September 8-12, 2013, Germany, 4p.
93. S. Chouhan and K. Halonen, "A Simple All MOS Voltage Reference for RFID Applications," *31st Norchip Conference*, November 11-12, 2013, Lithuania.
94. S. Chouhan and K. Halonen, "The DT MOS based UHF RF to DC conversion," *IEEE International Conference on Electronics, Circuits, and Systems*, December 8-11, 2013, Abu Dhabi, United Arab Emirates.
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96. S. Chouhan and K. Halonen, "A micropower $4.8 \text{ ppm}/^\circ\text{C}$ CMOS voltage reference circuit for linear drop out regulator used in RFID," *IEEE International Conference on Electronics, Circuits, and Systems*, December 8-11, 2013, United Arab Emirates.
97. K. Östman, M. Englund, O. Viitala, K. Stadius, J. Ryyänen, and K. Koli, "Design tradeoffs in N-path GmC integrators for direct delta-sigma receivers," *European Conference on Circuit Theory and Design (ECCTD)*, September 8-12, 2013, Germany.
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- Personal, Indoor and Mobile Radio Communications (PIMRC)*, London, United Kingdom, September 2013.
99. M. Vehkaperä, M. Girnyk, T. Riihonen, R. Wichman, and L. Rasmussen, "On Achievable Rate Regions at Large-System Limit in Full-Duplex Wireless Local Access," *1st International Black Sea Conference on Communications and Networking (BlackSeaCom)*, Batumi, Georgia, July 2013.
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 101. E. Antonio-Rodriguez, R. Lopez-Valcarce, T. Riihonen, S. Werner, and R. Wichman, "Autocorrelation-based Adaptation Rule for Feedback Equalization in Wideband Full-Duplex Amplify-and-Forward MIMO Relays," *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Vancouver, Canada, May 2013.
 102. T. Riihonen, M. Vehkaperä, and R. Wichman, "Large-System Analysis of Rate Regions in Bidirectional Full-Duplex MIMO Link: Suppression versus Cancellation," *47th Annual Conference on Information Sciences and Systems (CISS)*, Baltimore, Maryland, March 2013.
 103. T. Riihonen, P. Mathecken, and R. Wichman, "Effect of Oscillator Phase Noise and Processing Delay in Full-Duplex OFDM Repeaters," *46th Annual Asilomar Conference on Signals, Systems, and Computers (ACSSC)*, Pacific Grove, California, November 2012.
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 105. T. Riihonen and R. Wichman, "Analog and Digital Self-interference Cancellation in Full-Duplex MIMO-OFDM Transceivers with Limited Resolution in A/D Conversion," *46th Annual Asilomar Conference on Signals, Systems, and Computers (ACSSC)*, Pacific Grove, California, November 2012.
 106. K. Schober, M. Enescu, R. Wichman, "MIMO adaptive codebook for cross-polarized antenna arrays," *IEEE Personal Indoor and Mobile Radio Communications (PIMRC)*; London, United Kingdom; 8-11 September 2013, pp. 1125-1129.
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 109. A. Ahmedin, A. Elsherif, X. Liu, J. Hämäläinen, R. Wichman, "Macrocell Resource Adaptation for Improved Femtocell Deployment and Interference Management," *World Congress on Multimedia and Computer Science (WCMCS)*, 2013, Hammamet, Tunisia, October 4-6, 2013.
 110. J. Ojaniemi, J. Kalliovaara, J. Poikonen, R. Wichman, "A practical method for combining multivariate data in radio environment mapping," *IEEE Personal, Indoor and Mobile Radio Communications Conference (PIMRC)*; London, United Kingdom; September 8-11, 2013. pp. 734-738.
 111. J. Ojaniemi, J. Kalliovaara, A. Alam, J. Poikonen, R. Wichman, "Optimal field measurement design for radio environment mapping," *47th Annual Conference on Information Sciences and Systems (CISS)*, Baltimore, USA, March 20-22, 2013. pp. 1-5.

112. R. Arablouei, K. Dogancay, S. Werner, "Estimating frequency of three-phase power systems via widely-linear modeling and total least-squares," *IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing*, Saint Martin, USA, December 2013.
113. R. Arablouei, K. Dogancay, S. Werner, "Partial-diffusion recursive least-squares estimation over adaptive networks," *IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing*, Saint Martin, USA, December 2013.
114. F. Ribeiro, M. de Campos, S. Werner, "Distributed cooperative spectrum sensing with double-topology," *IEEE International Conference on Acoustics, Speech and Signal Processing*, Vancouver, Canada, May 2013.
115. R. Arablouei, K. Dogancay, S. Werner, "Diffusion-based distributed adaptive estimation utilizing gradient-descent total least-squares," *IEEE International Conference on Acoustics, Speech and Signal Processing*, Vancouver, Canada, May 2013.
116. R. Arablouei, K. Dogancay, S. Werner, "Adaptive frequency estimation of three-phase power systems with noisy measurements," *IEEE International Conference on Acoustics, Speech and Signal Processing*, Vancouver, Canada, May 2013.
117. R. Arablouei, K. Dogancay, S. Werner, "Reduced-complexity distributed least-squares estimation over adaptive networks," *IEEE International Workshop on Signal Processing Advances in Wireless Communications*, Darmstadt, Germany, June 2013.
118. H. Naseri, J. Salmi, and V. Koivunen, "Synchronization and Ranging by Scheduled Broadcasting," *IEEE International Conference on Acoustics, Speech and Signal Processing*, Vancouver, Canada, May 26—31, 2013, pp. 4878—4882.
119. T. Aittomäki, and V. Koivunen, "Improved MIMO Radar Channel Estimation Using Spatial Coding," *IEEE International Conference on Acoustics, Speech and Signal Processing*, Vancouver, Canada, May 26—31, 2013, pp. 4120—4124.
120. E. Ollila, H.-J. Kim, and V. Koivunen, "Robust Regularized M-Estimators of Regression Parameters and Covariance Matrix," *International Workshop on Advances in Regularization, Optimization, Kernel Methods and Support Vector Machines*, Leuven, Belgium, July 8—10, 2013, pp. 67—68.
121. H.-J. Kim, E. Ollila, V. Koivunen, and C. Croux, "Robust and Sparse Estimation of Tensor Decompositions," *IEEE Global Conference on Signal and Information Processing*, Austin, USA, December 3—5, 2013, pp. 965—968.
122. H.-J. Kim, E. Ollila, and V. Koivunen, "Sparse Regularization of Tensor Decompositions," *IEEE International Conference on Acoustics, Speech and Signal Processing*, Vancouver, Canada, May 26—31, 2013, pp. 3836—3840.
123. K. Pölönen, and V. Koivunen, "Control Symbol Based Fluctuating Target Detection in DVB-T2 Passive Radar Systems," *IEEE Radar Conference*, Ottawa (ON), Canada, April 29—May 3, 2013.
124. A. Chis, J. Lundén, and V. Koivunen, "Scheduling of Plug-in Electric Vehicle Battery Charging with Price Prediction," *4th IEEE European Innovative Smart Grid Technologies Conference*, Copenhagen, Denmark, October 6—9, 2013.
125. T. Rautiainen, J. Lundén, S. Werner, and V. Koivunen, "Demand Side Management Through Electricity Pricing in Competitive Environments," *4th IEEE European Innovative Smart Grid Technologies Conference*, Copenhagen, Denmark, October 6—9, 2013.
126. J. Lundén, S. Werner, and V. Koivunen, "Distributed Demand-Side Optimization with Load Uncertainty," *IEEE International Conference on Acoustics, Speech and Signal Processing*, Vancouver, Canada, May 26—31, 2013, pp. 5229—5232.
127. J. Lundén, M. Motani, and H. V. Poor, "Distributed Iterative Time Slot Allocation for Spectrum Sensing Information Sharing in Cognitive Radio Ad Hoc Networks," *IEEE Wireless*

- Communications and Networking Conference*, Shanghai, China, April 7—10, 2013, pp. 35—40.
128. S. Chaudhari, J. Lunden, and V. Koivunen, “On the BEP Walls for Soft Decision Based Cooperative Sensing in Cognitive Radios,” *IEEE International Conference on Communications*, Budapest, Hungary, June 10—13, 2013, pp. 2627—2632.
 129. J. Rajasekharan, J. Lundén, and V. Koivunen, “Competitive Equilibrium Pricing and Cooperation in Smart Grids with Energy Storage,” *Conference on Information Sciences and Systems*, Baltimore, MD, March 20—22, 2013.
 130. S. Chaudhari, and V. Koivunen, “Impact of Reporting-Channel Coding on the Performance of Distributed Sequential Sensing,” *IEEE Signal Processing Advances in Wireless Communications*, Darmstadt, Germany, June 16—19, 2013, pp. 185—189.
 131. J. Aho, J. Salmi, and V. Koivunen, “Adaptive Processing and Realistic Signal Propagation Modeling for Multiantenna Vital Sign Radar,” *IEEE Radar Conference*, Ottawa (ON), Canada, April 29—May 3, 2013.
 132. D. Korpi, M. Valkama, T. Riihonen, and R. Wichman, “Implementation Challenges in Full-Duplex Radio Transceivers,” *XXXIII Finnish URSI Convention on Radio Science*, Espoo, Finland, April 2013.
 133. U. Ugurlu, T. Riihonen, and R. Wichman, “Optimized Full-Duplex MIMO Relay in SISO Link,” *XXXIII Finnish URSI Convention on Radio Science*, Espoo, Finland, April 2013.
 134. T. Riihonen, “Recent Advances in Full-Duplex Relaying,” *XXXIII Finnish URSI Convention on Radio Science*, Espoo, Finland, April 2013.
 135. M. Costa and V. Koivunen, “Applications of Manifold Separation in Polarimetric Beamforming and Source Tracking,” *XXXIII Finnish URSI Convention on Radio Science*, Espoo, Finland, April 2013.
 136. K. Pölönen and V. Koivunen, “Control Symbol Based Fluctuating Target Detection in DVB-T2 Passive Radar Systems,” *XXXIII Finnish URSI Convention on Radio Science*, Espoo, Finland, April 2013.
 137. J. Oksanen and V. Koivunen, “Order Optimal Policy for Identifying Idle Spectrum in Cognitive Radio Networks,” *XXXIII Finnish URSI Convention on Radio Science*, Espoo, Finland, April 2013.
 138. J. Salmi and V. Koivunen, “Non-Contact Vital Sign Estimation Using Micro-Doppler Radar,” *XXXIII Finnish URSI Convention on Radio Science*, Espoo, Finland, April 2013.

13.3 Published monographs

No monographs published in 2013.

13.4 Other scientific publications

1. R. Valkonen, “Impedance matching and tuning of non-resonant mobile terminal antennas,” No. 40/2013 in Aalto University publication series DOCTORAL DISSERTATIONS, Aalto University, Helsinki, Finland, 2013.
2. M. Yüçetas “Capacitive accelerometer interfaces utilising high-Q micromechanical sensor elements,” No. 99/2013 in Aalto University publication series DOCTORAL DISSERTATIONS, Aalto University, Helsinki, Finland, 2013.
3. P. Jänis “Interference management techniques for cellular wireless communication systems,” No. 108/2013 in Aalto University publication series DOCTORAL DISSERTATIONS, Aalto University, Helsinki, Finland, 2013.

4. A. Karttunen, "Millimetre and submillimetre wave antenna design using ray tracing," No. 127/2013 in Aalto University publication series DOCTORAL DISSERTATIONS, Aalto University, Helsinki, Finland, 2013.
5. A. Tamminen, "Developments in imaging at millimeter and submillimeter wavelengths," No. 131/2013 in Aalto University publication series DOCTORAL DISSERTATIONS, Aalto University, Helsinki, Finland, 2013.
6. A. Abdullah Al-Hadi, "Multi-element antennas for mobile communication systems: Design, evaluation and user interactions," No. 146/2013 in Aalto University publication series DOCTORAL DISSERTATIONS, Aalto University, Helsinki, Finland, 2013.
7. M. Costa, "Wavefield modeling and signal processing for sensor arrays of arbitrary geometry," No. 149/2013 in Aalto University publication series DOCTORAL DISSERTATIONS, Aalto University, Helsinki, Finland, 2013.

13.5 Text books and other books related to scientific research

No text books published in 2013.

13.6 Chapters in books

1. P. Alitalo and S. Tretyakov, "Experimental characterization of electromagnetic cloaking devices at microwaves," in *Transformation Electromagnetics and Metamaterials: Fundamental Principles and Applications* (D. Werner and D.-H. Kwon, eds.), Berlin-Heidelberg, Springer, 2013, pp. 315-347.
2. F. Bilotti and S. Tretyakov, "Amorphous metamaterials and potential nanophotonics applications," in *Amorphous Nanophotonics* (C. Rockstuhl and T. Scharf, eds.), Berlin-Heidelberg, Springer, 2013, pp. 39-66.
3. J. Lundén, V. Koivunen, and H. V. Poor, "Spectrum Exploration and Exploitation," In: E. Biglieri, A. J. Goldsmith, L. J. Greenstein, N. Mandayam, and H. V. Poor (eds.), *Principles of Cognitive Radio*, New York, NY, 2013, Cambridge University Press, pp. 184—258.
4. M. Costa, V. Koivunen, and M. Viberg, "Array Processing in the Face of Nonidealities," In: R. Chellappa and S. Theodoridis, *Academic Press Library in Signal Processing: Array and Statistical Signal Processing*, Oxford, UK 2013, Academic Press, Elsevier.

14. Other scientific activities of SMARAD members in 2011–2013

University Boards:

Kari Halonen

- Member, Steering group of Aalto School of Electrical Engineering
- Member, Doctoral Programme Committee of Aalto School of Electrical Engineering
- Member, Board of Directors of MilliLab
- Department Head, Department of Micro and Nanosciences

Visa Koivunen

- Vice-leader, SMARAD CoE
- Aalto University Tenure Track committee
- member of 2 faculty search committees

Juha Mallat

- Deputy member, Steering group of Aalto University Language Center

Jussi Ryynänen

- Head of Electronics and Electrical Engineering (EST) study programme
- Vice Chair, EST degree programme committee
- Member, Aalto Bachelor study renewal committee
- Member, School of Electrical Engineering Steering group of Teaching

Antti Räisänen

- Chairman, Doctoral Programme Committee of Aalto School of Electrical Engineering
- Member, Steering group of Doctoral Education of Aalto University
- Member, Steering group of Aalto School of Electrical Engineering
- Department head, Department of Radio Science and Engineering
- Leader, SMARAD CoE
- Chairman, Board of Directors of MilliLab

Participation in Organization of Scientific Conferences and Membership in Expert Boards**Juha Ala-Laurinaho**

- Member of the Editorial Board: Radioengineering, Journal of Czech and Slovak Technical Universities
- Guest Editor: Special Issue of Radioengineering: Advanced RF Measurements, 2012
- Member of the TPC: EuCAP 2013, The 7th European Conference on Antennas and Propagation, Gothenburg, Sweden, 8-12 April, 2013
- Doctoral Thesis external review, Alfonso Muñoz-Acevedo, Universidad Politécnica de Madrid, Spain, 2012
- Evaluation Board Member of the doctoral thesis of Mr. Carlos Vázquez Añituna, University of Oviedo, Spain, June 2013

Katsuyuki Haneda

- Associate Editor, IEEE Transactions on Antennas and Propagation
- Editor, IEEE Transactions on Wireless Communications
- TPC member, IEEE 78th Vehicular Technology Conference (VTC2013-Fall), Las Vegas, NV, September 2013.
- TPC member, IEEE International Conference on Communications (ICC '13), Workshop on Advances in Network Localization and Navigation (ANLN), Budapest, Hungary, June 2013.
- TPC member, 2013 IEEE 77th Vehicular Technology Conference (VTC2013-Spring), Dresden, Germany, May 2013.
- Opponent in a doctoral thesis defense of Mr. Brutesfa Godana, Norwegian University of Science and Technology, December 2013.
- A jury member of a doctoral thesis defense of Mr. Olivier Renaudin, Ecole Polytechnique de Louvain, August 2013.

Kari Halonen

- TPC Member, European Solid-State Circuits Conference
- TPC Member, IEEE International Solid-State Circuits Conference

- TPC Chair and member of Organizing Committee of ESSCIRC 2011 Conference in Helsinki
- Member, Management Group of NORCHIP Conference
- Member, Management Group of PRIME workshop
- Associate Editor, IEEE Journal of Solid-State Circuits
- Member, Editorial board of Springer International J. of Analog Integrated Circuits and Signal Processing

Visa Koivunen

- Fellow, IEEE
- Associate Editor, Signal Processing
- Associate Editor, IEEE Transactions on Signal Processing
- Associate Editor, IEEE Signal Processing Magazine
- Associate Editor, EURASIP Journal of Wireless Communications and Networking, 2011
- Member and industry liason, IEEE Signal Processing for Communications Technical Committee (SPCOM-TC)
- Member, IEEE Sensor Array and Multichannel Signal Processing Technical Committee (SAM-TC)
- COST IC902 Cognitive Radios, Finland representative
- IEEE ICASSP 2012, session chair and technical program committee member
- 2012 Asilomar conference, special session organizer and session chair
- 2012 CISS conference, Princeton, NJ, session chair
- IEEE SAM 2012, program committee member
- KTH, Sweden, member of RAE evaluation team
- Doctoral Thesis opponent, TU Darmstadt, Germany, 2012
- Doctoral Thesis opponent, Linköping University, Sweden, 2012
- Doctoral Thesis committee member, University of Pennsylvania, USA, 2012
- Scientific Publication Board, Ministry of Education, panel chair
- IEEE Signal Processing Society, SAM technical committee, member
- IEEE Signal Processing Society, Industrial Relations Board, member
- TPC member, IEEE SAM 2013, IEEE SPAWC 2013
- IEEE ICASSP 2013, session chair and technical program committee member
- Doctoral Thesis opponent, NTNU, Norway, 2013
- Eta Kappa Nu, member

Jussi Ryynänen

- TPC Member, European Solid-State Circuits Conference ESSCIRC2011, 2012, 2013
- TPC Member, European Conference on Circuit Theory and Design, ECCTD 2011
- Workshop chair ESSCIRC 2011
- TPC Member, IEEE International Solid-State Circuits Conference ISSCC
- Doctoral thesis opponent of Yasar Amin, KTH Royal Institute of Technology, 2013

Antti Räsänen

- Fellow, IEEE
- Edmond S. Gillespie Fellow, AMTA
- Member of the Kenneth J. Button Prize Committee, International Conference on Infrared, Millimeter and Terahertz Waves
- Member, Steering Committee of the European School of Antennas
- Member, Steering Committee, ESF NEWFOCUS

- Member of the Board of HPY Research Foundation
- Member of the Board of Directors, Member of the General Assembly, European Microwave Association (EuMA), 2006-2011
- Chairman of the EuMA Awards Committee, 2010-2011
- Member of the TPC, 5th European Conference on Antennas and Propagation, EuCAP2011 (Rome, Italy, 11-15 April, 2011)
- Co-Chair of the Steering Committee, 4th Global Symposium on Millimeter Waves, GSMM2011 (Espoo, Finland, May 23–25, 2011)
- Member of the TPC, 14th European Microwave Week, EuMW2011 (Manchester, UK, 9-14 October, 2011)
- Member of the TPC, 6th ESA Workshop Workshop on Millimetre-Wave Technology and Applications (Espoo, Finland, May 23-25, 2011)
- Member of the TPC, 33rd Annual Antenna Measurement Techniques Association (AMTA) Symposium (Denver, USA, 16-21 October, 2011)
- Organizer of the convened session “Antenna & Propagation Aspects for Multi-Gigabit Communication at 60 GHz and beyond”, EuCAP2013
- General Vice-Chair of the Steering Committee, 5th Global Symposium on Millimeter Waves, GSMM2012 (Harbin, China, May 27-30, 2012)
- Member of the TPC, 34th Annual Antenna Measurement Techniques Association (AMTA) Symposium (Bellevue, WA, USA, October 21-26, 2012)
- Doctoral Thesis opponent of Yogesh Karandikar, Chalmers University of Technology, Sweden, 2012
- Doctoral Thesis external examiner of Paavo Huttunen, University of Oulu, Finland, 2012
- Doctoral Thesis committee member of Amin Enayati, KU Leuven, Belgium, 2012

Sergei Tretyakov

- Fellow, IEEE
- Fellow, Electromagnetics Academy
- President, the Virtual Institute for Artificial Electromagnetic Materials and Metamaterials
- Deputy member, URSI Finnish National Committee
- Associate Editor, journals Electromagnetic Waves and Applications; Electromagnetics; book series Progress in Electromagnetics Research.
- Member, Optical Society of America
- Member, European Microwave Association
- Member, Finnish Academy of Technical Science
- Member, Steering Committee of the European Doctoral Programme on Metamaterials, 2011
- General chair, 5th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics (Barcelona, Spain, October 2011)
- Member of the TPC, Optics & Optoelectronics Congress on 18-22 April 2011 in Prague
- Member of the TPC, SPIE Optics + Photonics, Metamaterials: Fundamentals and Applications IV, 21-25 August 2011, San Diego, California, USA
- Member of the TPC, 2011 International Conference on Problems of Interaction of Radiation with Matter, October 26-28, 2011, Gomel, Belarus
- Member of the TPC, Loughborough Conference on Antennas and Propagation, 14-15 Nov. 2011, UK
- Member, Expert Advisory Group for Nanosciences, Nanotechnologies, Materials and New Production Technologies (European Commission, 7th Framework Programme)

- Member of the TPC, SPIE Optics + Photonics, Metamaterials: Fundamentals and Applications IV, 12-16 August 2012, San Diego, California, USA
- Member of the TPC, SPIE Photonics Europe, 16 - 20 April 2012, Brussels, Belgium
- Member of the TPC, Loughborough Conference on Antennas and Propagation, 12-13 Nov. 2012, UK
- General Chair, Metamaterials 2012, 17-20 September 2012, St. Petersburg, Russia
- Member of the TPC, 19th International Conference on Microwave, Radar and Wireless Communications MIKON-2012, May 21-23, 2012, Poland
- Doctoral thesis opponent of Tiiti Kellomäki, Tampere Technical University, Finland, 2012
- The Seventh International Congress on Advanced Electromagnetic Materials in Microwaves and Optics – Metamaterials 2013, 16-21 September 2013 - General chair
- 4th International Topical Meeting on Nanophotonics and Metamaterials (NANOMETA-2013), Seefeld, Austria, 3-6 January, 2013 - TPC member, invited talk
- SPIE Optics and Photonics 2013, San Diego, 25-29 August, 2013; Metamaterials: Fundamentals and Applications VI - TPC member, invited talk "Modeling and understanding of effects of randomness in arrays of resonant meta-atoms"
- Days on Diffraction 2013, pp. 143-144, St. Petersburg, Russia, 27-31 May, 2013 - plenary talk "Thin composite layers for arbitrary transformations of plane electromagnetic waves"
- PIERS in Taipei, TAIWAN, 25-28 March, 2013 - TPC member
- EuCAP 2013, 8-12 April 2013, Göteborg, Sweden - TPC member, convened session talk "Low-reflection inhomogeneous microwave lens based on loaded transmission lines"
- "Physics of Metamaterials and Complex Media" of the ICONO 2013 conference (International Conferences on Coherent and Nonlinear Optics), June 18-22, 2013, in Moscow, Russia - TPC member
- PIERS 2013 in Stockholm, August 12-15, 2013 - TPC member
- Donostia International Conference on Nanoscale Magnetism and Applications (DICNMA), San Sebastian, Spain, September 9th to September 13th, 2013 - International Advisory Committee member
- European Microwave Week, EuMC, 6-11 October, 2013, Nürnberg, Germany - TPC member (Sub-committee chair)
- Doctoral thesis defense opponent, Inigo Liberal, University of Navarra, Spain, 2013

Constantin Simovski

- Member of the TPC, Metamaterials 2012, 17-20 September 2012, St. Petersburg, Russia
- Doctoral thesis opponent of Aurelie Poncinet, University of Bordeaux I, France, defended on Nov. 19, 2013

Risto Wichman

- Steering Group Member, COST IC0803 RF/Microwave Communication Subsystems for Emerging Wireless Technologies
- Official Member, URSI Finnish National Committee, Radiocommunication Systems and Signal Processing
- Local liaison officer, EURASIP
- Steering Group Member, COST IC0803 RF/Microwave Communication Subsystems for Emerging Wireless Technologies
- Guest Editor, IEEE Journal on Selected Areas of Communications, 2013
- Doctor thesis opponent of Vinod Kumar Malamal Vadakital, Tampere University of Technology, 2012

- TPC Member in IEEE Globecom 2012, 2013, IEEE VTC Spring 2012, Crowncom 2012, IEEE ICC 2013, IEEE WCNC 2013
- Doctoral thesis opponent of Animesh Yadav, University of Oulu, Finland, and Jarkko Itkonen, Tampere University of Technology, Finland, 2013
- Member of Ph.D. thesis board, Dongkyu Kim, Yonsei University, South Korea, 2013
- Guest Editor, IEEE Journal on Selected Areas of Communications

Review Activities

Juha Ala-Laurinaho

- Reviews for *IEEE Transactions on Antennas and Propagation*, *IEEE Antennas and Wireless Propagation Letters*, *PIERS/JEMWA*, and *Radioengineering*

Katsuyuki Haneda

- Reviews for *IEEE Transactions on Antennas and Propagation*, *IEEE Transactions on Wireless Communications*, *IEEE Transactions on Vehicular Technology*, *IEICE Transactions on Fundamentals*
- Reviews for *IEEE Vehicular Technology Conferences* and *IEEE International Conference on Communications*.

Kari Halonen

- Reviews for *IEEE Journal of Solid-State Circuits*, *IEEE Transactions on Circuits and Systems I and II*, *IEEE Transactions on Microwave Theory and Design*, *Int. Journal of Analog Integrated Circuits and Signal Processing*
- Reviews for *NORCHIP Conference*, *European Solid State Circuits Conference*, *IEEE International Solid-State Circuits Conference*, *IEEE Symposium on Circuits and Systems*, *European Conference on Circuit Theory and Design*, *PRIME workshop*

Visa Koivunen

- Reviews for conferences *IEEE PIMRC 2011*, *IEEE ICC 2011*, *IEEE ICASSP Conference 2011*, *2012*, *2013*, *IEEE SAM Conference 2011*, *2012*, *2013*, *IEEE SPAWC Conference 2011*, *2012*, *2013*
- Evaluator, ERC Advanced Grant proposals, European Research Council, 2012
- Reviews for *IEEE Signal Processing Magazine*, *IEEE Transactions of Signal Processing*, *IEEE JSTSP*, *Signal Processing*, *IEEE Journal of Selected Areas in Communications*, *IEEE Transactions on Antennas and Propagation*
- *IEEE Fellow References*

Juha Mallat

- Reviews for *PIER & JEMWA*
- Conference paper reviews: *EuMW2013*

Jussi Ryynänen

- Review for research proposal, NWO, The Netherlands Organisation for Scientific Research, 2011
- Reviews for *IEEE Transactions on Circuits and Systems-Part I&II*, *IEEE Journal of Solid-State Circuits*, *IEEE Transactions on Microwave Theory and Design*, *IEEE European Solid State Circuits Conference*, *Journal of Analog Integrated Circuits and Signal Processing IEEE*, and *International Solid-State Circuits Conference 2011*

Antti Räisänen

- Editorial Board Member, *Experimental Astronomy*
- Evaluations for ERC
- Evaluations for IEEE Fellow Committee, USA
- Expert committee member: The Swedish Foundation for Strategic Research (SSF), a call directed towards “Post CMOS”, “More than Moore” electronics, and techniques for high data-rate communications
- Evaluator for the Knut and Alice Wallenberg Foundation, Sweden
- Evaluator for the Killam Program at the Canada Council of the Arts
- Evaluator for the Estonian Research Council: National roadmap of research infrastructures
- Evaluations for ESF Research Networking Programme
- Evaluation for Technology Foundation STW, The Netherlands
- Evaluation for a faculty position in Information and Communication Technology, Chalmers University of Technology, Sweden, 2012
- Evaluation for a faculty position (promotion) in Electrical and Computer Engineering, University of Virginia, 2012
- Evaluation for Agence Nationale de la Recherche, France, 2011
- Evaluation for a faculty position in Information and Communication Technology: Chalmers University of Technology, Sweden, 2011
- Reviews for *Applied Physics Letters*, *IEEE Proceedings*, *IEEE Transactions on Microwave Theory and Techniques*, *IEEE Transactions on Antennas and Propagation*, *IEEE Transactions on Instrumentation and Measurement*, *IEEE Microwave and Wireless Components Letters*, *IEEE Antennas and Propagation Letters*, *IEEE Transactions on Electron Devices*, *IEEE Transactions on Electromagnetic Compatibility*, *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *IEEE/ASME Journal of Microelectromechanical Systems*, *IET Electronics Letters*, *IET Microwaves, Antennas & Propagation*, *Progress in Electromagnetics Research*, *Journal of Electromagnetic Waves and Applications*, *Int. Journal of Microwave, and Wireless Technologies*, *SPIE Optical Engineering*
- Conference paper reviews: *EuCAP 2011, 2012, 2013*, *EuMW 2011, 2012, 2013*, *ESA Workshop on Millimetre Wave Technology 2011*, *GSM 2011, 2012*, *33rd AMTA Symposium*, *34th AMTA Symposium*

Constantin Simovski

- Reviews for *Nature Materials*, *Nature Communications*, *Physical Review Letters*, *Physical Review B*, *Physical Review E*, *IEEE Trans. Antennas Propagation*, *IEEE Trans. Microwave Theory Techniques*, *IEEE Antennas Wireless Propagation Letters*, *IEEE Journal of Lightwave Technology*, *Journal of Optics (Pure and Applied)*, *Journal of Physics D (Condensed Matter)*, *Optics Letters*, *Optics Express*, *Photonics and Nanostructures: Fundamentals and Applications*, *Journal of Optical Society of America B*, *Nature Communications*, *Optics Communications*, *Metamaterials*
- Conference paper reviews for *Days on Diffraction'2012, 2013*, *Metamaterials'2012, 2013*
- Editorial Board Member, *Scientific and Technical Journal of Information Technologies, Mechanics, and Optics*

Sergei Tretyakov

- Editorial Board Member, *Progress in Electromagnetics Research*, *Electromagnetics; Problems of Physics, Mathematics, and Technics*
- Reviews for *Science*, *Nature Materials*, *IEEE Transactions on Antennas and Propagation*, *Physical Review*, *Physical Review Letters*, *Journal of the Optical Society of America A and B*,

Optics Letters, Journal of Applied Physics, Optics Express, Optics Communications, IET Proceedings, New Journal of Physics, etc. Conference paper reviews for European Microwave Conference and Metamaterials

Pertti Vainikainen

- Reviews for *IEEE Transactions on Instrumentation and Measurement, IEEE Transactions on Antennas and Propagation,, IET Electronics Letters, IEEE Antennas and Wireless Propagation Letters*

Risto Wichman

- Reviews for *IEEE Trans. Signal Processing, IEEE Trans. Wireless Communications, IEEE Trans. Communications, IEEE Trans. Vehicular Technology, Signal Processing, IEEE Wireless Communication Letters IEEE Signal Processing Letters*



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