Antti Räisänen (editor) SMARAD Centre of Excellence in Smart Radios and Wireless Research Activity Report 2008 - 2010 Aalto University

Department of Radio Science and Engineering

SMARAD

Centre of Excellence in Smart Radios and Wireless Research

Activity Report 2008 - 2010

Antti Räisänen (editor)

Aalto University

SCIENCE + TECHNOLOGY

REPORT

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SMARAD

Centre of Excellence in Smart Radios and Wireless Research

Activity Report 2008 - 2010

Antti Räisänen (editor)

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

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Centre of Excellence in Smart Radios and Wireless Research

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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 such as Graduate School in Electronics, Telecommunications and Automation (GETA).

During years 2008 – 2010, 21 doctor degrees were awarded to the students of SMARAD. In the same period, the SMARAD researchers published 141 refereed journal articles and 333 conference papers.

Contents

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.

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.” There are altogether 41 Centres of Excellence: the Academy Board has appointed 23 centres of excellence for the national centre of excellence programme in 2006–2011 and 18 for the years 2008–2013.

The current SMARAD was formed in 2006 by the Radio Laboratory, the Electronic Circuit Design Laboratory and the Signal Processing Laboratory of the Department of Electrical and Communications Engineering, Helsinki University of Technology (TKK). After the restructuring of the TKK organization, 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 Faculty of Electronics, Communications and Automation (now Aalto University School of Electrical Engineering).

SMARAD provides world-class research and education in RF, microwave and millimeter wave engineering, in integrated circuit design for multi-standard radios as well as in wireless communications. In microwave and millimeter 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 TKK). The total number of employees within the research unit is about 100 including about 30 senior scientists and about 40 graduate students and several undergraduate students working on their Master thesis.

This unit has significantly evolved from the SMARAD CoE in research appointed for the years 2002–2007. In particular, one strong research group and two new professors have joined the unit and new research areas related to fast and low power electronic circuits, to system architectures and platforms for wireless applications, to THz and optical imaging, and to microwave nondestructive testing are included. Moreover, the research dealing with multiantenna communications and advanced transceiver structures is now expanded to communication theory, cognitive radio technologies, and cooperative communications including relay networks. More emphasis is put towards research into THz technology due to its high importance for instance in safety monitoring and characterization of materials. In the education sector, the participating faculty provides curricula in radio engineering, electronics and circuit design and signal processing for communications.

The relevance of the unit 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 also diverse including the Academy of Finland, 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 such as GETA.

Principal Investigators:
Prof. Antti Räisänen, chairman: Millimeter wave techniques
Prof. Visa Koivunen, vice-chair: Communications and statistical signal processing
Prof. Kari Halonen: Electronic circuit design
Prof. Sergei Tretyakov: Artificial electromagnetic materials and smart structures
Prof. Pertti Vainikainen: RF applications in mobile communications and non-destructive testing

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Mr. Tuukka Lehtiniemi, Academy of Finland (2009 -)
Dr. Hannu Kauppinen, Nokia Research Center

2 Research groups (in the end of 2010)

1. **Millimetre wave techniques.** The research group is led by Prof. Antti Räisänen. There are 4 other senior researchers with a doctoral degree (Dr. Juha Mallat, Dr. Juha Ala-Laurinaho, Dr. Sergey Dudorov, and Dr. Dmitri Lioubtchenko) and 8 researchers working towards their doctoral degree. In addition, Prof. Constantin Simovski works half-time in this group.
2. **Advanced artificial materials and smart structures.** This research group is led by Prof. Sergei Tretyakov. The research group includes 2 senior researchers, and 3 researchers working towards their doctoral degree. In addition, Prof. Constantin Simovski works half-time in this group.
3. **RF applications in mobile communications and non-destructive testing.** This research group is led by Prof. Pertti Vainikainen. There are 5 other senior researchers with a doctoral degree (Dr. Clemens Icheln, Dr. Tommi Laitinen, Dr. Katsuyuki Haneda, Dr. Valeri Mikhnev, and Dr. Yelena Maksimovitch) and 7 researchers working towards their doctoral degree.
4. **Communications and statistical signal processing.** The research group is led by Academy prof. Visa Koivunen. There are 5 other senior researchers with a doctoral degree in the group. There are 9 researchers working towards their doctoral degree. In addition, Prof. Risto Wichman works full time in this research group.
5. **Electronic circuit design.** The research group is led by Prof. Kari Halonen. The group includes 2 senior researchers with a doctoral degree and 11 researchers working towards their doctoral degree. In addition, Prof. Jussi Ryynänen works full time in this research group.

3 Highlights of SMARAD research in 2010

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 2008 - 2010 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 require ever higher data rates and wider bandwidths, and 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 traditional network planning may not be feasible in some deployments (e.g. in pico-cells and homes). 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 for, e.g., evolution of DVB-T/H.
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 in short-range communications and it lacks mechanisms to support, e.g., mobility, necessary to wide area systems. Also, system architectures for local area communications combining the mobility and services of cellular systems and high data rates and autoconfigurability of WLAN would be highly desirable.

Improving isolation between mobile terminal antennas around 900 MHz. Modern mobile terminals operate in a number of different radio systems and thus require multi-band functionality and multiple antennas. The number of antennas in mobile terminals will further increase with the use of MIMO techniques. Since the space reserved for the antennas is not growing, obtaining sufficient isolation between the antennas is challenging, especially below 1 GHz. A novel method improving the isolation between antenna elements on a mobile terminal was developed for the 900-MHz frequency band. The idea is to use a combination of a balanced (bow-tie) and an unbalanced (capacitive coupling element, CCE) antenna structure, see Fig. 1. It was shown that the proposed structures can achieve upto 100 dB of port-to-port isolation.

Multi-probe systems, MIMO over-the-air testing and probe-corrected spherical near-field antenna measurements. Multi-antenna systems can enhance significantly the adaptation of radio communications systems to the usage environment at the link level. The use of multi-antenna configurations will increase the need for testing the antenna performance. Thus, fast test systems are preferable. In this work, multiple probe systems for fast testing of antennas were investigated. A method for fully compensating the reflections from the neighboring probes in a multi-probe system was developed.

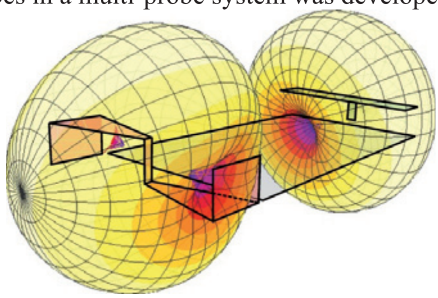


Fig. 1. Novel antenna structure with a capacitive coupling element (CCE, right) and a bow-tie antenna (left). The unbalanced (CCE) and balanced (bow-tie) antenna elements have almost orthogonal radiation patterns.

This method is based on an over-the-air calibration of a multi-probe system using a known calibration antenna and subsequent measurement of the pattern of the antenna under test. This compensation is analogous to the traditional probe correction in spherical near-field antenna measurements with a single probe.
MIMO over-the-air (OTA) test technology was developed. Here, in particular, the interest was to find out the relations between the number of required probe antennas in the MIMO-OTA test system and the size of the test zone. As well, the opportunities of the probe array compensation for MIMO-OTA testing purposes were illustrated. Probe-corrected spherical near-field antenna measurements were developed together with Technical University of Denmark. Here methodology for probe-corrected spherical near-field antenna measurements with a specific double phi-step theta-scanning scheme was developed.

Multi-link MIMO propagation channel modeling using a geometry-based approach. A reference propagation channel model is an important tool to develop next generation radio systems to evaluate different candidates of transmission schemes. Geometry-based stochastic channel models (GSCMs) are promising options for reference channel models because of their realistic physical properties. This work performed in co-operation with Lund University made an important addition to the GSCMs so that they can support multi-link simulations. This was achieved by the concept of common clusters, i.e., physical scatterers that produce multipath propagation for different links simultaneously as illustrated in Fig. 2.

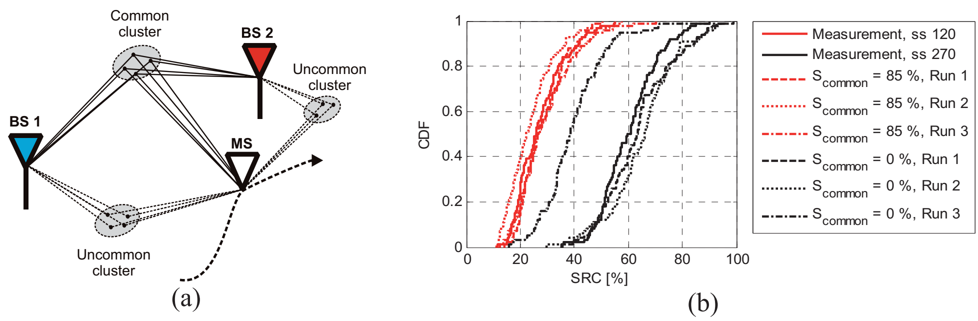


Fig. 2. (a) A multi-link GSCM based on the concept of common cluster (CC). (b) Sum rate capacity (SRC) comparison between measurements and simulations.

The channel measurement and modeling results were inputted to the COST 2100 action to enhance the propagation channel model. To validate the channel model, channel responses created by the new COST2100 model were compared to channel measurements. Various evaluation metrics were used, such as delay and angular spreads, ergodic channel capacity in single-link scenarios, and inter-link correlation in multi-BS and multi-MS scenarios.

In multi-user multiple-input multiple-output (MIMO) radio communications, correlation between links for different users results in degradation of sum rate capacity of the radio network. Since there has existed a very limited number of analyses on the inter-link correlation in real radio networks, the work described above provides insights on the inter-link correlation using measured multi-user MIMO channels. In Fig. 3 results for the inter link correlation on the mobile side are given based on calculating inner products of eigenvectors from two links to the fixed nodes (base station/access point). The interlink correlation indicated moderate to very high values even with large spatial separation of the fixed nodes.

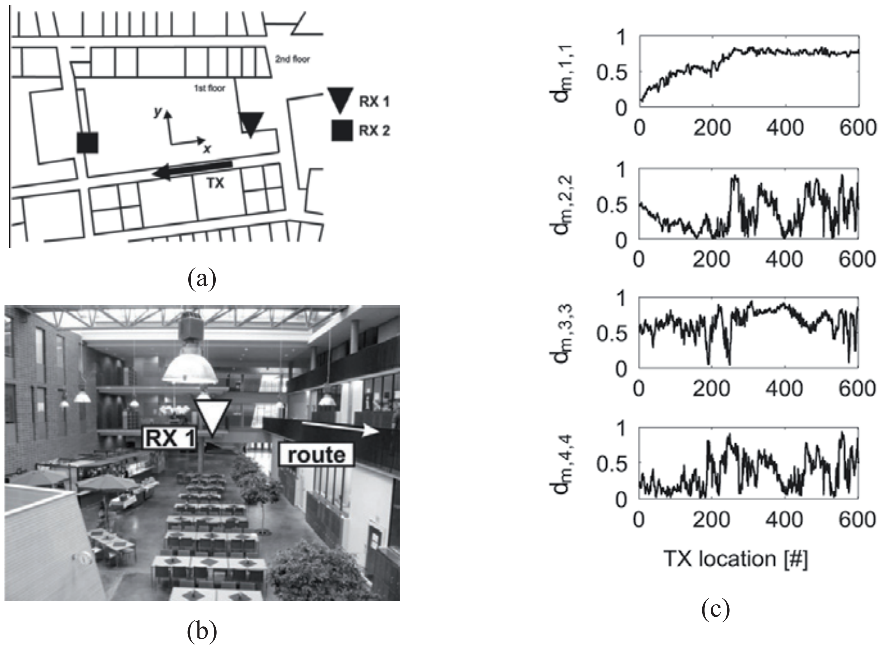
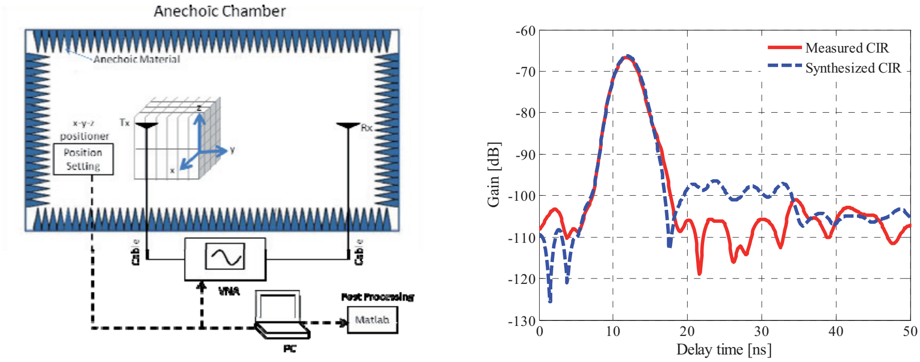


Fig. 3. (a) Floor plan and the coordinate system of the measurement, (b) photograph of the environment, and (c) correlation of the ith eigenvectors from the Tx-Rx1 and Tx-Rx2 links.

Methodologies for spherical wave modeling of radio channels. Recently, spherical wave modeling has gained attention in radio propagation channel modeling. In such modeling, the channel is treated as a spherical-mode to spherical-mode channel matrix, which relates each outward propagating spherical mode at the transmitter to those of the inward-propagating spherical modes at the receiver. Such a channel matrix allows complete antenna de-embedding, and hence, once such a channel matrix is available, it can then be applied, for example, for UWB and MIMO performance studies of arbitrary antennas both at the transmitter and receiver without a need to repeat the measurement every time for a new transmit or receive antenna. In our work, we have investigated how linear scanners could be used for generating the channel matrices. Example results on the application of the spherical wave synthesis technique for UWB application are shown in Fig. 4.



(a) (b)

Fig. 4. (a) Measurement set-up in an anechoic chamber (b) Synthesized CIR vs. measured CIR, by using a bicone antenna at both Rx and Tx sides.

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. Furthermore, relays can operate in the half-duplex mode, i.e. they do not transmit and receive simultaneously in the same band, or in the full-duplex mode. The latter requires 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 relays are higher than those of half-duplex ones, but on the other hand full-duplex relays may improve system throughput when the relay does not require two channel resources for reception and transmission.

From the 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. Spectral shaping of the transmitted signal requires advanced techniques for digital filter design. Full-duplex MIMO relays require in addition to new high-isolation antenna systems also adaptive loop interference cancellation techniques, outlined in Fig. 5. The relay 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.

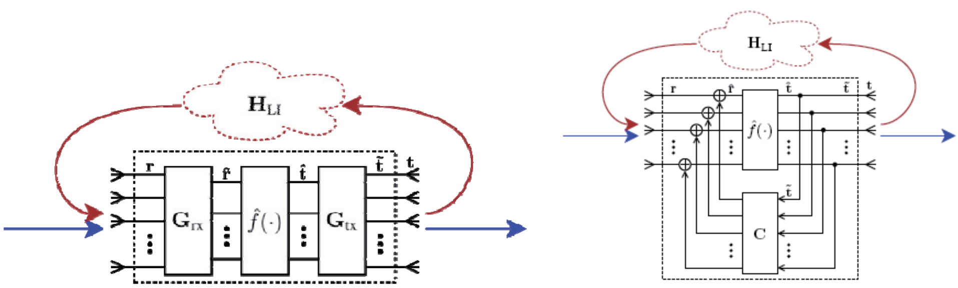


Fig. 5. Loop interference cancellation in spatial domain or subtraction of estimated loop interference.

The research benchmarks AF and DF relays, and full-duplex and half-duplex modes, taking into account the aforementioned issues.

Dirty RF. Building flexible, compact, high-quality, and yet low-cost radio equipments 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 multiantenna transceivers. The emphasis is on the analytical work to characterize the resulting distortion and their effect on to system performance in closed-form, and to develop digital signal processing algorithms for the mitigation of dirt 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 multiantenna 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 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 estimation schemes for estimating and tracking an unknown common parameter, e.g., temperature, level of water contaminants, or a target position, using multiple displaced sensors. Signal collection through a distributed network of sensor nodes improves robustness of performance and reliability of the network due to redundancy and provides spatial diversity due to multiple viewing angles. In the particular case of sensor networks, the bandwidth and power requirements are closely linked to whether the sensored data is processed in a centralized or a decentralized manner, see Fig. 6. 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) 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 the 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 is informative. Such algorithms will lead to improved performance, prolonged lifetime for the sensor nodes, and improved reliability of the entire network.

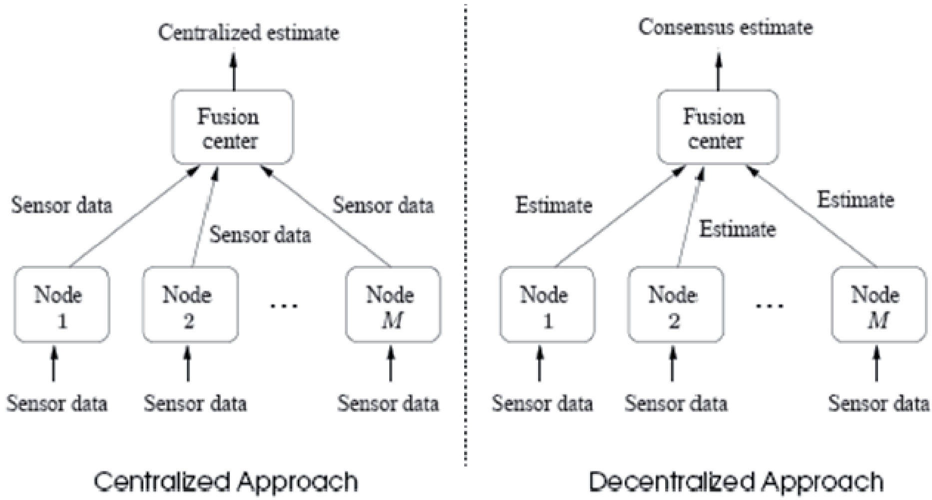


Fig. 6. Centralized and decentralized estimation in a network with M nodes.

Optimal signal processing for arbitrary array configurations. In this work signal processing techniques for sensor arrays of arbitrary geometry are developed. Optimal, robust and high-resolution techniques are derived and their statistical properties are established. The methods can deal with array imperfections by incorporating the array calibration data in an elegant manner. Conformal arrays and azimuth, elevation and polarimetric data processing may be handled. 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 imperfections 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 imperfections. 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. 7 has been implemented in cooperation with Nokia Research center and it will be coming out as a commercial product for tracking other users carrying RF tags or mobile phones. 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.

MIMO radar and novel radar concepts. Another interesting line of research followed in this research is MIMO 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. Similarly to MIMO

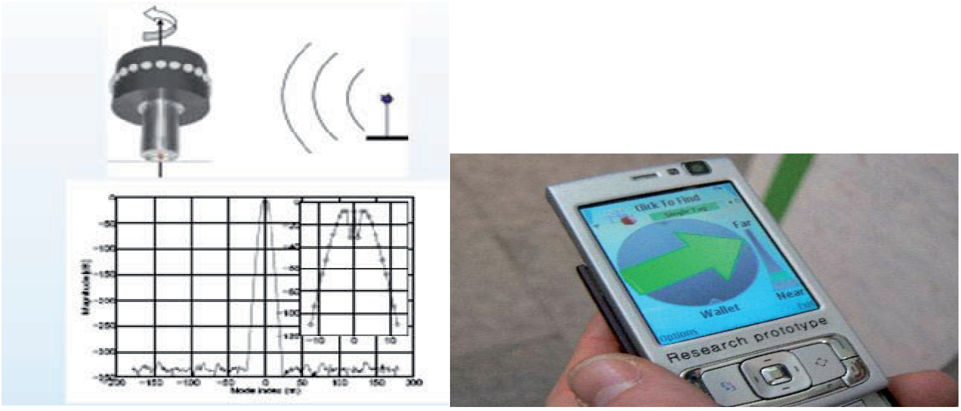


Fig. 7. Optimal and computationally efficient array processing techniques may be generalize to arbitrary array configurations by using Fourier transform of the array calibration data and non-trivial manipulation of input-output matrix model for the array data. Practical application of our method: implementation of 2-D antenna array of arbitrary geometry in a mobile terminal and application in direction finding and ranging (Right).

communications, spatial diversity (induced by radar cross section) may be exploited. Novel techniques for high resolution localization and tracking, parameter estimation and accurate time synchronization for distributed MIMO radar are developed. In co-located MIMO radars, different waveforms may be launched from each antenna, see Fig. 8. The possibility of using different probing signals in each antenna provides many benefits in target identification and interference cancellation, for example. Novel methods for beamforming, direction finding and adaptive and optimal waveform design are developed and their performance is analyzed under different Swerling models. Additional radar related topics include OFDM based ranging and radar operation and detection of vital signs using radar.

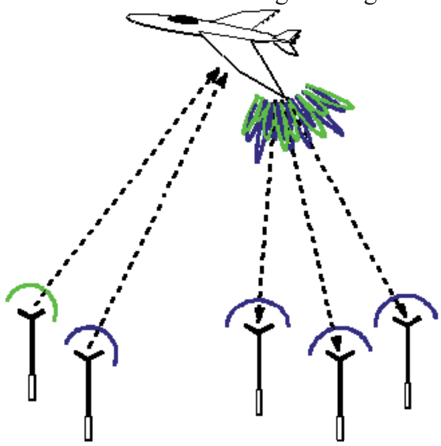


Fig. 8. Multistatic, MIMO Radar configuration using waveform diversity. Virtual aperture may be created using signal processing for designing and optimizing the waveforms launched from each antenna.

Electromagnetic cloaking based on waveguiding structures. We propose ways to make metallic objects practically invisible to the electromagnetic radiation (in certain frequency bands) by employing various waveguiding structures that enable the electromagnetic wave either to go through an object or around an object. The first technique is referred to as transmission-line cloaking and the latter as metal-plate cloaking. Various techniques have been proposed that enable the design of these structures for specific microwave frequency bands, with emphasis on making the objects as electrically large as possible. It is found that very effective cloaking is achieved if the diameter of the cloaked object is limited to approximately one wavelength or smaller. Fig. 9 demonstrates plane-wave scattering from an uncloaked and a cloaked object.

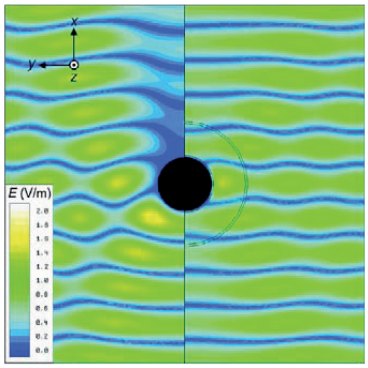


Fig. 9. Snapshot of simulated electric field when a plane wave hits an uncloaked (left) and a cloaked (right) object. The cloak is made of periodically stacked conical metal sheets.

Huygens source antennas. Huygens source antennas are electrically small antennas that radiate unidirectionally and in the ideal case have perfect polarization purity. The proposed antennas are composed of both electric and magnetic dipoles and the polarization of radiation is defined by the orientation and feeding of these dipoles. We have designed practical realizations of such antennas employing chiral particles (for circular polarization) and omega-particles (for linear polarization). The antennas have been studied analytically, numerically, and experimentally, confirming this concept for obtaining electrically small antennas with very useful radiation properties. Fig. 10 shows numerical and experimental radiation patterns for a linearly polarized Huygens source antenna.

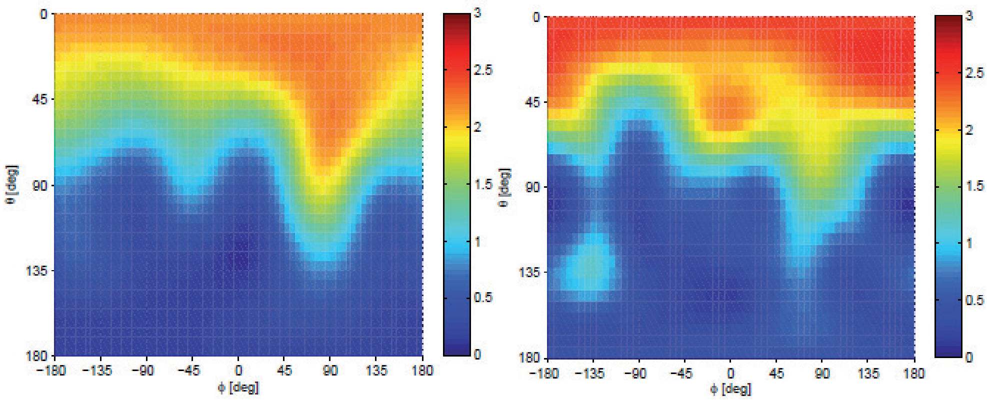


Fig. 10. Simulated (left) and measured (right) directivity patterns of a linearly polarized Huygens source comprised of two omega-particles.

High-impedance surface based antenna. High-impedance surfaces (HISs) have been used as artificial magnetic conductors for low-profile dipole antennas. Usually, the desired operation has been designed using the phase-reflection simulations for normal incidence. We studied the properties of a mushroom-type HIS using reflection-phase calculations for oblique incidence and found two orthogonal resonant modes. An antenna based on a finite-sized HIS was designed to utilize both of these modes, Fig. 11. The antenna was measured, and we found two separate modes with asymmetric radiation patterns. The first mode provides a dipole-like radiation pattern and the second one a broadside pattern. Further, the second mode can be coupled to the antenna with a proper coupling element in order to obtain a wide bandwidth. Both of the modes can be matched to 50-Ohm coaxial cables and good isolation levels between the ports are seen due to the orthogonality of the modes in the HIS.

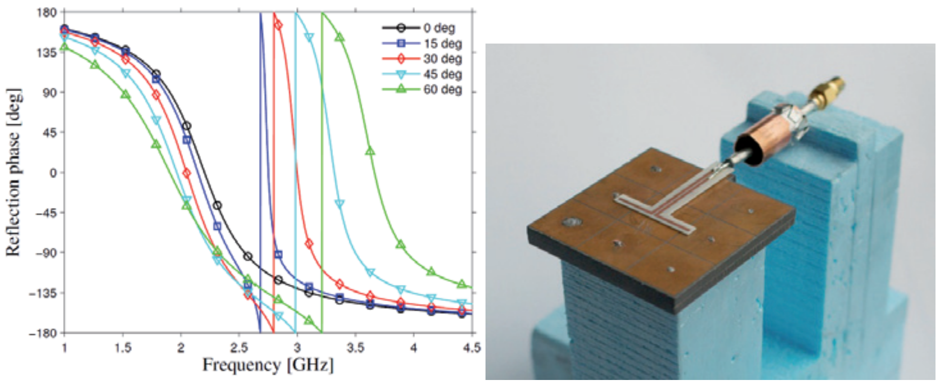


Fig. 11. Reflection-phase diagram for an infinite HIS with two resonance bands (left). Manufactured and measured dual-mode antenna (right).

3.2 Cognitive Radio

This research concentrates on enabling technologies for 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 users may use unused spectrum if 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 using it for data transmission while controlling the level of interference caused to other users, see Fig. 12. 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.

Spectrum exploration and exploitation. Research in spectrum exploration and exploitation has focused on identifying and exploiting unused spectrum in a cooperative and distributed manner. Distributed detectors developed for finding spectrum opportunities provide diversity gain since they can mitigate shadowing and fading effects. Moreover, user cooperation facilitates fast scanning of the spectrum as well as using simple individual detector structures. The concrete research problems

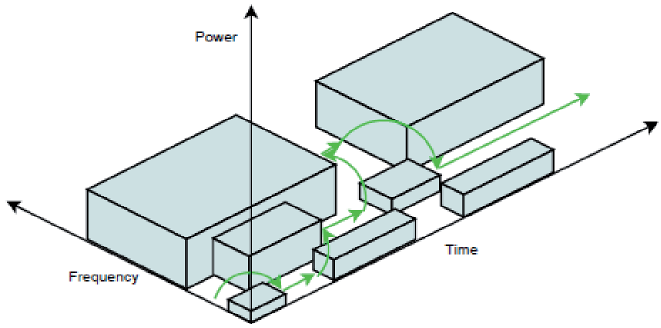


Fig. 12. Flexible use of time-frequency-location varying underutilized spectrum.

addressed in this work are dealing with decentralized detection of primary users by a group of cooperating secondary, sensing policies for distributed detection by multiple sensors over multiple potentially scattered subbands as well as cooperative spectrum access policies to secondary users. The work on sensing policies has focused on optimizing cooperative sensing in the face of time-frequency and location varying spectrum usage. Optimization is based on trading off between the exploration and exploitation of the spectrum such that sensing is focused on subbands where high quality spectrum is idle persistently, see Fig. 13. As a result, the system learns the dynamic behavior of the spectrum and can maximally exploit 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.

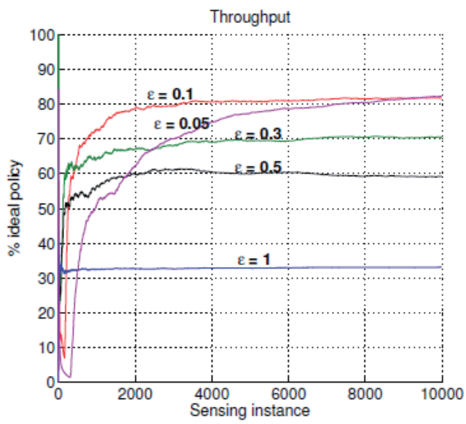


Fig. 13. Trading off between spectrum exploration and exploitation. Developed greedy spectrum sensing policy allocates sensing to subbands that provide idle spectrum persistently and as a result performance close to ideal sensing policy is achieved.

Implementation issues in spectrum sensing and exploitation. The quality of the spectrum sensor decisions and decision statistics, and the decision frequency are the key parameters in optimization of the spectrum utilization and the overall performance of the cognitive radio system. The most important properties of a single detector entity are, firstly the ability to make the decisions quickly and reliably, and secondly the ability to observe a wide frequency range and multiple primary systems simultaneously. In addition, the implementation must be optimized such that the change of primary signal under detection has as small as possible effect on the receiver front-end parameters. Reconfiguring the front-end takes time and slows down the hopping between different bands and signal types. Spectrum sensing applications also set high requirements for RF hardware (wide bandwidth, wide tuning range, high dynamic range, high linearity), which is a limiting factor in current implementations. Sensing algorithm should be selected so that it enables the flexible configuration of the sensor parameters with software. In order to enable the sensing of multiple systems simultaneously, the functionality of the DSP implementation should be independent of the sampling rate and signal bandwidth of the system to be detected.

While targeting a battery operated application it is of utmost importance to minimize the power consumption of the sensor both at circuit and architectural level. Therefore, in the implementation of a simultaneous multisystem spectrum sensor, one should lead up to a solution in which the amount of hardware does not increase linearly with the number of systems under detection (or even with number of transmit/modulation parameters in a single system). In addition to spectrum sensing functionalities, DSP may have to implement support functions such as additional filtering and gain control. As the functional requirements on the DSP domain increase, it becomes more and more important to optimize the energy and cost efficiency of the realized circuits. While performing spectrum sensing, it might also be beneficial to obtain additional information for example about the adjacent channels and their power levels. For example in some cases, presence of a strong signal on the channel adjacent to the one under detection could affect the reliability of the detection results. In addition, this knowledge could be to adjust RF functions in the receiver.

In this work we have developed energy and cost-efficient hardware implementations. These implementations have concentrated on the RFIC receivers, synthesizers and on the most promising spectrum sensing methods. The RFIC implementations (see Fig. 14) have demonstrated several dBs of linearity improvement in receiver side and the wideband synthesizer has reduction (about 70%) of silicon area over the previous designs. Moreover, efficiently realizable architectures for both RF front-end (radio architecture and circuits) and digital front-end are studied for expanding the detections to apply simultaneously on multiple primary signal types and/or multiple frequency bands, not forgetting the necessary support functions.

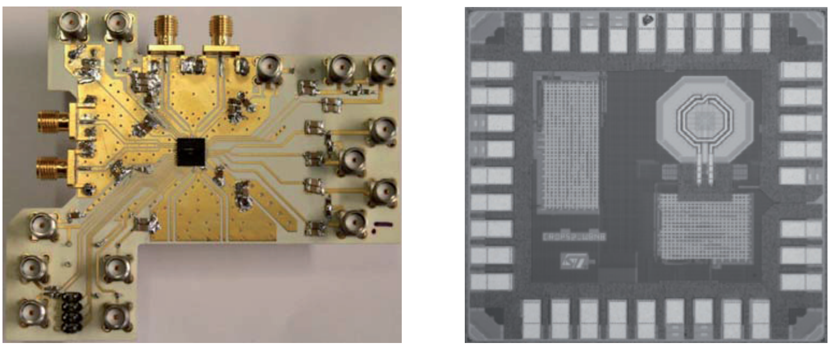


Fig. 14. a) Implemented wideband receiver b) Chip photograph of implemented synthesizer.

Broadband equivalent circuit model for mobile terminal antennas based on capacitive coupling elements. While designing antennas for cognitive radios working over broad frequency ranges, it is important to understand the mechanisms behind the frequency response of the antenna impedance. These include interactions of different conductive and dielectric antenna parts of the terminal with each other and with the user holding the device. These are often so complex that EM simulation tools are typically used to evaluate and optimise the performance of new designs. The theory of wavemodes simplifies the characterisation of the electromagnetic interaction between the different radiating antenna parts. The proposed resulting equivalent circuit model (see Fig. 15) improves the general understanding of the operation of the antenna structure.

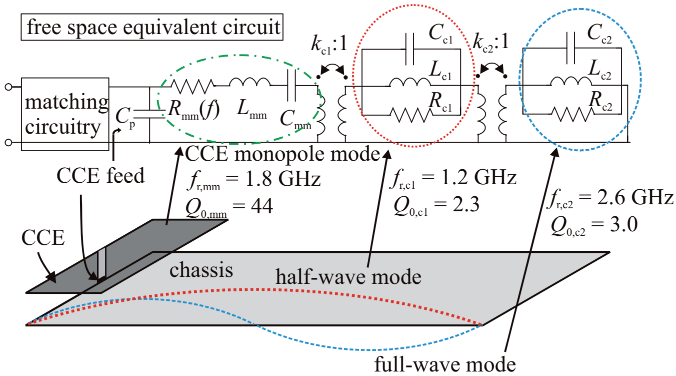
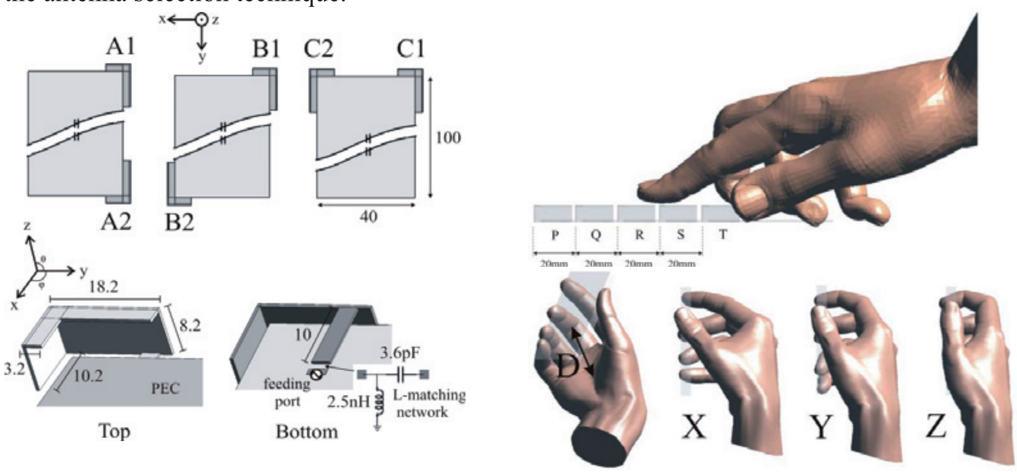


Fig. 15. Capacitive coupling element (CCE) on a ground plane (chassis) and the equivalent circuit model representing the CCE and the illustrated first two wavemodes that are excited on the ground plane.

Reduction of the effect of the user's hand on antenna structures in mobile terminals. One important aspect in the adaptation of the terminal device into its usage environment is the presence of the hand of the user, which has been shown to significantly deteriorate the performance of the antennas. It is studied how to at least partially compensate this effect by using antenna selection. Both the effect of only the index finger, which is often the main reason for the deterioration, and that of different grips (Fig. 16) of the hand are studied. Measurements around 2 GHz show that the total efficiency can be improved by 2–6 dB with the antenna selection technique.



(a) (b)

Fig. 16. (a) Coupling element –based dual-antenna structures with different configurations, (b) Multivariable study on hand effects.

3.3 Millimetre Wave and THz Techniques

Millimetre wave integrated circuits. A power combining CMOS power amplifier utilizing cascode topology and transformer-based matching elements was designed and successfully measured. The amplifier achieves +13 dBm saturated output power at 94 GHz with a standard 1.2 V supply and occupies an active area of 0.069 mm^2 only. The amplifier is implemented in an industrial 65nm CMOS process taking into account reliability issues at high output power level. Further, the amplifier is ESD-protected at the input and at the output. The micrograph of the CMOS amplifier is presented in Fig. 17.
In addition, 165 and 183 GHz low noise amplifiers were designed in 50- and 100-nm metamorphic HEMT technology. The measured results show a 25 dB gain and a 4.8 dB noise figure at 165 GHz. The 183-GHz amplifiers have attained a gain of 20 dB and a noise figure of 6.7 dB. The micrograph of the 183-GHz metamorphic HEMT low noise amplifier is presented in Fig. 18.

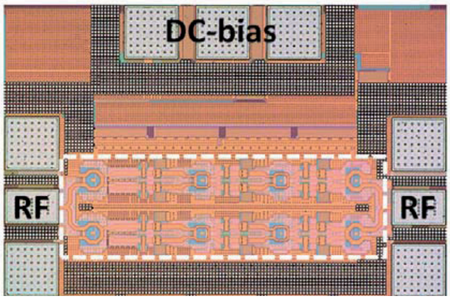


Fig. 17. Chip micrograph of the 94-GHz CMOS power amplifier. The area, including pads is 0.24 mm^2 (610 µm x 400 µm) and the active area (encircled with the dashed white line) is 0.069 mm^2 only.

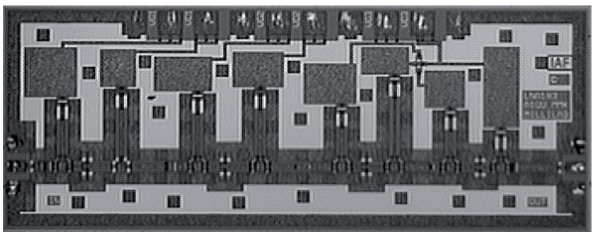


Fig. 18. Chip micrograph of the 183-GHz metamorphic HEMT low noise amplifier. The circuit area is 2.5 mm^2 (2.5 mm x 1.0 mm).

Characterisation, modelling, and applications of nonlinear 2 terminal millimetre wave devices. ESA-related activities for the characterisation of Schottky devices in standardised set-ups for IV, CV and S-parameters have continued. A major new aspect was included in the characterisation of Schottky diodes: measurements in a mixer test jig where the performance of different diodes can be assessed in mixer operation and under comparable conditions at 183 GHz. Among the results of this research is a new break-through in Schottky diode series resistance extraction. As a major improvement over the commonly used traditional method, the novel method takes holistically into account also important self-heating related effects in THz Schottky diodes having submicron junction dimensions.
Development of Schottky diode-based demonstrators has been continued. Demonstator designs include a monolithic Schottky diode based frequency tripler which has been

produced and successfully tested. Monolithically integrated frequency doubler and 340 GHz sub-harmonic mixer designs based on two different monolithic microwave integrated circuit (MMIC) Schottky diode technologies are under fabrication.

MEMS tuneable metamaterials for smart wireless applications. MEMS tuneable metamaterials can be used for beam steering applications at millimetre wavelengths. A particular case of the metamaterial surface, high-impedance surface can be introduced into waveguides to obtain analogue type phase shifters for a phased array antenna. Alternatively, the high-impedance surface can perform as a smart beam steering reflective surface. Proposed multi-layer MEMS tuneable high-impedance surface consists of an array of coupled MEMS capacitors, much smaller than the wavelength of an incident field, placed on a grounded dielectric wafer, see Fig. 19 (lhs). Since the size of the MEMS varactors is much smaller than the wavelength, its electromagnetic response can be described in terms of the effective surface impedance. The input impedance of the grounded dielectric substrate, the thickness of which was chosen to be smaller than quarter of the wavelength, is inductive. Together with the capacitive array this forms a resonant structure. At a resonance frequency, the effective surface impedance of the structure becomes very large compared to the free space impedance, and the phase of the reflection coefficient changes from ±180º to 0º. If a control voltage is applied to the MEMS capacitors, the value of the capacitance changes, as well as the effective surface impedance. Due to this, the phase factor of the propagation constant of the field above the structure and the phase of its reflection coefficient can be controlled in analogue way by the applied voltage.

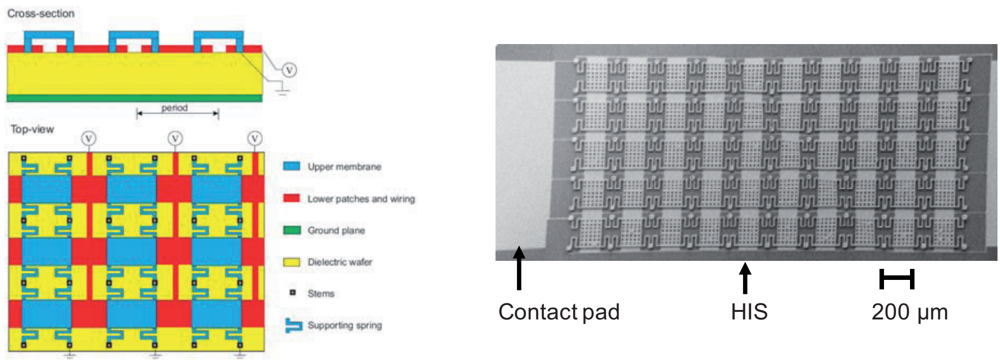


Fig. 19. Multilayer MEMS tuneable high-impedance surface (part of a larger array shown): design (lhs) and SEM image of the fabricated prototype (rhs).

New prototype of the MEMS based high-impedance surface has been recently fabricated, see Fig. 19 (rhs), and characterized, see Fig. 20, by measurements S_{11} of a sample placed as a backshort of a rectangular metal waveguide. The reflection phase of the MEMS tunable HIS changes gradually from nearly 180º to 0º at the resonance frequency 83.4 GHz and then to -180º, showing that the structure has high input impedance at the resonance. As soon as the MEMS varactors are actuated, the resonance shifts toward lower frequencies and the reflection phase changes dramatically for an operation frequency near the resonance. Typical insertion loss at the resonance referenced to the waveguide loss is 3.5 dB, whereas minimal insertion loss outside the resonance is as low as 0.7 dB. This is a dramatic improvement over our previous prototype, where insertion loss at and outside the resonance was 18 dB and 7 dB, respectively.

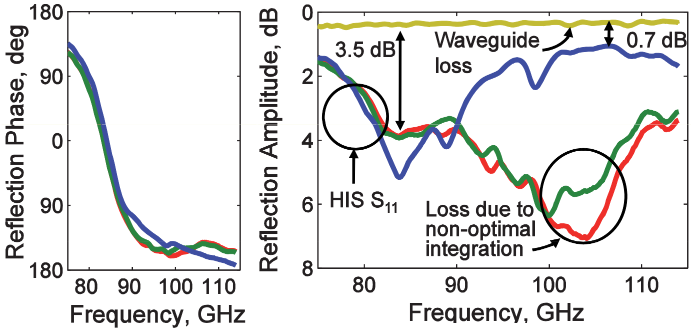


Fig. 20. Measured S_{11}-parameter of the reflection type phase shifter with MEMS tunable HIS over W-band. Reflection phase is 0° at the resonance frequency of 83.4 GHz. Minimum insertion loss of the HIS outside of the resonance is 0.7 dB.

A MEMS tuneable analogue type phase shifter is based on a dielectric rod waveguide (DRW) with adjacent MEMS tuneable high-impedance surface (HIS). Two samples of MEMS HIS have been fabricated by KTH (Royal Institute of Technology, Stockholm), each consisting of 120 x 24 MEMS varactors placed on a dielectric wafer with a ground plane, see Fig. 21.

Fig. 21. Fabricated MEMS tuneable high-impedance surface for an analogue type phase shifter.

The tapering part (6 mm) of the DRW with cross-section 0.5x1.0 mm^2 made of Si is fixed with holders inside the WR-10 waveguides for measuring S-parameters. The sample is fixed adjacent to the DRW. The S-parameters of the phase shifter aree measured applying to the MEMS HIS bias voltage, which is gradually changing from 0 V to 40 V. The analogue type phase shift shown in Fig. 22 (lhs) is a difference between S_{21} of voltage biased phase shifter and S_{21} of unbiased phase shifter.

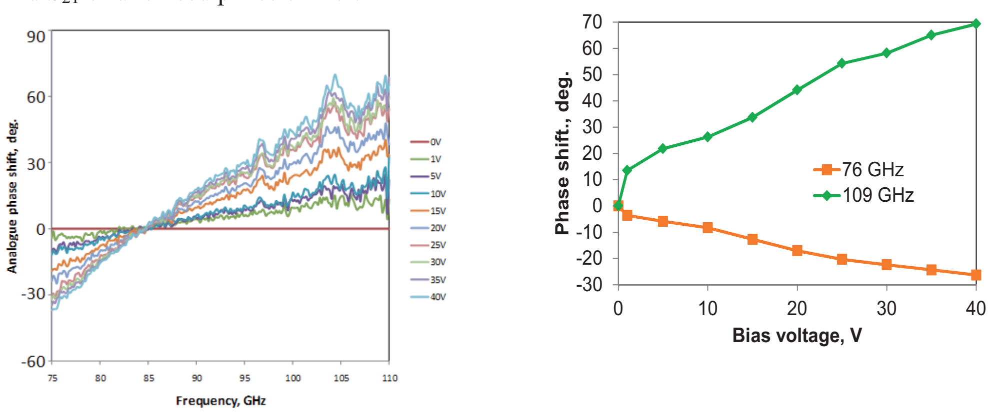


Fig. 22. Analogue type phase shift: frequency dependence for different bias voltages (lhs) and voltage dependence (rhs).

Other dielectric rod waveguide components. Nowadays DRW is one of the most efficient devices to transfer millimetre waves due to its low losses. Studies of dielectric rod waveguides made of high permittivity dielectric materials were continued in 110–170 GHz and 220–325 GHz frequency bands, Fig. 23. A study for determination of DRW antenna phase centre at W band was finalized in cooperation with Universidad Politécnica de Madrid.

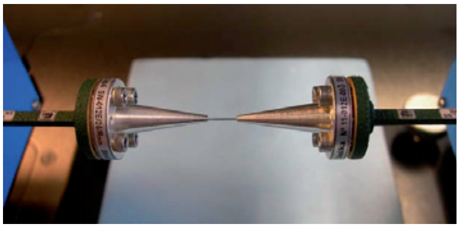


Fig. 23. Measurement setup of a silicon rod waveguide at 220–325 GHz.

A novel type of bolometer power sensor for millimetre wave applications was created and tested. It consists of a metallic antenna-like structure on top of Si DRW. Under the incident mm-wave power the bolometer antenna-like structure is heated and the resistance of the structure is changing. By measuring the change of resistance one can detect and measure power applied to the power sensor. This power sensor can be integrated into a DRW and thereby it allows to measure amount of power inside the DRW. The power sensor has several advantages in comparison with other existing power sensors, for example it is capable of measuring high values of power in continuous mode (200 mW and higher), while typical value of burnout power for thermoelectrical heterostructure power sensors is 55 mW. This sensor is also extra wide band power sensor. It was tested in the frequency range of 95 – 1011 GHz and it demonstrates good performance at all these frequencies.

Lens antenna with feed array for beam steering. A lens antenna with an integrated feed array can be used for beam-steering applications with high directivity. The conventional integrated lens types are extended hemispherical lens and elliptical lens. A Rexolite lens with optimised eccentricity was designed and tested at 77 GHz. The lens shape was optimised to achieve constant and high directivity over maximum beam-steering range. A LTCC feed array for the lens was designed and manufactured in VTT, see Fig. 24.

Fig. 24. A photograph of the designed Rexolite lens with optimised eccentricity. A photograph of the feed array with eight aperture coupled patch antennas on LTCC.

Linear 5-element antenna array for beam steering applications at 60 GHz. To obtain high-data-rate links indoors at 60 GHz, beam steering is one solution to overcome the high path loss. A linear 5-element antenna array with phase shifters was designed in co-operation with Nice University using membrane technology. With the so-called membrane process mm-wave antennas with high radiation efficiency and good radiation characteristics can be realized. The same process can be used to manufacture phase shifters based on MEMS switches. The simulated maximum gain of the developed 5-monopole antenna array is 9.0 dBi and the radiation efficiency is 87 %. Five equally spaced monopole antennas, each with a gain of 3.2 dBi, form the array. The return loss of the antenna elements is over 13.5 dB over the frequency range 57-64 GHz, The results show that the membrane technology is a good option for implementing a beam steering antenna system for 60 GHz communications applications.

Statistical channel models for 60 GHz radio propagation in hospital environments. In this work a radio channel model for 60 GHz very-high-speed radio systems in hospital environments has been developed. Two possible applications of those systems were considered: real-time high definition video streaming for angiography and ultrasonic imaging. These applications require data rates of 1 Gb/s or even higher, which can be realized with 60 GHz radio systems. Channel modeling was based on extensive radio channel measurement campaigns in the angiography and ultrasonic inspection rooms in Yokohama City University Hospital, Japan. The measurements revealed that the power delay profile in the angiography and the ultrasonic imaging rooms is significantly different to existing standards and therefore novel model structures were developed for these hospital scenarios. The channel models are useful for the performance evaluation of the wireless systems in hospital environments.

Reconfigurable millimetre-wave reflectarray for MMID and imaging applications. Reflectarray operating at 120 GHz is being developed. The 150-mm reflectarray is suitable for use in, e.g., millimetre-wave identification (MMID) or imaging application. The reflectarray will consist of approximately 3700 patch antennas coupled to micro-electro-mechanical-system (MEMS) based phase shifters, which are individually computer controlled. As a preliminary study perceiving the actively controlled system, static reflectarrays are designed and manufactured. Different test schemes cover focusing the beam to a certain distance and to certain offset from boresight. The static reflectarray elements are based on grounded coplanar waveguide (GCPW) patch antennas coupled to a stub with length according to the desired phase shift.

Indirect holographic imaging. In indirect holographic imaging, a synthetic-aperture-type approach is used to reconstruct an image of the target. The phase of electric field is not measured directly but by using the holographic principle adopted from its well known counterpart in optics. The holographic method enables the possibility to use simple receiver technology, such as square-law power detectors, making large 2D receiver arrays less challenging to produce when compared to complex assembly with heterodyne receivers in active imaging methods.
Imaging experiment at 310 GHz is presented in Fig. 25. A Gaussian wave was used as the reference wave in the holographic process. The amplitude of the reference wave is measured directly and the phase is simulated with phase pattern of a spherical wave originating from the place of the reference antenna. Images retrieved with aperture size of 40 x 40 cm^2 show close-to-theoretical performance in cross-range resolution: details down to 2 mm are visible 1.5 m away from the target. For comparison, the images are taken by both indirect holographic method and by directly measuring the complex object wave. The image quality does not vary between the two methods, indicating successful phase retrieval in indirect holographic process.

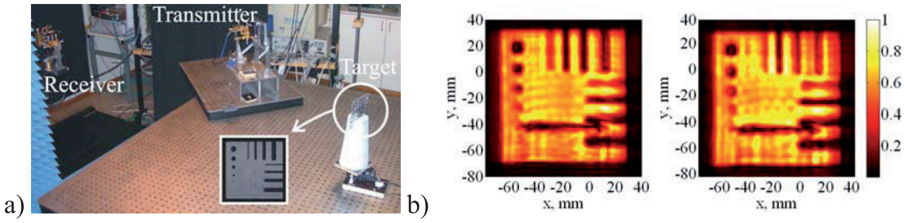


Fig. 25. Indirect holographic imaging. a) The setup. b) The images taken with holographic method (lhs) and with direct phase measurement (rhs).

Indirect holographic imaging: image quality evaluation. In indirect holographic process, amplitude and phase of field reflected from target is recovered from amplitude of an interference pattern. Various image quality parameters are evaluated for 310-GHz imaging system, Fig. 26. Estimates for the point spread function (PSF), SNR of the image, and for the noise equivalent reflectivity difference (NEΔR) are measured. SNR and NEΔR are evaluated also for different system noise levels in the imager. System noise level is artificially reduced, since laboratory equipment provides over-optimistic signal quality compared to realistic imager.

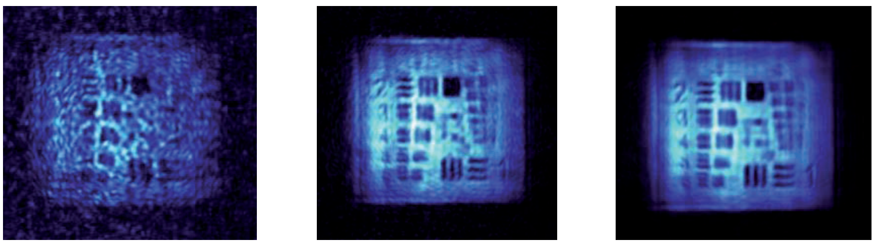


Fig. 26. Millimetre-wave image of USAF 1951 with system SNR of 0 dB, 10 dB, and 20 dB.

Integrated microbolometer detectors for passive imaging. A passive video-rate THz-imager has been developed at VTT in collaboration with SMARAD. Lens-bolometer detectors from VTT are characterized at 321-850 GHz. The radiation patterns are measured with horizontal and vertical polarizations. Performance differences between individual detectors in a single module are studied. Also, success to align the lens on the bolometer is evaluated.

The imager utilizes superconducting antenna-coupled microbolometers as sensitive detectors for submm-radiation. A 2-mm hyper-hemispherical silicon substrate lens is used to focus incident sub-mm radiation on the microbolometer. An air-suspended niobium nitride bolometer with an equiangular spiral antenna is located on the backside of the substrate lens. Such a device is a sensitive, wide-band bolometric detector when biased on its superconducting transition at a few Kelvin. Packed to an array of bolometers, the detectors are used in the focal plane of the imager. Fig. 27 a-c show microbolometer dimensions with an equiangular spiral antenna and a module of eight detectors.

Measurement setup: A room-temperature measurement range is used to characterize the radiation properties of above described detectors. A faithful measurement campaign with 4-K cryocooler is ruled out due to need for easy rotation of the detectors in the range. This leads to dramatic decrease in the sensitivity of the bolometer. The irradiance on the detectors needs to be correspondingly greatly increased compared to the superconducting operation of the bolometers. The reduced sensitivity must be compensated by use of powerful backward-wave oscillators (BWO) and by reducing the propagation path length in the range. Also, the read-out bolometer signal is easily buried in noise without dedicated data-acquisition incorporating low-noise amplification and lock-in detection.

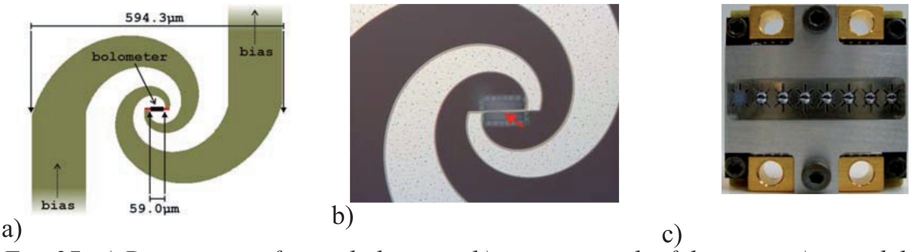


Fig. 27. a) Dimensions of microbolometer, b) a micrograph of the same, c) a module of eight bolometers with silicon lenses.

Radiation patterns: Radiation patterns for antenna-coupled microbolometers are measured at selected frequencies at 321-850 GHz (Figs. 28 a-e). The beam profile becomes more symmetrical as the frequency increases. At the same, beamwidth narrows from 25.3 degrees to 12.2 degrees. Also, azimuth cuts of the radiation patterns are measured at 321-500 GHz at

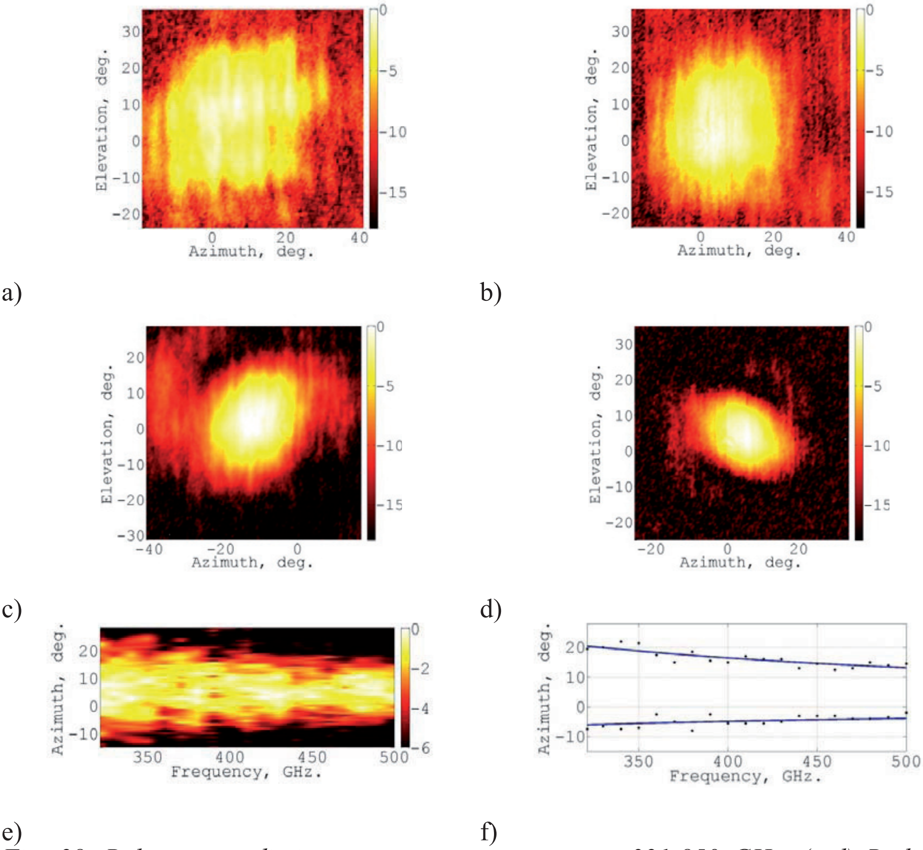
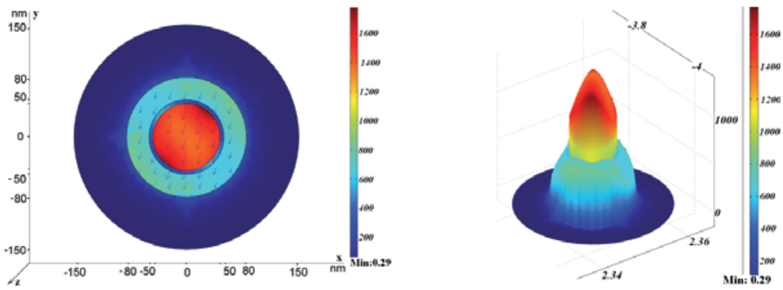


Fig. 28. Bolometer radiation pattern measurements at 321-850 GHz. (a-d) Radiation patterns at 321 GHz, 400 GHz, 654 GHz, and 780 GHz, respectively. (e) Azimuth cut of the radiation pattern at 321-500 GHz. (f) least squares fit to the radiation pattern cuts gives relation FWHM = 8.5° per THz. The scales in the patterns are in decibels

closely spaced frequencies. These measurements fitted with least squares method show 8.5-degrees-per-THz relation for the FWHM beamwidth of such a detector (Fig. 28 f).

Plasmonic coaxial waveguides. Waveguide properties of new optical waveguides made of noble metals and filled with glass and air have been studied. Such waveguides are coaxial cables and they differ from the conventional coaxial by the shape of their central rods. Coaxial waveguides with annular and elliptic central rods are considered. Numerical simulations demonstrate that these waveguides, having nanosize cross-sections, support propagation of a few comparatively low-loss modes, having phase velocity close to the speed of light and the fields localized in a small area outside metal, see Fig. 29.



a) b)

Fig. 29. Cross-section of the annular waveguide (a) and power flow distribution (b).

Electromagnetic waves in arrays of carbon nanotubes. Electromagnetic modes, guided by infinitely long single-wall metallic carbon nanotubes (CNTs), forming two-dimensional periodic array, were studied theoretically. It was demonstrated that electromagnetic coupling dramatically raises the slow-wave factor of modes propagating in arrays compared to that observed in single carbon nanotubes. It was shown that the array of CNTs exhibit properties of indefinite media, i.e. media with different signs of components of the permittivity tensor. Fig. 30 illustrates the conic-like dispersion, inherent in indefinite media.

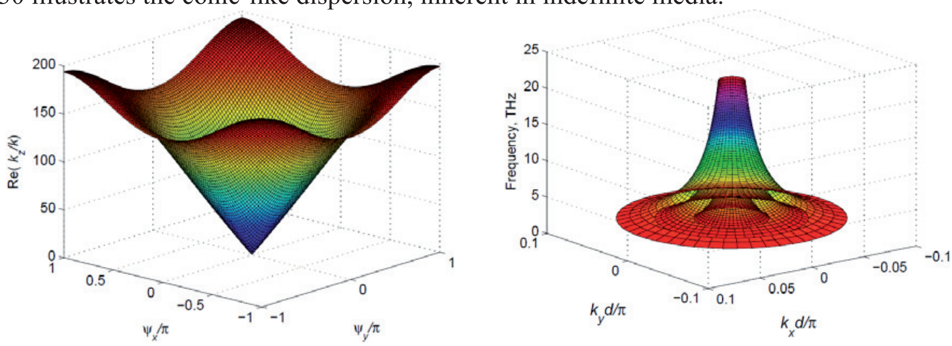
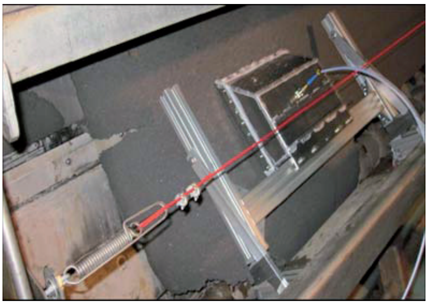


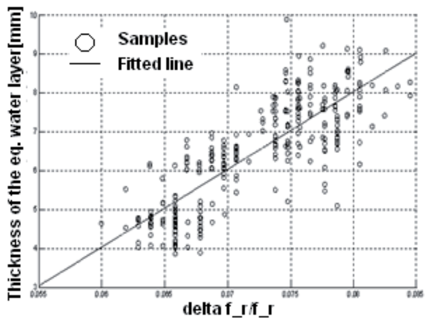
Fig. 30. Slow-wave factor for waves, propagating along CNTs over the transversal wave vector plane (isofrequency surface). b) Surface of dispersion for waves, propagating in a finite-thickness CNT slab.

We have shown that a finite-thickness slab of vertically standing metallic CNTs supports propagation of backward waves in ultra-broadband frequency range and by this reason can be referred to as a perfect planar THz metamaterial. Considerably low attenuation at terahertz frequencies is demonstrated. Transmission of a plane wave through a finite-thickness slab, which can be used as a terahertz polarizer, has been analyzed.

3.4 Sensors

Moisture measurements of a bio-material web using an RF resonator sensor. The objective of the project was to determine the moisture content of a bio material web (sludge from a paper factory) non-destructively using a resonator sensor (Fig. 31). The determination of the moisture content is based on the resonant frequency shift of the resonator due to change of the permittivity of the material inserted in the resonator. The comparison of the measurement results with reference moisture values obtained by oven drying indicate that the residual standard deviation in determining the amount of water per area is about 10 %.





a) b)

Fig. 31. a) Measurement setup in the factory measurements, b) results.

Nanostructures for very broadband or multi-frequency transition from wave beams to subwavelength light distributions. In this work we suggest and theoretically study a tapered plasmonic nanostructure which connects the incident wave beam with a sub-wavelength spatial region where the field is locally enhanced in a broad frequency range or for different operation frequencies, Fig. 32. This spatial region has a frequency stable location near the contour of the tapered structure. This results from a special waveguide mode which can also exist in the tapered structure. We foresee many possible applications for our structure from prospective near-field scanning optical microscopes to interconnect between conventional optical waveguides and prospective optical nanocircuits.

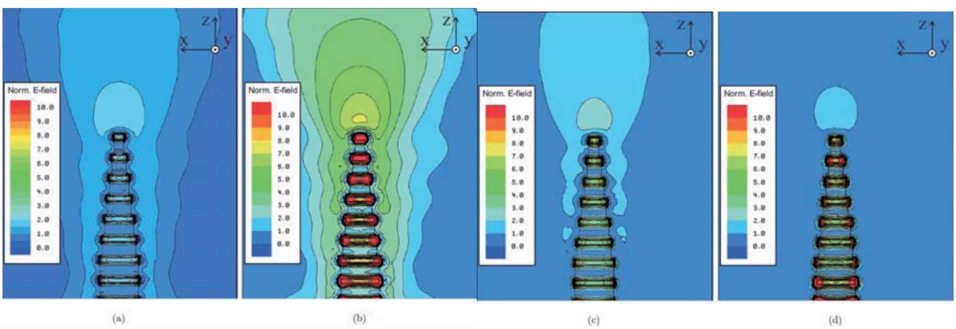


Fig. 32. The normalized amplitude of the electric field at (a) 550 THz, (b) 570 THz, (c) 590 THz, and (d) 610 THz.

Perfect lensing with phase-conjugating surfaces: approaching practical realization. In 2003, it was shown that two parallel sheets with phase-conjugation boundary conditions for tangential fields on the two sides of the sheets have the property of the *perfect lens*. Perfect lens is a device which focuses the field of a point source into a point, that is, the perfect lens focuses both propagating and evanescent fields. Considering the ideal phase-conjugating boundary conditions, we have realized that the induced electric and magnetic surface currents should form Huygens sources. These electric and magnetic surface currents form sets which radiate only towards one of the sides of the sheet, negating fields incident from one side of the sheet in the other half space and creating complex-conjugated fields in the corresponding half space. We have developed first conceptual designs of structures that can potentially realize such performance. The suggested structures contain electrically and magnetically polarizable particles with appropriate nonlinear loads. The necessary balance between electric and magnetic polarizations can be ensured by using combinations of complex-shaped resonant particles, such as helices with symmetrically positioned nonlinear elements. For potential optical applications, where the realization of complex-shape nonlinear inclusions is probably not realistic, a possible realization route is the use of layered structures (the thickness cannot be negligible because both electric and magnetic currents are needed).

MEMS gyroscope. The interface for a double axis gyroscope had been realized with cost and power optimized open-loop secondary readout method. The interface was first implemented in 2008 and presented at the International Conference on Solid-State Circuits 2009 and published in Journal of Solid-State Circuits. Similarly the realized drive-loop for the gyroscope was published in Analog Integrated Circuits and Signal Processing. The successful first period of the project continued with a second period, where the interface was completed with references and improved functionality where no external components would be required. The implementation allowed the whole interface to fit within a chip area of 4.3 mm^2. This version of the interface was presented at European Solid-State Circuit Conference 2010. The ASIC was also directly bonded to the sensor element and resulting in improved performance. This version of the MEMS gyroscope is shown in Fig. 33, where the ASIC lies on top of the sensor element. A journal paper comprising the results for the system in Fig. 33 has been accepted to the Journal of Solid-State Circuits.

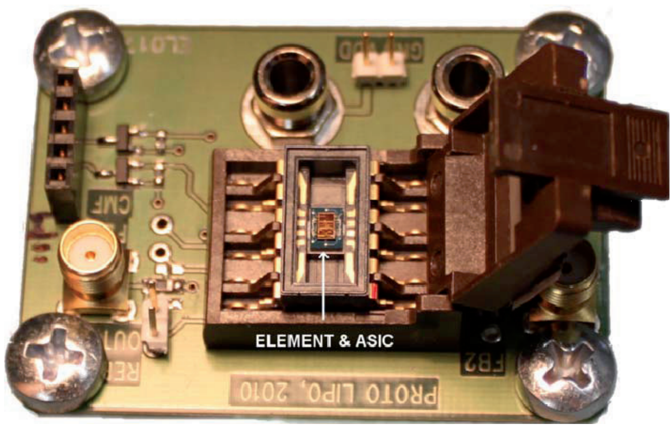


Fig. 33. The prototype PCB, which also shows the sensor element and the ASIC, which are directly wirebonded.

MEMS accelerometer. The accelerometer interface design that started in 2009 focused on realizing a closed-loop sensor. The goal was to minimize the complexity and maximize the performance of an accelerometer, where the element is strongly underdamped. One of the main objectives was to realize the electronic damping of the sensor, so that proper operation in practice was possible to achieve with the accelerometer. Noise density of 2 μg/√Hz and linearity of 0.33% was measured for the system. The results were published at the International Conference on Solid-State Circuits 2010. This research continued in 2010 with the design of a new interface, which will combine the benefits of both open- and closed-loop operation. This would eliminate the sensitivity of a fully closed-loop system to the drift in reference voltages, but also allow the use of high-Q and low-noise sensor element for the accelerometer. The accelerometer prototype is currently under measurements, and initial tests indicate proper functionality. The realized ASIC includes all the functional blocks on-chip and hence requires only minimal amount of external components.

MEMS frequency reference. The design of the interface for the temperature compensation of a MEMS frequency reference also continued in 2010. The chip that was designed and implemented in 2009 and included the electronics for realizing an interface for a MEMS oscillator, was tested to be functional. The measurements on the MEMS oscillator prototype however showed to be challenging, while the biggest obstacle was the lack of proper model for the MEMS resonator. The functionality of the system level ideas, which included a design of a microelectromechanical PLL, was finally measured using a discrete interface to complete the implemented interface chip. The concept of microelectromechanical PLL is currently being patented. The measured performance of the system, however, was modest and is currently being improved. One step taken to improve the modelling was to initialize the use of Coventor MEMS+ software, which allows moderately precise modelling of the MEMS structures, and straightforward inclusion of the models into circuit simulation tools. The design of the resonators for the MEMS PLL system was published at Eurosensors 2010 conference.

3.5 Materials and Energy

Investigations of fuel cells under the exposure of electromagnetic fields. It was examined whether the efficiency of fuel cells could be enhanced by exposing them to the influence of electromagnetic fields. A matching part between the feeding coaxial cable and the fuel cell was designed and constructed. Electrical properties of liquids in the fuel cell were measured to know how the electromagnetic fields propagate in the fuel cell. The output power of the fuel cell was measured with and without external electromagnetic field over the frequency range from 50 MHz to 5 GHz to find the frequencies at which the efficiency enhancement might occur. The results from the first series of measurements did not show any enhancement of the efficiency while, however, noting that the measurements were subject to several uncertainties.

Extraction of electromagnetic material parameters. Approaches of automated evaluation of electromagnetic material parameters have received a lot of attention in the literature. Among others, one method is to retrieve the material parameters from the reflection and transmission measurements of the sample material. Compared to other methods, this is a rather wide-band method, but suffers from an intrinsic limitation related to the electrical thickness of the measured material. In this work we propose a novel way to overcome this limitation. Although being based on the classical Nicolson-Ross-Weir (NRW) technique, the proposed extraction technique does not involve any branch seeking and is therefore capable of extracting material parameters from samples thicker than half a wavelength, a measure that would otherwise cause problems in the NRW extraction technique. The proposed derivative of the NRW extraction technique is then used to study the effect of thermal noise on the extracted material parameters.

Electromagnetic characterization of planar and bulk metamaterials. The most convenient way to describe the electromagnetic behavior of metamaterials is the utilization of so-called effective material parameters, obtained by a homogenization procedure. In our work we generalize a new method of electromagnetic characterization of planar metamaterials (metasurfaces) recently suggested in the literature. Using an example of a bilayer of plasmonic nanospheres we theoretically demonstrate that the results of this characterization method are suitable to predict scattering parameters of bilayer metasurfaces for any angle of incidence. Further, we develop an original electrodynamic approach which allows one to extract the effective material parameters of bulk lattices from reflection and transmission coefficients of a single generic metasurface. We show that the suggested method gives effective material parameters of bulk composite which satisfy the locality conditions. However, the frequency behavior of the dynamic material parameters is more complex than the simple Lorentzian dispersion predicted by the quasi-static approximation. Particularly, the resonances of electric permittivity and magnetic permeability become coupled with one another.

Negative effective permeability at optical frequencies produced by clusters of plasmonic nanoparticles. We suggest and study design solutions of metamaterials made of clusters of silver nanoparticles. These design solutions are modifications of the known effective rings formed by plasmonic nanospheres. Instead of nanospheres we suggest to use particles of different shapes, namely bi-spheres (dimers) and triangular nanoprisms. Nanoparticles are arranged into circular pattern on the dielectric core forming a raspberry-like magnetic nanocluster, Fig. 34. We show that these two designs theoretically allow one to obtain negative effective permeability in the near infrared and visible range even taking into account real dissipative losses in silver. Our designs fit the conditions of the optical smallness of the individual magnetic scatterer which is necessary for the homogenization procedure. In our study we have utilized two independent methods of calculation of material parameters. The results will be used as a basis for our future studies directed towards practical creation of an isotropic doubly negative metamaterial operating in the visible range.

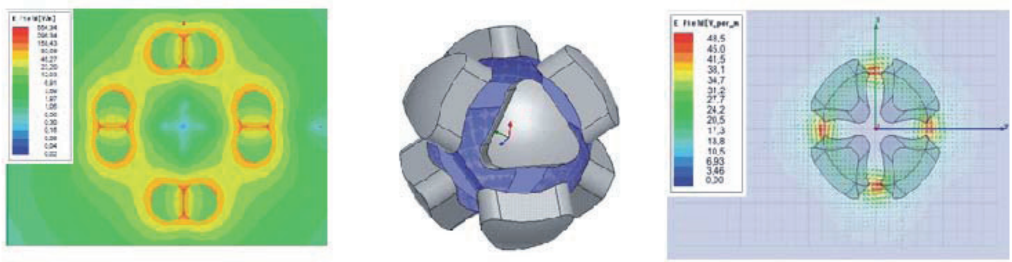


Fig. 34. (left) - Spatial distribution of the amplitude of electric field at 369 THz for an effective plasmonic loop comprising four dimers; (center) - A cluster made of eight triangular nanoprisms on a dielectric core; (right) - Spatial distribution of the electric field vector at 400 THz for the cluster comprising eight triangular nanoprisms.

4 Participation in European networks

Co-ordination:

METAMORPHOSE
SMARAD coordinated the FP6 Network of Excellence *Metamorphose* (Coordinator Prof. Sergei Tretyakov), which successfully concluded its joint program of activities in May 2008. As the main result of the Network work on European integration of research, Virtual Institute for Artificial Electromagnetic Materials and Metamaterials ”Metamorphose VI” has been established. This is a non-for-profit international association whose purposes are the research, the study and the promotion of artificial electromagnetic materials and metamaterials. Prof. Tretyakov, one of the principal investigators of SMARAD, is the President of this Association. The website of the Association is http://www.metamorphose-vi.org.

ECONAM
From April 2008 till March 2011, SMARAD was active in the FP7 Coordination and Support Action ECONAM. The main project goal was to consolidate efforts and bring coordination in the European work towards development, testing, and dissemination of methods and tools for electromagnetic characterisation and metrology of nanostructured composite materials. Prof. Simovski, a SMARAD member, is the scientific coordinator of this project. The web site of the project is http://econam.metamorphose-vi.org/.

TUMESA
SMARAD is the coordinator of project TUMESA (*MEMS Tuneable Metamaterials for Smart Wireless Applications*), which is funded by the European Community within Seventh Framework Programme, Information and Communication Technologies theme. Prof. Antti Räisänen is the Chairman of the Governing Board and Mr. Dmitry Chicherin, Lic.Sc., the Project Manager. In addition to Aalto University, the project partners are KTH - Royal Institute of Technology, University of Rennes I, Autocruise S.A. and MicroComp Nordic AB. The objective of the project is 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 are: 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. Duration of the project is 3 years and 4 months, from 1 June 2008 to 30 September 2011. The project website is http://radio.tkk.fi/tumesa.

Participation:

SENDORA
SMARAD (Aalto University MNT and SA) are project partners of project SENDORA. Dynamic spectrum allocation has become a key research activity in wireless communications field and in particular a key technology for "The Network of the Future" objective proposed in ICT FP7.Following these current trends towards dynamic spectrum allocation, the SENDORA project (January 2008-December 2010) has developed innovative techniques

based on sensor networks, that will support the coexistence of licensed and unlicensed wireless users in a same area. The SENDORA project ideas stem from recent fundamental works on cognitive radio technology.The capability to detect spectrum holes, without interfering with the primary network currently in use, is the actual major difficulty faced by the cognitive radio. The innovative concept proposed in SENDORA project consists in developing a "Sensor Network aided Cognitive Radio" technology which will allow to solve this issue, thanks to the introduction of sensor networks and associated networking capabilities. Prof. Ryynänen and Prof. Koivunen are WP leaders in this project.

METACHEM
SMARAD members (C. Simovski and S. Tretyakov) represent Aalto University as project partners in project METACHEM (Nanochemistry and self-assembly routes to metamaterials for visible light). Metamaterials are artificial composite materials whose electromagnetic properties are induced by an appropriate structuring of the medium at scales much smaller than the operational wavelength. For visible light, this effective medium requirement implies typical sizes of the artificial structures around a few tens of nanometers or less, hence setting the framework for the present project. The goal of the METACHEM research project is to tackle and solve crucial fabrication issues by creating a radically new generation of metamaterials at infrared and optical frequencies, which could be fabricated by nano-chemistry and self-assembly of materials as an alternative fabrication route that clearly veers away from lithography. One of targeted optical properties of these materials is the isotropic negative permeability and isotropic negative refraction index in the visible range. This task forms WP1 of the project. New design solutions and electromagnetic analysis methods suggested by Prof. C. Simovski who is the principal theorist of WP1 are intended to play a decisive role, by providing chemists with realisable models of nanostructured metamaterials with targeted optical properties. Prof. S. Tretyakov is the leading expert in workpackages 2-4 dedicated to metamaterials with extremal and useful properties, such as: nearly zero refraction index for transparent materials, nearly zero group velocity, high figure of merit for composites with large refraction index, etc.

5 SMARAD funding in 2008 – 2010

2008:

	RA	SA	MNT	TOTAL
Univ. budget (incl. extra funding for CoE)	848.000	509.000	526.000	1.883.000
External (competitive) funding	1.878.000	981.000	1.268.000	4.127.000
Total	2.726.000	1.490.000	1.794.000	6.010.000
External funding from the following sources:				
- Academy of Finland CoE	384.000	126.000	126.000	636.000
- Academy of Finland	271.000	30.000	0	301.000
- TEKES	450.000	202.000	401.000	1.053.000
- GETA	53.000	113.000	108.000	274.000
- ESA	199.000	0	0	199.000
- EU	312.000	40.000	17.000	369.000
- Finnish industry and other domestic sources	209.000	470.000	616.000	1.295.000

2009:

	RAD	SA	MNT	TOTAL
Univ. budget (incl. extra funding for CoE)	865.000	493.000	560.000	1.918.000
External (competitive) funding	2.168.000	1.004.000	1.269.000	4.441.000
Total	3.033.000	1.497.000	1.829.000	6.359.000
External funding from the following sources:				
- Academy of Finland CoE	382.000	127.000	127.000	636.000
- Academy of Finland	365.000	0	17.000	382.000
- TEKES	428.000	208.000	267.000	903.000
- GETA	67.000	101.000	0	168.000
- ESA	200.000	0	142.000	342.000
- EU	416.000	40.000	106.000	562.000
- Finnish industry and other domestic sources	310.000	528.000	610.000	1. 448.000

2010:

	RAD	SA	MNT	TOTAL
Univ. budget (incl. extra funding for CoE)	1.321.000	503.000	500.000	2.324.000
External (competitive) funding	2.031.000	1.442.000	1.465.000	4.938.000
Total	3.352.000	1.952.000	1.966.000	7.262.000
External funding from the following sources:				
- Academy of Finland CoE	382.000	127.000	127.000	636.000
- Academy of Finland	377.000	526.000	20.000	923.000
- TEKES	504.000	198.000	288.000	990.000
- GETA	67.000	54.000	76.000	197.000
- ESA	104.000	0	120.000	224.000
- EU	404.000	107.000	130.000	641.000
- Finnish industry and other domestic sources	193.000	430.000	704.000	1.327.000

6 SMARAD personnel in 2008 – 2010

In the Department of Radio Science and Engineering:

Ala-Laurinaho, Juha, D.Sc. (Tech.)	Senior scientist
Alitalo, Pekka, D.Sc. (Tech.)	Research associate, Post-doctoral researcher
Bin Al-Hadi, Azremi, M.Sc.	Research associate, from 14 November 2008
Blattmann, Bernhard, B.Sc.	IAESTE stipendiate, 7 June–31 August 2009
Beuerle, Bernhard, B.Sc.	Stipendiate, from 9 October 2009
Braute, Tom, M.Sc.	Stipendiate, 2 September–30 November 2009
Chicherin, Dmitry, Lic.Sc.(Tech.)	Research associate
Costa, Filippo, M.Sc.	CIMO stipendiate, 2 March–15 August 2009
Dahlberg, Krista, Ms.	Research assistant, from 22 May 2008
Dashti, Marzieh, M. Sc.	CIMO stipendiate, from 29 July 2009
Doudorov, Sergey, D.Sc. (Tech.)	Post-doctoral researcher, on leave of absence 1 June–30 November 2010
Du, Zhou, M.Sc.	Research associate, from 1 February 2009
Dupuy, Florian, B.Sc.	Stipendiate, 4 February–31 May 2008
Expósito, Gonzalo, B.Sc.	Erasmus stipendiate, 20 February–31 August 2009
Garrigas, Salvador, B.Sc.	Erasmus stipendiate, from 15 October 2008
Generalov, Andrey, M.Sc.	Summer trainee 1–30 June, Doctoral student from 25 October 2010
Geng, Suiyan, Lic.Sc. (Tech.)	Research associate, until 31 August 2010
Haneda, Katsuyuki, Ph.D.	Post-doctoral researcher
Holopainen, Jari, Lic.Sc. (Tech.)	Research associate
Hyötyläinen, Sami, Mr.	Research assistant, until 17 May 2008
Icheln, Clemens, D.Sc. (Tech.)	Professor pro tem, until 31 July 2008, leading scientist, 1 August–31 December 2008, Senior lecturer, from 1 January 2009
Ikonen, Harri, Mr.	Trainee, 19 October–4 December 2009
Ilvonen, Janne, Mr.	Research assistant, from 1 June 2008
Järveläinen, Jan, Mr.	Research assistant from 8 February 2010
Kahra, Eino, Mr.	Laboratory technician
Kanevska, Valentyna, M.Sc.	Project coordinator, until 31 May 2010
Kangasperko, Leena, BBA	Secretary, 9 January 2009–31 August 2010
Karilainen, Antti, M.Sc. (Tech.)	Research associate
Karttunen, Aki, Lic.Sc. (Tech.)	Research associate
Khatun, Afroza Mst, M.Sc.	Research associate, from 1 February 2009
Kim, Bumman, Ph.D.	Visiting professor, 25 August–25 October 2008
Kiuru, Tero, M.Sc. (Tech.)	Research associate
Kivekäs, Outi, D.Sc. (Tech.)	Research associate
Kolmonen, Veli-Matti, D.Sc. (Tech.)	Research associate, Post-doctoral researcher
Kyrö, Mikko, M.Sc. (Tech.)	Research associate
Laakso, Lauri, Mr.	Laboratory technician
Laitinen Tommi, D.Sc. (Tech.)	Senior scientist, Pro tem professor from 17 May 2010
Lehto, Arto D.Sc. (Tech.)	Senior lecturer, until 31 August 2008
Lesnyak, Natalia, M.A.	Project secretary, 12 February–31 May and 1 August–30 September 2008, from 1 January 2009
Li Yanfeng, B.Sc.	Research assistant, 1 June 2009–31 October 2010
Lindberg, Stina, B.Sc. (Econ.)	Secretary

Lioubtchenko, Dmitri, Ph.D.	Research associate, until 31 July 2008, Academy Research Fellow, from 1 August 2008
Luukkonen, Olli, D.Sc. (Tech.)	Research associate, on leave of absence 4 August 2009–31 August 2010
Maksimovitch, Ylena, Dr.	Visiting researcher, 5 November–22 December 2008, 8 June-19 July and 19 November–22 December 2009, 19 July–1 August 2010
Mallat, Juha, D.Sc. (Tech.)	Teaching scientist
Martinéz de Falcon Pérez, Jose, B.Sc.	Erasmus stipendiate, until 31 May 2008
Martinez Navarrete, Laura, B.Sc.	Erasmus stipendiate, from 2 November 2009
Medina Acosto, Gerardo, M.Sc.	Research associate from 1 October 2010
Mikhnev, Valeri, Dr.	Visiting researcher, 25 September–22 December 2008, 10 May-5 July and 1 November–22 December 2009, 1 July-31 August and 22 November-13 December 2010
Moradi Shahrbabak, Shahla B.Sc.	Research assistant, 27 June 2008–30 March 2009
Morits, Dmitry, M.Sc.	Research associate, from 2 November 2009
Muñoz-Acevedo, Alfonso, M.Sc.	Stipendiate, 17–28 August 2009
Mustonen, Maria, Lic.Sc. (Tech.)	Research associate, until 31 May 2008
Mustonen, Tuomas, Mr.	Research assistant, until 31 January 2008
Mylläri, Tuula, Ms.	Secretary, on leave of absence 19 January–13 August 2009
Nagy, Sorana, M.Sc. (Econ.)	Project secretary
Nefedov, Igor, Ph.D., Dr. Sc.	Senior scientist
Niemi, Teemu, Mr.	Research assistant, 18 May 2009–31 August 2010
Nieminen, Heini, Ms.	Research assistant, 19 May–17 August 2008
Nyberg, Lasse, Mr.	Research assistant, until 31 August 2009
Olkkonen, Martta-Kaisa, M.Sc. (Tech.)	Research assistant, Research associate, 1 June–31 August and from 26 October 2009
Olkkonen, Mikko, Mr.	Research assistant, until 31 March 2008
Otewa, Strasdosky, Mr.	Research assistant, 13 April 2009–31 October 2010
Padilla, Pablo, M.Sc.	Stipendiate, 11 May–30 September 2009
Parveg, Dristy, M.Sc.	Research associate, from 16 December 2010
Podlozny, Vladimir, Ph.D.	Project manager and Senior scientist
Pousi, Patrik, D.Sc. (Tech.)	Research associate, Post-doctoral researcher
Poutanen, Juho, M.Sc. (Tech.)	Research associate
Ranvier, Sylvain, Lic.Sc. (Tech.)	Research associate, until 31 October 2009
Rapoport, Yuri, Dr.	Visiting professor from 1 September 2010
Rasilainen, Kimmo, Mr.	Research assistant, from 18 May 2009
Robertson, Jean-Baptiste, M.Sc.Eng	Project coordinator from 1 June 2010
Räisänen, Antti, D.Sc. (Tech.)	Professor, Head of the Department
Salicrú Cortés, Monica, B.Sc.	Erasmus stipendiate, 2 February–30 June 2009
Schmuckli, Lorenz, Mr.	Laboratory technician
Sibakov, Viktor, M.Sc. (Tech.)	Laboratory manager
Simola, Jarno, Mr.	Research assistant, 18 May 2009–30 June 2010
Simovski, Constantin, Ph.D., Dr.Sc.	Senior scientist, 1 February–30 June 2008, Visiting professor, from 1 July 2008
Suoranta, Tanya, Ms.	Project secretary, 1 June–15 November 2010
Tamminen, Aleksi, M.Sc. (Tech.)	Research associate
Titz, Diane, B.Sc.	Stipendiate, 8 May–30 June 2009
Tiuri, Martti, D.Sc. (Tech.)	Professor emeritus

Toivanen, Juha, M.Sc. (Tech.)	Research associate
Tretyakov, Sergei, Ph.D., Dr.Sc.	Professor
Vaaja, Matti, M.Sc. (Tech.)	Research associate, until 31 December 2009
Valkonen, Risto, M.Sc. (Tech.)	Research associate
Vainikainen, Pertti, D.Sc. (Tech.)	Professor, on leave of absence until 31 July 2008 (Senior Scientist by the Academy of Finland)
Vaismaa Elina, M.Sc.	Project secretary, until 31 July 2008
Valagiannopoulos, Costas, Dr.	Post-doc researcher, from 21 September 2010
Vehmas, Joni, Mr.	Research assistant, 19 May–31 August 2008, 19 May-31 August 2009, and from 19 May 2010
Viitanen, Jarkko, Mr.	Research associate, until 31 July 2008
Västi, Juha, Mr.	Research assistant, 1 January–31 December 2009
Zvolensky, Tomas, M.Sc.	Research associate, from 1 March 2009

In the Department of Signal Processing and Acoustics:

Abrudan, Traian, D.Sc. (Tech)	Research associate, Post doc researcher, until 31 August 2010
Aittomäki, Tuomas, M.Sc. (Tech.)	Research assistant, until 31 May and from 22 September 2008
Arce, Gonzalo, Dr.Sc.	Fulbright professor, 28 June–31 December 2010
Arguello, Henry, Mr.	Fulbright stipendiate, 1 July–31 December 2010
Balakrishnan, Arun, Mr.	Stipendiate, from 17 November 2010
Belloni Fabio, D.Sc. (Tech.)	Research associate, until 31 July 2008
Bica, Marian, B.Sc.	Research assistant
Chaudhari, Sachin, M.Sc.	Research associate
Cheong, Mei Yen. Lic.Sc. (Tech.)	Research associate
Cierny, Michal, M.Sc.	Research assistant, until 31 August 2008, Research associate, from 1 August 2009
Cousseau, Juan, Ph.D.	Visiting professor, 2 May–30 June 2008, and 22 January–22 May 2010
Del Val Conejos, Maria, Ms.	Research assistant, 14 November 2008–30 June 2010
Dhamala, Ujjwal, Mr.	Research assistant, from 1 September 2010
Ekholm, Pyry, Mr.	Computer administrator, until 11 January 2009
Eratt Parameswaran, Sumesh, Ph.D.	Visiting professor, from 4 June 2010
Eriksson Jan, D.Sc. (Tech.)	Senior scientist
Florea, Mihail, Mr.	Research assistant, 1 March–30 April 2010
Haghparast, Azadeh, M.Sc.	Research associate, from 1 September 2008
Hynninen, Jussi, M.Sc.	Computer administrator
Jacob Mathecken, Pramod, Mr.	Research assistant, from 11 May 2009
Jänis, Pekka, M.Sc. (Tech.)	Research associate
Kashyak, Neelabh, B.Sc.	Research assistant, from 1 July 2010
Koivisto, Tommi, M.Sc. (Tech.)	Research associate, from 1 August 2008
Koivunen, Visa, D.Sc. (Tech.)	Professor, Academy professor ftom 1 August 2009
Le, Vieth Anh, M.Sc.	Research associate, from 1 September 2010
Lemetyinen, Mirja, Ms.	Secretary
Lundén, Jarmo, D.Sc. (Tech.)	Research associate, Post doc researcher
Mohammed, Mohammad, M.Sc. (also known as Shoaib, Mobien)	Research associate, until 15 November 2009
Muhammad, Asghar, M.Sc.	Stipendiate, 1 February–31 July 2010
Oborina, Alexandra, M.Sc	Research associate
Oksanen, Jan, M.Sc. (Tech.).	Research associate

Ollila, Esa, PhD	Senior scientist, Academy Research Fellow, from 1 August 2010
Pardina Garcia, Ivan, Mr.	Stipendiate, 15 March–31 July 2010
Pereira Da Costa, Mario, M.Sc	Research associate
Pölönen, Keijo, M.Sc. (Tech.)	Research associate
Rajasekharan, Jayaprakash, M.Sc.	Research associate, from 1 July 2008
Ramachandran, Vidhyalavnya, M.Sc.	Visiting researcher, 1 August–30 September 2010
Ramirez-Silva, Ana, M.Sc.	Fulbright stipendiate, 1 July–31 December 2010
Richter, Andreas, Dr.Ing.	Senior scientist, until 31 July 2008, Pro tem professor, from 1 August 2009
Riihonen, Taneli, M.Sc. (Tech.)	Research associate
Saeed, Umar, Mr.	Research assistant, from 10 May 2010
Salmi, Jussi, D.Sc. (Tech.)	Research associate, Post doc researcher
Schmidt, Cristian, M.Sc.	Research associate, 1 September–30 November 2009
Schober, Karol, M.Sc	Research associate
Simonen, Tarmo, M.Sc. (Tech.)	Computer administrator
Ufano Peremós, Ibone, Ms.	Stipendiate, 4 February–31 July 2010
Werner, Stefan, D.Sc. (Tech.)	Senior scientist, Academy Research Fellow, from 1 August 2010
Wichman, Risto, D.Sc. (Tech.)	Professor
Zacarias, Eduardo, M.Sc.	Research associate, until 30 April 2009

In the Department of Micro and Nanosciences:

Aaltonen, Lasse, Lic.Sc. (Tech.)	Research associate
Abu Bakar, Faizah (M.Sc.)	Research associate, 2009
Bruzdzinksi, Jakub, M.Sc. (Eng.)	Research associate, until 31 August 2008
Caujolle-Bert, Sylvain, B.Sc.	Research assistant, until 31 August 2009
Gronicz Jakub, M.Sc. (Eng.)	Research associate
Halonen Kari, D.Sc. (Tech.)	Professor, Head of the department
Kadiri, Nasir, Mr.	Research assistant, 2009
Kalanti, Antti, M.Sc. (Tech.)	Research assistant
Kaltiokallio, Mikko, M.Sc. (Tech.)	Research associate
Kämäräinen, Mikko, Lic.Sc. (Tech.)	Research associate, until 30 September
Kärkkäinen, Mikko, Lic.Sc. (Tech.)	Research associate
Kosunen, Marko, D.Sc. (Tech.)	Senior researcher
Laulainen, Erkka, Mr.	Research assistant
Meuronen, Anja, Ms.	Secretary, 2009
Nehal, Kaiser, B.Sc.	Research assistant, 2009
Nieminen, Tero, M.Sc. (Tech.)	Research associate
Paavola, Matti, Lic.Sc. (Tech.)	Research associate, until 30 September
Pulkkinen, Mika, B.Sc.	Research assistant
Rapinoja, Tapio M.Sc. (Tech.)	Research associate
Ryynänen, Jussi, D.Sc. (Tech.)	Professor
Saari, Ville, Lic.Sc. (Tech.)	Research associate
Salovaara, Jarno, B.Sc.	Research assistant
Sandström, Dan, M.Sc. (Tech.)	Research associate
Saukoski, Mikko, D.Sc. (Tech.)	Research associate, until 28 February 2008
Speeti, Timo, M.Sc. (Tech.)	Research assistant, until 30 September 2008
Stadius, Kari, Lic.Sc. (Tech.)	Senior researcher
Söderman, Lea, Ms.	Secretary
Talonen, Mikko, M.Sc. (Tech.)	Research associate

Tikka, Tero, M.Sc. (Tech.)	Research associate
Turunen, Vesa, M.Sc. (Tech.)	Research associate
Ukkonen, Pekka, B.Sc.	Summer trainee
Varonen, Mikko, Lic.Sc. (Tech.)	Research associate
Viitala, Olli, M.Sc. (Tech.)	Research associate
Xu, Liangge, M.Sc. (Tech.)	Research associate
Yllö, Helena, Ms.	Secretary, until 30 June 2010
Yucetas, Mikail, M.Sc. (Tech.)	Research associate

7 Visitors to SMARAD in 2008 – 2010

Visiting Professors:

- Prof. Igor Nefedov, Institute of Radiotechnics and Electronics, Russian Academy Science, Saratov Department, Russia
- Prof. Constantin Simovski, St. Petersburg Institute of Fine Mechanics and Optics, Russia, 1 February–30 June 2008, Visiting Professor since 1 July 2008
- Prof. Bumman Kim, Pohang University of Science and Technology, Korea, from 25 August–25 October 2008
- Prof. Juan Cousseau, Universidad Nacional del Sur, Argentina, 2 May–30 June 2008, and 22 January–22 May 2010
- Prof. V.E. Lyubtchenko, Institute of Radioengineering and Electronics, RAS, Russia, 5 February 2010
- Prof. Alexey Vinogradov, Institute for Theoretical and Applied Electromagnetics - ITAE, Russia, 7–11 February and 17–21 May 2010
- Prof. Ahmet S. Turk, Yildiz Technical University, Istanbul, Turkey, 6-8 July 2010
- Prof. Yuriy Rapoport, Taras Shevchenko University, Kiev, Ukraine, 1 September–31 December 2010
- Prof. Gonzalo Arce, University of Delaware, USA, 28 June -31 December 2010
- Prof. Marcello De Campos, Federal University of Rio de Janeiro, Brazil, 28 June–5 July 2010
- Prof. H. Vincent Poor, Princeton University, USA, 15–21 August 2010
- Prof. E. Delp, Purdue University, USA, 27–28 August 2010

Visiting Researchers:

- Dr. Valeri Mikhnev, The Institute of Applied Physics, Minsk, Belorussia, 29 September–22 December 2008, 10 May–5 July and 1 November–22 December 2009, 1 July–31 August and 22 November–13 December 2010
- Dr. Yelena Maksimovitch, The Institute of Applied Physics, Minsk, Belorussia, 2 November–22 December 2008, 3–21 December 2009, 19 July–31 August 2010
- Dr. Katsuyuki Haneda, Tokyo Instute of Technology, Japan
- B.Sc. Salvador Garrigas, Universidad Polytechnica de Valencia, Spain, until 30 April 2008
- B.Sc. Jose Luis Martinez de Falcon Pérez, Univ. of Navarra, Spain, until 31 May 2008
- B.Sc. Florian Dupuy, University of Rennes, France, 4 February–31 May 2008
- B.Sc. Shahla Moradi Shahrbabak, Univ. of Gävle, from 26 June 2008–31 March 2009
- B.Sc. Carolina Mateo Segura, Heriot-Watt University, Edinburgh, GB, 24 July–25 September 2008
- M.Sc. Azremi Bin Abdullah Al-Hadi, University Malaysia Perlis, Malaysia, from 11 November 2008

- M.Sc. Mst. Afroza Khatun, University of Gävle, Sweden, from 10 February 2009
- M.Sc. Tomas Zvolensky, Brno University of Technology, Slovakia, from 1 March 2009
- M.Sc. Tom Braute, Trondheim University, Norway, 2 September–30 November 2009
- M.Sc. Filippo Costa, University of Pisa, Italy, 2 March–15 August 2009
- M.Sc. Marzie Dashti, Tokyo Institute of Technology, Japan, 29 July 2009–31 March 2010
- M.Sc. Alfonso Muñoz-Acevedo, Technical University of Madrid, Spain, 17–28 August 2009
- M.Sc. Pablo Padilla, Technical University of Madrid, Spain, 11 May–30 September 2009
- M.Sc. Zhou Du, University of Science and Technology Liaoning, China, from 1 February 2009
- B.Sc. Monica Salicrú Cortés, Universitat Politècnica de Catalunya, Spain, 2 February–30 June 2009
- M.Sc. Vasily Semkin, St. Petersburg State University of Aerospace, Russia, 1–31 August 2009
- B.Sc. Diane Titz, LEAT, France, 8 May–30 June 2009
- B.Sc. Bernhard Blattmann, Zurich Technical University, Switzerland, 7 July–31 August 2009
- B.Sc. Bernhard Beuerle, Dresden University of Technology, Germany, from 9 October 2009
- B.Sc. Gonzalo Expósito, Technical University of Madrid, Spain, 20 February–31 August 2009
- B.Sc. Laura Martinez Navarrete, Polytechnical University of Valencia, Spain, 2 November 2009–30 June 2010
- M.Sc. Dmitry Morits, Saint-Petersburg State Polytechnical University, from 2 November 2009
- M.Sc. Cristian Schmidt, Universidad Nacional del Sur, Argentina, 1 September–30 November 2009
- PhD Arkadi Chipouline, Friedrich-Schiller-Universität, Jena, Germany, 17–18 January 2010
- M.Sc. Michal Pokorný, Brno University of Technology, Czech Republic, 9–16 May 2010
- DSc Ilya Ryzhikov, Institute for Theoretical and Applied Electromagnetics - ITAE, Russia, 17–21 May 2010
- MSc Nikolay Menshikh, Institute for Theoretical and Applied Electromagnetics - ITAE, Russia, 1–7 July 2010
- PhD Andrey Lavrinenko, Technical University of Denmark (DTU), Denmark, 16–17 August 2010
- PhD Cumali Sabah, Wolfgang Goethe-Universität FaM, Germany, 1–15 November 2010
- B.Sc. Javier Gorroño Viñegia, Polytechnical University of Valencia, Spain, 20 February–30 September 2010
- B.Sc. Alvaro Palacios Morales, Polytechnical University of Catalunya, 1 February–31 July 2010
- Mr. Xu, Lei, Hubei University of Technology, China, from 25 May 2010
- Dr. Constantinos Valagiannopoulos, University of Athens, Greece, from 21 September 2010
- M.Sc. Nilüfer Özdemir, University of Louvain, Belgium, 25 October–25 November 2010
- M.Sc. Gerardo Medina, Polytechnic University of Catalunya, Spain from 1 October 2010
- Dr. Eratt Paramerwaran Sumesh, Amrita Vishwa Vidyapeetham University, India, from 4 June 2010

- M.Sc. Ramachandran Vidhyalavanya, Amrita Vishwa Vidyapeetham University, India, from 1 August–30 September 2010
- M.Sc. Henry Arguello, University of Delaware, USA, from 1 July–31 December 2010
- M.Sc. Ana Ramirez-Silva, University of Delaware, USA, from 1 July–31 December 2010

8 Visits from SMARAD to foreign institutes in 2008 – 2010

- M.Sc.(Tech.) Tero Kiuru, ESA ESTEC, The Netherlands, until 10 December 2008
- Lic.Sc.(Tech.) Pekka Alitalo, Ecole Polytechnique Federal de Lausanne, EPFL, Lausanne, Switzerland, 1 July–21 December 2008
- Prof. Pertti Vainikainen, University of Bologna, Italy, 5–27 June 2008
- M.Sc. (Tech.) Mikko Talonen The Royal Institute of Technology, Stockholm, Sweden, 8–14 September 2008
- M.Sc. (Tech.) Jarmo Lundén, University of Pennsylvania, USA, until 1 April 2008
- D.Sc. (Tech.) Stefan Werner, Federal University of Rio de Janeiro and Military Institute of Engineering, Rio De Janeiro, Brazil, 23 August–7 September 2008
- D.Sc. (Tech.) Olli Luukkonen, University of Pennsylvania, USA, 3 August 2009–30 August 2010
- M.Sc. (Tech) Dan Sandström, ST-Microelectronics, Grenoble, France, 1 February–31 July 2009
- D.Sc. (Tech.) Tommi Laitinen, Tokyo Institute of Technology, Japan 6-17 April and Technische Universität München, 28 September–18 December 2009
- M.Sc. (Tech.) Mikko Kyrö, National Institute of Information and Communications Technology Japan, 21 October–3 November 2009
- M.Sc. (Tech.) Mikko Kyrö, Nice-Sophia Antipolis, France, 23 November–3 December 2009
- Lic.Sc. (Tech.) Jari Holopainen, University of Birmingham, U.K., 26 June–30 September 2009
- M.Sc. (Tech.) Risto Valkonen, Nice-Sophia Antipolis, France, 16 February–26 June 2009
- Lic.Sc. (Tech.) Aki Karttunen, Université de Rennes, France 16 March–15 May 2009
- M.Sc. Mohammed Mohammad, Prince Sultan Advanced Technology Research Institute, Kingdom of Saudi Arabia, 1 April–15 November 2009
- D.Sc. (Tech.) Jussi Salmi, University of Southern California, USA, 24 August 2009–September 2010
- D.Sc. (Tech.) Jarmo Lunden, Princeton University, USA, from August 2010
- D.Sc. (Tech.) Esa Ollila¸ Princeton University, USA, from August 2010
- Academy prof. Visa Koivunen, Princeton University, USA, June–August 2010
- M.Sc. (Tech.) Tuomas Aittomäki, Drexel University and Princeton University, USA, July 2010

9 Post-graduate degrees in 2008 – 2010

9.1 Doctor of Science (Technology)

2008:

Saukoski Mikko:	System and circuit design for a capacitive MEMS gyroscope Thesis defense: 18 April 2008 Opponent: Professor Robert Puers, Katholieke Universiteit Leuven, Belgium Preliminary examiners: Professor Kofi Makinwa, Delft University of Technology, The Netherlands, and Professor Richard Carley, Carnegie Mellon University, Pittsburgh, PA, USA Supervisor: Prof. Kari Halonen
Cássio Ribeiro:	Propagation parameter estimation in MIMO systems Thesis defense: 25 April 2008 Opponents: Prof. Reiner Thomä, TU Ilmenau, Germany, and Prof. Christoph Mecklenbräuker, TU Wien, Austria Preliminary examiners: Prof. Christoph Mecklenbräuker, TU Wien, Austria, and Dr. Juha Ylitalo, Elektrobit Oyj Supervisor: Prof. Visa Koivunen
Jouni Kaukovuori:	CMOS radio frequency circuits for short-range direct-conversion receivers Thesis defense: 9 May 2008 Opponent: Dr. Kåre Christensen, Oticon Ab, Sweden Preliminary examiners: Prof. Pietro Andreani, University of Lund, Sweden, and Dr. Domine Leenaerts, NXP, The Netherlands Supervisor: Prof. Jussi Ryynänen
Järvinen Jere:	Analog baseband circuits for sensor systems Thesis defense: 16 May 2008 Opponent: Professor Ari Paasio, University of Turku Preliminary examiners: D.Sc. (Tech.), Kimmo Koli, ST Microelectronics, Finland, and Professor Svante Signell, The Royal Institute of Technology, Kista, Sweden Supervisor: Prof. Kari Halonen
Teikari Ilari:	Digital predistortion linearization methods for RF power amplifiers Thesis defense: 26 September 2008 Opponent: Professor Timo Rahkonen, Oulu University, Oulu, Finland Preliminary examiners: Professor Lars Sundström, Ericsson Mobile Platforms and Lund University, Lund, Sweden, and Professor Mairtin O'Droma, University of Limerick, Ireland Supervisor: Prof. Kari Halonen
Mervi Hirvonen	Performance enhancement of small antennas and applications RFID Thesis defense: 7 October 2008 Opponent: Prof. Juan Mosig, EPFL Ecole Polytechnique Federale de Lausanne, Switzerland Preliminary examiners: D.Sc.(Tech.) Pekka Ikonen, Nokia Research Center, and Prof. Filiberto Bilotti, University Roma Tre, Italy Supervisor: Prof. Sergei Tretyakov
Traian Abrudan:	Advanced optimization algorithms for sensor arrays and multi-antenna communications

Thesis defense: 21 November 2008
Opponent: Prof. Athina Petropulu, Drexel University, USA, and Prof. Erik G. Larsson, Linköping University, Sweden
Preliminary Examiners: Prof. Corneliu Rusu, Technical University Cluj-Napoca, Romania, and Prof. Keijo Ruotsalainen, University of Oulu.
Supervisor: Prof. Visa Koivunen

2009:

Sylvain Ranvier	Radiowave propagation and antennas for high data rate mobile communications in the 60 GHz band Thesis defense: 3 April 2009 Opponents: Prof. Lluis Jofre (Universitat Politècnica de Catalunya), Spain, and Prof. Thomas Zwick (Universität Karlsruhe), Germany Preliminary examiners: Prof. Lluis Jofre (Universitat Politècnica de Catalunya), Spain and Prof. Michael Jensen (Brigham Young University), Utah, USA Supervisor: Prof. Pertti Vainikainen
Pekka Alitalo	Microwave transmission-line networks for backward-wave media and reduction of scattering Thesis defense: 7 August 2009 Opponent: Prof. Christophe Caloz, École Polytechnique Montréal, Canada Preliminary examiners: Dr. Andrea Alù, University of Texas, Austin, USA, and Dr. Min Qiu (Royal Institute of Technology, KTH), Stockholm, Sweden Supervisor: Prof. Sergei Tretyakov
Salmi Jussi	Contributions to measurement-based dynamic MIMO channel modeling and propagation parameter estimation Thesis defense: 14 August 2009 Opponents: Professor Claude Oestges, Université Catholique de Louvain, Belgium, and Dr. Juha Laurila, Nokia Research Center, Lausanne Preliminary examiners: Professor Claude Oestges, Université Catholique de Louvain, Belgium, and Ph.D. Terhi Rautiainen, Nokia Research Center Supervisor: Prof. Visa Koivunen
Lundén Jarmo	Spectrum sensing for cognitive radio and radar systems Thesis defense: 13 November 2009 Opponents: Prof. Brian M. Sadler, Army Research Laboratory MD, USA, and Prof. Sergio Barbarossa, University of Rome, Italy Preliminary examiners: Prof. Brian M. Sadler, Army Research Laboratory MD, USA, and Ph.D. Kimmo Kansanen, NTNU, Trondheim, Norway Supervisor: Prof. Visa Koivunen
Olli Luukkonen	Artificial impedance surfaces Thesis defense: 14 December 2009 Opponent: Prof. Stefano Maci (University of Siena), Italy Preliminary examiners: Dr. Christopher L. Holloway, National Institute of Standards and Technology, Boulder, Colorado, USA, and

Dr. Alexandros Feresidis, Loughborough University, Loughborough, U.K.
Supervisor: Prof. Antti Räisänen

2010:

Ollila Esa	Contributions to independent component analysis, sensor array and complex-valued signal processing Thesis defense: 5 March 2010 Opponents: Professor Abdelhak Zoubir, Technische Universität Darmstadt, Germany and Prof. Gonzalo Arche, University of Delaware, USA Preliminary examiners: Professor Abdelhak Zoubir, Technische Universität Damstadt, Germany and Professor Mikko Valkama, Tampere University of Technology Supervisor: Prof. Visa Koivunen
Veli-Matti Kolmonen	Propagation channel measurement system development and channel characterization at 5.3 GHz Thesis defense: 28 April 2010 Opponent: Prof. Matti Latva-aho, Oulu University, and D.Sc.(Tech.) Kimmo Kalliola, Nokia Oyj Preliminary examiners: Dr. Yves Lostanlen,Siradel, Toronto, Canada, and Prof. Jørgen Bach Andersen, Aalborg University, Denmark Supervisor: Prof. Pertti Vainikainen
Mikko Varonen	Design and characterization of monolithic millimeter-wave active and passive components, low-noise and power amplifiers, resistive mixers, and radio front-ends Thesis defense: 29 April 2010 Opponent: Prof. Piet Wambacq, Katholieke Universiteit Leuven, Belgium Preliminary examiners: Ass.Prof. Patrick Reynaer, Katholieke Universiteit Leuven, Belgium, and Prof. Henrik Sjöland, Lund University, Sweden Supervisor: Prof. Kari Halonen
Juha Toivanen	Measurement methods for mobile terminal antenna performance Thesis defense: 24 September 2010 Opponents: PhD Philip Miller, National Physical Laboratory, UK, and D.Sc. (Tech.) Jussi Raholala, Optenni Oy Preliminary examiners: Prof. Edward B. Joy, Bolder, Colorado, USA, and Ass. Prof. Buon Kiong Lau, University of Lund, Sweden Supervisor: Prof. Pertti Vainikainen
Matti Paavola	Integrated reference circuit for low-power capacitive sensor interfaces Thesis defense: 1 October 2010 Opponent: Prof. Trond Ytterdal, Norwegian University of Science and Technology, Norway Preliminary examiners: Prof. Philip K. T. Mok, Hong Kong University of Science and Technology, Hong Kong, and TkT Teemu Salo, VTI Technologies Oy, Finland Supervisor: Prof. Kari Halonen
Mika Kämäräinen	Low-power front-ends for capacitive three-axis accelerometers Thesis defense: 29 October 2010 Opponent: Prof. Juha Kostamovaara, Oulu University, Finland

	Preliminary examiners: Prof. Gary Fedder, Carnegie Mellon University, Pittsburgh, USA, and Ass. Prof. Remco Wiegerink, University of Twente, Enschede, The Netherlands Supervisor: Prof. Kari Halonen
Lasse Aaltonen	Integrated interface electronics for capasitive MEMS intertial sensor Thesis defense: 12 November 2010 Opponent: Prof. Pieter Rombouts, Ghent University, Belgium Preliminary examiners: Prof. Michael Kraft, University Highfield, Southampton, United Kingdom, and Prof. Haluk Külah, Middle East Technical University, Ankara, Turkey Supervisor: Prof. Kari Halonen
Kari Stadius	Integrated RF Oscillators and LO signal generation circuits Thesis defense: 23 November 2010 Opponent: Prof. Markku Åberg, VTT Technical Research Centre, Finland Preliminary examiners: Prof. Andrea Lacaita, Politecnico di Milano, Milano, Italy, and Prof. John R. Long, Delft University of Technology, The Netherlands Supervisor: Prof. Kari Halonen
Patrik Pousi	Active and passive dielectric rod waveguide components for millimetre wavelengths Thesis defense: 26 November 2010 Opponent: Prof. Dr.-Ing. Lorenz-Peter Schmidt, Universität Erlangen-Nürnberg, Germany Preliminary examiners: Dr. Alex Schuchinsky, Queens University, Belfast, N.I., and Prof. Andrea Neto, TU Delft, The Netherlands Supervisor: Prof. Antti Räisänen

9.2 Licentiate of Science (Technology)

2008:

Maria Mustonen	Multi-element antennas for future mobile terminals Graduation date: 14 January 2008 Supervisor: Prof. Pertti Vainikainen
Jari Holopainen	Handheld DVB and multisystem radio antennas Graduation date: 26 May 2008 Supervisor: Prof. Pertti Vainikainen
Pekka Puhakka	Calibration of the Kumpula polarimetric weather radar Graduation date: 16 December 2008 Supervisor: Prof. Antti Räisänen

2009:

Aki Karttunen	Design of feed systems for hologram-based compact antenna test-ranges (Syöttöjärjestelmien suunnittelu hologrammiin perustuviin kompakteihin antennimittauspaikkoihin) Graduation date: 28 September 2009 Supervisor: Prof. Antti Räisänen

2010:

Matti Vaaja	Design and realisation of L-band frequency scanning radiometer (L-alueen taajuspyyhkäisevän radiometrin suunnittelu ja toteutus) Graduation date: 17 May 2010 Supervisor: Prof. Antti Räisänen
Mikko Kyrö	Wideband radio channel measurements and antennas for millimeter wave communications (Laajakaistaiset radiokanavamittaukset sekä antennit millimetriaaltoalueen tietoliikennesovelluksiin) Graduation date: 7 June 2010 Supervisor: Prof. Pertti Vainikainen
Juho Poutanen	Radio wave propagation analysis for single and multilink MIMO channel models (Radioaaltojen etenemisen analysointi yhden ja usean linkin MIMO-kanavamalleja varten) Graduation date: 7 June 2010 Supervisor: Prof. Pertti Vainikainen

10 Awards, honors and prizes in 2008 – 2010

2008:

- Professor Sergei Tretyakov was awarded the Fellowship of the IEEE with citation "For contributions to artificial electromagnetic media for applications in wireless and optical systems".
- Professor Antti Räisänen was awarded the Edmond S. Gillespie Fellowship with citation "For outstanding and pioneering contributions to the theory, practice and art of antenna and RF measurements" by the Antenna Measurement Technique Association.
- Aleksi Tamminen (with his co-authors) received the EuRAD Young Engineers Prize of the European Radar Conference at the European Microwave Week in Amsterdam.

2009:

- Professor Visa Koivunen was appointed to the position of Academy professor.
- Professor Antti Räisänen received the AMTA Distinguished Achievement Award.
- Professor Sergei Tretyakov was elected as member of Finnish Academy of Technical Sciences (Teknillisten Tieteiden Akatemia).
- Professor Pertti Vainikainen was elected as member of Finnish Academy of Technical Sciences (Teknillisten Tieteiden Akatemia).
- Dr. Tommi Laitinen received the IEEE Antennas and Propagation Society 2009 R. W. P. King Award.
- Azremi Bin Abdullah Al-Hadi received the Loughborough Antennas & Propagation Conference Committee 2009 Best Student Paper Award.

2010:

- Academy professor Visa Koivunen was elevated to IEEE Fellow.
- Aleksi Tamminen won the Best Student Paper Award at GSMM2010 conference held on April 14-16, 2010, in Incheon, Republic of Korea. Aleksi's paper is titled "Wide-band measurements of antenna-coupled microbolometers for THz imaging".
- Dr. Tommi Laitinen won the Best Paper Award of the 32nd ESA Antenna Workshop held on 5-8 October, in Nordwijk, The Netherlands. Tommi's paper is titled "Fast pattern measurement of electrically large antennas by spherical near-field technique".

11 Publications 2008

11.1 Articles in scientific journals with peer-review

[1] A. Tamminen, A. Lönnqvist, J. Mallat, and A.V. Räisänen, “Monostatic reflectivity and transmittance of radar absorbing materials at 650 GHz,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 56, no. 3, pp. 632-637, March 2008.

[2] F. Fuschini, H. El-Sallabi, V. Degli-Esposti, L. Vuokko, D. Guiducci, and P. Vainikainen, “Analysis of multipath propagation in urban environment through multidimensional measurements and advanced ray tracing simulation,” *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 3, pp. 848-857, March 2008.

[3] A. Sihvola and S. Tretyakov, “Comments on boundary problems and electromagnetic constitutive parameters,” *Optik – International Journal for Light and Electron Optics*, vol. 119, pp. 247-249, 2008.

[4] T.A. Laitinen and O. Breinbjerg, “A first/third-order probe correction technique for spherical near-field antenna measurements using three probe orientations,” *Transactions on Antennas and Propagation*, vol. 56, no. 5, pp. 1259-1268, May 2008.

[5] T.A. Laitinen, “Double ϕ-step Θ-scanning technique for spherical near-field antenna measurements,” *Transactions on Antennas and Propagation*, vol. 56, no. 6, pp. 1633-1639, June 2008.

[6] J. Villanen, P. Suvikunnas, C. Icheln, J. Ollikainen, and P. Vainikainen, “Performance analysis and design aspects of mobile terminal multi-antenna configurations,” *IEEE Transactions on Vehicular Technology*, vol. 57, no. 3, pp. 1664-1674, May 2008.

[7] O. Luukkonen, C. Simovski, A. Räisänen, and S. Tretyakov, “An efficient and simple analytical model for analysis of propagation properties in impedance waveguides,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 56, no. 7, pp. 1624-1632, 2008.

[8] O. Luukkonen, C. Simovski, C. Granet, G. Goussetis, D. Lioubtchenko, A. Räisänen, and S. Tretyakov, ”Simple and accurate analytical model of planar grids and high-impedance surfaces comprising metal strips or patches,” *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 6, pp. 1624-1632, 2008.

[9] P. Alitalo and S. Tretyakov, “A three-dimensional backward-wave network matched with free space,” *Physical Letters A*, vol. 372, no. 15, pp. 2720-2723, 2008.

[10] P. Alitalo, O. Luukkonen, L. Jylhä, J. Venermo, and S. Tretyakov, “Transmission-line networks cloaking objects from electromagnetic fields,” *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 2, pp. 416-424, 2008.

[11] P. Alitalo, O. Luukkonen, J. Vehmas, and S. Tretyakov, “Impedance-matched microwave lens,” *IEEE Antennas and Wireless Propagation Letters*, vol. 7, no. 1, pp. 187-191, 2008.

[12] P. Alitalo, O. Luukkonen, and S. Tretyakov, “A three-dimensional backward-wave network matched with free space,” *Physics Letters A*, vol. 372, pp. 2720-2723, 2008.

[13] P.A. Belov, Y. Zhao, S. Tse, P. Ikonen, M.G. Silveirinha, C.R. Simovski, S. Tretyakov, Y. Hao, and C. Parini, “Transmission of images with subwavelength resolution to distances of several wavelengths in the microwave range,” *Physical Review B*, vol. 77, p. 193108, 2008.

[14] S. Maslovski, P. Alitalo, and S. Tretyakov, “Subwavelength imaging based on frequency scanning,” *Journal of Applied Physics*, no. 104, p. 103109, 2008.

[15] P. Suvikunnas, J. Salo, L. Vuokko, J. Kivinen, K. Sulonen, P. Vainikainen, J. Kivinen, and K. Sulonen, "Comparison of MIMO antenna configurations: Methods and experimental results," *IEEE Transactions on Vehicular Technology*, vol. 57, no. 2, pp. 1021-1031, 2008.
[16] A. Viitanen, I. Nefedov, and S. Tretyakov, "Guided waves along Lorenz-resonant layers," *Electromagnetics*, vol. 28, no. 7, pp. 544-551, 2008.
[17] M. Hirvonen and S.A. Tretyakov, "Near-zero permittivity substrates for horizontal antennas: Performance enhancement and limitations," *Microwave and Optical Technology Letter*, vol. 50, no. 10, pp. 2674-2677, 2008.
[18] M. G. Silveirinha, P.A. Belov, and C.R. Simovski, "Ultimate limit of resolution of subwavelength imaging devices formed by metallic rods," *Optics Lett*., vol. 33, pp. 1726-1729, 2008.
[19] C.R. Simovski, "Analytical modeling of double negative composites," *Metamaterials*, vol. 2, pp. 169-185, 2008.
[20] K.R. Simovski, A.A. Sochava, and I.V. Mel'chakova "A high-impedance surface with a stable low-frequency resonance," *Journal of Communications Technology and Electronics*, vol. 53, no. 5, pp. 497-506, 2008.
[21] I.V. Mel'chakova and K.R. Simovski, "Efficient simple analytic model of artificial impedance surfaces based on resonance microstrip grids," *Journal of Communications Technology and Electronics*, vol. 53, no. 8, pp. 874-882, 2008.
[22] P. Alitalo, S. Ranvier, J. Vehmas, and S. Tretyakov, "A microwave transmission-line network guiding electromagnetic fields through a dense array of metallic objects," *Metamaterials*, vol. 2, no. 4, pp. 206-212, 2008.
[23] S. Tretyakov, I. Nefedov, and P. Alitalo, "Generalized field-transforming metamaterials," *New Journal of Physics*, vol. 10, p. 115028, 2008.
[24] K. Guven, E. Saenz, R. Gonzalo, E. Ozbay, and S. Tretyakov, "Electromagnetic cloaking with canonical spiral inclusions," *New Journal of Physics*, vol. 10, p. 115037, 2008.
[25] S. Tretyakov and C. Simovski, "Electromagnetic response of thin metamaterial layers", *SPIE Newsroom*, p. 10.1117.2.1200805.1160, 2008.
[26] E. Saenz, I. Semchenko, S. Khakhomov, K. Guven, R. Gonzalo, E. Ozbay, and S. Tretyakov, "Modeling of spirals with equal dielectric magnetic, and chirals susceptibilities," *Electromagnetics*, vol. 28, pp. 476-493, 2008.
[27] J. Kaukovuori, K. Stadius, J. Ryynänen, and K Halonen, "Analysis and design of passive polyphase filters," *IEEE Transactions on Circuits and Systems I*, vol. 55, no. 10, pp. 3023-3027, 2008.
[28] T. Tikka, J. Ryynänen, and K. Halonen, "Low-noise amplifiers for WCDMA base-station receiver," *Analog Integrated Circuits and Signal Processing,* vol. 54. no. 2, pp. 105-111, Feb. 2008.
[29] V. Saari, J. Mustola, J. Jussila, J. Ryynänen, S. Lindfors, and K. Halonen, "Programmable SiGe BiCMOS low-pass filter for a multicarrier WCDMA base-station receiver," *Analog Integrated Circuits and Signal Processing*, vol. 54. no. 2, pp. 77-84, Feb. 2008.
[30] M. Saukoski, L. Aaltonen, and K.A.I. Halonen, "Effects of synchronous demodulation in vibratory MEMS gyroscopes: A theoretical study," *IEEE Sensors Journal*, vol. 8, no. 10, pp. 1722 – 1733, Oct. 2008.
[31] M. Varonen, M., Kärkkäinen, M., Kantanen, and K. Halonen, "Millimeter-wave integrated circuits in 65-nm CMOS," *IEEE Journal of Solid-State Circuit*s, vol. 43, no. 9, pp. 1991-2002, Sept. 2008.

[32] J.A.M. Järvinen, M. Saukoski, and K.A.I. Halonen, "A 12-bit ratio-independent algorithmic A/D converter for a capacitive sensor interface," *IEEE Transactions on Circuits and Systems* I, vol. 55, no. 3, pp. 730 - 740, April 2008.
[33] T. Rapinoja, K. Stadius, and K. Halonen, "A low-power phase-locked loop for UWB applications," *Analog Integrated Circuits and Signal Processing*, vol. 54. no. 2, pp. 95-103, Feb. 2008.
[34] M. Kantanen, M. Kärkkäinen, M. Varonen, M. Laaninen, T. Karttaavi, R. Weber, A. Leuther, M. Seelmann-Eggebert, T. Närhi, J. Lahtinen, and K.A.I. Halonen, "Low noise amplifiers for D-band," *Proceedings of the European Microwave Association (EuMA)*, vol. 4, no. 4, pp. 268-275, December 2008.
[35] J. Kaukovuori, J. Järvinen, J. Jussila, and J. Ryynänen, "Efficient current reuse for low-power transceivers," *Analog Integrated Circuits and Signal Processin*g, vol. 56, pp. 241-244, Sept. 2008.
[36] T. Abrudan, J. Eriksson, and V. Koivunen, "Steepest descent algorithms for optimization under unitary matrix constraint," *IEEE Transactions on Signal Processing*, vol. 56, no. 3, pp. 1134-1147, 2008.
[37] E. Ollila, H. Oja, and V. Koivunen, "Complex-valued ICA based on a pair of generalized covariance matrices," *Computational Statistics and Data Analysis,* vol. 52, pp. 3789-3805, 2008.
[38] E. Ollila, H-J. Kim, and V. Koivunen, "Compact CRB expression for independent component analysis," *IEEE Transactions on Signal Processing*, vol. 56, no. 4, pp. 1421-1428, 2008.
[39] E. Ollila, "On the circularity of a complex random variable," *IEEE Signal Processing Letters*, vol. 15, pp. 841-844, 2008.
[40] M. Shoaib, S. Werner, and J.A. Apolinrio Jr., "Reduced complexity solution for weight extraction in QRD-LSL algorithms," *IEEE Signal Processing Letters*, vol. 15, pp. 277-280, Feb. 2008.
[41] I.V. Semchenko, S.A. Khakhomov, and S.A. Tretyakov, "Chiral metamaterial with unit negative refraction index," *European Physical Journal Applied Physics,* DOI: 10.1051/epjap:2008131, 2008.
[42] P. Ikonen and S. Tretyakov, "On the advantages of magnetic materials in microstrip antenna miniaturization," *Microwave and Optical Technology Lett.,* vol. 50, no. 12, pp. 3131-3134, 2008.
[43] S.N. Dudorov, D.V. Lioubtchenko, and A.V. Räisänen, "Influence of metal-semiconductor contact on the transmission characteristics of image dielectric waveguide," *Microwave and Optical Technology Letter*s, vol. 50, no. 11, pp. 2925-2928, 2008.
[44] M. Elmustrati, H. El-Sallabi, and H. Koivo, "Applications of multi-objective optimization techniques in radio resource scheduling of cellular communication systems," *IEEE Transactions on Wireless Communications*, vol. 7, no. 1, pp. 343-353, 2008.
[45] K. Nordhausen, H. Oja, and E. Ollila, "Robust independent component analysis based on two scatter matrices," *Austrian Journal of Statistics,* vol. 37, no. 1, pp. 91-100, 2008.

11.2 Articles in conference proceedings

[1] A. El-Damak, A. Safwat, S. Tretyakov, and H. El-Hennawy, "Patch antenna on a high impedance wire," in *Proceedings of the 38th European Microwave Conference*, Amsterdam, October 2008, pp. 932-935.

[2] O. Renaudin, V.-M. Kolmonen, P. Vainikainen, and C. Oestges, "Wideband MIMO car-to-car radio channel measurements at 5.3 GHz," in *68th IEEE Vehicular Technology Conference*, Calgary, Alberta, September 2008.
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11.5 Text books and other books related to scientific research

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11.6 Chapters in books

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12 Publications 2009

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13.3 Published monographs

No monographs published in 2010

13.4 Other scientific publications

[1] T. Hult, F. Tufvesson, V.-M. Kolmonen, J. Poutanen, and K. Haneda, “Analytical dual-link MIMO channel model using correlated correlation matrices,” COST 2100 Meeting tech. rep., Athens, Greece, 2-5 Feb. 2010, TD(10)10052.
[2] V.-M. Kolmonen, K. Haneda, T. Hult, J. Poutanen, F. Tufvesson, and P. Vainikainen, “Measurement-based evaluation of interlink correlation for indoor multi-user MIMO channels,” COST 2100 Meeting tech. rep., Athens, Greece, 2-5 Feb. 2010, TD(10)10070.
[3] O. Renaudin, V.-M. Kolmonen, P. Vainikainen, and C. Oestges, “Description of the august 2009 car-to-car radio channel measurement campaign,” COST 2100 Meeting tech. rep., Athens, Greece, 2-5 Feb, 2010, TD(10)10013.

[4] V.-M. Kolmonen, Propagation channel measurement system development and channel characterization at 5.3 GHz, TKK Radio Science and Engineering Publications, Report R12, March 2010, 110 p.

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[6] J. P. Pousi, “Active and passive dielectric rod waveguide components for millimetre wavelengths,” No. R18 in TKK Radio Science and Engineering Publications, Espoo, November 2010, 204 p.

[7] A. Sihvola and S. Lindberg, “Aalto University school of science and technology department of radio science and engineering research and education 2009,” No. R16 in TKK Radio Science and Engineering Publications, Espoo, 2010, 86 p.

[8] J. Toivanen, “Measurement methods for mobile terminal antenna performance,” No. R17 in TKK Radio Science and Engineering Publications, Espoo, Sept. 2010, 132 p.

[9] M. Valkama and R. Wichman, RF-signaalia ehostetaan digitaalisesti, *Prosessori,* no. 3, pp. 29-33, 2010.

[10] E. Ollila, *Contributions to independent component analysis, sensor array and complex-valued signal prosessing*, Aalto University, Department of Signal Processing and Acoustics, Report 14, 2010, 106 p.

[11] M. Rinne, *Covergence of packet communications over the evolved mobile networks; signal processing and protocol performance*, Aalto University, Department of Signal Processing and Acoustics, Report 15, 2010, 126 p.

[12] K. Doppler, *In-band relays for next generation communication systems*, Aalto University, Department of Signal Processing and Acoustics, Report 19, 2010, 133 p.

13.5 Text books and other books related to scientific research

None published in 2010.

13.6 Chapters in books

[1] E. Ollila, and V. Koivunen, “Robust estimation techniques for complex-valued random vectors,” in *Adaptive Signal Processing: Next Generation Solutions,* (T. Adali and S. Haykin, ed.), Hoboken New Jersey, Wiley-InterScience, 2010, pp. 89-141.

[2] P. Ilmonen, K. Nordhausen, H. Oja, and E. Ollila, “A new performance index for ICA: properties, computation and asymptotic analysis,” in *Latent Variable Analysis and Signal Separation,* (V. Vigneron, V. Zarzoso, E. Moreau, R. Gribonval, and E. Vincent, ed.), Springler, Heidelberg, 2010, pp. 229-236.

14 Other scientific activities of SMARAD members in 2008 – 2010

University Boards:

Kari Halonen
- Member, ETA Faculty Council
- Chairman, ETA Faculty Degree Committee
- Member, Board of Directors of MilliLab
- Department Head, Department of Micro and Nanosciences

Visa Koivunen
- Vice-leader, SMARAD CoE
- TKK Dissertations Committee, member (- 2009)

Jussi Ryynänen
- Head of Electronics and Electrical Engineering (EST) study programme
- Member, EST degree programme committee

Antti Räisänen
- Chairman, TKK Dissertations Committee
- Member, TKK Education and Research Council
- Member, ETA Faculty Council
- Department head, Department of Radio Science and Engineering
- Leader, SMARAD CoE
- Chairman, Board of Directors of MilliLab

Pertti Vainikainen
- Member, TKK Committee for Research Affairs and Doctoral Education
- Vice Member, ETA Degree Programme Committee for Bachelor's Degree Programmes
- Vice Member, Joint Degree Programme Committee for Electronics and Communications Engineering

Risto Wichman
- Vice Member, Graduate School Committee, ETA faculty
- Department vice-head, Department of Signal Processing and Acoustics (2010)

Participation in Organization of Scientific Conferences and Membership in Expert Boards

Kari Halonen
- TPC Member, European Solid-State Circuits Conference
- TPC Member, IEEE International Solid-State Circuits Conference
- Member, Management Group of NORCHIP Conference
- Member, Management Group of PRIME workshop
- Member, Evaluation committee of the Swedish Foundation for Strategic Research (SSF)
- Associate Editor, IEEE Journal of Solid-State Circuits
- Guest Editor, special issue on ESSCIRC'08 of IEEE Journal of Solid-State Circuits
- Guest Editor, special issue on ISSCC2010 of IEEE Journal of Solid-State Circuits

- Member, Editorial board of Springer International J. of Analog Integrated Circuits and Signal Processing
- Organizing Co-Chair of NORCHIP 2010 Conference

Visa Koivunen
- Fellow, IEEE
- Associate Editor, Signal Processing
- Associate Editor, EURASIP Journal of Wireless Communications and Networking
- Millenium Technology Prize, official host of finalist Dr. Viterbi (2008)
- Nokia Foundation, board member and vice-chair (2008)
- Technical Program committee: IEEE SPAWC (2008)
- Session Convener, URSI General Assembly (2008)
- IEEE Signal Processing for Communications Technical Committee (SPCOM-TC) member and industry liason
- Associate Editor, IEEE Transactions on Signal Processing
- IEEE Signal Processing Society, Industrial Liason board
- Member, IEEE Sensor array and Multichannel Signal Processing Technical Committee (SAM-TC)
- KTH advisory board, ICT area
- Evaluator: Center of excellence program: VINNOVA and Strategic Research Area program, Sweden
- TPC Member, IEEE SPAWC 2009
- TPC Member, IEEE SAM 2009
- TPC Member, IEEE SPAWC 2010
- TPC Member, IEEE SAM 2010
- COST IC902 Cognitive Radios, Finland representative

Jussi Ryynänen
- Track Chair, ECCTD 2009
- TPC Member, European Solid-State Circuits Conference ESSCIRC 2011
- TPC Member, European Conference on Circuit Theory and Design, ECCTD 2011
- Workshop chair ESSCIRC 2011

Antti Räisänen
- Fellow, IEEE
- Edmond S. Gillespie Fellow, AMTA
- Member of the Board of Directors, Member of the General Assembly, European Microwave Association (EuMA)
- Chairman of the EuMA Awards Committee (2009 -)
- Global Symposium on Millimeter Waves, GSMM 2008, Nanjing, China, April 21-24, 2008, Conference Co-Chair
- 19th International Symposium on Space Terahertz Technology, ISSTT2008, Groningen, The Netherlands, April 28-30, 2008, member of the Scientific Organizing Committee
- 30th ESA Antenna Workshop on Antennas for Earth Observation, Science, Telecommunication and Navigation Space Missions, Noordwijk, The Netherlands, May 27 30, 2008, member of the TPC
- European Microwave Week and 38th European Microwave Conference, Amsterdam, The Netherlands, October 27-31, 2008, member of the TPC

- 30th Annual Symposium of the Antenna Measurement Techniques Association (AMTA), Boston, MA, USA, Nov. 16–21, 2008, member of the TPC
- TPC Member, 31th Annual Symposium of the Antenna Measurement Techniques Association (AMTA)
- TPC Member, 3rd European Conference on Antennas and Propagation (EuCAP 2009)
- TPC Member, 5th ESA Workshop on Millimetre Wave Technology and Applications and 31st ESA Antenna Workshop
- TPC Member, 20th International Symposium on Space Terahertz Technology ISSTT2009
- TPC Member, European Microwave Week 2009
- General Vice-Chair, Global Symposium of Millimeter Waves, GSMM 2009
- Member of the TPC, 21st International Symposium on Space Terahertz Technology, ISSTT2010 (Oxford, UK, 23 - 25 March 2010)
- Member of the TPC, 4th European Conference on Antennas and Propagation, EuCAP2010 (Barcelona, Spain, 12–16 April, 2010)
- General Vice Chair, Global Symposium on Millimeter Waves, GSMM2010 (Incheon, Korea, April 14–16, 2010)
- Member of the Kenneth J Button Prize Committee, 35th International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz 2010 (Rome, Italy, 5-10 September, 2010)
- Member of the TPC, 20th International Conference on Applied Electromagnetics and Communications, ICECom 2010 (Dubrovnik, Croatia, 20-22 September, 2010)
- Member of the TPC, European Microwave Week, EuMW2010 (Paris, France, 26 September – 1 October, 2010)
- Member of the TPC, 32nd ESA Antenna Workshop (ESTEC, Noordwijk, The Netherlands, October 5-8, 2010)
- Member of the TPC, 32nd Annual Antenna Measurement Techniques Association (AMTA) Symposium (Atlanta, USA, 11-15 October, 2010)

Sergei Tretyakov
- Fellow, IEEE
- Fellow, Electromagnetics Academy
- President, the Virtual Institute for Artificial Electromagnetic Materials and Metamaterials
- Member, Steering Committee of the European Doctoral Programme on Metamaterials
- Deputy member, URSI Finnish National Committee
- Advisory Group Member, EU 7th Framework Programme on Nanosciences, Nanotechnologies, Materials and New Production Technologies
- General Chair, 2nd International Congress on the Advanced Electromagnetic Materials in Microwaves and Optics, Metamaterials'2008, Pamplona, Spain, September 2008
- European Microwave Conference 2008 - member of the review board
- Member of the editorial board: Metamaterials (until June 2008), Electromagnetics, and J. Electromagnetic Waves and Applications
- Member of the International Bianisotropics Conference Committee (2008)
- TPC member of SPIE Optics and Photonics (Metamaterials: Fundamentals and Applications), San Diego, USA, August 2008
- Member of the Steering Committee of the European Doctoral Programme on Metamaterials

- TPC Member, Loughborough Antennas & Propagation Conference 2009, Loughborough, United Kingdom, November 2009
- TPC Chair, Metamaterials 2009: The Third International Congress on Advanced Electromagnetic Materials in Microwaves and Optics, London, UK, September 2009
- TPC Member, Progress In Electromagnetics Research Symposium, Moscow, Russia, August 2009
- TPC Member, The Sixth IASTED International Conference on Antennas, Radar and Wave Propagation, Banff, Alberta, Canada, July 2009
- TPC Member, SPIE Europe Optics and Optoelectronics Symposium 2009, Prague, Czech Republic, April 2009
- General chair, Fourth International Congress on Advanced Electromagnetic Materials in Microwaves and Optics (Karlsruhe, Germany, September 2010)
- Member of the TPC: META'10, 2nd International Conference on Metamaterials, Photonic Crystals and Plasmonics (22-25 February, 2010, Cairo, Egypt)
- Member of the TPC, SPIE Photonics Europe 2010 (12 - 16 April 2010, Brussels, Belgium)
- Member of the TPC, CIMTEC'2010 International Ceramics Congress, 5th forum on new materials, (13-18 June 2010, Montecatini Terme)
- Member of the TPC, 7th Kharkov Symposium on Physics and Engineering of Microwaves, Millimeter, and Submillimeter Waves (MSMW'10 and TERATECH'10) (June 21-26, Kharkov)
- Member of the TPC, Loughborough Conference of Antennas and Propagation (LAPC), (Loughborough, UK, November 8-9, 2010)
- Member, Expert Advisory Group for Nanosciences, Nanotechnologies, Materials and New Production Technologies (European Commission, 7th Framework Programme)

Pertti Vainikainen

- 17th International Conference on Microwaves, Radar and Wireless Communications, MIKON"08, Wroclaw, Poland, May 19-21, 2008, member of the TPC
- IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, Amsterdam, Cannes, France, 15 – 18 September 2008, member of the TPC
- Conference Chair, The 8th International Conference on Electromagnetic Wave Interaction with Water and Moist Substances ISEMA 2009, Espoo, Finland, June 1-5, 2009

Risto Wichman

- Offical Member, URSI Finnish National Committee, Radiocommunication Systems and Signal Processing: Comission
- Local liaison office, EURASIP
- TPC Member IEEE Globecom, IEEE ICC, Finnish URSI Convention on Radio Science
- Steering Group Member, COST IC0803 RF/Microwave Communication Subsystems for Emerging Wireless Technologies

Review Activities

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*
- Reviewer for research project "CMOS-based realization of transmit and receive architectures for sub-THz applications", the Research Foundation – Flanders (FWO), appl. no. 34456, Belgium
- Reviewer of Doctoral theses of Lucian Stoica: "Non-coherent Energy Detection Transceivers for Ultra Wideband Impulse Radio Systems", Oulu University, Oulu, Finland
- Opponent of Doctoral thesis of N. Nejad: "Ultra-Wideband Impulse-Radio in Umbiquitous Wireless sensing and Identification", the Royal Institute of Technology, Kista, Sweden. December 4, 2008
- Member of Dissertation Committee of J. Atallah: "Integrated frequency synthesis for convergent wireless solutions", the Royal Institute of Technology, Kista, Sweden. November 20, 2008.
- Opponent for the doctoral thesis of Rashad Ramzan, Linköping University, Sweden (2009)
- Opponent for the doctoral thesis of Tajeshwar Singh, Norwegian University of Science and Technology, Norway (2009)
- Opponent for the doctoral thesis of Karen Scheir, Vrije Universiteit Brussels, Belgium, Karen Scheir, Belgium (2009)
- external expert for University Lecturer position, Lund University (2010)
- Reviews for research project "Sub-THz CMOS sensors for electromagnetic aquametry", the Research Foundation – Flanders (FWO), appl. no. 63429, Belgium (2010)
- Oppponent for the doctoral thesis of Markus Törmänen, Lund University, Sweden (2010)
- Oppponent for the doctoral thesis of Wei Chan, Delft University of Technology, The Netherlands (2010)

Visa Koivunen

- Doctoral thesis pre-examiner, M.Sc. Lev Smolyar, Tel-Aviv University, Israel, 2008
- Evaluator: Swedish Graduate School programs (Högskoleværket), Sweden, 2008
- Evaluator: research programs, Science Foundation of Ireland, 2008
- Evaluator: Center of excellence program: VINNOVA, Sweden, 2008
- Evaluator: grant proposals, Israel Science Foundation, 2008
- Evaluator, grant proposal, Air Force Office of Scientific Research, USA, 2009
- Evaluator, Vetenskaprådet, strategic research fund, Sweden, 2009
- Evaluator, Israel Science Foundation, 2010
- Reviews for journals: *IEEE Transactions on Signal Processing, IEEE Signal Processing Magazine, IEEE Journal of Selected Areas in Communications, IEEE Transactions on Antennas and Propagation, IEEE Jornal of Selected Topics in Signal Processing*
- Reviews for conferences *IEEE ICASSP, IEEE SPAWC, IEEE SAM, IEEE PIMRC, IEE ICC, URSI GA*

Jussi Ryynänen

- Reviews for *IEEE Transactions on Circuits and Systems-Part I, IEEE Journal of Solid-State Circuits, Integration, the VLSI Journal, IEEE Transactions on Instrumentation & Measurement, IEEE International Solid-State Circuits Conference ISSCC 2008, and IEEE International Symposium on Circuits and Systems ISCAS 2008, IEEE International Solid-State Circuits Conference ISSCC 2010, and IEEE International Symposium on Circuits and Systems ISCAS 2010*

Antti Räisänen

- Editorial Board Member: *Experimental Astronomy*
- Evaluations for IEEE Fellow Committee, USA
- Reviews for *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, IET Electronics Letters, IET Proceedings on Microwaves, Antennas and Propagation, Progress in Electromagnetics Research, Journal of Electromagnetic Waves and Applications, Int. Journal of Microwave, and Wireless Technologies*
- Reviews *ESA Antenna Workshop, Int. Symp. Space THz Technology, European Microwave Week, Annual Antenna Measurement Techniques Association (AMTA) Meeting & Symposium, EuCAP, etc.*
- Evaluations of ERC Advanced Grant applications (2008 and 2009)
- Expert statement in professor nomination for Danish Technical University (2008)
- Expert statement in professor nomination for Ohio State University (2008 and 2009)
- Expert statement in professor nomination for Danish Technical University (2009)
- Expert statement in research professor nomination for Jet Propulsion Laboratory, California Institute of Technology (2009)
- Expert statement in docent nomination for Chalmers University of Technology (2009)
- Member, Examination Committee of Doctoral Thesis of Sylvain Ranvier, Université de Nice-Sophia Antipolis, France (2009)
- Evaluation for Technologiestichting STW, The Netherlands (2010)
- Evaluation for ESF Research Networking Programme, France (2010)
- Evaluation for a faculty position in Information and Communication Technology: Chalmers University of Technology, Sweden (2010)

Sergei Tretyakov

- Editorial Board Member, *Progress in Electromagnetics Research, Problems of Physics, Mathematics, and Technics*
- Reviews for *Science, Nature Photonics, Nature Materials, Nature Communications*, *IEEE Trans. on Antennas and Propagation, IEEE Transactions on Microwave Theory and Techniques, Physical Review, Physical Review Letters, Journal of the Optical Society of America A and B, Optics Letters, Journal of Applied Physics, Metamaterials, Optics Express, Optics Communications, IET Proceedings, New Journal of Physics,* etc.
- Opponent for the doctoral thesis of Elena Saenz, Public University of Navarra, Spain (2008)
- Opponent for the doctoral thesis of Frederic Bongards, Ecole Polytechnique Federale de Lausanne, Switzerland (2009)
- Expert statement in associate professor nomination, Universtiy of Crete, Greece (2009)

- Expert statement in Research Chair nomination, Ecole Polytechnique Montreal, Canada (2009)
- Expert statement for the MacArthur Foundation (2009)
- Pre-examination of a doctoral thesis: Tel Aviv University (2010)

Pertti Vainikainen

- Expert statement in professor nomination for Tampere University of Technology (2008)
- Opponent of licentiate thesis of A. Paz: Water content measurement in woody biomass using dielectric constant at radio frequencies, Mälardalens University, Västerås, Sweden, September 26, 2008
- Opponent for the doctoral thesis of Troels Pedersen , Aalborg University, Denmark (2009)
- Member, Examination Committee of the Doctoral Thesis of Marc Mowler, Royal Institute of Technology, Sweden (2009)
- Expert statement in docent nomination, Åbo Akademi University, Finland (2009)
- Review committee member for the PhD thesis defence of Ana Perez, Mälardalen Högskola, Västerås, Sweden (2010)
- Reviews for *IEEE Transactions on Antennas and Propagation, IEEE Transactions on Microwave Theory and Techniques, IEEE Transactions on Wireless Communications, Electronics Letters, Microwave and Optical Technology Letters, IEEE Antennas and Wireless Propagation Letters, Sensing and Imaging: An International Journal, IEEE Transactions on Instrumentation and Measurement, Wireless Personal Communications, IET Electronics Letters, IEEE Antennas and Wireless Propagation Letters*

Risto Wichman

- Review for Wiley on a book proposal (2008)
- Review of project proposals, European Regional Development Fund (2008)
- Opponent for the doctoral thesis of M.Sc. Jouko Leinonen University of Oulu (2009)
- Opponent for the doctoral thesis of M.Sc. Tobias Hidalgo Stitz, Tampere Univ. of Technology (2010)
- Reviews for *IEEE Trans. Wireless Communications, IEEE Communications, IEEE Communications Magazine, EURASIP Journal on Advances in Signal Processing, IEEE Signal Processing Letters, EURASIP Journal on Wireless Communications and Networking, International Journal of Communication Systems, IEEE Transactions on Vehicular Technology, IEEE Transactions on Wireless Communications, Springer Wireless Networks, Springer Wireless Personal Communications*

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