ABSTRACT

Smart and Novel Radios Research Unit (SMARAD) is aiming at world-class research and education in radio engineering and related signal processing in radio transceivers. SMARAD was formed in 2000 by the Radio Laboratory and the Signal Processing Laboratory of the Department of Electrical and Communications Engineering of TKK. In 2001, the Academy of Finland selected SMARAD as one of the centres of excellence in research for the period 2002 – 2007. In SMARAD there are 5 research groups each led by a Principal Investigator. The total number of employees within the research unit is about 80 including over 30 graduate students and several undergraduate students working on their Master’s thesis. During years 2002 – 2004, 16 doctor degrees were awarded to the students of SMARAD. In the same period, the SMARAD researchers published 120 refereed journal articles, 290 conference papers, 8 books, a number of book chapters, and received a few patents. SMARAD is involved in two EU Networks of Excellence of the 6th Framework Programme, namely Antenna Centre of Excellence, ACE (partner) and Metamorphose (coordinator). This report describes the highlights of SMARAD research and other activities during 2002 – 2004.
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1 Introduction to SMARAD

Smart and Novel Radios Research Unit (SMARAD)
Centre of Excellence in Research

The Academy of Finland has selected SMARAD as one of the centres of excellence in research for the period 2002 – 2007. According to the Academy: “A unit selected as a centre of excellence is a research unit or researcher training unit which comprises one or several high-standard research teams with shared, clearly defined research goals, and which is at, or has good potential for reaching, the international forefront in its field. The Academy funds the centres of excellence in research together with other funders, such as the universities, the National Technology Agency Tekes, ministries, business enterprises and foundations.” Twenty-six centres of excellence were selected for the period 2000 – 2005 and sixteen more centres of excellence were selected for the period of 2002 – 2007.

SMARAD is aiming at world-class research and education in radio engineering and related signal processing in radio transceivers. SMARAD was formed by the Radio Laboratory and the Signal Processing Laboratory of the Department of Electrical and Communications Engineering of TKK. The total number of employees within the research unit is about 80 including over 30 graduate students and several undergraduate students working on their Master’s thesis. All the involved faculty are active members of the IDC (Institute of Digital Communications) and are co-operating in radio and communications engineering related projects. IDC is a joint institute of several laboratories in the ECE and Department of Information Technology at TKK that coordinates both basic and applied research projects. In addition, the Radio Laboratory is the initiator and a contributor to MilliLab, ESA External Laboratory (a joint institute between VTT and TKK). SMARAD has a well-established network of co-operating partners in industry, research institutes and academia worldwide. Its funding sources are also diverse including the Academy of Finland, Tekes and industry. In the education sector, the participating faculty provides curricula in radio engineering and signal processing in communications, and supervision to post-graduate students in these fields, also through national graduate schools such as GETA.

Principal Investigators:
Prof. Antti Räisänen, chairman
− Millimeter wave techniques
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Members of the the Scientific Advisory Board:
− Prof. Leo Ligthart, Delft University of Technology, The Netherlands
− Prof. Björn Ottersten, Royal Institute of Technology (KTH), Sweden
− Professor, Vice-Rector Mauri Airila, TKK
Funding sources of SMARAD are diverse including the Academy of Finland, Tekes, industry, Finnish Defense Forces, ESA and EU. The total annual funding of SMARAD is currently about 3.5 Meuro, including 550 keuro from the Academy of Finland and Tekes as a special Centre-of-Excellence funding.

On the 18th of March 2004, a public full day SMARAD Review Seminar was organized in Micronova, Otaniemi. On the following day the Scientific Advisory Board had a meeting. Based on the information gathered in these meetings plus from reports and publications, the SAB international members gave a mid-term review report on SMARAD research and recommendations for years 2005 – 2007.
2 Highlights of SMARAD research in 2002 – 2004

The Smart and Novel Radios Research Unit SMARAD specialises in research into RF, microwave and millimeter wave techniques and data communications signal processing. 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, receiver structures and architectures and the signal processing algorithms they require. The results will have practical applications especially in future wireless communication systems. ‘Smart’ in SMARAD’s name refers to adaptability of antennas or materials to RF signals or fields.

In the following some highlights of SMARAD research are presented. First each group is briefly introduced as it was in the end of 2004.

2.1 Millimeter Wave Techniques

The research group is led by Prof. Antti Räisänen. In the end of 2004 there were 6 other senior researchers with a doctoral degree working in the group: prof. Jussi Tuovinen (docent, research director of VTT Information Technology), Dr. Arto Lehto, Dr. Juha Mallat, Dr. Juha Ala-Laurinaho, Dr. Sergey Dudorov, and Dr. Dmitri Lioubtchenko. In addition there are 7 researchers working towards their doctoral degree, and a few master thesis workers. During 2002 – 2004 there have been three foreign visiting professors in this group.

Current research interests of the mm-wave group include computer-generated holograms, mm-wave antennas, antenna measurements, permittivity measurements at mm-wavelengths, characterization and modeling of mm-wave diodes, and applications of RF-MEMS at mm-wavelengths.

2.1.1 Hologram CATR and studies on computer generated holograms

Testing of electrically large reflector antennas at submillimeter wavelengths is an extremely challenging task. Far-field measurements are ruled out because of atmospheric effects, near-field measurements are technically very complicated and expensive, and conventional compact antenna test range measurements are difficult due to high surface accuracy requirement of the reflectors. In the hologram CATR, the needed plane wave is formed with the use of a binarized amplitude hologram. The feed horn transmits a spherical wave onto one side of a computer-generated amplitude hologram structure that modulates the field so that a planar wave is emanated from the other side of the structure. The hologram pattern is determined numerically by calculating the structure required to change the known input field (radiation pattern of the feed) into the desired output field (plane wave). The pattern is realized on a metal layer that is on top of a dielectric substrate. The plane wave is designed to leave the hologram at a certain angle so that the other diffraction modes generated by the hologram do not disturb the plane wave. The antenna under test (AUT) is illuminated with this plane wave. The design and analysis of the hologram for CATR is based on the combination of physical optics (PO) and finite-difference time-domain (FDTD) method.

Recently (2001 – 2004), the Radio Laboratory carried out an ESA project, where the feasibility and applicability of a submm-wave hologram CATR were studied. In the
A project, a 1.5-m telescope, ADMIRALS representative test object, was measured at 322 GHz. Also, 1-m-size holograms were manufactured for operation at 650 GHz to demonstrate the capabilities of the hologram CATR at higher submm-wave frequencies.

ADMIRALS RTO tests

The ADMIRALS representative test object (RTO) was constructed by EADS Astrium for comparison of potential antenna testing methods at mm- and sub-mm wavelengths. The diameter of the ADMIRALS RTO main reflector is 1.5 m. The diameter of the quiet-zone extent had to be larger than that. The required hologram was made from three 1 m × 3 m pieces, which were joined together to form the final 3 m × 3 m hologram structure. The patterns were exposed with a laser on the photosensitive resist on top of the copper layer of the hologram material (17 µm copper on 50 µm Mylar). Chemical wet etching was used for processing the slots to the copper layer. The pieces were aligned with hair crosses and a magnifying glass. For exact match of the edges, the pieces were cut one on top of the other. The metal stripes of the hologram pieces were soldered together, thus forming a mechanically strong and electrically invisible seam. A vacuum table was used to support the hologram pieces and to keep them firmly in place during the cutting of the edges and the actual joining. Fig. 2.1.1 shows the hologram surrounded by absorber walls.

Figure 2.1.1. The 3 m × 3 m hologram for the ADMIRALS RTO tests.

The tests of the ADMIRALS RTO were carried out in the large test hall of the High Voltage Institute at HUT during summer 2003. The measurement set-up was removed from the test hall after the measurements. Thus, the constructions had to be easy to assemble and disassemble. However, the strict accuracy requirements, e.g., for the antenna positioner and the plane-wave scanner were to be fulfilled at the same time. The layout of the CATR, i.e., its orientation in the hall and the position of the installed absorbers were carefully designed in order to avoid reflections and to minimize the amount of needed absorbers. The quiet-zone field of the CATR was probed with a planar scanner to verify the quality of the plane wave. The scanner has a 2-m linear stage that allows rotation to fixed positions so that horizontal, vertical, and both diagonal scans.
could be made. The planarity of the scanner was tested with a laser tracker in the beginning of the quiet-zone probing. The information was later used for the correction of the measured phase in the quiet-zone probing.

A high-accuracy antenna positioner capable of carrying the large mass (400 kg) of the AUT was built by modifying the pedestal of an old anti-aircraft gun. The transportable antenna positioner is elevation-over-azimuth type and during the antenna rotation the centre of the ADMIRALS RTO main reflector stayed in the centre of rotation. The realized positioner is capable of rotating the antenna from $-12^\circ$ to $+90^\circ$ in elevation and full $360^\circ$ in azimuth. The angle information is read from digital 26-bit absolute angle encoders, which give reading precision of $0.0001^\circ$. The positioner has variable speed AC drives in both rotation directions. The Laboratory of Machine Design at TKK designed and carried out the modification work. Fig. 2.1.2 shows the modified antenna positioner and the mounted ADMIRALS RTO.

![Antenna positioner and mounted ADMIRALS RTO](image)

*Figure 2.1.2. Antenna positioner and mounted 1.5 m ADMIRALS RTO.*

The dedicated transmit module constructed for ADMIRALS RTO tests at EADS Astrium was used as the transmitter both in the quiet-zone probing and in the antenna measurements. In the quiet-zone measurements, AB Millimètre MVNA-8-350 mm-wave network analyzer with its receiver extension ESA-2 was used. This configuration gave a sufficient dynamic range of about 50 dB and allowed also the phase measurement of the quiet-zone field. Phase errors due to the cable flexing during the probe movement were corrected with a phase correction system, which is based on the use of a pilot signal. In the measurements of the high gain RTO the dynamic range was about 80 dB, when a dedicated receiver module of the RTO was used. The radiation pattern of the RTO was measured in angular ranges of $-85^\circ$...$+85^\circ$ in azimuth direction and $-12^\circ$...$+12^\circ$ in elevation direction. Also a two-dimensional radiation pattern in the vicinity of the main beam lobe was measured. The general agreement between the measured results and the results obtained by EADS Astrium in their reflector CATR is good.

**Hologram CATR for 650 GHz**

The submm-wave hologram manufacturing and performance was also tested at 650 GHz. Two holograms about 1 metre in size were manufactured on two different materials. Good
performance was achieved with both holograms, thus proving the applicability of the holograms for antenna testing at high submm-wavelengths.

For the demonstration CATR at 650 GHz, a powerful phase-locked transmitter and a sensitive receiver were needed in the quiet-zone field verification. The used transmitter was a backward-wave oscillator (BWO). The phase locking of the BWO was accomplished by controlling the acceleration voltage of the tube. A down-conversion mixer operating with the $5^{th}$ harmonic was developed for the use in the BWO phase-locking loop at 500–700 GHz. The receiver was a wave-guide type Schottky harmonic mixer pumped by a phase-locked Gunn-oscillator. The source oscillator and receiver were associated with a mm-wave vector network analyser (MVNA), thus enabling both amplitude and phase measurements.

Mm-wave beam shaping with holograms

Study of holograms for shaping mm-wave beams was carried out together with the Materials Physics Laboratory of TKK. Amplitude holograms were designed and manufactured for the production of different kinds of radio-wave beams: Bessel beams of different orders, vortices, and custom-designed beams. The synthesis of holograms that produce complicated field patterns at the desired signal window requires other design methods than the one used for the holograms in CATR. Using the back-propagation design scheme in combination with local design of the hologram illustrated in Fig. 2.1.3 we have realized a hologram that yields the field pattern of the form ‘HUT’; the field is measured at the signal window 1 m from the hologram center.

![Figure 2.1.3. Scheme of the back-propagation method and the actual measured radio wave field pattern of a custom designed amplitude hologram.](image)
2.1.2 Measurement of dielectric constants of thin films on substrates

Dielectric properties of deposited layers of materials are often of interest at millimeter wavelengths. Therefore the problem of measurements of dielectric properties of thin films on substrates is important. The open resonator method seems to be the simplest, most precise and convenient method. Its theory for the single layer case is well developed. Multiple layer case is considered as well, but if one layer is very thin compared with the wavelength, the proposed method is inconvenient, because it is necessary to know very accurately the geometry of the resonator, thicknesses of all layers, dielectric properties of the substrate, phase corrections have to be calculated very accurately, etc. Therefore, differential approach is more appropriate in this case. The idea is that the resonant frequency of the resonator containing the substrate only is measured, after which the film is deposited, and the resonant frequency (or two frequencies) is (are) measured again. From measured resonant frequency shifts one can extract the permittivity of the film.

Figure 2.1.4. Open Fabry-Perot resonators: (a) hemispherical; (b) spherical.

In case of the hemispherical resonator [Fig. 2.1.4 a], using the fact that one layer is very thin compared to the wavelength, we can consider the cases when the film is on the upper side of the substrate and when the sample is turned up side down. After approximations,
simplifications [Fig. 2.1.4 b] and transformations one can obtain a simple relation. The spherical resonator case is somewhat similar to the case of the hemispherical resonator, but it becomes difficult to place the sample in the middle of the resonator (beam waist). A thin film can be deposited and the resonant frequency shift due to that can be measured. When this sample is moved, the resonant frequency change is negligible when the surfaces of the sample are at the nodes of the electric field, and decreases, when they are at the maxima. The difference can be measured and the permittivity of the film can be extracted. Dielectric properties of AZ4562 photoresist films deposited onto different substrates were measured with both spherical and hemispherical resonators. The obtained permittivity was 2.9.

2.1.3 Subharmonic and harmonic mixers at submm-wavelengths

We have constructed a subharmonic waveguide mixer for 650 GHz. As the LO source we use a BWO at 325 GHz. The mixing is accomplished with an anti-parallel pair of quasi-vertical Schottky diodes integrated into a single GaAs chip (Technical University of Darmstadt). The advantage of this is an inherent fundamental mixing rejection. The structure of the mixer is sketched in Fig. 2.1.5. An integrated diagonal horn antenna is used as the signal feed. RF and LO signals are input to on-a-quartz-substrate-soldered diode chip through rectangular waveguides and a quartz microstrip filter. The ends of the filter work as probes for RF and LO waveguide-to-microstrip transitions. Impedance matching is provided by series and parallel waveguide tuners. The produced IF signal is output through an IF filter and a coaxial connector.

\[\text{Figure 2.1.5. 650 GHz subharmonic waveguide mixer.}\]
Designing of the quartz filters and the mixer block required characterisation and modelling of the quasi-vertical Schottky diodes. The design of the 650 GHz mixer was preceded by a set of scale models (10 GHz and 220 GHz). A conversion loss of 9.2 dB and an SSB noise temperature of 3500 K were measured for the 220 GHz mixer. Tests of the final 650 GHz mixer with the integrated antenna and contacting backshorts as waveguide tuners (see Fig. 2.1.6) yielded a conversion loss of about 17 dB.

For phase-locking of backward-wave oscillators (BWO) at 500 and 650 GHz we designed and constructed a wideband fifth-harmonic waveguide mixer using two planar Schottky diodes. The mixer was designed for a wideband operation (500–700 GHz RF range with 100–140 GHz LO range) without any tuners. This feature makes it very useful in complicated test facilities where frequencies are often changed. Now, operation can only be tuned by changing the LO power level (no biasing). However, a separate tuning mechanism can be used for optimizing the LO matching if considered necessary.

The mixer block was fabricated by using the split-block techniques. It was assembled of two, almost similar, gold-plated brass blocks. The overall size of the mixer is 20 mm x 25 mm x 20 mm (width, length, and height, respectively). Due to a novel transition structure (see Fig. 2.1.7 b) used in the LO waveguide the RF and LO signals can be fed in line. The RF feed is formed by an integrated diagonal horn antenna and a short waveguide section. The diagonal horn antenna was designed for directivity of larger than 20 dB with an aperture side of 1.5 mm and a length of 11.8 mm. The LO input is provided with a WR-08 (2.03 mm x 1.02 mm) waveguide access.

Two single-anode planar Schottky diodes from Virginia Diodes Inc. are used in a balanced-type configuration (T-configuration). For the RF signal the diodes are coupled in series whereas for the LO and IF signal they are in parallel. This configuration is appropriate for fifth-harmonic mixing since mixing products due to even harmonics of the LO are eliminated (if the diodes are identical) with a proper circuit design. The diodes applied are SC1T5-S20 planar single-anode mixer diodes which have earlier been applied successfully in submm-wave mixers. The diodes were flip-chip soldered on gold metallization of a 40 mm thick quartz RF substrate. Designed RF and IF filter structures are shown in Fig. 2.1.7 with overall dimensions. The RF signal is coupled to the diodes through the integrated diagonal horn antenna, the short input waveguide section, a waveguide-to-fin-line transition, and a short fin-line. The input waveguide is 340 µm x
200 µm. The width is 340 µm in order to increase the waveguide cut-off frequency close to 440 GHz and to present a reactive termination (toward the waveguide) for the third harmonic of the LO signal. The diodes are soldered side by side to the end of the fin-line as commonly done in balanced mixers. In addition to the fin-lines and diode mount, the RF filter comprises a microstrip bandstop filter to pass only the LO and IF signals (reactive termination for the RF signal and the third harmonic of the LO signal). The IF filter comprises a coplanar waveguide (CPW) filter for an IF coaxial waveguide output and the novel CPW-to-waveguide transition for the LO feed. Connections to the end of the microstrip RF filter and to the IF SMA coaxial connector are accomplished with gold-wire (diameter of 17.5 µm) bonding.

![RF filter (260 µm x 2000 µm x 40 µm)](image)

![IF filter (1150 µm x 2750 µm x 40 µm)](image)

*Figure 2.1.7. Fifth-harmonic mixer: RF filter (a) and IF filter together with the novel coplanar waveguide-to-rectangular waveguide transition for LO-coupling (b).*

### 2.2 Advanced Artificial Materials and Smart Structures

This is a recently established research group led by Prof. Sergei Tretyakov. He joined the faculty at HUT in August 2000. The first graduate student joined the group on January 1, 2001. The number of researchers working towards their doctoral degree in 2002 – 2004 has been from 1 to 3, and also there have been 1-2 master thesis workers. During 2002 – 2004 there have been 2 foreign visiting professors in this group.

#### 2.2.1 Near-field detection, imaging, and enhancement of evanescent waves

We have shown that there is a direct analogy between the phenomena taking place at the slab interfaces and at a couple of phase-conjugating planes placed in free space. One does not necessarily need a composite medium possessing negative material parameters or another kind of backward-wave medium to realize a superlens. The same effect can be achieved using two parallel artificially made surfaces or sheets imposing boundary conditions of field conjugation. Nonlinear or active materials acting as wave mixers can be used for this purpose. Working as a planar lens, the proposed device will be able to focus propagating modes of a source (due to the negative refraction at the interfaces) and, in the same time, “amplify” the evanescent modes (due to surface mode resonances), i.e., it will provide sub-wavelength resolution imaging.

In our recent work [J. Applied Phys. 96, 1293 (2004)] we have shown how the amplification of the evanescent modes can be achieved in a coupled pair of planar resonating grids or arrays. We have shown that a simple passive and linear system of two coupled planar material sheets possessing surface mode (polariton) resonances can be
used for the purpose of evanescent field restoration and, thus, for sub-wavelength near-field imaging.

In 2004, we made experiments with a cylindrical arrangement of resonant particles, which models a cylindrical device for amplification and imaging of evanescent fields. The experimental set-up is shown in Fig. 2.2.1, left. Two arrays are put into the measuring cell. Because of the reflections in the walls a pair of coaxial cylindrical arrays is formed. Only evanescent modes are excited in the cell.

**Figure 2.2.1.** Experimental demonstration of near-field enhancement and image enlargement. Left: The experimental set-up. Resonant particles were positioned on two circular foam holders located between two highly conducting planes. The probe used to scan the field distribution is seen on the top. Similar antennas were used as the sources. Right: The field amplitude distribution in the “lens”. Amplification of the evanescent fields created by two small dipole antennas is clearly seen.

This way we have experimentally demonstrated resonant amplification of evanescent fields in planar and cylindrical arrays of resonating particles. Such arrays can act as near-field sensors or imaging “lenses”. One interesting feature of the cylindrical geometries is that it is possible to get some linear magnification of the image.

**2.2.2 Antennas with the use of artificial materials**

This research direction includes antenna design, manufacturing, and measurements. During 2002 – 2004, we have proposed novel solutions for the design of artificial material and artificial impedance layers of for this application. Artificially engineered magneto-dielectric substrates designed for small antennas have been investigated numerically and experimentally. New antenna prototypes using artificial materials to improve antenna performance have been developed.

For example, we have tested a new artificial magnetic material layer designed to shrink patch antenna dimensions. In simulations a 0.34λ antenna and in practice a 0.38λ patch antennas have been realized, with the 6-dB bandwidth of 4.35%. The antenna bandwidth of these reduced-size antennas is practically of the same order as for usual air-filled patch...
antennas with the patch size $0.5\lambda$, that resonate at the same frequency. Thus, we have demonstrated in practice a technique to miniaturize patch antennas with the use of a certain high-impedance surface (working as an artificial magnetic material layer) without worsening the bandwidth. The typical current distribution in such antennas is shown in Fig. 2.2.2. Our studies also concerned the problem of near-field control with the use of artificial impedance surfaces.

### 2.2.3 Development of computational methods

These activities include modeling of lossy wire arrays and wire grids, as well as thin material layers and conducting (lossy) surfaces using higher-order surface impedance and sheet conditions. For example, this enables fast modeling of certain frequency-selective surfaces without the need to discretize all the fine geometrical details of the structure.

This work also covers FDTD simulation techniques for novel exotic materials, such as materials with negative or null-valued effective parameters. An example of our results in this direction is shown in Fig. 2.2.3. A snapshot electric field distribution inside and around a dispersive material slab with negligible permittivity and permeability at a fixed frequency is shown in Fig. 2.2.3. The line source is visible inside the material slab. The spatially very slowly varying field distribution inside the slab is in agreement with theoretical results.

### Figure 2.2.2. Current distribution in a patch antenna filled with an artificial magnetic layer.

### Figure 2.2.3. A snapshot electric field distribution around a zero-index slab excited by a line source in the center. Note the uniform field distribution at the slab surface.
2.2.4 Artificial and controllable materials and surfaces for antenna and microwave applications

Various possibilities to design artificial and especially adjustable materials have been studied. In particular, we have developed an analytical theory of dispersion and reflection for the electromagnetic crystals formed by rectangular lattices of parallel infinite loaded wires. New design and control opportunities offered by periodical loading of the wires (in the control of material dispersion and reflection from interfaces) have been discussed. We have analyzed in details the properties of reactively loaded wire media. We have found that capacitive loading makes the crystal an ordinary artificial dielectric at low frequencies without any changes of the properties at high frequencies. Most recently, the possibility of utilizing reactively loaded wire medium as an artificial material for beam shaping element in base station antenna applications has been studied. We have concentrated on the Universal Mobile Telecommunications System (UMTS) frequency range with the aim to design a compact dual-mode base station antenna having two modes corresponding to two beam-widths in the H-plane. A prototype antenna has been manufactured and measured, see Fig. 2.2.4 b. It has been shown that promising performance can be achieved with a simple structure and cheap manufacturing process.

![Figure 2.2.4](image)

**Figure 2.2.4.** a) Schematic illustration of capacitively loaded wire medium. b) Prototype of a base station antenna utilizing the loaded wire medium lens.

We have considered electromagnetic behavior of artificial magnetic conductors, both theoretically and experimentally. The performance of the known mushroom layer has been compared with novel designs that involve more complicated shapes of metal patches.

2.2.5 Other research directions

Artificial transmission lines with exotic dispersion, especially for applications in phase shifters and delay lines. Recently, important results showing opportunities offered by backward-wave structures and positive anomalous dispersion lines have been published. We also study waveguiding structures formed by plasmonic resonant particles for optical and terahertz applications. Analytical studies of the dispersion relation reveal new
potential applications in nano-imaging and detection. We have worked on metamaterials with negative parameters. Some fundamental physical results have been found (e.g., a general expression for the energy density function). New design approaches have been explored (e.g., arrays of resonant spheres and chiral composites).

2.3 RF Applications in Mobile Communications

This research group is led by Prof. Pertti Vainikainen. There are 6 other senior researchers with a doctoral degree working in the group: Dr. Hassan El-Sallabi, Dr. Clemens Icheln, Dr. Jarno Kivinen, Dr. Yelena Maksimovitch, Dr. Valeri Mikhnev, and Dr. Xiongwen Zhao. In addition there are 11 researchers working towards their doctoral degree, and a number of master thesis workers in this group.

2.3.1 Wideband radio channel measurements and modeling

SMARAD has a long tradition in developing radio propagation channel measurement techniques. With channel sounding system of TKK IDC, many measurement setups are possible today. Center frequencies 275 MHz, 2.154 GHz, 5.3 GHz and 60 GHz can be used and large 16x64 and 32x32 MIMO (multiple input multiple output) matrices can be measured at 2 and 5 GHz. At 60 GHz, MIMO measurements are possible with the synthetic aperture principle and also some UWB (ultra wide band) measurements have been performed.

During 2002 – 04, the development of the MIMO channel sounder at 5.3 GHz was completed, the system was constructed, and extensive MIMO measurements were performed. Two spherical arrays with dual-polarized elements were constructed (see Fig. 2.3.1 a). Thus, a double-directional characterization of MIMO radio channel with DoA and DoD (direction of arrival/departure) estimation in azimuth and elevation as well as full characterization in the polarization domain can be performed. Also, a planar 4x4 dual-polarized (32 channels) array (Fig. 2.3.1 b) was designed. The planar array is used in the transmitter with high elevation, e.g. in macro or micro cells. Large measurement distances are possible due to high transmitted power of up to 5 watts.

![5 GHz antenna arrays for MIMO channel sounding: a) semi-spherical array, b) planar array.](image)
Measurements with the 5 GHz system were performed in several micro and macro cell configurations with TX antenna heights up to 40 meters. Distances up to 500 meters could be covered in the macro cell configurations. In these measurements, the planar antenna array was used in the transmitter and the 15-element semi-spherical antenna array in the receiver. The same configuration was used also in urban outdoor indoor measurements as well as in suburban measurements, where the TX planar antenna array height was 30m. These measurements included also outdoor-indoor cases. Indoor measurements were performed in two different buildings using the semi-spherical antenna configurations both in TX and RX. Also indoor-outdoor and ad-hoc system type outdoor measurements were performed with this configuration.

A MIMO measurement system at 60 GHz was realized in 2004 with two matrix shifters (see Fig. 2.3.2). This enables measurements of arbitrary virtual antenna arrays in 2 dimensions. Very good phase stability was achieved by having a common 14 GHz source, whose frequency is multiplied by 4 in the RX and TX units. To our knowledge, this is the first 60 GHz MIMO measurement system in the world.

Figure 2.3.2. 60 GHz MIMO measurement system.

MIMO measurements have been and will be used for following purposes: 1) DoD and DoA estimation using advanced methods, 2) studying antenna performance by convolving measured radiation patterns with the DoD and DoA data, 3) modeling of MIMO radio propagation channels (empirical, semi-empirical), 4) studying of propagation mechanisms (deterministic modeling). Examples of these are given in the following sections.

2.3.2 Deterministic and stochastic propagation modelling

a) Propagation mechanisms and characteristics

Polarization behavior at 2, 5, and 60 GHz has been studied for indoor and outdoor mobile communications. For example, it was shown that there is no obvious difference between powers received with VP or HP in LOS corridors. Definite difference can be observed in
NLOS corridors, but it is not too significant to be considered in a system design. Depolarization effects are more serious in the NLOS case, and they depend strongly on the antenna types applied at the terminals.

It has been shown based on the measurements that propagation paths in a radio channel tend to appear in clusters. A practical data analysis problem is from estimated channel parameters. For small data records the extraction of clusters can be done by visual inspection. However, manually clustering the measurement data of large measurement campaigns, such as the ones described above, is impractical. Therefore procedures for automated clustering of channel parameter estimates have been developed.

Both mobile and DoA measurements have been performed at 60 GHz in indoor environments to study propagation behavior and mechanisms in the millimeter wave frequency band. Empirical radio channel models and parameters have also been derived from the measured data for future MBS and WLAN systems. The study shows that at 60 GHz diffraction is still quite important for NLOS propagation links. In LOS links, the first and second order reflections from smooth surfaces are also important.

b) Improved diffraction coefficients

Accurate prediction of radio wave propagation depends on models of propagation mechanisms. Diffraction process usually works as a secondary source of the field in the non-line-of-sight-cases. The choice of the diffraction coefficient is important for accurate prediction of the signal amplitude resulted from the diffraction process. Diffraction formulas are well established for perfectly conducting infinite wedges, for absorbing wedges, and for impedance-surface wedges. The impedance-surface diffraction formulas are rather cumbersome to use for propagation prediction in mobile communications. Thus, the difficulty of using the rigorous solutions for propagation prediction forces simplifications. In this work, several new formulations for the diffraction coefficients have been proposed.

c) MATLAB implementation of the 3GPP SCM channel model

The 3GPP TR25.996 specifies a MIMO channel model for use in UMTS system simulations. However, there is no publicly available implementation of this SCM channel model. In this work the channel model was implemented in MATLAB with certain parts programmed also with ANSI-C. The program code and documentation are freely downloadable in [http://www.tkk.fi/Units/Radio/scm/](http://www.tkk.fi/Units/Radio/scm/). This work has been performed in co-operation with Technische Universität Ilmenau and Elektrobit and it was supported by the WINNER project of EU FP6 IST programme.

2.3.3 Assessment of radio system performance

a) Performance analysis of MIMO systems

Mutual information is a measure of the highest achievable rate of information transmission of a communication channel. The results of this work can be divided into three groups. (i) An upper bound in derived on the ergodic (average) mutual information of a Rician fading MIMO channel. (ii) It is shown that at high SNR the mutual information of a MIMO channel can be decomposed as a sum of three terms that entail
the effects of average SNR, SNR fading and the eigenvalue dispersion of the channel. (iii) An approximation for the distribution of mutual information in Rayleigh fading MIMO channels is derived.

Both multiplexing and signal transferring properties have to be considered in MIMO system evaluation. The antenna element orientations and the radiation properties of the antenna elements can influence remarkably on the capacity. The new figure of merit for the MIMO antenna system evaluation called mean effective link gain (MELG) was studied. MELG is the extension of mean effective gain (MEG) for Single−Input Single−Output (SISO) systems as it defines the ability of a MIMO antenna system to transfer power from the transmitter to the receiver.

b) Investigations on impact of bandwidth on orthogonality factor for WCDMA systems

The WCDMA specification for 3rd generation mobile systems allows variable data rates. The nominal bandwidth of the first phase of the WCDMA systems is 5 MHz but in the future also 10 or 20 MHz can be used. The choice of a wide bandwidth of transmitted signal can provide high data rates. One of the important issues that has to be considered in increasing the bandwidth is the influence of bandwidth on the downlink capacity of the WCDMA systems.

2.3.4 Antennas for mobile terminals

The continuing size reduction of handsets, the development of UMTS and multiband terminals, and the requirement to keep the power absorbed by the user below the standardized levels regardless of the handset size, continue to set more stringent requirements and create new challenges for small antenna research.

One main achievement of 2002 – 2003 was the development of non-resonant coupling elements that can be used to significantly reduce the volumes of mobile terminal antenna elements by efficiently utilizing the radiation of the currents on the mobile terminal chassis. The volume of these new structures can be less than 2 cm$^3$, which is many times smaller than that of traditional internal handset antennas. These antenna structures are tuned to resonance with separate matching circuits, as depicted in Fig. 2.3.3. Year 2004 was marked by successful implementations of low-volume and low-profile multi-band and multi-resonant antenna structures for handheld portable equipment. Additionally, the effects of the changing mechanics of e.g. clamshell phones on the antenna performance were studied. The effect of the user on the antenna performance was also investigated with SEMCAD simulations.

As an example for a non-cellular application, a DVB-H antenna was designed using a compact (1.5 cm$^3$) coupling element structure, which facilitates optimization of the antenna structure to fit best to the purpose. Optimization and design were made using the IE3D and Aplac simulators. Based on these simulations, several prototypes were manufactured. The prototypes operate efficiently enough for DVB-H applications.
During 2002 – 2004 also the effects of chassis-related parameters on the operation bandwidth, radiation efficiency, and SAR (Specific Absorption Rate) of internal handset antennas have been investigated. Computer simulations and measurements were carried out at 900 MHz and 1800 MHz, using both a multi-layer head model and a flat phantom filled with fat-tissue simulating liquids. Firstly, it was confirmed that the effect of the chassis length on impedance bandwidth is significant. When the chassis approaches the resonant length the bandwidth increases due to the increased chassis radiation. At the same time an increase in SARs and a decrease in radiation efficiency occur compared to the general trend. So, there is a clear connection between the general behavior of SARs, radiation efficiency, and impedance bandwidth.

In addition, the general energy-absorption mechanism in the human tissue has been studied for different tissue types. Our results lead to the conclusion that the peak SAR is not actually related to the antenna current, as has been commonly believed. Instead, high values of the real part of permittivity cause the perpendicular electric-field components to be attenuated substantially in the tissue, and the SAR maximum can then be found in a location with low total original electric field but significant components parallel to the surface of the tissue. The simulated field plots depicted in Fig. 2.3.4 show that the maximum field strength near a dipole in free space is near the tips, but once it is placed next to human tissue the maximum is located near the centre of the dipole.

**Figure 2.3.3.** Example of a small non-resonant coupling structure for mobile terminals GSM900/1800 MHz (left), and for DVB-H (right).

**Figure 2.3.4.** Simulated electric field of a dipole in free space (left), and in the tissue-equivalent liquid + bone + muscle layers.
2.3.5 Measurements of radiated fields of mobile terminals

The total radiated power and the directional field pattern are important radiation characteristics of mobile terminals. Both can be determined, e.g., by measuring the electric field on a spherical surface enclosing the mobile terminal. A spherical measurement system called RAMS (Rapid Antenna Measurement System) has been developed in SMARAD. 32 dual-polarized antennas are placed on a spherical surface (1 m radius) around the device under test. The signals from all 64 channels are measured consecutively, using a switching network (Figure 2.3.5 a). A phase retrieval network determines the signal phase relative to a reference signal. One of the measurement channels is used as the phase reference.

The measurement setup with a small-antenna prototype is shown in Figure 2.3.5 b. Active mobile terminals can be measured by controlling the terminal with a base station simulator, in which case no RF feed cable is used. With RAMS it is possible to retrieve both phase and amplitude information of the radiated field with good accuracy (see Fig. 2.3.6). The measurement of a complete 3-D directional pattern takes 3 seconds per frequency point. The operational frequency range of the system is 0.8 – 3 GHz.

Figure 2.3.5. a) 64-channel switching network (below) and the phase retrieval network (above). b) Mobile phone antenna model measurement setup.

Figure 2.3.6. 2-D pattern-cut comparison between RAMS and 2 references at 1710 MHz.
In this area, SMARAD Radio Laboratory has also contributed actively to the ongoing international standardization work on mobile terminal antenna performance measurements. In the COST 273 project SMARAD has participated in preparing a pre-standard on the antenna performance testing of 3G terminals. The pre-standard document has been accepted by 3GPP RAN4, which also starts the actual standardization process.

2.3.6 Antenna structures and their evaluation for adaptive antenna systems

a) MEBAT

New antenna evaluation method called MEBAT (Measurement-based antenna test bed) has been developed. In this method, the measured or simulated radiation patterns of the tested antenna system are convolved with propagation channel data. The new method was verified by performing the MIMO and diversity analysis of some test antenna configurations, and by comparing them with the results of direct channel measurements with the same antenna configurations. Based on these comparisons, the new method is shown reliable.

The new antenna evaluation method was used in several antenna system analyses. For example, a prototype antenna for a laptop type device was developed at 5 GHz range. That microstrip antenna with two feeds was simulated and also manufactured. The preliminary antenna evaluation of the prototype antenna was carried out using MEBAT. Different diversity combining methods, like maximal ratio combining (MRC), equal gain combining (EGC), and selection combining (SC), were adopted and several practical diversity antenna configurations were evaluated.

b) Mutual coupling

The pattern distortion due to mutual coupling can be corrected in adaptive arrays by modifying feed voltages. Linear correction can be performed using a correction matrix derived by matrix pseudoinverse. This method was used e.g. for obtaining array amplitude patterns with wide nulls. Furthermore, the connection between pattern correlation and scattering matrix was established and proven with simulated two-element array data with 3-dimensional patterns.

2.3.7 Propagation phenomena in dielectric structures and application for structure characterization

In this area, the work has been directed to several problems relevant to high-resolution subsurface radar measurements. These have applications like humanitarian de-mining and detection of breast cancer. Below a couple of latest results are described.

A fast forward solver for the ground penetrating radar geometry has been developed. As the ground penetrating radar is a half-space problem, the wave propagation can be represented in terms of four Green functions. Then, the electric field in the subsurface domain can be determined from a linear integral equation. Integration of the subsurface electric field with corresponding Green function over the domain containing inhomogeneities, yields electric field at the receiver positions in the upper half-space. To calculate Green functions, a fast Fourier transform has been widely used. The integral equation being a core element of the forward solver, has been solved by a conjugate
gradient method. The matrix products needed in the conjugate gradient method have been also computed using fast Fourier transform. The whole algorithm is very fast and can be used at the next stage to develop a robust inverse scattering method.

A modified bow-tie antenna consisting of a central metal sector and strip-slot area has been designed and fabricated for step-frequency radars. Such dipole is a planar version of the finite bi-conical dipole applied widely in subsurface impulse radar. As a rule, main drawbacks of the simple bow-tie antenna are related with poor wideband impedance matching and ringing caused by reflections from flare ends. Our design aims to suppress these sources of clutter.

2.4 Statistical and Array Signal Processing in Communications

The research group is led by Prof. Visa Koivunen. In this group there are 4 senior researchers with a doctoral degree, 8 researchers working towards their doctoral degree, and a number of Master’s thesis workers. During 2002 – 2004 there have been two foreign visiting professors in this group. Three group members have been working in foreign labs as post-doctoral researchers (Dr. Samuli Visuri, at Institut Eurecom year 2002, ETH Zurich 2003, Dr. Juha Karvanen, at Riken Research Institute, Japan 2002-2003, Dr. Mihai Enescu, at Technische Universität Wien, Austria, 2004, 3 months).

2.4.1 Signal processing for spread spectrum systems

In this project, transceiver structures for spread spectrum systems are developed. In particular, WCDMA system and its future extensions and satellite navigation systems such as GPS and Galileo are considered.

In case of WCDMA systems, the goal of the research is to increase effective data rates and spectral efficiency of the system as well as to improve the quality of the radio link. Novel receiver structures are derived and their performance is studied. In particular, so-called HSDPA system used to provide high datarates to a user. Multicode transmission where more than one spreading-code is dedicated is to one user. Moreover, the amount of control signalling may be reduced by employing blind and semi-blind receiver structures. Then more informations symbols may be transmitted. Blind receivers allow for using the information symbols for refining the channel estimates or equalizer. This is of particular interest in fast-fading channels. Semi-blind receiver employs both the pilot and the information symbols. Hence, maximal sample support is achieved which leads to reduced variance in estimating the channel parameters.

Multiantenna transmission, i.e., MIMO-systems may be used to improve the spectral efficiency of the spread spectrum systems, cancel interferences as well as improve the quality of the radio link. In this project, multiantenna receiver algorithms for future evolution WCDMA system are developed. Their performance is studied in simulation using realistic channel models and mobile user scenarios.

In the area of navigation systems, antijamming receivers are developed. Smart antennas employing space-time processing allow cancelling multiple broadband and narrowband jammers as well as unintentional interference simultaneously. The developed methods stemming from multi-stage Wiener filtering are exploiting the low-rank structures of the
signal model. Computationally efficient and numerically stable Householder transformations are employed in the methods. The performance of such anti-jamming processors is studied under highly demanding jamming scenarios and in the face of multipath. The co-existence of navigation systems and other wideband systems is also studied.

![Response of a space-time antijamming navigation receiver in the face of several broadband and narrow band jammers.](image)

**Figure 2.4.1.** Response of a space-time antijamming navigation receiver in the face of several broadband and narrow band jammers.

The problem of direction finding is spread spectrum systems is addressed as well. Direction finding and emitter localization are needed in beamforming as well as in other applications where the location of the user is of interest. Such applications include safety-of-life and different spectrum management and surveillance applications. The SNR's of spread spectrum signals are very low. Hence, the direction finding is highly challenging problem. In particular, the problem of blind despreading, i.e. obtaining the processing gain without explicit knowledge of the spreading codes is addressed. This allows of high-resolution angle of arrival estimation of transmitters where spreading codes are not known.

### 2.4.2 Multicarrier and MIMO systems

In this project transceiver structures for Multiple-Input Multiple-Output systems are developed. Such systems allow linear increase in spectral efficiency as a function of number of antennas in transmitter or receiver. Moreover, the radio link quality may be improved so that ADSL quality radio link is experienced in a wireless system.

Multicarrier modulation schemes are of special interest in this research. Multicarrier systems turn a broadband frequency-selective channel into number of narrowband channels. This makes the receiver design particularly simple. Multicarrier communications and MIMO systems together are the key technologies in future high data rate wireless communication systems as well as in wireless LAN's and broadcast systems.
In this work channel estimation and synchronization methods are developed for MIMO-OFDM systems. The carrier frequency compensation problem caused by mobility, oscillator inaccuracies and rich scattering environments is important because the offset degrades the desirable properties of the multicarrier transmission. Also time synchronization and estimation of time-frequency-space selective radio channel is studied. Adaptive receiver structures operating both on time-and frequency domain are derived. Also low complexity receivers are developed that exploit the special structure of the matrices used in the MIMO-OFDM model. Blind and semi-blind receiver structures are developed in order to improve effective data rates. Both statistical and structural properties of multicarrier signals are exploited.

![Typical MIMO-OFDM system configuration.](image)

**Figure 2.4.2.** Typical MIMO-OFDM system configuration.

### 2.4.3 Fundamentals of statistical and array signal processing

In this research new statistical methods and models for different signal processing applications are developed. This research stems from estimation theory and applied mathematics. Optimal and suboptimal statistical procedures are derived. The properties of the new methods are established using large sample analysis (asymptotics) and matrix theory.

The specific research problems include complex random vectors and processes and their statistical models and estimation procedures, optimization under unitary matrix constraints using Riemannian geometry, linear and nonlinear state-space models, estimation methods for angular distribution models, robust estimation theory, subspace analysis and signal separation and independent component analysis. The fundamental results obtained in this research have applications in communications, sensor networks, biomedicine and data analysis in general. Different statistical pattern recognition problems especially in the context of wireless communications and radar are investigated as well. The applications include spectrum management and electronic warfare.

Also methods for smart antennas for different antenna configurations are developed. Small antenna arrays that may be used for example in mobile terminals are of interest. Particular examples include uniform circular arrays and dual-polarized antenna systems. Computationally efficient high-resolution methods are developed considering also practical antenna gain patterns. This requires deriving beamspace transforms and procedures for reducing possible bias and excess variance from the estimates.
2.4.4 Radio channel propagation parameter estimation

The interest in the multidimensional structure of the mobile radio channel is growing rapidly. This is mainly due to the fact that future beyond 3G wireless systems will employ multi-antenna transceivers in order to improve spectral efficiency and radio link quality. Consequently, realistic channel models that are verified by real-world measurement campaigns are needed especially for transceiver design and network planning purposes.

![Figure 2.4.3. Blind signal separation problem.](image)

![Figure 2.4.4. Tracking time-delay of arrival propagation parameter using extended Kalman filter.](image)
Channel sounding and related propagation parameter estimation are key tasks in creating such channel models. In particular, the double-directional modeling of the radio channel has attracted a lot of interest because it gives a better physical insight into the wave propagation mechanism in real radio environments and it has the ability to remove the measurement antenna influence from the channel observation. Moreover, studying and comparing the performance of various MIMO (multiple-input-multiple-output) transceiver structures requires such advanced channel models as well.

In the research we address the problem of parametric channel estimation in channel sounding. Propagation parameter estimation is crucial in creating realistic channel models that may be used to study the performance of multi-antenna (MIMO) transceivers as well as in network planning. Novel optimal and sub-optimal estimation procedures are developed and their asymptotic properties are established. Special emphasis is put on using appropriate angular distribution models for parameters that are defined in angular domain, modeling both the specular and diffuse component of the propagations, tracking time-varying propagation parameters in mobile radio channels and well as developing models that allow describing arbitrary scattering environments.

2.5 Signal Processing in Communications: Receiver Architectures and Algorithms

The research group is led by Prof. Timo Laakso. The group includes 1 senior researcher with a doctoral degree, 4 researchers working towards their doctoral degree, and in addition 2 Master’s thesis workers. In 2002 – 2004 there have been two visiting professors in this group. One group member have been working in a foreign institute as post-doctoral researcher (Dr. Stefan Werner, Federal University of Rio de Janeiro, Brazil, year 2003, 6 months) and one as a Ph.D. student (M.Sc. Mei Yen Cheong, Technische Universität Wien, Austria, year 2004, 3 months).

Current research of the Signal Processing in Telecommunication Research (SPITRES) group focuses on design and implementation of receiver algorithms for diverse communications systems, including both wireline and wireless systems. Topics include efficient adaptive filter algorithms, adaptive estimation and equalization of nonlinearities, adaptive notch filters, synchronization algorithms, tunable fractional delay filter structures, and power amplifier nonlinearities in multiple-antenna systems.

2.5.1 Adaptive filtering

Data selective adaptive filtering algorithms

This research investigates new data selective adaptive filtering algorithms using the framework of set-membership filtering (SMF). These algorithms combine a bounded error specification on the adaptive filter with the concepts of proportionate adaptation and data reusing in order to obtain efficient algorithms for both sparse and dispersive systems. The resulting algorithms have low average computational complexity because coefficient update is not performed each iteration. The adaptation algorithms can be adjusted to achieve a desired computational complexity by allowing a variable number of data-reuses for the filter update.
Figure 2.5.1. Block diagram of set-membership filtering.

Analysis of partial-update adaptive filters

This research analyzes partial-update normalized adaptive filters. Partial-update adaptive filtering is a technique suitable for applications where the order of the adaptive filter is so high that it may impair even the implementation of low computational complexity algorithms, such as the NLMS algorithm. Partial-update adaptive filters reduce the algorithm complexity by properly decreasing the number of filter coefficients that is updated each iteration so that the filter order may be kept fixed. Order statistics is used to analyze the mean-squared error of the adaptive filter output.

Linearly constrained adaptive filters

Adaptation algorithms that satisfy linear constraints find applications in various areas of communications, e.g., in antenna array processing and multiuser detection. In this project, new linearly constrained adaptive filtering (LCAF) algorithms are derived and analyzed,
which are tailored to specific applications and have advantageous performance regarding convergence and robustness. Reduced complexity adaptive filtering algorithms were developed through input-signal transformation, set-membership filtering, and data-reusing.

**Fast adaptive filtering algorithms for APLAC system simulator**

This project provides an insight into adaptive filtering algorithms, ranging from the simplest to the more sophisticated algorithms. A testbench is designed for the algorithms in order to measure their performances for two applications: channel equalization and system identification. The goal of the project is to provide a systematic approach on how to choose a suitable algorithm given a set of application requirements. The approach assumes only little knowledge of the underlying theory of the algorithms and targets engineers with no expertise in the field. Finally, this thesis project provides C code implementations of the recent algorithms for implementation in the APLAC System Simulator.

**Adaptive multiple-notch filters**

This research investigates IIR realization of adaptive notch filters. We focus on the multiple notch case. We study a new family of IIR adaptive notch filters which is based on a second-order factorization of the all-pass transfer function that forms the multiple notch filter. Compared to the previous research done on this topic, these realizations avoid finding a high-order polynomial root to obtain the unknown frequencies of interest. For the case of low SNR, a smaller bias can be achieved using the new realizations as compared with previous realizations available in the literature. This property is particularly attractive for multiple sinusoids estimation and tracking. Furthermore, we derive several updating algorithms dealing with multiple notches. Algorithms used include gradient descent and Steiglitz-McBride algorithms. This research also includes analysis of the convergence properties, analysis of the relationship of the frequency estimation errors, analysis of the signal to noise ratios, and characterisation of the stationary points.
2.5.2 Nonlinearity

Measurement and analysis of nonlinearities of power amplifiers for wireless communications

In this project, single-tone and multi-tone input signals are applied to high-power amplifiers and the output of the device is measured in order to obtain enough data to characterize their nonlinearities. The results of this research are further used for amplifier modelling and predistorter design.

Memoryless distortions can be represented by the measured AM-AM and AM-PM characteristics, which show how the amplitude and phase of the output changes with the input power level. Nonlinear distortions may depend on thermal, biasing or supply conditions, which can appeared as mixed (in form of noise) with the basic AM-AM/AM-PM characteristics. In this case and in systems with memory, the normal AM-AM and AM-PM measurements are not enough to characterize the nonlinearity of the devices, so a Two-Tone transfer characteristics measurement may be done.

Figure 2.5.5. Measurement of power amplifiers.
This research investigates identification techniques for nonlinear systems. The goal is to find a suitable model for a power amplifier that can be utilized in the design of linearization techniques that can alleviate the distortion generated by the power amplifier.

Narrowband amplifiers can usually be estimated using frequency-independent models, whilst wideband amplifiers require frequency-dependent models. In this project a Hammerstein model is proposed for frequency-dependent estimation of power amplifier nonlinearities.

The static nonlinearity has been implemented as polynomial model and the linear dynamic block as an FIR filter. A simplified parameter estimation technique based on the measured AM/AM and AM/PM characteristics using linear least-squares estimation was developed. In order to determine the filter coefficients, a weighted least-squares FIR approximation technique for use on a discrete frequency grid has been derived. Very good results were obtained for single-tone inputs.

Adaptive digital predistortion for broadband power amplifiers

This project aims at developing an adaptive digital predistorter that compensates nonlinearity with memory (NLWM) caused by the power amplifier (PA) in broadband wireless communication systems. The logical way to develop a pre-distorter (PD) is to find the inverse characteristic of the PA such that the cascaded system of PD-PA produces a linear output. Volterra series is a classical model for nonlinearity with memory. However, a Volterra model based predistorter may suffer from a prohibitive computational complexity as well as ill-conditioned kernels for a high-order series expansion. This project considers models based on the Wiener-Hammerstein structure that separates the NLWM into a nonlinear static system and linear dynamic system. Piecewise linear functions are considered for modelling the static nonlinearity. The models of the PA and PD are extracted from measurement data of the Mini-Circuits ZVE-8G amplifier.
made within the group. The piecewise linear function was found to provide an accurate and robust nonlinear model which is also easy to invert.

Amplifier nonlinearities in multiple-antenna systems

In this project, design techniques and algorithms for switched-beam antenna systems and adaptive beamforming arrays are evaluated with the objective to reduce the nonlinear effects in cellular system.

Antenna array systems are used with Multicarrier Power Amplifier (MCPA) in order to reduce the number of amplifiers placed in the base-station. The combination of different signals with different phase and frequency give a large Peak-to-Average ratio, which results in severe clipping effects if the composite signal is amplified by a MCPA with nonlinear transfer function. The nonlinear amplifier distortion can seriously degrade the transmit beamforming performance. First, the directions of the nulls and the main beam will change, increasing the interference level for mobiles using the same frequency channel. On the other hand, intermodulation beams are created that radiate the intermodulation products in different directions. Hence, multiple-antenna systems employing nonlinear amplifiers should be designed with special care.

Fast multichannel QRD-RLS algorithms for efficient nonlinear filtering

This project studies the application of multichannel fast QRD-RLS algorithms for the identification equalization of nonlinear systems that can be modelled by a Volterra series. Of particular interest is the design of predistorters for broadband power amplifiers, where the use of fast QRD-RLS algorithms provides a numerically robust solution of reduced computational complexity.
2.5.3 Synchronization in communication systems

![Variable filter implementation structure.](image)

*Figure 2.5.8. Variable filter implementation structure.*

This research investigates efficient algorithms and implementation structures for the purpose of timing synchronization in communication systems. The more efficient algorithms and implementation structures aim to lower the complexity and cost of the communication devices while improving their performance. We developed an efficient generalized scheme for synchronization using synchronous sampling and arbitrary oversampling ratios. We have also developed a closed-form design method for tunable fractional delay (FD) approximation when constraining the magnitude response to be constant for different delays. Recently we have studied FD-based efficient interpolation techniques for carrier frequency offset correction in OFDM systems.
## 3 SMARAD funding

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## 4 SMARAD personnel 2002 - 2004

**In the Radio Laboratory:**

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<td>Ala-Laurinaho Juha</td>
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<td>Azzinnari Leonardo</td>
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<tr>
<td>Belov Pavol</td>
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<tr>
<td>Chicherin Dmitry</td>
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<td>Denchev Vasil</td>
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<td>Doudorov Sergey</td>
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<td>El-Sallabi Hassan</td>
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<td>Ermutlu Murat</td>
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<td>Eskelinen Pekka</td>
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<td>Kolmonen Veli-Matti</td>
<td>Research associate from 20.5.2002</td>
</tr>
<tr>
<td>Koskinen Tommi</td>
<td>Research associate</td>
</tr>
<tr>
<td>Kuokkanen Mika</td>
<td>Research associate 1.1. – 30.6.2003 and from 10.1.2004</td>
</tr>
<tr>
<td>Krogerus Joonas</td>
<td>Research associate from 1.9.2004</td>
</tr>
<tr>
<td>Kärkkäinen Mikko</td>
<td>Research associate</td>
</tr>
<tr>
<td>Laakso Lauri</td>
<td>Laboratory technician</td>
</tr>
<tr>
<td>Laaninen Mikko</td>
<td>Research assistant until 31.7.2003</td>
</tr>
<tr>
<td>Laitinen Tommi</td>
<td>Research associate until 31.3.2003</td>
</tr>
<tr>
<td>Lehto Arto</td>
<td>Senior lecturer</td>
</tr>
<tr>
<td>Lindberg Stina</td>
<td>Secretary</td>
</tr>
<tr>
<td>Lioubtchenko Dmitri</td>
<td>Research associate</td>
</tr>
<tr>
<td>Lunttila Timo</td>
<td>Research associate until 31.12.2002</td>
</tr>
<tr>
<td>Lönnqvist Anne</td>
<td>Research associate</td>
</tr>
</tbody>
</table>
Mallat Juha  Senior scientist
Mikkola Milla  Research assistant from 17.5.2004
Mustonen Maria  Research associate from 1.6.2004
Mylläri, Tuula  Secretary
Möttönen Ville  Research associate
Nakari Risto  Research assistant 1.1. – 30.9.2003
Noponen Eero  Senior researcher until 31.8.2003
Ollikainen Jani  Research associate until 31.1.2003
Pousi Patrik  Research associate from 29.3.2004
Podlozny Vladimir  Project manager and research associate from 22.4.2004
Rekanos Ioannis  Visiting researcher until 31.10.2002
Ranvier Sylvain  Research associate from 1.11. 2003
Räisänen Antti  Professor, Director of the Radio Laboratory
Saarela Ilpo  Research assistant until 30.4.2002
Salo Jari  Research associate from 11.11.2002
Salonen Ilkka  Research associate
Salmi Jussi  Research assistant from 24.5.2004
Sanmartin Alejandro  Research assistant until 16.6.2002
Schmuckli Lorenz  Laboratory technician
Sibakov Viktor  Laboratory manager
Sulonen Kati  Research associate until 31.3.2004
Suvikunnas Pasi  Research associate
Säily Jussi  Research associate
Tarvainen Teemu  Research associate until 31.5.2002
Teräsranta Hannele  Research associate until 30.9.2003
Tiuri Martti  Professor emeritus (Member of Parliament until 31.3.2003)
Toivanen Juha  Research assistant from 20.5.2002
Tretiakova Natalia  Project secretary 2.6. – 18.7. and from 1.11.2004
Tretyakov Sergei  Professor
Vainikainen Pertti  Professor
Viikari Ville  Research associate from 17.5.2003
Villanen Juha  Research associate
Vuokko Lasse  Research associate
Zhao Xiongwen  Research associate until 30.9.2004

In the Signal Processing Laboratory:

Abrudan Traian  Researcher
Aittomäki Tuomas  Research assistant from 1.6.2003
Belloni Fabio   Researcher from 1.9.2002  
Cheong Mei Yen   Researcher from 17.2.2003  
Ekholm Pyry   Computer administrator from 17.5.2004  
Enescu Mihai   Post doc researcher  
Eriksson Jan   Post doc researcher  
Ferrante Alessandro   Research assistant 1.10.2002 – 31.5.2003  
Gregorio Fernando   Researcher from 9.10.2003  
Grönroos Mikko   Computer administrator until 31.7.2004  
Jantunen Peter   Researcher 1.2.2003 – 31.8.2004  
Jänis Pekka   Research assistant from 1.8.2004  
Jääskeläinen Anne   Secretary  
Karvanen Juha   Post doc researcher until 9.9.2003  
Koivisto Tommi   Researcher from 1.6.2003  
Koivunen Visa   Professor  
Laakso Timo   Professor  
Lehtonen Mikko   Research assistant 5.7. – 5.9.2004  
Lemetyinen Mirja   Secretary  
Liu Yaohui   Researcher until 30.6.2004  
Lundén Jarmo   Researcher from 1.6.2003  
Makundi Martin   Researcher  
Martin Martinez Julian   Research assistant 26.5.2003 – 31.5.2004  
Mélvasalo Maarit   Researcher  
Oja Eino   Research assistant 1.7.2002 – 30.4.2003  
Ollila Esa   Post doc researcher from 17.4.2003  
Pöllönen Keijo   Research assistant from 19.5.2003  
Quattropani Luca   Research assistant 1.1. – 31.8.2002  
Ribeiro Cassio   Researcher from 4.9.2003  
Richter Andreas   Research scientist from 6.9.2004  
Roman Timo   Researcher  
Seppola Anne-Mari   Research assistant from 1.5.2004  
Shoaib Mobien   Research assistant from 17.5.2004  
Sirbu Marius   Researcher until 30.4.2004  
Valkama Mikko   Part-time post doc researcher 1.2. – 30.6.2002 and 1. – 30.11.2004  
Venäläinen Juha   Researcher until 31.10.2004  
Visuri Samuli   Post doc researcher 1.1.2002 – 30.4.2004  
Werner Stefan   Post doc researcher  
With Matias   Researcher  
Xu Hai   Research assistant until 31.8.2003  
Zhang Xiaojing   Research assistant from 1.11.2003
5 Visitors to SMARAD 2002-2004

Visiting Professors:

- Prof. Masami Kihara, Nippon Telegraph and Telephone Corporation, Japan, until 18 June, 2002
- Prof. Igor Nefedov, Institute of Radiotechnics and Electronics, Russian Academy of Science, Saratov Department, 1 April – 31 August, 2002; and from 1 July 2004
- Prof. Vladimir E. Lyubchenko, Institute of Radioengineering and Electronics, Russian Academy of Sciences, Russia, 7 October – 1 November, 2002, and 22 September - 24 October, 2003
- Prof. David Rutledge, Californian Institute of Technology, from 1 September to 31 December, 2003
- Prof. K.V.S. Hari, India Institute of Science, Bangalore, India, 20 May – 7 July, 2002
- Prof. Santosh Venkatesh, University of Pennsylvania, Philadelphia, USA, 3 August – 2 September, 2002
- Professor Juan Cousseau, Universidad National del Sur, Argentina, 1 February - 31 May, 2003
- Prof. José Apolinario, Instituto Militar de Engenharia (IME), Brazil, 3 November-31 December, 2004

Visiting Researchers:

- Dr. Sergey Dudorov, Moscow Institute of Physics and Technology, Russia
- Dr. Natalia Ermolova, Moscow University of Radio Engineering, Electronics and Automatics, Russia until 31 June, 2002
- M.Sc. Filip Mikas, Czech Technical University from 1 September, 2003
- Dr. Ioannis Rekanos, Aristotle University of Thessaloniki, Greece until 31 October, 2002
- M.Sc. Cassio Ribeiro, Federal University of Rio de Janeiro, Brazil since 4 September 2003
- Dr.Ing. Andreas Richter, Technical University of Ilmenau, Germany, since 6 September, 2004
6 Visits from SMARAD to foreign institutes

- Tommi Laitinen: Danish Technical University, 1 April, 2003 –
- Antti Räisänen: Observatoire de Paris and Université Pierre et Marie Curie (Paris 6), 1 August, 2001 – 29 July, 2002
- Jari Salo: Technische Universität Wien, Austria, 1 October 2004 –
- Samuli Visuri: ETH Zurich, Switzerland, 1 January – 31 December, 2003
- Juha Karvanen: Riken research institute Japan, 1 October, 2002 – 31 July, 2004
- Are Hjörungnes: Federal University of Rio de Janeiro, Brazil, 15 March – 15 April, 2003
- Stefan Werner: Federal University of Rio de Janeiro, Brazil, 1 February – 1 August, 2003
- Mihai Enescu: Technische Universität Wien, Austria, 1 December, 2003 – 31 March, 2004
- Esa Ollila: University of Bruxelles, Belgium, 5 – 24 May, 2003
- Tuomas Aittomäki: University of Pennsylvania, USA, 1 September –
- Mei Yen Cheong, Technische Universität Wien, Austria, 1 October –
7 Post-graduate degrees

7.1 Doctor of Science (Technology)

2002:
Kimmo Kalliola: Experimental analysis of multidimensional radio channels
Thesis defence: 15 February, 2002
Supervisor: Prof. Pertti Vainikainen
Opponents: Prof. Jørgen Bach Andersen (Aalborg University, Denmark) and prof. Erkki Salonen (University of Oulu, Finland).
Preliminary examiners: Dr. Robert Bultitude (Communications Research Centre, Ottawa, Canada) and Dr. M. A. Beach (University of Bristol, UK)

Sergey Dudorov: Rectangular dielectric waveguide and its optimal transition to a metal waveguide
Thesis defence: 3 June, 2002
Supervisor: Prof. Antti Räisänen
Opponent: Prof. Richard de la Rue (University of Glasgow, UK)
Preliminary examiners: Dr. Tomas Sehm (Nokia, Finland) and Prof. Vladimir Lyubchenko (Russian Academy of Sciences, Russia)

Jaana Laiho: Radio network planning and optimization for WCDMA
Thesis defence: 1 July, 2002
Supervisor: Prof. Pertti Vainikainen
Opponent: Prof. Jens Zander (Royal Instutute of Technology, Stockholm, Sweden)
Preliminary examiners: Prof. Ian Opperman (University of Oulu, Finland) and Prof. Roberto Verdone (University of Bologna, Italy)

Xiongwen Zhao: Multipath propagation characterization for terrestrial mobile and fixed microwave communications
Thesis defence: 13 December, 2002
Supervisor: Prof. Pertti Vainikainen
Opponents: Dr. Jukka Henriksson (Nokia, Finland) and Dr. Ari Viiitanen (Helsinki University of Technology, Finland)
Preliminary examiners: Dr. Wei Zhang (National Institute of Standards and Technology, USA) and Prof. Andreas Molisch (Lund University, Sweden)

Mihai Enescu: Adaptive methods for blind equalization and signal separation in MIMO systems
Thesis defence: 23 August, 2002
Supervisor: Prof. Visa Koivunen
Opponents: Prof. K.V.S. Hari (India Institute of Science, India) and Prof. Ioan Tabus (Tampere Univ. of Technology, Finland)
Preliminary examiners: Dr. Juha K. Laurila (Nokia Group, Finland) and Prof. Ioan Tabus (Tampere University of Technology, Finland)

Juha Karvanen: Adaptive methods for score function modeling in blind source separation
Thesis defence: 26 August, 2002
Supervisor: Prof. Visa Koivunen
Opponents: Prof. A. Cichocki (Riken research Institute, Japan) and Prof. Santosh Venkatesh (University of Pennsylvania, USA)
Preliminary examiners: Dr. Aapo Hyvärinen (Helsinki University of Technology, Finland) and Dr. Jyrki Möttönen (Tampere University of Technology, Finland)

Stefan Werner: Reduced complexity adaptive filtering algorithms with applications to communications systems
Thesis defence: 15 November, 2002
Supervisor: Prof. Timo Laakso
Opponents: Prof. Ioan Tabus (Tampere Univ. of Technology, Finland) and Prof. Y-F. Huang (University of Notre Dame, USA)
Preliminary examiners: Prof. Markku Juntti (University of Oulu, Finland) and Prof. Yih-Fang Huang (University of Notre Dame, USA)

2003:

Hassan M. El-Sallabi: Modeling and characterization of urban radio channels for mobile communications
Thesis defence: 7 July, 2003
Supervisor: Prof. Pertti Vainikainen
Opponents: Prof. Jun-ichi Takada (Tokyo Institute of Technology, Japan) and Dr. Terhi Rautiainen (Nokia, Finland)
Preliminary examiners: Prof. Pierre Degauque (Université de Lille, France) and Prof. I-Tai Lu (Polytechnic University in Brooklyn, USA)

Jussi Säily: Instrumentation of a submillimetre wave hologram compact antenna test range
Thesis defence: 19 September, 2003
Supervisor: Prof. Antti Räisänen
Opponent: Dr. Philippe Goy (Ecole Normale Superieur, France)
Preliminary examiners: Prof. Neal Erickson (University of Massachusetts, USA) and Dr. Taavi Hirvonen (PJMicrowave, Finland)

Kimmo Kettunen: Soft detection and decoding in wideband CDMA systems
Supervisor: Prof. Timo Laakso
Opponents: Prof. B. Aazhang (Rice University, Houston, Texas, USA) and Prof. M. Latva-aho (University of Oulu, Finland)
Preliminary examiners: Prof. Behnaam Aazhang (Rice University, USA) and prof. Ian Opperman (University of Oulu, Finland)

Markku Pukkila: Iterative receivers and multichannel equalisation for time division multiple access systems
Thesis defence: 10 October, 2003
Supervisor: prof. Timo Laakso
Opponent: Prof. Markku Renfors (Tampere University of Technology, Finland)
Preliminary examiners: Prof. Tony Ottosson (Chalmers University of Technology, Sweden) and Prof. Tadashi Matsumoto (University of Oulu, Finland)
Marius Sirbu: Channel and delay estimation algorithms for wireless communication systems
Thesis defence: 4 December, 2003
Supervisor: Prof. Visa Koivunen
Opponents: Prof. Erik Ström, (Chalmers University of Technology, Sweden) and Dr. Kari Pehkonen (Nokia Mobile Phones, Finland).
Preliminary examiners: Prof. Erik Ström (Chalmers University of Technology, Sweden) and Dr. Mikko Valkama (Tampere University of Technology, Finland)

2004:
Mikko Kärkkäinen: Modeling of interfaces and layers with the finite-difference time-domain method
Thesis defence: 22 March, 2004
Supervisor: Prof. Sergei Tretyakov
Opponent: Prof. John L. Volakis (Ohio State University, USA)
Preliminary examiners: Prof. Keith W. Whites (South Dakota School of Mines and Technology, USA) and Dr. Jaakko Juntunen (Aplac Solutions, Finland)

Kati Sulonen: Evaluation of performance of mobile terminal antennas
Thesis defence: 2 July, 2004
Supervisor: Prof. Pertti Vainikainen
Opponents: Prof. Olav Breinbjerg (Technical University of Denmark, Denmark) and Dr. Hannu Kauppinen (Nokia, Finland)
Preliminary examiners: Prof. Werner Wiesbeck (Universität Karlsruhe, Germany) and Dr. Tokio Taga (NTT DoCoMo Inc., Japan)

Jani Ollikainen: Design and implementation techniques of wideband mobile communications antennas
Thesis defence: 26 November, 2004
Supervisor: Prof. Pertti Vainikainen
Opponent: Prof. Juan R. Mosig (Ecole Polytechnique Fédérale de Lausanne, Switzerland) and Dr. Timo Tolmunen (Turku Polytechnic, Finland).
Preliminary examiners: Prof. Kin-Lu Wong (National Sun Yat-Sen University, Taiwan) and Dr. Taavi Hirvonen (PJMicrowave, Finland)

Jan Eriksson: Contributions to theory and algorithms of independent component analysis and signal separation
Thesis defence: 20 August, 2004
Supervisor: Prof. Visa Koivunen
Opponents: Prof. Douglas C. Scott, (Southern Methodist University, Dallas, USA) and Prof. Christian Jutten (University of Grenoble, France)
Preliminary examiners: Prof. Christian Jutten (University of Grenoble, France) and Dr. Arie Yeredor (Tel-Aviv University, Israel)
7.2 Licentiate of Science (Technology)

2002:
Ilkka Salonen: Pattern distortion and impedance mismatch in small microstrip antenna arrays  
Supervisor: Prof. Pertti Vainikainen  
Graduation date: 2 September, 2002
Janne Häkli: Design of a dual reflector feed system for a hologram compact antenna test range  
Supervisor: Prof. Antti Räisänen  
Graduation date: 23 September, 2002
Pasi Suvikunnas: Optimization of multielement antenna arrays at the base stations  
Supervisor: Prof. Pertti Vainikainen  
Graduation date: 21 September, 2002
Mikko Kärkkäinen: Using the surface impedance concept in the finite-difference time-domain method  
Supervisor: Prof. Sergei Tretyakov  
Graduation date: 21 October, 2002
Yaohui Liu: Adaptive radio frequency interference cancellation in very high speed digital subscriber line (VDSL) systems  
Supervisor: Prof. Timo Laakso  
Graduation date: 10 January, 2002
Maarit Melvasalo: Blind channel estimation algorithms and a simulation software for long code CDMA systems  
Supervisor: Prof. Visa Koivunen  
Graduation date: 16 December 2002

2003:
Jari Salo: Detection of the number of multipath components for measured propagation channels  
Supervisor: Prof. Pertti Vainikainen  
Graduation date: 16 June 2003
Viacheslav Golikov: Passive intermodulation in mobile communications antenna  
Supervisor: Prof. Pertti Vainikainen  
Graduation date: 16 June 2003

2004:
Leonardo Azzinnari: Analysis of broadband small antennas  
Supervisor: Prof. Pertti Vainikainen  
Research done at: TKK Radio Laboratory  
Graduation date: 19 January, 2004
Anne Lönnqvist: Kompakti tutkapoikkipinnan mittauspaikka skaalatuille malleille (Compact RCS range for scaled models)  
Supervisor: Prof. Antti Räisänen  
Graduation date: 29 March, 2004
Tomi Koskinen: Submillimeter wave compact antenna test range based on a hologram  
Supervisor: Prof. Antti Räisänen  
Graduation date: 29 March, 2004
Pavel Belov: Analytical studies of complex microwave stop band structures
(Аналитические исследования сложных микроволновых структур с запрещенными зонами)
Supervisor: Prof. Sergei Tretyakov
Graduation date: 20 September, 2004

Juha Venäläinen: Modulation Recognition in Dispersive Communication Channels
Supervisor: Prof. Visa Koivunen
Graduation date: 10 November, 2004
8 Publications in 2002

8.1 Books and Chapters in Books


8.2 Refereed Journal Articles


### 8.3 Published Proceedings of International Conferences


43. O. Kivekäs, J. Ollikainen, P. Vainikainen: Frequency-tunable internal antenna for


61. I.S. Nefedov, S.A. Tretyakov: Theoretical study of waveguiding structures containing backward-wave materials, URSI XXVIth General Assembly, Maastricht, the


8.4 Other Published Presentations at Scientific Meetings


8.5 Refereed Final Reports of Research Projects


2. S. Dudorov: *Rectangular Dielectric Waveguide and Its Optimal Transition to a Metal


### 8.7 Patents


9 Publications in 2003

9.1 Books and Chapters in Books


9.2 Refereed Journal Articles


9.3 Published Proceedings of International Conferences


52. J. Salo, H.M. El-Sallabi, P. Vainikainen: Detection of the number of two-dimensional cisoids in white Gaussian noise for array processing algorithms, IEEE 2003 Vehicular Technology Conference, Orlando, FL, USA, 6-9 October, 2003, paper 08A. 03 in CD


64. S.A. Tretyakov, S.I. Maslovski: Thin absorbing structure for all incidence angles based on the use of a high-impedance surface, Proceedings of European Microwave Week 2003, Munich, Germany, 6-10 October 2003, pp.1107-1110 p.


68. T. Abrudan, M. Sirbu, V. Koivunen: Blind Multi-user receiver for MIMO-OFDM systems. IV IEEE Workshop on Signal Processing SPAWC2003, Rome Italy, 15-18
June 2003.


2003, pp. 2659-2663.

9.4 Other Published Presentations at Scientific Meetings


7. T. Laitinen, P. Vainikainen, T. Koskinen, and O. Kivekäis: Characterization of the radiated fields of mobile terminal antennas from a small number of amplitude-only and complex field samples, COST Temporary Document TD (03) 051, 6th Management Committee Meeting of COST 273, Towards Mobile Broadband Multimedia Networks, Barcelona, Spain, 15-17, January, 2003.


9.5 Refereed Final Reports of Research Projects


5. V. Möttönen, A. Räisänä: Final report: Mm and sub-mm-wave open structure


9.7 Patents


10 Publications in 2004

10.1 Books and Chapters in Books


10.2 Refereed Journal Articles

14. T.A. Laitinen, J. Toivanen, C. Icheln, P. Vainikainen: Spherical measurement system


### 10.3 Published Proceedings of International Conferences


17. J. Salo, P. Suvikunnas, H.M. El-Sallabi, P. Vainikainen: On the characteristics of MIMO mutual information at high SNR. *Proc. of the 6th Nordic Signal Processing


35. M. Kärkkäinen: Application of impedance sheet conditions to modeling of frequency selective surfaces. Proceedings of the 10th Conference on Complex Media and


55. M. With, S. Werner, V. Koivunen: Householder-based anti-jamming navigation


10.4 Other Presentations at Scientific Meetings


10.5 Refereed Final Reports


10.6 Nonrefereed Articles and Reports

11 Other scientific activities of SMARAD principal investigators in 2002 – 2004

Participation in organization of scientific conferences and membership in expert boards:

Antti Räisänen:
- Fellow, IEEE
- International Conference on Microwave and Millimeter wave Technology (ICMVT2002), Beijing, China, August 18 – 21, 2002; member of the Technical Programme Committee (TPC)
- URSI/IEEE XXVII Convention on Radio Science, Espoo, Finland, October 17 – 18, 2002; member of the TPC
- The 3rd ESA Workshop on Millimetre Wave Technology and Applications: circuits, systems, and measurement techniques, Espoo, Finland, May 21 – 23, 2003; Co-Chair of the Organizing Committee and TPC
- The 11th Microcoll, Hungarian Academy of Science, Budapest, Hungary, September 10 – 12, 2003; member of the TPC
- Member, General Assembly of the European Microwave Association 2003 –
- Member of the Board, SSF Program of High Frequency Electronics, Chalmers University of Technology, until April 2003
- Member of the Board, SSF Strategic Research Centre: High Speed Electronic and Photonic Centre, Chalmers University of Technology, 2003 –
- URSI, member of the Finnish National Committee
- Member of the Board, CSC-Center for Scientific Computing, until June 2003
- Chairman, Board of Directors of MilliLab, 1995 –
- Fifteenth International Symposium on Space Terahertz Technology, Northampton, MA, USA, 27 – 29 April, 2004, member of the TPC
- MSMW’04 Symposium, Kharkov, Ukraine, 21 – 25 June 2004, member of the International Program Committee
- 2004 European Microwave Conference, Amsterdam, The Netherlands, October 6 – 10, member of TPC
- 2004 Asia-Pacific Microwave Conference; New Delhi, India, December 12 – 18, 2004; member of the TPC

Sergei Tretyakov:
- Chairman of the Organizing Committee, URSI/IEEE XXVII Convention on Radio Science, Espoo, Finland, October 17 – 18, 2002
- Member, General Meeting of the European Microwave Association (until 2002)
- Member of the International Biaxisotropics Conference Committee
- Member of the Technical Program Committee (TPC), XIV International Conference on Microwaves, Radar, and Wireless Communications MIKON’2002, Gdansk, Poland, May 20 – 22, 2002
- General Chair, The 2003 International Student Seminar on Microwave Applications of Novel Physical Phenomena, Espoo, Finland, May 26 – 27, 2003
- Expert statement for University of Arizona 2004
- Member of the Steering Committee, International Conference on Complex Media Electromagnetics (Biaxisotropics’2004), Ghent, Belgium
- Coordinator of Metamorphose Network-of-Excellence, 2004 –
Pertti Vainikainen:
- Finnish National Committee on Radio Frequency Administration, member
- Member of the Technical Program Committee of PIMRC’02
- Chairman of the 1st Workshop of COST273, Espoo, Finland, May 2002
- Member of the Technical Program Committee of URSI/IEEE XXVII Convention on Radio Science, Espoo, Finland, October 17 – 18, 2002
- Member of the Technical Program Committee of EPMCC’03
- Member of the Technical Program Committee of Nordic Radio Symposium ‘04

Visa Koivunen:
- XXVIIth General Assembly URSI2002, Maastricht 17 – 24 August 2002, Special session convener
- Program committee member of Baiyona Workshop on Communications 2003
- Program committee member of ICA 2003 Conference
- Appointed to Adjunct Professor in the University of Pennsylvania, Philadelphia, USA, December 2003 –
- Nokia Leading Science Program, tutoring professor, 2004 –

Review Activities:

Antti Räisänen:
Associate Editor, IEEE Transactions on Microwave Theory and Techniques, 2002 – 2005
Experimental Astronomy, member of the Editorial Board
Reviews and evaluations for
- IEEE Transactions on Microwave Theory and Techniques
- IEEE Transactions on Antennas and Propagation
- IEEE Transactions on Electromagnetic Compatibility
- IEEE Microwave and Wireless Components Letters
- IEE Electronics Letters
- European Microwave Conference
- International Symposium on Space Terahertz Technology
- Asia Pacific Microwave Conference
- IEEE Fellow Committee
- U.S. Immigration & Naturalization Service (candidates for the green card)
- Vetenskapsradet (Swedish Science Council)
- Research Grants Council, City University of Hong Kong
Expert statements in professor nominations for:
University of Oulu, Finland
Chalmers University of Technology, Sweden

PhD thesis opponent at:
Chalmers University of Technology, Sweden
Universite Paris 6, France

Sergei Tretyakov:
Associate Editor of Radio Science
Member of Editorial Board of Electromagnetics
Reviews for
- IEEE Transactions on Antennas and Propagation
- IEEE Transactions on Microwave Theory and Techniques
- Journal of Electromagnetic Waves and Applications
- Journal of the Optical Society of America
- Journal of Physics A: Mathematical and General
- European Physical Journal
- IEE Proceedings
- Physical Review E
- Applied Physics Letters
- Optics Letters

**Pertti Vainikainen:**
Reviews for
- IEEE Transactions on Antennas and Propagation
- IEEE Transactions on Instrumentation and Measurement
- Wireless Personal Communications
- Subsurface Sensing Technologies and Applications
- IEEE Journal on Selected Areas in Communications
- IEE Electronics Letters
- Microwave and Optical Technology Letters
- IEEE Antennas and Wireless Propagation Letters

**Visa Koivunen:**
Associate editor for IEEE Signal Processing Letters
Reviews for a number of international conferences and the following journals:
- IEEE Transactions on Antennas and Propagation
- Signal Processing
- IEEE Transactions in Signal Processing
- IEEE Transactions on Circuits and Systems II
- IEEE Transactions on Neural Networks
- IEEE Transactions on Communications
- IEEE Signal Processing Magazine

Expert statement in professor nominations for University of Delaware, USA and Tampere University of Technology, Finland

**Timo Laakso:**
Reviews for a number of international conferences and following journals:
- IEEE Electronic Letters
- Signal Processing
- Applied Signal Processing
- IEEE Transactions in Signal Processing
- IEEE Transaction on Circuits and Systems II
- IEEE Transactions on Instrumentation and Measurement
- IEEE Transactions on Communications