Netherlands Antenna Research Framework (NARF)
Proposal for Strategic Research Area NIRICT

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NARF industrial and research partners (National)

Industry: Thales, NXP, Tyco, EPCOS/TDK, CHL, WMC, Catena

Research centers: TNO, IMEC-Holst, ESA-ESTEC, ASTRON, SRON, NLR, Erasmus MC.

Introduction

In September 2011 the official kick-off was held of a new 3TU initiative to strengthen the activities in the field of Antenna systems and Propagation within the departments of Electrical Engineering. The role of the NARF can be further strengthened when the NARF is a Strategic Research Area (SRA) within the NIRICT. This document describes the mission, vision and other relevant background information of the NARF.

Mission

The NARF focuses on the domain of Antenna systems and Propagation (A&P), including theory, experiments and applications. By cooperating with related disciplines such as signal processing, electronics, material sciences and mathematics new breakthroughs can be created that will enable improvements in existing applications and will enable new application domains.

A&P play a key role in today's society. The number of wireless devices and application domains are growing exponentially. It is crucial to maintain and further expand our strong expertise in the Netherlands in the domain of A&P. This requires top-research in this domain that attracts talented students.

The NARF will drive and align the academic research in A&P in the Netherlands. This should provide the required critical mass in terms of manpower and experimental facilities. It will also provide an improved visibility on national and international level. The NARF will support national industry, SME's and research centers in R&D related to the field of A&P. In addition, we will organise master and post-master level education.

The NARF will define and maintain a national research roadmap in the field of A&P. The roadmaps are based on the input of our stakeholders (industry, research centers and universities).

Vision

Antenna systems and the associated propagation channel form an essential element in any system that make use of electromagnetic waves. For the year 2020 the World Wireless Research Forum estimates that 7 trillion wireless devices will serve about 7 billion people, not only in telecommunication systems but also in new application areas such as e-health, traffic management and smart buildings. People will be served by many wireless devices, sensors and tags (e.g. in transport and weather systems), providing ambient intelligence and context sensitivity. This fast growth can only be enabled by developing smart antenna systems that can combat for spectrum and energy efficiency at low-cost and small size and can operate in variable embeddings (e.g. chip packaging or human body).

Besides the number of antenna-enabled devices, also the performance will increase significantly. Based on Edholm's law (increase of bandwidth by factor 2 each 18 month), we can expect Tbit/s data rates in wireless communication in 10-15 years from now. This will require new concepts with electronic beam steering operating at much higher frequencies as today (e.g. 60 GHz up to THz).

Also break-throughs in other disciplines, like material sciences and nanostructures, will enable new antenna concepts.

Our dream position for the NARF is to have a well-established cooperation with our stakeholders in which the 3TU research teams will work on new research themes that will enable future product development. This research will be well embedded within the NIRICT framework.

Scientific Challenges

Together with the stakeholders of the NARF we have defined three research themes.

Theme 1: Intelligent Antenna Systems

Intelligent antenna systems will be required to enable high data rate wireless communication with improved spectrum and energy efficiency. Let us for example take a closer look at today's wireless infrastructure. A 3G base station typically consumes 5 kW. Several new MegaWatt power plants have to be built each year to combat the growth of the number of base stations worldwide. Main problem is that existing base stations are not intelligent, they radiate the energy in all directions of the cell. Of course, this is not very efficient in terms of radiated power and in terms of capacity. By using multi-functional antennas with electronic beam steering (phased-arrays) both the power efficiency as well as the spectrum capacity (which is important in the existing overcrowded spectrum) can be increased.

It is believed that the main route to improve the spectrum efficiency is cognitive radio, which provides communication links at frequencies which are not intensively used by license users in combination with radiation pattern null steering in the license user directions. Realization of such an approach requires both electronic beam steering and frequency reconfiguration of the antenna systems.

Support of multiple communications standards by a single base station, which is the main way to decrease the number of base stations in future, requires multi-band RF front-ends and frequency-reconfigurable antenna systems.

In remote sensing, the development of frequency reconfigurable antenna array systems will allow functioning of different radar systems (air traffic control, weather radar, naval surveillance radar, etc.) through the same antenna system. The same is valid for a combination of car-to-car communication with the driver assistant radar system.

Last but not least, a considerable part of the foreseen 7 trillion wireless devices in 2020 will be wearable devices, which should operate in the direct proximity (or within) human bodies. Antenna systems of wearable/ handheld/embedded devices are very sensitive to the properties of the environment (iPhone 4 story is one of well-known confirmations), and thus should be tuned depending on their position on a body and body properties in order to provide reliable communication without power overspending.

When moving to higher frequencies in the future (e.g. 60 GHz and 160 GHz), the need for intelligent antennas will become even more relevant due to large available bandwidth, antenna integration into a system-on-chip and multi-functional nature of the wireless front-ends.

Key research areas for intelligent antennas are:

- Phased arrays with electronic beam steering and hybrid systems, such as focal plane arrays.
- Reconfigurable antenna systems in frequency, power consumption, functionality and polarization.
- Embedded antenna reconfigurability for adjustment to the environment.
- Highly integrated ("Element-in-package")
- Applying artificially engineered materials.
- Cognitive radios.
- Accurate propagation models for base station planning.

Theme 2: THz Technologies and Antenna Systems

With the expected increase of wireless communication needs, future systems will soon run out of available spectral BW. In order to achieve wireless internet connections at speeds millions of times faster than now, higher (>100 GHz) spectrum will need to be exploited. The maturity of the THz technology is however extremely limited, with no real mass market industrial player active yet, in the Netherlands or elsewhere. Most of the present state of the art has been achieved thanks to niche, space science driven developments. In this field SRON has been a key player since 30 years. However, very recently, 1K-pixel THz cameras, based on mass producible CMOS technology has been demonstrated. This is probably the first successful receiver realized with low cost technology. Further research is required to obtain levels of transmit power and/or sensitivity that render the THz spectrum user friendly. However, the route to for indoor wireless communication schemes, of optical capacity (T-bits/sec), at this time seems feasible in the next 10 years.

The entire communication chain needs to be investigated, as no system solutions exist yet. As a consequence cooperative efforts between several research areas will naturally arise and NIRICT could provide the ideal environment to coordinate and harmonize these efforts.

Key research areas THz technologies and Antenna systems are:

- Phased-arrays/focal plane arrays on (Bi-)CMOS IC's
- Wide-band systems for imaging and spectroscopy
- MIMO antenna arrays for fast imaging without mechanical scanning
- Integration of antennas with photonics circuits.

Theme 3: Antenna systems for Health

Wireless communication in Healthcare is used more and more. Especially the communications in and around the body attracts more attention. We expect that in a few years the number of people using a BAN (Body Area Network) will increase significantly in the areas of medical healthcare, personal monitoring, etc. The most popular frequency bands for on-body propagation are the 2.4-2.5 GHz industrial, scientific and medical (ISM) band and the European 868-MHz band. But if in-body communication and sensing is also considered and higher bandwidths are required, other frequency bands must be considered also. When moving to higher frequencies in the future (e.g. 60 GHz), the need for intelligent antennas will become even more relevant.

Key research areas in the domain of Health are:

- Bio-implantable antennas with adaptive properties
- On/off-body and wearable antennas
- Wireless power transfer and energy harvesting
- Imaging antennas systems
- Body as propagation channel.

Research approach

In our research we develop new concepts and corresponding theoretical models in the area of antenna systems and propagation. In-depth know-how of new developments on materials and thin-film/semiconductor technologies is essential. The research challenges require new concepts and architectures, for example integrated antennas in semiconductor technologies and adaptive antennas embedded in variable environments. Since antennas and the corresponding propagation channel are (in general) quite large in terms of the wavelength, a lot of effort is put on accurate and efficient modeling. A full-wave electromagnetic model is often very time consuming or even impossible. The theoretical models that we develop either aim to give physical insight or to diminish the computation effort which is needed. This will enable synthesis and optimization. Experimental validation of prototypes is key in our work. This requires expensive antenna test facilities. Fortunately, we have several state-of-the-art test facilities available at 3TU. The NARF will help to maintain and upgrade these facilities in the next 10-15 years.

Applications

The number of applications of antenna systems is growing very fast. A&P play an essential role in the High-Tech Systems and Materials (HTSM) top sector. A short description is given on the key application areas.

Wireless communication.

The Netherlands plays an important role in the area of wireless communication, with strong involvement of our industry. This includes both the infrastructure as well as the mobile devices. For example, NXP is a top-2 player in RF electronics for wireless infrastructure. Future trends in this domain include intelligent antenna systems to replace the existing 2G/3G systems up to 2.5 GHz and new ultra-high data rate systems operating at mm-wave frequencies.

Radar.

Radars can be installed on ground stations as well on moveable platforms like cars, ships, aircraft and unmanned vehicles. The Netherlands is a world-wide leader in the development and manufacturing of naval military radar, coastal surveillance radar and police radar (Thales and CHL). Recently, innovative developments resulted in the appearance of a Dutch segment at the synthetic aperture radar market. Future trends are bringing different sensing functions (search, tracking, classification) in the same device with a single fixed antenna aperture which requires among others implementation of wide angle electronic scanning, multi-band operation and polarimetric reconfiguration. Increase of the operational bandwidth is another trend in sensing applications.

Radio astronomy.

Several national and international antenna-enabled initiatives are ongoing or started in the domain of radio astronomy with frequencies ranging from 10 MHz up to THz. The Netherlands plays a leading role in this by means of our NWO institutes, ASTRON and

SRON. One of these initiatives is the Square Kilometer Array, in which a very large phased-array antenna will be built in South-Africa.

Another initiative is OLFAR the Orbiting Low Frequency Array. OLFAR is a project whose aim is to develop a detailed system concept for space-based very low frequency large aperture radio interferometric array observing at very long wavelengths (0.3-30 MHz). The OLFAR cluster could either orbit the moon, whilst sampling during the Earth-radio eclipse phase, or orbit the Earth-moon L2 point, sampling almost continuously or Earth-trailing and leading orbit. Antenna systems for reception of these low frequencies, the inter satellite link and the link to Earth are the main challenges for OLFAR.

Space and satellite communications.

The use of array antennas in space systems is going to increase drastically in the coming decade. This is what emerges very clearly from a number of strategic documents produced by Eurospace (Eurospace is the trade association of the European Space Industry. Its member companies today represent 90% of the total turnover of the European Space Industry) and by the European Space Agency (ESA). This tremendous increase will be mostly fuelled by the Satcom market, where novel flexible and reconfigurable antenna systems are required to cope with rapidly changing user needs, standard changes and with the evolution of the terrestrial network. From this point of view, it is clear that phased-array antennas can offer a level of flexibility and reconfigurability that cannot be provided by the currently most widely used reflector antenna technology. The use of advanced focal plane arrays to feed reflectors and/or active/passive arrays can indeed increase the flexibility in terms of number of multiple independently agile beams, as well as frequent and complex beam reconfiguration and scanning.

The use of arrays for Satcom user terminals (Satcom on–the-move) has also great market perspectives. These systems based on low profile, low weight and agile antenna systems will offer the possibility to install mobile entertainment centers and mobile satellite TV on board also of cars, aircraft, trains, and small/medium boats.

Another space sector where array antennas are used is Earth Observation, although the number of missions is much smaller than the one expected for Satcom. State-of-the-art high performance SAR instruments are already equipped with active phased arrays. The next generation of SAR systems asks also for array antennas with beam agility, polarization purity, wider bandwidth, more sensitivity and simultaneous beam reception.

Based on the above trends, the antenna market seems to be open to array antenna solutions, but at the same time, the complexity and high cost of arrays render often very difficult the trade-off versus reflector solutions. It is therefore necessary to develop innovative solutions for arrays that would allow to reduce costs, by introducing advanced technologies for Transmit/Receive modules, by developing innovative antenna topologies for the integration of more functionalities at antenna level (e.g. frequency filtering) and by using low cost printed technologies (e.g. inkjet printing).

Security

In the national roadmap of the Top Sector HTSM Security, the biggest technological challenges and the highest market potential have been identified in the two following areas:

- risks to people, goods and society arising from deliberate acts;
- incidents, crises and disasters where the government is responsible for repression, aftercare and the preparation of prosecution.

In order to cope with the challenges and the increasing level of complexity of these scenarios in the security domain, it is necessary to develop innovative solutions based on an integrated approach. The information provided by different sensors and sensor networks and by intelligence operations must be made available at the right people, at the right moment, for an efficient decision making process. Such an integrated approach requires that all the different systems contributing to the collection, fusion and elaboration of the information can cooperate in a very efficient and flexible way not only among themselves, but also with communication systems.

In such a framework, antennas play a fundamental role as enabling technology for complex sensors (e.g. radars and imagers), as well as for sensor networks (e.g. small deployable sensors connected together to form an intelligent network) and communication systems. For each one of these applications, different requirements and challenging developments can be identified:

- Highly miniaturized/integrated but yet efficient antennas used on small deployable sensors to create smart networks for monitoring purposes;
- Smart/adaptive and efficient antennas for base stations able to effectively interact with many network nodes;
- Reconfigurable active array antennas for multiband complex sensors and communication systems, like radars and imagers.

Also imagers are going to play a more and more important role in security scenarios. These are used for screening people, bags/luggage and postal packages in sensitive areas like airports, stadiums, public buildings, etc. The main improvements for the new generations of these systems are: higher resolutions (to detect small metallic and non-metallic objects with good accuracy) and higher throughput (to operate in real time). Once again antennas are a key enabling technology for these systems.

Imaging

Wireless imaging is done using two different technological approaches: THz imaging and microwave imaging. One of the advantages of THz imaging is that an object under investigation might be very remote. Microwave imaging can be done only in close proximity to the sensor. In recent years, short-range microwave imaging became an emerging application of RF wireless technology and is used in security (concealed weapon detection in airports and entry ports to large events such as festivals), industry (non-destructive testing of goods such as plywood and plastics) , construction (road and tunnel walls inspection) and infrastructure (buried pipe and cable detection, water leakage detection, etc.). Antenna systems developed for these purposes use ultra-wideband antenna arrays with electronic beamsteering. A solid theoretical foundation, which is available for the conventional phased arrays, is still missing for UWB antenna arrays and its development represent one of research challenges in this field.

Smart buildings.

Smart buildings are buildings able to react to the environment and/or to human activities in an adaptive way. In this case, key parameters of the indoor environment (e.g. heating, ventilation, air conditioning systems, light, etc.) and human activities (presence, movements, identification of the type of activity etc.) are monitored together, providing the required information to allow a proper tuning of the system's parameters. New buildings, e.g., have the potential to become "positive energy" office buildings that generate more energy than they consume. This can be achieved by drastically decreasing the current power demand. One element in such a program is to turn on heating and lighting only in those areas where they are needed. At present, 42% of the energy consumed is used for heating, ventilation, and air conditioning (HVAC), and 23% is used for lighting. This situation calls for a large deployment of wireless sensors able to detect the presence or absence of human beings. Energy scavenging (e.g. thermal, PV) or wireless energy transfer will become very important as to overcome the need to replace batteries.

Logistics.

Our logistic chain for perishable goods (food, medicine) is currently quite ineffective, leading to a lot of waste. In the future, these goods can be equipped with a smart shipping label. In first instance, this label can be used for logistic purposes, but in a later phase, one could envision that these antenna-enabled smart tags could be read-out in people's home as well, by interfacing with domestic appliances (e.g. refrigerator). The smart tags include a long-range and robust RFID-like wireless system and include many sensors (temperature, humidity, etc.).

Medical/health.
One of the many medical applications of wireless systems is neuro-stimulation. In order to make implantable neuro-stimulation systems more intelligent, stimulation and sensing need to be implemented in different locations in the body. Since in-body locations are not physically accessible (or at least difficult and with some risks), wireless communication between the dispersed stimulation and sensing modules is required. In-body antenna systems are essential for the links. Another important research area in the Netherlands is Hyperthermia. Antenna arrays are used to locally heat tissue to approx. 42 ^{0}C. In this way, traditional cancer treatments (e.g. chemotherapy) works more efficient.

Education and knowledge transfer

We have initiated a couple of events to enhance the education and knowledge transfer of our MSc/PDEng/PhD-students:

- *Yearly NARF workshop*. The first workshop was held in September 2011 at the TU/e. PhD students presented their work to the NARF partners.
- *(Post-) master course.* Currently we are setting up a new course on antenna systems intended for post-master level. This course should also attract employees from our partners for Life-long-learning.
- *EUCAP 2014.* We have taken the initiative to organize the European Conference on Antennas & Propagation of 2014 in the Netherlands. The EUCAP is one of the largest conferences in the world in our field of research, with ~1000 participants.

In addition, we participate in courses which are organized by the European School of Antennas.

Participating Chairs of NIRICT

TUD

The following chairs will participate:

- Prof. DSc. Alexander Yarovoy – Microwave Sensing, Signals and Systems
- Prof.dr. Andrea Neto – TeraHertz Sensing
- Dr. ir. Marco Spirito - ELCA

UT

The following chairs will participate:

- Dr.ir. Mark Bentum – Telecommunication Engineering
- Prof.dr.ir. F.E. van Vliet – Integrated Circuit Design
- Prof.dr.ir. Peter Veltink – Bio-medical signals and systems

TUE

The following chairs will participate:

- Prof.dr.ir. Bart Smolders, Dr.ir. Matti Herben – Electromagnetics in wireless communications
- Prof.dr. Giampiero Gerini - Novel Structures and Concepts for Advanced Antennas
- Prof.dr.ir. Peter Baltus – Mixed-Signal Microelectronics & CWT/e

Academic Partners (incl. NWO institutes)

National (apart from 3TU)

- Radboud University Nijmegen; dr.ir. John Schermer, Prof.dr. Heino Falcke
- Erasmus Medisch Centrum; Prof.dr. Gerard van Rhoon, dr.ir. Maarten Paulides
- Amsterdam Medisch Centrum/UvA; dr. Gerard van Stam
- ASTRON; Prof.ir. Arnold van Ardenne,ir. W. van Cappellen, dr.ir. A.J. Boonstra
- SRON; dr. H. Hoevers, dr. J. Gao, dr. Jochem Baselmans; dr. A. Baryshev

International

- Chalmers University; Prof.dr. Per-Simon Kildal
- Technische Universität Hamburg-Harburg; Prof. Dr. -Ing. Arne Jacob
- Technische Universität Erlangen- Nuremberg; Prof. Dr.-Ing. Lorenz- Peter Schmidt
- Universität Ulm; Prof. Dr.-Ing. Wolfgang Menzel
- Fraunhoffer FHR; Dr. Peter Knott
- XLIM institut de recherche/University of Limoges; Prof. Bernard Jarry, Prof. Bernard Jecko and Dr. Julien Lintignat
- ESIEE Paris; dr. Corinne Berland
- University of Sophia-Antipolis: Prof.dr. Christian Pichot
- University of Rennes: Prof.dr. Ronan Sauleaou
- LEAT, University Sophia-Antipolis; Prof. Christian Pichot, Prof. Jean-Yves Dauvignac, Prof. Claire Migliaccio
- University of Siena; Prof. Stefano Maci
- University of Rome La Sapienza; Prof. dr. Alessandro Galli
- University of Trento; Prof. Andrea Massa
- Universiteit van Gent; Prof.dr. ir. Daniel den Zutter
- Universiteit van Leuven; Prof.dr.ir. Guy Vandenbosch
- Université Catholique de Louvain: Prof. Dr. Christophe Craeye
- EPFL (Lausanne): Prof.dr. Juan Mosig, Prof.dr. Anja Skrivervik
- University of Siena : Prof. Stefano Maci
- Polytechnic University of Turin: Prof. Mario Orefice; Prof. Giuseppe Vecchi; Prof. Paola Pirinoli
- University of Firenze: Prof. Angelo Freni
- University of Ancona: Prof. Dr. Tullio Rozzi, Prof. Dr. Antonio Morini
- University of South California: Prof.dr. Andy Molisch
- Jet Propulsion Laboratory: Dr. Pieter Siegel.
- University of Michigan: Prof.dr. Anthony Grbic
- University of Toronto: Prof.dr. George Eleftheriades
- European Space Agency: Dr.ir. Peter de Maagt, dr.ir. Cyril Mangenot, dr.ir. Bertram Arbesser-Rastburg, dr.ir. Maarten van der Vorst
- Technical University of Munich: Prof.dr. Dipl-Ing. Thomas Eibert
- Fraunhofer institute (Bonn): dr. Peter Knott, dr. Thomas Bertuch
- Aalto University: Prof.dr. Anti Raissanen
- Queens University of Belfast: Prof.dr. William Scanlon

Past Performance

The partners of the NARF have already a long track-record in joint activities. This includes national and European projects as well as organizing workshops, courses and conferences. A nice example of this was the proposal that was submitted (and accepted) in 2011 by the Dutch and Belgium Antenna community for organizing the EUCAP conference in 2014. As a result of this long tradition of cooperation, the initiative of the NARF was taken in 2011 in order to further improve on the level of cooperation and to become even more visible towards our stakeholders.

Funding (national and international programs)

The "Top Sector" that is most closely linked with this SRA is the High-tech systems and Materials (HTSM) sector. Antenna systems are part of several roadmaps of this segment (e.g. Components and Circuits, Security, Space).

We will give a couple of examples of running projects which show that the research themes within the framework of the NARF are recognized on national and international level.

- *FREEBEAM* (*STW funding*). TU/e developes a broadband focal-plane array concept with optical beamforming. Supporting partners are NXP, TNO, ASTRON, SATRAX, ESA, ESO, Thales.
- *RF2THz (Catrene funding)*. TU/e and TUD are involved in this large European project. Key partners are NXP and ASTRA. Main focus is on intelligent antenna systems for internet via Satellite.
- *PANAMA (Catrene funding)*. TU/e and TUD are involved in power efficient RF front-ends and antenna systems for next generation wireless infrastructure (base stations).
- *PASTEUR (Catrene funding)*. This project is led by NXP and focuses on the development of smart long-range RFID tags for perishable goods (e.g. flowers, meat).
- *STARS (FES)*. TUD is involved in this large project on development of new Sensor Technology Applied in Reconfigurable systems for sustainable Security. Thales and NXP are key industrial partners, while TNO is the key knowledge institute. (Alex/Giampiero to ADD)
- ATOM (FP7). TUD is involved in this large European project with development of UWB antenna arrays for short-range imaging applications as used by airport security.
- ORFEUS (FP7). Within this large European project TUD develops adaptive UWB antenna systems for subsurface imaging. This project is led by Thales

and investigates re-configurable antenna systems for security and communication applications.

- *European Research Council (ERC) Starting Grant*: Advanced Antenna Architectures for Tera-Hertz Sensing Instruments. 2011-2016 (TUD Andrea Neto).
- *OLFAR (STW funding)*. Orbiting Low Frequency Antennas for Radio Astronomy. This project is led by the UT and focuses on the development of a space-based radio astronomical observatory for ultra low frequencies.
- *DCIS (NanoNext-FES funding)*. Distributed Colonies in Space. UT and TUD are involved in this large FES project. Main focus is on an active antenna system for low frequency radio astronomy.