MASTER THESIS PROJECTS
TeraHertz Sensing Group
2020-2021
Experimental Validation of the Theoretical Limits of Channel Capacity for Wireless Base Stations

Problem statement: The number of independent links that can be hosted by an antenna platform for wireless Line-of-Sight communication has not been quantified systematically. Such number of links is limited by the interference between the beams associated with different users. The interference is higher for smaller volumes (in terms of the wavelength) allocated to the platform. For such a given volume, the coupling between patterns looking in different directions can be reduced by tapering their associated current distribution. This reduces the side lobes of each pattern, even if at the cost of a lower aperture efficiency of the main beams. This strategy fails when the antenna platform is small or moderate with respect to the wavelength. In these cases, the aperture efficiency becomes larger than one and is no longer a useful parameter to describe the performance of the antennas. In order to quantify the independence of the patterns for these small-moderate configurations, one can resort to the concept of observable field, which allows the introduction of a coupling coefficient between the incident field and the patterns of the antennas in reception. This coefficient allows a direct trade-off between the cross talk between patterns and the effective use of the platform volume. Eventually the maximum number of independent links is established uniquely for large as well as for small platform volumes.

Project goal: The observable field, used to estimate the number of beams that a platform can sustain, can be evaluated with different theoretical tools. Spherical mode expansion is the classic procedure. A more recent approach is based on the use of Physical Optics (PO). The resulting differences in terms of number of beams are substantial for small to medium dimension platforms. These occur in many proposed for 5G base stations, but also in terminal antennas, for 5G but also for 6G architectures. The objective of this project is to demonstrate that the increased degree of freedom on the design that is theoretically promised by the use of the PO is actually real. This will be achieved by designing an array of receiving antennas, contained within a predefined volume.

For more information Contact: Andrea Neto, a.neto@tudelft.nl

Independent Communication Links

Phased Arrays for Future Wireless Base Station

Topic: Antenna array for base stations
Application: 5G and beyond

Problem statement: Phased arrays have emerged as a key solution for 5G base stations, to provide higher capacity by means of directive and electronically steerable beams. Wireless communications in the near future will heavily rely on the possibility to transmit and receive multiple data streams through directive beams connecting the base station with different users. Antenna arrays will focus the radiation in smaller angular regions with the aim to improve the energy and spectral efficiency, while reducing interference levels. Thus, multibeam phased array antennas are regarded as a key technology for enabling massive multiple-input and multiple-output (MIMO) and high speed mobile networks. Today’s massive MIMO systems comprise relative small antenna arrays, with 32 or 64 elements, and up to hundreds in some cases. However, for future base stations, the trend is to increase the number of elements in order of thousands, to reduce the amount of power for each transmit/receive module. A larger number of elements is also important because it is proportional to the maximum number of simultaneous independent beams that can be realized with the phased array.

Project goal: The objective is to design a 2048-element planar antenna array for wideband base station with optimized performance. The array is required to be wideband, to be able to cover different 5G frequency bands in a single antenna. Moreover the array should be capable of steering a pencil beam over a very wide scan range, up to +/-60 degrees from broadside in all azimuthal planes.

For more information Contact: Daniele Cavallo, d.cavallo@tudelft.nl
Design and Experimental characterization of Silicon Based Photo-Conducting Antennas

**Problem statement:** Photo-Conductive (PC) antennas have been receiving increasing attention as sources of pulsed THz signals to be used in time domain spectrometers. A particularly interesting aspect of pulsed PC Systems is that the readout of THz signals can be performed directly in DC, by down-converting pulsed signals, resorting to stroboscopic sampling.

In the THz Sensing Group one such commercial systems is available, able to provide up to a few tens of microwatt of average power with spectra distributed in the Bandwidth (BW) from 100 GHz to 4 THz. The design, manufacturing and characterization of new antennas for such types of spectrometric systems is an active line of research in the THz Sensing Group.

The possibility to have significant sources of THz power, together with the simplicity of the readout of the signals suggests to exploit these systems also for **Radar** applications. In this case application scenario, a BW of 400 GHz (from 100 to 500 GHz) would guarantee roughly half a mm of depth resolution which would be more than sufficient for any security scenario one could anticipate. This BW goal opens the way to employ silicon as Photo-conductive material rather than the low-temperature grown Gallium Arsenide, that is routinely used to reach the highest frequencies. In the EKL facilities, processes to micro-fabricate silicon wafer dedicated for Photo Conductive Antennas are being developed.

**Project goal:** The goal of these project is to design and then contribute to the manufacturing and testing of a number of silicon antenna prototypes that could be used as Photo-Conductive sources. The design will be successful upon demonstration of the feasibility of silicon as PC material for Radar applications,

For more information Contact: Andrea Neto, a.neto@tudelft.nl

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Femto Second Electromagnetics

**Problem statement:** Photo-Conductive antennas have been receiving increasing attention as sources of pulsed THz signals to be used in time domain spectrometers. In the THz Sensing Group one such commercial systems is available that is able to provide up to a few tens of microwatt of average power for spectroscopic investigations over a bandwidth from 100 GHz to 4 THz. Despite their availability, the pulse preservation properties of these systems are poor.

There are a number of reasons why the modelling is poor. Up to a few years ago, it was fair to say that the main mechanisms by which the power was generated were largely misunderstood. Recently, and also thanks to efforts of the Tera-Hertz Sensing group, the modelling of the sources and of the receivers have progressed very significantly. Nevertheless a bottleneck that remains is the fact that the pulses that can be generated via these sources span enormous spectral bandwidths, making the modelling in the frequency domain very challenging.

**Project goal:** In this project we would like to characterize, for the first time, a transmitter-receiver link directly in the time domain. The interest for this modelling is two-fold:

1. It is the only real possibility allowing for a much timely description of the properties of the entire system, and of all the separate components. Some of them are active and can be investigated only in time domain.
2. On the other hand, it will allow to gain an enormous insight into what are the key characteristics of possible targets to be investigated by the THz Radar being developed in the TS group, once it will be available.

For more information Contact: Andrea Neto, a.neto@tudelft.nl
150GHz Lens antenna based systems for wireless communications

**Problem statement:** A large gap between the current (4G & 5G) technology capabilities and prospected (Beyond 5G) wireless communication systems is in the capacity to provide wideband access in high density environments (i.e. stadiums, concert and conference halls, etc). To address at low-cost the request for extreme instantaneous bandwidth from the large number of users, one of the main difficulties is the generation of thousands of simultaneous and independent high data throughput channels.

One of the key areas of the TU Delft XG research theme, shared between the TS and the ELCA groups of the micro-electronics department, is the development of Fly’s Eye Antenna systems that can provide in the future base stations reaching point to multi-point Tb/s overall throughputs for this kind of environments. The Fly’s Eye Antenna system is based on the combination of spatial and frequency multiplexing achieved via an integrated lens antenna array capable to generate >100 simultaneous, independent, high-gain and wideband beams combined with efficient 150GHz wide-band front-ends.

**Project goal:** The objective of the fly’s eye activity is to develop integrated front-ends and lens arrays together with over the air link demonstrations to show the capabilities of the proposed antenna system. Several master project activities can be embedded into this bigger project ambition based also on the own student interests (details can be discussed on request).

For more information Contact: Nuria Llombart, n.llombartjuan@tudelft.nl

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**EM Modelling Tools for Quasi-Optical Systems**

**User interface for the advanced design of Quasi-Optical antennas**

**Problem statement:** Quasi-optical (QO) components are commonly used in complex sensing and imaging systems operating at (sub)-mm wavelength. These QO components lead to generation of highly directive beams. In the TS Group, we have being developing under an ERC framework, advanced modelling techniques to design integrated QO antennas. These modelling techniques can be now used by any researcher in the world by downloading a freely accessible graphical user interface (GUI) tool. This tool employs Fourier Optics (FO) and Geometrical Optics (GO) based methods. Specifically, the FO method represents the field focalized by a QO component on its focal plane as a Plane Wave Spectrum (PWS) when the component is illuminated by an incident plane wave. However, the tool currently covers only canonical single layer geometries limiting the applicability of the tool for the optimization of the QO feed antenna.

**Project goal:** The objective of this activity will be the upgrade of this GUI for the analysis of more advanced quasi-optical antenna geometries. In particular, the emphasis will be done on shaped dielectric lenses. The use of this more advanced geometries can enhance the field of view or angular coverage of a canonical lens. Now there are no commercial softwares capable to perform the analysis of such integrated advanced lenses in an efficient way. A full wave simulation in CST will last for hours making in practice the optimization of the lens shape very difficult.

For more information Contact: Nuria Llombart, n.llombartjuan@tudelft.nl
Problem statement: THz imaging cameras are attracting high interest due to their intrinsic capability to see through materials and acquire high resolution images. Up to date commercial THz images have not been developed due to the lack of low-cost, low-power integrated systems, capable of being portable and employing technologies with high-volume capabilities. Recent developments employing silicon technologies have begun to show the possibility of bridging this gap. Nevertheless, current research emphasis and system implementations are only focusing on active imaging systems, which require bulky and expensive external sources.

Project goal: The goal of this project is to improve the system sensitivity in order to achieve near real time passive imaging on silicon technology. The target improvements rely on the three key areas: antennas, integrated circuit design and device modeling. By efficiently employing an ultra large detection bandwidth, reducing the active device noise contribution and truly co-designing the system front-end, the sensitivity of passive imagers can be increased by a factor 20.

For more information Contact: Maria Alonso-delPino, M.AlonsoDelPino@tudelft.nl

Problem statement: There is an exponential interest in wireless systems at sub-THz frequencies (100GHz-300GHz) for XG sensing and communications applications. The main interest of the industry in this frequency band is due to the intrinsic large bandwidth available. Both ultra-fast wireless links reaching Tbps as well as ultra-high resolution radar (resolutions of less than 1cm) are only viable in this high frequency band. Such wireless systems required of a dynamic beam scanning of a high-beam to operate properly. In the TS Group we are developing a new antenna system idea based on scanning lens phased arrays that can achieve a compact, integrated, low-power mechanism for such dynamic beam steering.

Project goal: Within this project we will develop lens phased array antenna systems with electrically large element-to-element distances, where only a small number of front-ends need to be fed coherently. This dynamic beam steering architecture combines low mechanical complexity (reduced mass with respect to translating a single lens) with a greatly reduced number of phase shifters. This antenna architecture facilitates the integration and mitigates heat dissipation problems of silicon based front-ends, while exploiting the lens steering capabilities to achieve the desired high gain beamforming without grating lobes. During this project, we plan to develop proof of concept demonstrators with different commercial front-end technologies available.

For more information Contact: Maria Alonso-delPino, M.AlonsoDelPino@tudelft.nl
Wideband Phased Arrays for Satcom

**Topic:** Aircraft antennas for in-flight entertainment

**Application:** Satellite communication

**Problem statement:** In satellite communication (satcom) applications, the need of terminal antennas able to scan to larger and larger angles is emerging, to guarantee agile connections to different satellites. However, conventional planar phased array antennas exhibit limitations when steering a pencil beam in a large field of view, due to the increase of the antenna active reflection coefficient when scanning. Moreover, another problem of terminal antennas, especially on mobile platforms, is the limited space allocated to cover multiple required bands. In this regard, it is beneficial to use a wideband array covering simultaneously multiple bands, to provide significant reduction of the overall cost and volume of the system. For example, a tunable phased array terminal working in both Ku- and Ka-band can yield reduced footprint, size and weight of the system, with consequent decrease of operational costs, including fuel costs created by the weight and drag from the antenna.

**Project goal:** The objective is to design a user terminal antenna array for satellite communication with optimized performance. The array is required to be ultra-wideband, to be able to combine in a single shared aperture both Ku- and Ka-bands simultaneously. Moreover the array should be based on a planar solution and should be capable of steering a pencil beam over a very wide scan range, up to +/-60 degrees from broadside in all azimuthal planes.

For more information Contact: Daniele Cavallo, d.cavallo@tudelft.nl

Phased Arrays for Future Wireless Base Station

**Topic:** Antenna array for multifunction radars

**Application:** Defence radars

**Problem statement:** There has been a growing interest, in the last decade, in the development of phased arrays that can operate over wide bandwidths and wide scan ranges. Such characteristics are desired to support multifunction operation for both communication and radar applications and to reduce the number of antennas on complex platforms, where there is limited space available. An antenna concept to achieve very wide bandwidth with large scan angles was developed in the THz group and consists of a connected array of slots with artificial dielectric structures. These latter can be fabricated to achieve gradually decreasing refractive indices to implement wideband matching between the antenna feed and free space. The artificial dielectric solutions were demonstrated to achieve very wide bandwidth, with a scan range exceeding ±60 degrees. However, artificial dielectrics generate high cross-polarization (X-pol) in the radiated signals, when used over ultra-wide bandwidths.

**Project goal:** The goal of this project is to design arrays with new classes of artificial dielectrics, with non-uniform or non-planar characteristics, with the goal of reducing the X-pol.

For more information Contact: Daniele Cavallo, d.cavallo@tudelft.nl
Increasing the multiplexing of detector arrays for astronomy

Problem statement: In the Experimental Astronomy group, together with SRON, we develop superconducting Microwave Kinetic Inductance Detectors (MKIDs) for the detection of THz radiation. One of the key advantages of MKIDs is the intrinsic multiplexing capability: Many detectors can be read-out at microwave frequencies (2-4 GHz or 4-8 GHz) since each detector is a very narrow band resonator, whose properties change upon radiation detection. The graph below shows the resonances for a typical 1000 pixel array as shown in the photograph. We designed the resonances to be regularly spaced, but as is obvious, they are not. The observed random scatter of resonant frequencies results in some of the resonance features to overlap, which results in dead pixels. As a result, we can multiplex not as many detectors as we want. This is an experimental project where you will be involved in the design, fabrication and measurement of large MKID arrays in the cryo lab of EWI to optimize the frequency scatter.

Project goal: The goal of the project is to find the mechanisms that cause the random scatter in resonant frequencies, to identify the dominant effects and to find possible solutions. Your results will be directly applied to the DESHIMA-2 spectrometer that will be installed in a telescope in Chile in 2021-2022.

For more information, contact: Prof. Jochem Baselmans (J.Baselmans@tudelft.nl)

mmWave Antenna Array for Car Radars

Topic: Antenna array for automotive radars
Application: Autonomous driving

Problem statement: The Terahertz Sensing Group closely collaborates with NXP for the developments of advanced antenna solutions for car radars. Current automotive radars are mainly operating in the mmWave band (76-81 GHz). At these frequencies, the interconnection between the radar chips and the antennas are usually very lossy transitions that reduce the performance of the radar systems. Typical antenna solutions are also characterized by poor efficiency due to surface wave losses: the power remains trapped inside the dielectric slabs rather than being radiated. Novel antenna solutions have been developed in the Terahertz Sensing group to increase the radiation performance of car radar systems: the approach consists of integrating the antenna in the chip package and exploiting artificial dielectrics to enhance the efficiency and to shape the radiation patterns. The next step in this development is to find solutions that are suitable with commercially available package technologies and that can be scaled to higher frequencies (140 GHz) for the next generations of automotive radars.

Project goal: The objective is to design, manufacture and test an antenna array for automotive radars. The array will be implemented in printed circuit board (PCB) technology, as a proof of concept. The antenna should improve the current design used by NXP in terms of scan performance and gain coverage. Despite the prototype will be on PCB, the feasibility of an in-package implementation and the scalability to higher frequencies should also be addressed.

For more information Contact: Daniele Cavallo, d.cavallo@tudelft.nl
In your project,

- You will develop **high-quality, open-source software** with novel algorithms, to analyze data taken with the DESHIMA spectrometer on the **ASTE telescope**.
  - *It is not just for a project — you work will actually be used by many astronomers!*
- You will learn how to systematically develop software in a collaboration using **GitHub flow**
- You will work with the international/multi-disciplinary DESHIMA team with **engineers, astronomers** and **physicists**. You will report your results on our wiki, and in teleconference with researches from SRON and also Japan.
- You will work efficiently using modern software-developing and collaboration tools:

**Student team** presenting their 1st, 2nd, 3rd-author paper the **international SPIE 2020 conference @ USA!**

**Simulated spectrum of a dusty galaxy in the early Universe**

**Open-source Python packages from previous student projects**
- **TIEMPO**
  - [github.com/deshima-dev/tiempo_deshima](https://github.com/deshima-dev/tiempo_deshima)
  - [pypi.org/project/tiempo-deshima/](https://pypi.org/project/tiempo-deshima/)
- **GalSpec**
  - [github.com/deshima-dev/GalSpec](https://github.com/deshima-dev/GalSpec)
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**TiEMPO**: Open-source time-dependent end-to-end model for simulating ground-based submillimeter astronomical observations

**Students!**

Fumika Fujita, Yannick Boekstra, Stefanie A. Brandenburg, Akio Tanimoto,Tom J.C. Beke, Klaus-Dieter Marte, Stan Zschaak, Jochem J.A. Baselmans, Kari Wuyts Chin, Robert Huyten, Kenichi Karatsu, Alejandro Paesuza Laguna, Yoichi Tamura, Tatsuya Takakoshi, Stephen Yates, Maarten van Hoven, and Akira Endo

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For more information Contact: Akira Endo [a.endo@tudelft.nl](mailto:a.endo@tudelft.nl)
Project:
Innovative THz filter for future Astronomy

Why are we here?
How did the universe begin?
How did the universe structure grow over cosmic time?
How did galaxies/stars evolve?

Astronomy is a journey to find answers to these fundamental questions. And it needs your help now!

Due to the limited efficiency of the THz filter we have in hand now, THz imaging spectrometer, which is a key instrument for next decades’ astronomical observations, is hard to realize.

So, we need your help! In this project, you are going to investigate possible ways to improve efficiency of THz filter by developing innovative planner THz superconducting filter. This is a challenge to make a new standard for future astronomical instruments.

THz filter for DESHIMA

👇 Current superconducting THz filter. The efficiency is limited to 50% at a maximum. We want to increase it to > 80%.

For more information, please contact: Kenichi Karatsu (k.karatsu@sron.nl)
We have been developing a superconducting detector called MKID for astronomical instruments for years. Currently used material for MKID is aluminum (Al) that determines the lowest frequency threshold as 90 GHz.

Looking up the sky, there is an atmospherically transparent (high $\eta_{\text{atm}}$) window around 70-110 GHz, which is also known as W-band. As long as using Al MKID, we miss a part of this range.

In this project, you will try different materials than Al to develop MKID that can fully use W-band for an astronomical observation.

Possible astronomical application: Cosmic Microwave Background (CMB)

- Sunyaev Zel’dovich effect → galaxy cluster science
- CMB polarization → neutrino mass, cosmic inflation

For more information, please contact: Kenichi Karatsu (k.karatsu@sron.nl)
Problem statement: Recent developments in solid-state, ultra-short pulse generators open a wide range of opportunities for ultra-high data rate, ultra-low power communications and radar applications. The crucial point in the electromagnetic (EM) design of such systems is the adequate modelling of the pulsed EM transfer between two antennas. The analysis of such configurations requires a combination of semi-analytical, spectral techniques and numerical studies. As far as the former class, the celebrated Cagniard-DeHoop technique provides the basic instrument. While yielding results with arbitrary accuracy in terms of spatial and temporal resolution, this technique only allows for one lossy-lossless interface in the configuration and exploring more complex situations demands resorting to purely numerical techniques. Experience with EM software simulators shows that the time-domain study of such apparently elementary configurations entails extreme numerical complications, a definitive answer for which is not yet known.

Project goal: This MSc project will involve a succession of analytical and numerical studies that are expected to yield important scientific progress with a high potential of scientific output. The main research objective is developing a numerical model for validating the semi-analytical methods to describe loop-to-loop pulsed EM transfer in stratified media. Developing adequate models of transmit/receive loop antennas models opens the path towards modelling the pulsed EM transfer in a chip-to-chip configuration.

For more information Contact: Ioan E. Lager i.e.lager@tudelft.nl

Sensitivity analysis of surface electromagnetic transients on a high dielectric thin layer

Problem statement: Surface plasmon polaritons (SPPs) are in the literature described as frequency-domain, H-polarized surface electromagnetic (EM) waves propagating along the interface of a dielectric and a conductor. At the so-called surface plasmon frequency, SPPs exhibit large field confinement to the interface, which thanks to their high sensitivity to the variation of the near-field dielectric environment, shows a lot of promise in sensing and imaging applications. A time-domain (TD) analysis recently introduced has shown that a strongly oscillatory, E-polarized surface effect can be excited along the surface of a high-dielectric thin layer. Owing to its similarity with the TD surface phenomenon excited on a plasmonic sheet, a natural question arises whether the new TD EM oscillatory effect can find its practical applications.

Project goal: Therefore, the main goal of the thesis is to develop an efficient computational model (e.g. in CST Microwave Studio) that will enable to carry out an in-depth parametric study, thus exploring the potentialities of EM surface oscillations for the design of high-resolution sensing devices.

For more information Contact: Ioan E. Lager i.e.lager@tudelft.nl
Designing an ultra-wideband, EM transparent coating

Problem statement: (Perfectly) EM transparent, UWB coatings can present interesting applications as (protective) coatings for systems containing UWB or spectrally-widely-spaced, multi-band antennas (IC integrated systems, mobile units, etc.). Owing to the unavoidable physical limits, it has been rigorously proved that the concept of “metamaterials” is useless for these purposes. Therefore, fundamentally new design strategies are needed. A promising way to solve the issue is offered by thin films with combined magnetic and dielectric properties.

Project goal: Relying on the time-domain model of magneto-dielectric sheets, the main goal of the thesis is to design a planar, electromagnetically transparent structure that mimics an invisibility cloak over a wideband of frequencies. The conceptual model will be validated numerically with the aid of a time-domain electromagnetic solver (e.g. CST Microwave Studio).

For more information Contact: Ioan E. Lager i.e.lager@tudelft.nl

Novel Artificial Dielectrics for Antenna Design

Topic: Artificial Dielectrics

Problem statement: In millimeter wave communication and radar applications, wide angle scanning has become an attractive property for the antenna systems. In these applications, the field-of-view is very wide and typically includes the entire azimuth angle. Therefore, phased arrays capable of maintaining high gain over a wider scan range become necessary, so that a limited number of antennas is sufficient for the full azimuthal coverage. However, phased arrays are characterized by scan loss, i.e. a reduction of gain as a function of scan angle. To mitigate this problem, a wide angle impedance matching (WAIM) layer is often used. This consists of an electrically thin dielectric layer located in the close vicinity above a phased array antenna, to mitigate the impedance mismatch while scanning. Being planar and very close to the array plane, the WAIM can be integrated with the array in a single printed circuit board (PCB). Different types of WAIM structure have been subsequently investigated, using artificial dielectrics or metamaterials to improve the performance, either in scanning range or operational bandwidth.

Project goal: The objective is to investigate WAIMs made from non-square artificial dielectrics. The earlier works in this field always considered square patches arranged in a square periodic lattice. In this project we include an additional degree of freedom in the artificial dielectric design, which is the investigation of rectangular geometries, for which both the period and the with between patches can be different along x and y. The goal is to highlight the advantages of this more general structures compared to the traditional square artificial dielectrics, in terms of performance of the antennas.

For more information Contact: Daniele Cavallo, d.cavallo@tudelft.nl
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<td>Antonios Pelekanidis (2020)</td>
<td>Thesis: A THz Lens Antenna fed by a Photoconductive Connected Dipole Array</td>
<td>Now: PhD at Vrije Universiteit Amsterdam</td>
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<td>Steven de Rooij (2020)</td>
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<td>Thesis: Analysis of 3-D Array Antenna Elements to Achieve Asymmetric Active Element Patterns</td>
<td>Now: PhD at TUDelft, TS group</td>
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