This report describes the planned activities for Stage 4 (2015-2016) in GigaHertz Centre.

Jan Grahn, GHz Centre, 16 December 2014, to be approved by the new GHz Centre Board Stage 4.

Comments to this document shall be sent to jan.grahn@chalmers.se
Stage 4 Steering Board signatures
Executive Summary

The GigaHertz Centre (GHz Centre) is a joint research and innovation centre between Chalmers University of Technology and industrial partners. The mission of GHz Centre is to carry out collaborative research in selected high-frequency technologies and to bring the results from Chalmers to an industrial exploitation phase primarily through its company partners. GHz Centre is part of the VINN Excellence Centre program run year 2007-2016 by the Swedish Governmental Agency for Innovation Systems (VINNOVA).

GHz Centre has been run Stage 1 year 2007-2008, Stage 2 year 2009-2011, Stage 3 year 2012-2014, in total eight years. In the present document, the activities and budget for Stage 4 year 2015-2016 (two years) are described. The following companies and one research institute are participating in Stage 4: Comheat Microwave, Classic WBG Semiconductors, Ericsson, Gotmic, Infineon Technologies, Low Noise Factory, Mitsubishi Electric, National Instruments, NXP Semiconductors, Omnisys Instruments, Ruag Space, Saab, SP Technical Research Institute of Sweden, United Monolithic Semiconductors and Wasa Millimeter Wave. Six of the company partners are SMEs, most of them university spinoffs. At Chalmers, three laboratories at two Departments (Microtechnology and Nanoscience (MC2) and Signals and Systems (S2)) will participate. Chalmers, MC2 acts as the host for GHz Centre.

The total budget for Stage 4 is 66.6 MSEK (30.1 MSEK cash) of which industry finances 55% (37% cash), Chalmers 24% (17% cash), and VINNOVA 21% (47% cash). Around 70 people (10 female) are involved in the projects of which 25 are at Chalmers, 2 at institutes and the rest in industry. Around 17 person-years are provided in kind for the GHz Centre projects by the partners.

A research programme reflecting the long-term needs among the industrial partners is carried out consisting of five projects: Silicon-based Transmitters for Millimeter-wave Antenna Arrays (SITRA), Towards a Dispersion Free GaN HEMT (TOPGAN), Gallium Nitride Oscillators+ (GANOSC+), Integrated THz Electronics (INTHEL), and Massive MIMO test bed (MATE), the last one run jointly with the CHASE VINN Excellence Centre under a separate agreement and budget. Pre-defined indicators are used to highlight progress in the projects and create incitements for inventions and publications from the researchers. Seven impact parameters capture the industrial uptake of the research into innovation and commercialisation at companies. The parties rights and obligations to results emanating from the projects is regulated by a consortium agreement and individual agreement for the GHz Centre researcher at Chalmers, all signed before the kick-off of Stage 4.

Apart from the research activity defined here, the listing of goals and strategies shows that GHz Centre will be an active and visible player in the microwave community. Furthermore, we plan annual meetings, technical workshops, fostering leadership, and a recruitment campaign. An International Advisory Board consisting of outstanding experts has been recruited to give GHz Centre advice in its near and long-term development. A major activity during Stage 4 will be to continue the preparation of a common microwave-antenna centre starting 2017.
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1 Centre Objectives and Long-term Strategic Plan

GigaHertz Centre (GHz Centre) is a ten-year agreement between Chalmers University of Technology (Chalmers), research institutes, company partners and the Swedish Governmental Agency for Innovation Systems (VINNOVA) to carry out research and innovation in wireless communication and sensor technologies. All partners jointly invest resources in the GHz Centre in order to carry out research projects along a common plan. The projects are selected from common needs among the industrial partners. The GHz Centre is administered and hosted by Chalmers.

The GHz Centre is run within the VINN Excellence Centre programme initiated and organised by VINNOVA. The key issue of a VINN Excellence Centre is to run joint research and innovation projects between commercial and non-commercial actors. The long-term objective of the VINN Excellence Centre program is to promote sustainable growth effects in Sweden. A number of detailed success criteria for VINN Excellence Centres have been used as guide for the formulation of this research programme. The three most important criteria for success are:

- Promoting sustainable growth by ensuring that new knowledge and new technological developments generated lead to new products, processes and services.
- Leading international research in different fields in collaboration between the private and public sectors, universities and colleges, research institutes and other organisations which conduct research.
- Set up in innovation environments with effective innovation operations so that strong research and innovation milieus can be created (Centres of Excellence in Research and Innovation).

Stage definition
The GHz Centre is run 2007 - 2016 in four consecutive stages:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Year</th>
<th>Extension (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>2007 - 2008</td>
<td>2</td>
</tr>
<tr>
<td>Stage 2</td>
<td>2009 - 2011</td>
<td>3</td>
</tr>
<tr>
<td>Stage 3</td>
<td>2012 - 2014</td>
<td>3</td>
</tr>
<tr>
<td>Stage 4</td>
<td>2015 - 2016</td>
<td>2</td>
</tr>
</tbody>
</table>

For each Stage, a new Consortium Agreement and Research Programme are settled. This document describes Stage 4.
1.1 Vision

Our vision is an international research and innovation centre between Chalmers and industry dedicated to novel high-frequency technologies leading companies in the shaping of tomorrow's wireless world.

1.2 Mission

The GHz Centre mission is to bring scientific advances aimed for future wireless communication and sensor technologies faster to industrial prototyping and exploitation.

1.3 Goals

The original goals for the GHz Centre are:

- At least 180 publications in recognized international scientific journals and conference proceedings (refereed) from Chalmers with at least 40% industrial co-authorship
- At least 15 examples of documented transfer of results/ownership ("successful stories") from Chalmers to the industrial partners of which at least five patents. Three of the transfers indicate clear growth effects in industry and is acknowledged by companies.
- At least 10 PhDs produced by the Centre of which at least five have been employed by partner companies.

1.4 Strategy

- To identify and define multi-disciplinary research between Chalmers and companies in accordance with the centre mission
- To publish outstanding scientific papers and examine PhD students
- To pursue technology transfer and create impact from university to industry
- To create meeting places to present results exchange ideas and collaborate for Chalmers researchers and students with industrial partners at all levels: Projects, laboratories, boards, Centre Days, and scientific workshops and seminars.
1.5 Anticipated results Stage 4

The goals of Stage 4 are given in the right column of the table below together with previously achieved results from previous Stages:

<table>
<thead>
<tr>
<th>Result or goal</th>
<th>Stage 1 result</th>
<th>Stage 2 result</th>
<th>Stage 3 result</th>
<th>Stage 4 goal</th>
<th>Stage 1-4 original goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disclosures</td>
<td>30</td>
<td>91</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Publications</td>
<td>13</td>
<td>65</td>
<td>63</td>
<td>50</td>
<td>180</td>
</tr>
<tr>
<td>Co-authored Chalmers&amp;industry</td>
<td>3</td>
<td>28</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial transfer*</td>
<td>0</td>
<td>1</td>
<td>11</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>MSc</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lic</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PhD</td>
<td>0</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>

*The industrial transfer is measured through the sum of success stories (impact parameter G) and the number of patents (part of impact parameter C). Impact parameters are defined in Chapter 5.

The goals in bold denote the major centre goals. The other goal numbers are indicators used to measure the centre progress in more detail.

Scientific results

During Stage 4, we expect scientific results to be published in international leading refereed publications and conference proceedings in the following research areas:

- Single-chip BiCMOS mm-wave transmitters including co-design procedures with antenna (arrays) and signal processing for 5G telecom and defence applications
- Design, modelling and measurement of the new generation of GaN HEMT and GaN HEMT MMICs for industrial system in telecom, defence and space
- Exploration of GaN design for oscillators, a new field with potential breakthroughs
- Establishing and assessing high-power and low-noise processes for Schottky diodes and HEMT MMICs, respectively, with unique properties of interest for space modules

Parts of these results are expected to enable a targeted number of PhD students to defend their doctoral theses during Stage 4. Also licentiate examines and MSc theses are expected, see goals in table above.

Industrial results

The industrial results are targeted through so-called “success stories”. These constitute one (out of seven) measured impact parameters emanating from the GHz Centre. The definition of impact parameters are described in Chapter 5.
### 1.6 Strategic plan Stage 4

<table>
<thead>
<tr>
<th>Goal</th>
<th>Action</th>
<th>Responsible</th>
<th>Time planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publications</td>
<td>Pursue the publishing of outstanding research results from the GHz Centre at the best international conferences and journals. Use the indicators to highlight progress for each projects.</td>
<td>Project leaders</td>
<td>Followed up at each Steering Board meeting and each management group meeting (3x and 6 x per year). Documented in progress reports and annual reports. Publications are published on <a href="http://www.chalmers.se/ghz">www.chalmers.se/ghz</a></td>
</tr>
<tr>
<td>Industrial transfer</td>
<td>Follow up with the company partners all disclosed inventions and other technology transfer, e.g. in the form of patents, licensing or spinoffs. Exploitation plans are an integral part of each project plan.</td>
<td>Project leaders Board</td>
<td>Followed up at each Steering Board meeting and each management group meeting (3x and 6 x per year) Time: Each 12 month in progress report. Documented in progress reports</td>
</tr>
<tr>
<td>PhDs</td>
<td>The PhD students shall perform studies in the projects which are both scientifically rewarding and transferable to company partners</td>
<td>Supervisor of students (all supervisors are active in the projects)</td>
<td>Followed up once per year by the project leaders Followed up at each Steering Board meeting and each management group meeting (3x and 6 x per year)</td>
</tr>
</tbody>
</table>
2 Centre Partners

2.1 Academic & Institutional Partners

1. Chalmers University of Technology, Gothenburg, Sweden

Chalmers has two Departments involved:
- Department of Microtechnology and Nanoscience (MC2)
  Head: Dag Winkler
  MC2 is doing research with focus on future electronics, photonics and micro-/nanosystems. The materials, devices and systems studied find their applications in future systems for wireless communication, data transmission over fibre links, sensor systems, quantum computers and completely new forms of nanoelectronics.

Laboratories engaged at MC2:

- Microwave Electronics. Head Herbert Zirath.
- THz and Millimetre Wave Laboratory. Head: Jan Stake

- Department of Signals and Systems (S2)
  Head: Arne Svensson
  S2 conducts world leading research in biomedical engineering, antennas and signal processing, control, automation and mechatronics, and communication systems. The research deals to a large extent with the modelling and development of efficient systems for extracting and processing information.

Laboratory engaged at S2:

- Communication Systems. Head: Erik G. Ström

2. SP Technical Research Institute of Sweden (556464-6874), Borås, Sweden

SP Technical Research Institute of Sweden (SP) applies its internationally leading competence to the development and evaluation of technologies, material, products, and processes to meet its customers’ needs and provide an effective link between research and commercialisation.

In GHz Centre Stage 4, SP Measurement Technology is participating in measurement and modelling on GaN HEMT components and THz measurements.

- Contact person: Per-Olof Hedekvist, Manager
  Per.Olof.Hedekvist@sp.se
2.2 Industrial Partners

1. **Classic WBG Semiconductors AB (556965-1937) (SME < 5 employees), Linköping, Sweden**  
   The vision of Classic is to be one of the world leading supplier of nitride based HEMT structures. These will be tested in high frequency devices in the GHz Centre project TOPGAN.  
   **www.classicsemi.com**  
   - Contact person: Erik Janzén  
     erik.janzen@classicsemi.com

2. **Comheat Microwave AB (556642-7364), (SME < 5 employees), Sollentuna, Sweden**  
   Comheat Microwave develops innovative PA solutions based on advances in semiconductor technology. Comheat Microwave is relative to its size the most active member in GHz Centre contributing with a substantial effort in terms of maneffort and processed LDMOS devices using an innovative device design for highly efficient RF power output. Comheat Microwave is interested in RF power modeling and measurement expertise at Chalmers and will thus obtain valuable feedback for improved device designs.  
   - Contact person: Klas-Håkan Eklund, CEO,  
     eklund.kh@telia.com

3. **Ericsson AB (556056-6258), Sweden**  
   Ericsson is a world-leading provider of telecommunications equipment and related services to mobile and fixed network operators globally. Ericsson is the most active part in GHz Centre both in management, and three research projects. The Kista unit is engaged in the power amplifier design, signal processing and the GaN HEMT benchmarking. Chalmers offers the complete food chain here by mobilising both singal processing researchers, PA design group and access to the GaN HEMT process in the MC2 cleanroom. The Gothenburg unit is engaged in phase noise optimization of integrated MMIC oscillators using GaN HEMT technology.  
   Engaged local partners in GHz Centre:  
   - Ericsson AB, Kista, Sweden  
     Radio access networks - Radio base station development  
   - Ericsson AB, Gothenburg, Sweden  
     Microwave transmission and radio  
   - Ericsson Research, Gothenburg, Sweden  
     Microwave and High Speed Electronics Research Centre
   - Contact person: Peter Olanders, Research Leader,  
     peter.olanders@ericsson.com

4. **Gotmic AB (556759-4709), Gothenburg (SME < 5 employees)**  
   Gotmic is a high frequency MMW company with the vision and mission to make high frequency MMIC chips (50 - 120 GHz) affordable having high quality and yield.  
   **www.gotmic.se**
5. **Infineon Technologies AG, Villach, Austria**
   Infineon Technologies offers semiconductor and system solutions for automotive, industrial and multimarket sectors. In GHz Centre, Infineon is interested in testing their LDMOS technology versus GaN HEMTs provided by Chalmers targeted for base station applications.

   Engaged local partner in GHz Centre:
   - Infineon Technologies Austria AG, Villach, Austria
   - Contact person: Franz Dielacher, Manager, franz.dielacher@infineon.com

6. **Low Noise Factory AB (740330-6363 (SME<5 employees), Mölndal, Sweden**
   Low Noise Factory is a company founded in 2005 in Onsala, Sweden. Low Noise Factory specializes in state-of-the-art microwave low noise amplifiers, in particular for cryogenic applications. The company associates have over 15 years of experience in this field from California Institute of Technology, Jet Propulsion Laboratory and Chalmers University of Technology. The interest from LNF is how the low-noise InP HEMT can be optimized for even lower noise and power dissipation using device research methodology. Low Noise Factory contributes with design, measurement and packing competence and resources of the InP HEMT MMIC chips in collaboration with Chalmers. Successful project outcome for Low Noise Factory will lead to new generation of modules for customers requiring utmost performance in microwave receivers, e.g. in space and scientific systems.

   Contact person: Niklas Wadefalk, CTO, niklas.wadefalk@lownoisefactory.com

7. **Mitsubishi Electric Corporation, Kamakura, Kanagawa, Japan**
   Electronic devices such as Mitsubishi Electric's optical devices, power devices and high frequency devices are chips that help manufacturers get their products to market more quickly, competitively, and cost-effectively. Mitsubishi Electric makes power devices that are ushering in a new age of energy efficiency in motor control, optical devices essential for ubiquitous broadband connectivity, and high frequency devices required for high-speed, high-capacity wireless communications. In GHz Centre, Mitsubishi is interested in large-signal modelling for GaN HEMTs using both the model know-how as well as measurement capabilities at Chalmers.

   Contact person: Koji Yamanaka Ph.D., Manager, Amplifier Group
   Yamanaka.Koji@cj.MitsubishiElectric.co.jp
8. **National Instruments Corporation, Tx., USA**

National Instruments RF solutions make it possible to meet challenges in many applications including power amplifier testing, mobile device/wireless testing, radio prototyping, and spectrum monitoring. This will be applied in GHz Centre projects on efficient transmitters and massive MIMO in 4G/5G communication and sensing.

- Contact person: Takao Inoue, Senior RF Platform Engineer/AWR Lead User Program, takao.inoue@ni.com

9. **NXP Semiconductors BV, The Netherlands**

NXP is an independent semiconductor company founded by Philips with a fifty-year history of providing engineers and designers with semiconductors and software that deliver better sensory experiences for mobile communications, consumer electronics, security applications, contactless payment and connectivity, and in-car entertainment and networking. NXP is active in Europe pushing GaN HEMT technology towards industrialization. Through a visiting professorship, NXP is active at Chalmers for testing and modelling of innovative PA RF solutions using both established and novel device technologies, in particular targeted for base station applications.

Engaged local partner in GHz Centre:
- NXP Semiconductors, Nijmegen, The Netherlands
- Contact person: Rik Jos, RF Technology Fellow NXP Semiconductors, Innovation manager RF-Power/Base Stations, rik.jos@nxp.com.

10. **Omnisys Instruments AB (556454-6686) (SME < 250 employees), Gothenburg, Sweden**

Omnisys engages in custom design projects, incorporating advanced analog, microwave, ASIC and power electronics, in particular targeted for advanced subsystems in space. In GHz Centre, Omnisys is involved in MMIC design and Schottky diodes for radiometer solutions at 118, 183, 340 and 553 GHz. Omnisys provides contacts to European Space Agency (ESA) as well as the assembly of components. Omnisys has one GHz Centre project leader at Chalmers. At Chalmers, Omnisys is interested in the design expertise, the measurement and modelling capabilities (in particular noise performance), Schottky diode mixers and functional integration of components > 100 GHz.

- Contact person: Martin Kores, CEO, mk2@omnisys.se

11. **Ruag Space AB (556134-2204), Gothenburg, Sweden**

RUAG Space AB in Sweden specializes in highly reliable on-board satellite equipment including computer systems, antennas and microwave electronics and adapters and separation systems for space launchers. The company has a total of 378 employees. (December 2011). The interest from Ruag Space is in new robust emerging microwave devices such as GaN-based oscillators for exploitation in future space programmes. Ruag Space contributes with knowledge and advice in what the requirements of such components for future space systems must fulfil.
12. *Saab Aktiebolag (556036-0793), Sweden*

Business unit involved:
- Saab Electronic Defence Systems, Gothenburg, Sweden

Saab EDS is a leading supplier of airborne, ground-based and naval radar systems. Saab focus their efforts on the GaN HEMT and the arrays. This is due to the expected industrial acceptance of this novel semiconductor technology in defense applications replacing traditional Si, GaAs or even TWT solutions in present systems. Saab contributes with design expertise in Chalmers unique GaN HEMT process and subsequent testing and implementation in industrial test benches.

- Contact person: Johan Carlert, Technology Strategies, Microwave and Antennas, johan.carlert@saabgroup.com

13. *United Monolithic Semiconductors, Ulm, Germany*

United Monolithic Semiconductors (UMS) designs, produces and markets leading edge RF, microwave and millimetre wave components and components and integrated circuits (ICs) for the Telecom, Space, Defence, Automotive and ISM Industries. The company's strategy is to position itself as a "one-stop" supplier to the wireless microwave and millimetre-wave market, offering a broad range of standard and custom designed MMICs, along with an open foundry service. It has two production facilities, at Ulm in Germany, and Orsay in France, where the commercial headquarters and product design and development are also based. The standard product ranges include: power amplifiers, low noise amplifiers, mixers, multipliers, dividers, phase-shifters, up & down converters, frequency generation and highly integrated multifunction parts.

UMS is interested in improved understanding of the GaN HEMT non-idealities such as traps etc. This is done by advanced RF characterization and benchmarking in the project TOPGAN. Furthermore, runs in the GaN MMIC process at UMS for research purposes is discussed for the centre partners. Successful project outcome for UMS will lead to potential exploitation in future GaN-based products.

Contact person: Ulf Meiners, CTO ulf.meiners@ums.com

14. *Wasa Millimeter Wave AB (556719-1662) (SME<5 employees), Gothenburg, Sweden*

Wasa Millimeter Wave (WMMW) is a spin-off from MC2 at Chalmers. Wasa Millimeter Wave develops and manufactures compact mm- and sub-mm wave sources, mixers and amplifiers. WMMW is interested in having access to the cleanroom and assist in the development of a THz Schottky diode process for discrete and integrated mixer solutions in various THz applications. This would provide a unique European resource.

- Contact person: Tomas Bryllert, CEO, tomas.bryllert@wmmw.se
3 Centre Management and Organization

The Centre Management consists of a Steering Board, a Centre Director, assistant and communication officer, projects and their leaders and the management group. An international advisory board is connected to the Centre. The MATE project with the CHASE antenna centre is carried out under a separate budget and agreement.

3.1 General Assembly and Steering Board

The General Assembly consisting of all partners elect the Steering Board of GHz Centre Stage 4. The role and tasks of the General Assembly and Steering Board are given in detail in the Consortium Agreement.

In the Call for the first General Assembly Stage 4, nominees for the Steering Board will be asked for by Chalmers. The President of Chalmers will also appoint one own candidate as stipulated in the Consortium Agreement.
3.2 **International Advisory Board**

The IAB is informed about all activities and the results of the GHz. The task of the IAB is to review and advise the Centre Board, and its management about the standing of the Centre in an international context both from the academic, industrial and management viewpoint.

Nominated members to the International Advisory Board (IAB) Stage 4 are:

- Professor Arttu Luukanen, Asqella Oy. (also IAB member Stage 3) [www.asqella.com](http://www.asqella.com)
- Professor Dr.-Ing. Ilona Rolfes, Institute of Microwave Systems, Ruhr University Bochum (also IAB member Stage 3)
- Professor Fadhel Ghannouchi, iCORE/CRC Chair, Director [iRadio Laboratory](http://icore.rmu.ca), The University of Calgary (also IAB member Stage 1, 2 and 3)

3.3 **Centre Leadership and Management Structure**

**Centre Director**

Chalmers will after consultation with the partners appoint a Centre Director responsible for the operation of GHz Centre Stage 4.

The Centre Director is responsible for leading, execution and reporting of the activities in the plan of the Centre. This is reported to the Steering Board at each of its meetings.

Nominated Centre Director Stage 4: Jan Grahn, Chalmers

**Centre Coordinator**

The Coordinator works nominally 20% in the centre and assists the Director and Management team with qualified administrative functions: Progress monitoring, developing the network,
contacts with VINNOVA and partners, and participates in the executive meetings such as Board meetings and management meetings.

Nominated Coordinator Stage 4: Cristina Andersson, Chalmers

**Management group**

The projects are running their own agendas with their own industrial partners. In order to facilitate the communication between the projects, and also stimulate the development of the centre as one *tour de force*, Stage 4 forms an executive group.

The executive group consists of the Director, one Steering Board member (Herbert Zirath), and the project leaders. Meetings are held once every month. Deputy project leaders are also called for these meetings.

The executive group is through the Director a communication channel to the Board in all matters regarding the Centre. The task is to survey and recommend improvements in the projects and the centre with regard to resources, equipment, personnel and collaborations. During Stage 4, also essential strategic discussions will be initiated with the faculty for the future after Stage 4.

**Project level**

Projects are defined from the research programme agreed upon by the General Assembly and discussed prior to launching Stage 4. The generation of a project is thus reflecting the direct needs from the industrial partners in their long-term future businesses.

Since involvement in a project is associated with obligations and rights, the definition of a project is accurately formulated according to a specially assigned plan template. A project leader and a deputy project leader are appointed by the Centre Director for each project. The project leader can be either from an industrial partner, or Chalmers. For each project, the commitment from all ingoing partners are defined in working-hours and formulated in the project plan containing the technical planning, objectives, milestones and goals for all partners.

Progress and updating of the plans are made each 6 month and reported to the GHz Centre.

### 3.4 Forms of collaboration

The GHz Centre is based upon joint collaboration within the projects between researchers from Chalmers and industrial partners. Hence the project plan and its follow-ups is a common formulation where the total working effort and commitments are made transparent to all partners. The Centre is planned to enhance and to stimulate high mobility among partners, e.g. easy access for industry to Chalmers through the establishment of a physical hub at floor 6 at MC2.

Partners participating in different programs and projects gain knowledge from each other through the common seminars, workshops, Centre days, invention and manuscript disclosures and webpage as given in the communication strategy. Furthermore, the executive group meets regularly to share information and look for synergies between the projects.
3.5 **Formal agreements**
A VINN Excellence Centre is a formal centre with agreements between the partners. The three essential agreements are (1) the Chalmers-VINNOVA contract, (2) the Consortium Agreement (CA), and (3) the agreement between Chalmers and its researchers.

The CA is the agreement keeping the industrial group and Chalmers together. From a legal viewpoint, the collaboration is regulated in this agreement through the IPR conditions where the incoming partners in the project have a non-exclusive free license to use the results produced in the project. For results produced by Chalmers researchers, the result will be owned by Chalmers. In the CA Stage 4, Chalmers offers an option for participating industries to acquire the result.

The agreement between Chalmers and its researchers regulate the so-called teacher's exemption stipulated by Swedish law.

3.6 **Plan for equality of opportunity**
The area of microwave technology is an area strongly dominated by men both at university and in companies. This is the largest challenge for GHz Centre in equality. Typically, the proportion of female researchers and students is around 5%. This number must increase in the future. This shall be done by continuous mapping of talented female students and researchers in all recruitment campaigns.

During Stage 2, we run a large project on equality in gender. During Stages 1, 2 and 3, we increased the number of females involved in the centre from 2 to 7 to 11, respectively. It is our intention to continue to recruit more female researchers also during Stage 4. We will actively look to encourage women in recruiting new researchers to the Centre projects and executive teams. In order to achieve such goals, an active policy in recruitment of staff and delegates both at Chalmers and among industrial partners is carried out. Chalmers also discusses the lack of professional women in the microwave engineering field with industrial partners and how such issues are tackled among the companies.

The equality is taking up as a point on the agenda at each Board meeting.

The plan is to make a summary each 6 month in the progress report and follow up. Our goal is to reach between 10 and 15 females among all involved staff and students in the Centre when ending Stage 4.

3.7 **The Centre in the University Organisation: Interaction with the University Infrastructure**
Chalmers is a matrix organisation with seventeen Departments and eight Areas of Advance.

GHz Centre is part of the Area of Advance Information and Communication Technology (ICT) at Chalmers. The Centre Director communicates regularly with other Chalmers – industry consortia, CHASE and Software Centre. This is essential to synchronise and establish common practice from Chalmers to various company sectors participating in Chalmers research activities.
GHz Centre is active within two departments, MC2 and S2. The host is MC2. The Centre Director will be employed by MC2, Chalmers.

The GHz Centre will be a physical Centre where both industry and Chalmers have a common meeting point at floor 6. Dedicated office space is therefore offered for the Centre at the Microwave Electronics Laboratory and THz and Millimetre wave Laboratory. The industry will have three places dedicated for their personnel. Signs and posters will show the way in the MC2 house to the GHz Centre. Chalmers will make it straightforward for industrial partners to come and work in the Centre and to interact with the academic researchers.

The contact with the upper management of Chalmers will be carried out with the Chalmers representative in the Steering Board appointed by the President of Chalmers. The Centre Director is also expected to have frequent contacts with the Department Heads of MC2 and S2, as well as the Area of Advance Director for ICT, and the Vice President for utilisation and innovation at Chalmers.

### 3.8 Centre Communication Strategy and Plan

The communication serves several purposes:

- Internal communication within a project: Joint projects between partners from different organisations, countries etc must be made efficient in order to fulfil the commitments in the project plan.
- Internal communication between projects: Communication between projects is essential to develop the common Centre objectives. It is also important for various partners to learn from progress in other areas which may be of interest at a later stage.
- External communication within Chalmers: The university has many centres and initiatives constantly being launched. It is essential to highlight our area of research and our progress also at other faculties at Chalmers. This may create “best practices” and departmental policies how Chalmers and industry is working efficiently together.
- External communication outside Chalmers: GHz Centre shall create some branding effect in the research community. Even though we are only one agenda among many agendas at Chalmers, we know that a name not used everywhere creates some curiosity and respect.

#### 3.8.1 Internal communication

The internal communication is fundamental for a joint Centre between Chalmers and industrial partners:

- Once every year, the GHz Centre has an internal annual meeting where the progress is reviewed. The IAB is invited for this meeting.

We are planning one GHz Centre Annual Day in November 2015 for the partners of the GHz Centre.

- Mobility of researchers. Chalmers, MC2 will offer GHz Centre constant access to three office places for industry in the office area floor 6 at MC2. Chalmers researchers are also prepared to be at the companies during shorter periods.
- The project meetings organised by the project leaders at least two times per year will serve as the most important internal communication between the ingoing partners for
technical results. These meetings are reported to the Director and Steering Board. Participation by telephone for long-way partners will be offered.

- The management group is the most important group to bridge the projects, share experiences and propose changes. These meetings are held once every month. The management group is a link between the researchers at Chalmers and the Board.
- The Steering Board meeting three times per year will serve as a source of internal information and communication between the partners in the strategic questions.
- Access to Chalmers internal document area is made for external partners for documents and slides from meetings etc. This is made possible by a password protected home page.

The resources for these activities are normally taken from the projects. The office space for industry is a substantial in kind contribution from Chalmers to GHz Centre.

3.8.2 Internal communication - dissemination of inventions or manuscripts prior to publication

The disclosing of results from the projects is one of the benefits being a partner in GHz Centre. According to the consortium agreement signed by all Parties, Chalmers is responsible to disclose results from Stage 1 prior to publication for two reasons:

A. To prevent company confidential information being published
B. To check if results are patentable prior to being published

Chalmers discloses information either in the form of a Manuscript or Invention. The disclosure is e-mailed to designated contact persons among GHz Centre partners. The subject is: "GHz Centre Disclosure". The Manuscript disclosure is normally a draft meant for submission to either a conference or a scientific journal. An Invention disclosure is to reveal ideas or results from GHz Centre projects having the potential of being patentable.

After the disclosure, Chalmers is expecting that within 30 days after the reception reply on the e-mail if there are any reasons to delay the disclosure because of either reason A or B (or both) stated above.

If any partner wishes to delay the publication, Chalmers will as owner of results start an immediate negotiation with the Partner how to alter text as not to reveal confidential information or how to protect and register patentable results for maximising the exploitation potential of the invention.

The outcome of each disclosure of Manuscript or Invention will be reported to Steering Board and in Progress Reports. This reporting constitutes a major indicator of progress in a project.

At the first Steering Board meeting, each partner will give input of the names from its organisation to be put on the official disclosure list.

3.8.3 External communication

The external communication is carried out according to the following points:

- Publications from all partners must be made with the affiliation GHz Centre. It is important for branding in the scientific community and highlighting the
companies involved including VINNOVA as governmental body. This also shows that a publication obeys under the consortium agreement as opposed to traditional publishing at the departments.

- Continue the up-dated e-mail list of microwave community members with a potential interest in GHz Centre.
- Technical workshops, if possible in collaboration with CHASE antenna centre and Microwave Road.
- One printed folder and one set of viewgraphs describing the mission, projects and partners of GHz Centre.
- At relevant Swedish events, presenting a roll-up poster for showing the Centre research.
- Presenting a GHz Centre success story at the VINNOVA VINN Excellence Centre Day to be held 12 November 2015 at Chalmers. The GaN success story between Chalmers and Saab has been nominated by GHz Centre to the event.
- A homepage www.chalmers.se/ghz describing the GHz Centre, adding information continuously to attract interest to return to the web site.
- Participating in media – One feature article in Swedish press during Stage 4 is planned in conjunction with the final GHz Centre Day planned.
- Presenting the Centre at Chalmers’ and external partners request at site visits etc.

The resources for these activities are normally taken from the Management project. Assistance at MC2 is given to GHz Centre from the Communication officer who is responsible for the home page.

### 3.9 Learning activities for Centre progress

We are planning one workshops for the Centre during Stage 4 in space-based MW/MMW technologies. The leaders from the INTHEL project will arrange this.

We will also be active in the invitation of technical international experts giving lecture series for industry and Chalmers.
4 Research Programme

4.1 Centre Research Profile

The GHz Centre Stage 4 addresses four strategic thrusts for the high-frequency industry:

- DSP enhanced microwave front-ends
- Robust and high-power microwave components circuits
- Low phase noise oscillators
- Millimetre wave integrated front-ends for demanding applications, in particular space and science
4.2 *Research projects and partners Stage 1-4*

The industrial partners and the institute are active together with Chalmers in the four projects according to the following Table. (For abbreviations, see below)

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**Partner**

- Chalmers
- SP
- Classic WBG Semiconductors
- Comheat Microwave
- Ericsson
- Gotmic AB
- Infineon Technologies
- Low-Noise Factory
- Mitsubishi Electric
- National Semiconductors
- NXP Semiconductors
- Omnisys Instruments
- Ruag Space
- Saab
- Sivers IMA
- United Monolithic Semiconductors
- Wasa Millimeter Wave

**Project abbreviations:**

**Stage 1:**
- SMPA: High-efficiency switched mode power amplifiers and transmitter architectures
- WIDE-BAND: Robust and wideband wide-bandgap transceiver circuits
- FREQ: Frequency generation
- THZ: THz Sensors

**Stage 2:**
- DIGIPA: Digitally Enhanced Power Amplifiers
- EXPO: Exploring the potential of future GaN and LDMOS technologies
- INTOSC: Integrated Oscillators
- THZ+: THz Radiometers
Stage 3:
EMIT: Energy Efficient MIMO Transmitters (EMIT)
ACC: Advanced Characterization and Modeling for Technology Optimization of Multifunctional Circuits
GANOSC: GaN oscillators
SPACETHZ: THz Space Components

Stage 4:
SITRA: Silicon-based Transmitters for Millimeter-wave Antenna Arrays
TOPGAN: Towards a Dispersion Free GaN HEMT
GANOSC+: Gallium Nitride Oscillators+
INTHEL: Integrated THz Electronics
MATE: Massive MIMO test bed (together with CHASE VINN Excellence Centre)

All the four Stage 4 projects are described in detailed plans (not enclosed) set up according to a certain GHz Centre template. The plans have been approved by all partners and are updated each six month.

Gender perspective in the research programme
Each project is having an obligation to increase gender equality plan and action through recruiting of females in Master, PhD students and postdocs. This will be followed up by the management group and reported to the board at each meeting.
4.3 Research projects Stage 4

Silicon-based Transmitters for Millimeter-wave Antenna Arrays (SITRA)

Research partners
Chalmers, Gotmic, Ericsson, Infineon, National Instruments, NXP, Saab

Project leaders
Christian Fager, Chalmers
Deputy project leader
Tomas Eriksson, Chalmers

Motivation
Base stations or backhaul links with 100s of individually controlled antenna elements offer great potential for beam forming, MIMO communication, and energy savings. In contrast to related defence applications, lower output power per antenna and signals with strict distortion requirements will be used. The use of large antenna arrays operating at mmw frequencies is a dramatic paradigm shift with very large multi-disciplinary implementation challenges.

This project will investigate new SiGe BiCMOS based mmw transmitter solutions that combine high efficiency, high linearity, and low cost. The research is expected to play an important role in the development of next generation mobile communication and defence applications.

Objectives

- Determine efficiency/linearity trade-offs in SiGe BiCMOS based PAs and array transmitters at mmw-frequencies with spectrally efficient modulated signals.
- Demonstrate single-chip transmitter including PA and modulator/up-converter.
- Develop calibrated on-wafer nonlinear characterization and modelling of transmitter circuits with wideband modulated signals.
- Implement CAE based solution for co-design of transmitter circuits, antenna array, and signals that maximize system performance for given linearity, energy consumption, and radiated signal specs.
- Demonstrate a highly efficient and wideband multi-channel transmitter chip co-designed with an antenna array, for use in the MATE project demonstrator.

Project outcome

- Demonstration of CAE solution for cross-layer MIMO transmitter design
- 1 test-bed for wideband millimetre wave measurements
- Updated roadmaps for Si-based PAs and transmitters
- 5 articles in high impact journals
- 5 conference papers at high-impact conferences
- 2 co-authored (industry/academia) scientific article
- 3 invited or tutorial presentations at good conferences
Towards a Dispersion Free GaN HEMT (TOPGAN)

**Research partners**
Chalmers, SP, Classic WBG Semiconductors, Comheat Microwave, Ericsson, Infineon, Mitsubishi, Saab, UMS

**Project leader**
Mattias Thorsell, Chalmers

**Deputy project leader**
Hans Hjelmgren, Chalmers

**Motivation**

The GaN HEMT is today a standard product offered by several commercial suppliers. However, long term memory effects are preventing the use of GaN HEMTs in e.g. mobile communication systems. Although long term memory effects in GaN HEMTs has been a major research area for many years, a clear coupling between e.g. EPI specification and system performance has not been established. This project aims at connecting EPI growth and device processing to amplifier and oscillator performance.

Furthermore, the growing interest for mm-wave bands in future mobile communication systems set new demands on the amplifiers, and in the end the transistor. The power level will be significantly lower, especially in MIMO systems, and the bandwidth will be significantly wider (~1 GHz). These requirements preclude the use of digital pre-distortion, and hence the transistor needs to be inherently linear, and highly efficient.

To achieve this, new characterization methods together with new and improved models need to be developed.

**Objectives**

- Correlate system performance to material properties and device fabrication
- Optimize GaN HEMTs for linear transmitters for mm-wave applications
- Optimize GaN HEMTs for low phase noise oscillators
- Develop system like characterization methods at device level
- Develop improved models enabling transient simulations in TCAD and circuit simulators

**Project outcome**

- 5 articles in high impact journals
- 3 co-authored (industry/academia) scientific articles
- 1 test-bed for system like characterization
- Updated roadmaps for future GaN technology
- 1 growing start up company
- 1 success story related to improved EPI
Gallium Nitride Oscillators+ (GANOSC+)

Research partners
Chalmers, Ericsson, Ruag Space

Project leader
Dan Kuylenstierna
Deputy project leader
Szhau Lai

Motivation
High purity signal generation is a key issue in wireless communication systems and radar systems. The voltage controlled oscillator (VCO) is one of the bottle necks in modern systems using advanced modulation formats like higher order QAM or OFDM. Currently state-of-the-art low-phase noise commercial VCOs are designed in InGaP HBT technology, with key properties for low phase noise such as low flicker noise and relatively high breakdown voltage. A technology with significantly higher breakdown voltage is GaN HEMT. Thus, a voltage-controlled oscillator based on a GaN HEMT can potentially reach very low phase noise.

In GHz centre Stage 3 project GANOSC the potential of GaN HEMT oscillators was demonstrated, however some challenges remain in order to fully benefit from GaN HEMTs high breakdown voltage. The most important of these factors is the flicker noise, which limit near carrier phase noise performance. Other factors are varactor integration and finite Q of integrated resonators.

Objectives
The objective is to forward state-of-the-art performance for oscillators and VCOs in terms of phase noise and tuning range. Output power should be sufficient with reasonable variations over the tuning range. The project has two different tracks, one aiming at integrated oscillators with good phase noise and reasonable tuning range. The other track looks for best possible phase noise using a high-Q external resonator that is compatible with an industrial building practice. In all design work there is an underlying objective to be able to backtrack phase noise contributions.

- Design of integrated VCOs with good phase noise and reasonable tuning range within the frequency range 7.3-12.3GHz
- Design of ultra-low phase noise oscillators based on external resonators, e.g., MEMs
- Low-frequency noise measurements of GaN devices based on different material compositions
- Investigation of switch-mode oscillators
- Detailed study of the varactor’s contribution to oscillator phase noise
- Investigation of switch-mode oscillators

Project outcome
- 4 articles in high impact journals
- 3 co-authored (industry/academia) scientific articles
- 1 Ph. D
- MEMs-based VCO module with ultra-low phase noise
- Low-phase noise medium bandwidth X-band GaN MMIC oscillator
Integrated THz Electronics (INTHEL)

Research partners
Chalmers, SP, Omnisys Instruments, Low Noise Factory, Wasa Millimeter Wave

Project leader
Peter Sobis, Omnisys Instruments AB
Deputy project leader
Per-Åke Nilsson, Chalmers

Motivation
For high performance imaging, THz systems with state-of-the art integrated components are needed. In this project, these needs are addressed through the development of highly integrated modules based on cryogenic HEMT LNA MMICs and room temperature Schottky diode TMICs operating up to 200 GHz and 5 THz respectively.

Objectives
- Demonstrate a highly integrated high performance 1080-1280 GHz receiver module
- Develop a record ultra-low noise cryogenic W-band LNA module
- Perform a reliability study of Schottky diode and InP HEMT devices and RF modules
- Develop a method for THz S-Parameter characterization of membrane devices and circuits using the waveguide embedded TRL calibration technique

Project outcome
- Demonstration of a THz receiver module in combination with an LNA module as IF amplifier.
- A 10-20% growth potential for the industry partners in the projects consisting of three SME’s with a total of around 40 persons as a direct result of the centre collaboration.
- A mobility between University and industry corresponding to several man months for 3-4 persons from industry spending time at the university.
- 10 joint peer-reviewed publications and one PhD thesis
- Several of the developed devices are expected to be directly used by the company partners in their product lines, and the know-how created will influence their technology strategies
Massive MIMO test bed (MATE)
Project run together with VINN Excellence Centre CHASE
This project and budget is run under separate joint agreement between GHz and CHASE

Research partners
Chalmers, Ericsson, Saab, Infineon, National Instruments, NXP, Qamcom Research and Technology (CHASE partner)

Project leader
Thomas Eriksson, Chalmers
Deputy project leader
Koen Buismann, Chalmers

Motivation
By equipping mobile base stations, backhaul links, or radars with 100s or even 1000s of individually controlled antenna elements great possibilities for beam forming, MIMO communication, and energy savings is potentially enabled. However, there are still many challenges to address before deployment on a large scale, both in terms of hardware and building practices, and in terms of signal processing and synchronization issues.

In this project we will develop and build a test-bed with a large number of antennas (>=64, scalable), for potential use in communication and radar applications. Issues related to building practices and signal processing will be studied within the project, in order to build a flexible test-bed usable in many applications.

Objectives
In the first part of the project, we will build a massive transmitter, and in later stages we will also build a massive receiver. The intention is not to build a real-time system, instead we will rely on off-line processing. This will limit the possibility of tracking rapidly moving channels but should otherwise not limit the research considerably.

- Investigate techniques and architectures for building a massive set of RF transmitters and receivers integrated with an array of antennas
- Study pros and cons with different interfaces between digital and analog parts (I/Q, IF etc.)
- Study and develop synchronization techniques for massive MIMO transmission
- Study hardware bottlenecks and developing DSP techniques to overcome them
- Demonstrate massive MIMO transmission for wireless communication and radar

Project outcome
- 1 test-bed for system characterization
- 2 articles in high impact journals
- 3 conference papers at high-impact conferences
- 2 invited or tutorial presentations at good conferences
- 2 co-authored (industry/academia) scientific article
- 1 industry researcher spending >3 weeks at Chalmers
5 Plan for Evaluation Stage 4 in relation to general and specific goals

Self evaluation and systematic measurements of results

Indicators and goals
GHz Centre has developed a system of indicators to show the progress in a more rapid manner compared to the traditional “slow” goal measures such as examined PhDs. This indicator system is based on the disclosure model of manuscripts and inventions described in the communication strategy. The disclosures will result in publications and patents and eventually PhDs and exploitation of results in the form of industrial transfer of know-how and technology. Experience shows that we can expect 15 to 25 such disclosures per year hence giving a clear picture of progress for individual projects and the GHz Centre.

The following indicator table will be followed up by the Steering Board at each meeting:

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*The industrial transfer is measured through the sum of success stories (impact parameter G) and the number of patents (part of impact parameter C).

Industrial transfer
Industrial transfer is measured by seven parameters regularly monitored to capture industrial impact originating from GHz Centre results:

A. Mobility between Chalmers and industry
   - Industry people spending > 3 weeks at Chalmers.
   - Chalmers people spending > 3 weeks at industry
   - Chalmers PhD students and senior researchers hired by relevant industry

B. Joint know-how production Chalmers and industry
   - Co-published scientific papers Chalmers- industry

1 Research institutes are not counted as industry
- Updated industrial roadmaps of new RF/microwave technologies made possible by GHz Centre results

C. Know-how and IP from Chalmers to industry
- Manuscripts and inventions disclosed from Chalmers to all industrial partners long before being made public
- Patents and licenses

D. Demonstrators, test beds, prototypes and methods leading to new or improved products
- GHz Centre results utilized in the industrial development for new products

E. Manufacturing and selling of new or improved products
- GHz Centre results which are commercialized

F. New companies or industry growth
- Spin offs emanating from GHz Centre results
- GHz Centre results leading to industrial growth effects (such effects are normally only traceable for small companies, in particular recent spin offs)

G. Success stories from GHz Centre
- A success story is published in the form of a public viewgraph presenting a concrete academic and industrial result enabled by GHz Centre activity. The story is acknowledged by company officials. These success stories are published at http://www.chalmers.se/ghz/EN/success-stories

Individual progress for each project as well as Centre progress as a whole is reported each six month and informed to the whole centre by e-mail. At this time, project plans can also be updated and approved by incoming partners.
6 Actions taken on recommendations given in the Evaluation Report GHz Centre Stage 3

GHz Centre Stage 3 was subject to an International Evaluation during summer 2014 including a hearing onsite at Chalmers on 16 September 2014. In the official report dated 25 September 2014 from the evaluators to VINNOVA, the panel concluded that “GHz Centre is an excellent example of a VINN Excellence Centre producing good output with high impact.”

The following two recommendations were given from the panel to the GHz Centre:

Recommendation 1: That the Centre, supported by the University, continues its far-sighted planning for Stage 4 and beyond and continues the discussions with Chase about possible integration.

Recommendation 2: That the Centre initiates in-depth conversations with VINNOVA about which VINNOVA funding options might be suitable for beyond-Stage 4.

Recommendation 1 and 2 are implemented in this research programme through the actions described in detail in Chapter 8: Beyond Stage 4.

The following recommendations were given from the panel to VINNOVA:

- That VINNOVA considers allowing GHz Centre to have a more flexible Centre Agreement for Stage 4 which allows for a joint project with Chase.

- That VINNOVA considers continued funding of the integrated GHz and Chase Centres post-Stage 4.

The former point has been proposed, with the support by VINNOVA legal department, to be solved by a joint agreement for the common MATE project solely between the GHz and CHASE consortia Stage 4.

7 Plans to summarise the 10 year VINN Excellence Centre

The final report will be written Spring 2017. We are planning one final GHz Centre Day in autumn 2016 to summarise the whole ten-year entre and its achievements. This will be an open meeting. The GHz Centre web site will be up during at least one year to highlight the impact achievements. Resources will be taken from next centre initiative described below.
8 Plan for activities after Stage 4: Next generation of research centres in microwaves & antennas between Chalmers and industry

The VINN Excellence centres GHz and Chase have since late 2012 discussed on the future after the VINN Excellence period. During 2013 and 2014, these discussions among faculty and with industry have intensified and important consensus on the way forward has been reached. In total, 18 meetings in a strategy group have been held including one GHz Centre 24 hour workshop in March 2013.

8.1 Background analysis of the development in technology and applications

When GHz Centre was formulated year 2005-2006, the driving forces were efficient power amplifiers, robust wideband circuits, mm-wave/THz circuits and microwave photonic integration (which were eventually deselected in the research programme). Today, many of these challenges have been overcome and solved although market introduction may still be awaiting, in particular for the higher frequencies. The research activities in the Chase centre cover the areas antennas, signal processing, communication systems, electromagnetic computations, biomedical engineering and biological effects of microwaves.

The driving forces from the system applications in telecommunication, defence and space still remain the same as they did ten years ago. This is a natural reflection of the strength and stability among Swedish industry actors with needs in RF/microwave for their products. In fact, the development and re-structuring of wireless industry in (west) Sweden the last ten years has been most favourable for the GHz and Chase centres with more collaboration and hiring opportunities for our community.

Today we see an evolution in higher bandwidths, frequencies, integration and lower cost for most RF/microwave-based applications. Any revolution in our field such as massive deployment of graphene or other post CMOS technologies is not foreseen at the moment. This may change with time and as a result, we will always have an awareness of breakthroughs in science for wireless. For the next years, however, such ground-breaking research will be covered by traditional research funding and this is to some extent already done, e.g. through flagship in H2020. Again, the embedding of an industry-sponsored centre in a strong research milieu such as Chalmers is vital. The observed trends today of relevance for the centres can be summarized in:

In telecommunication, data rates will go to several Gb/s while maintain low(er) cost and high(er) energy efficiency. Integration, adaptivity and intelligence are key words. Other trends are many antennas (massive MIMO), small cells and higher frequencies (mm-wave). All this with be driven by the launch of a new 5G standard for the 2020’s. EU projects such as METIS are already paving the way in this direction and Chalmers and Ericsson are part of this.

In defence and security business, the trend is towards autonomous platforms such as UAVs. Bandwidths will be (much) larger and frequencies go up well into the mm-wave range. Radar sensors in general must be more compact, intelligent and energy efficient, still being robust. Fully digitalised T/R solutions are foreseen. Also in space business, the trend is towards higher integration and lower cost by new packaging, antennas and semiconductor
technologies. In space industry, the need for extreme robustness and associated space qualification are added to the list of challenges for future RF/microwave.

The trend towards ever higher integration and lower cost is driven by established, high volume segments such as telecom. However, this development serves also as an enabler for addressing challenges in other areas, using the same or similar technology. Sensor systems for medical and industrial applications are two examples of areas that can benefit from the availability of advances in microwave and antenna technologies. Combining the competence in Case/GHz core technologies with the understanding of the challenges and pre-requisites in un-addressed application areas represents a potential for innovative solutions and industrial growth.

8.2 Situation at Chalmers today

Today, the situation for wireless research at Chalmers involving industrial involvement is almost fully focused at MC2 and S2, the former on electronics hardware, the latter on systems and antennas. The GHz and CHASE Vinn Excellence Centres have been extremely successful in bringing MC2 and S2 together by marrying RF design with signal processing and antennas meeting the industrial needs for more power-efficient transmission.

GHz Centre and CHASE have been benchmarked against each other with respect to research programs and basic set up. While there are large similarities in basic agreement and organisation, there also exists large differences with respect to companies, application targets, and funding. Compared to GHz Centre, CHASE is a much broader centre with more potential application targets but also more diluted with respect to funding. Nonetheless, the benchmarking revealed there exists a large potential to combine the strengths of the two VINN Excellence centres.

In October 2014, the GHz Centre and CHASE received the official reports from the 3d International Evaluation arranged by VINNOVA. The outcome was extremely positive for both centres. In particular we note that one of the recommendations for both centres from the panel to VINNOVA is: “That VINNOVA considers continued funding of the integrated GHz and Chase Centres post-Stage 4”.

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\[2\] J. Grahn and S. Sjödin, Task force GHz-CHASE February 2014.
8.3 A new centre platform in microwave and antennas 2017-2026

The strategic group from GHz Centre arrived at a conclusion that the technical development outlined above necessitates that the next generation of centre between Chalmers and industry should broaden the scope to include both electronics hardware and antenna (including systems). In autumn 2013, GHz Centre Board therefore decided to invite CHASE for a new joint task force formation. The task force consisted of the Directors, the Chairmen, two key faculty professors and two other companies from both Steering Boards. Thus all significant industry and academia is represented.

The goal of the task force is to formulate a common centre platform between Chalmers and industry in microwave/antennas starting 2017. The task force have agreed on the following setup of the proposed centre:

Objectives
- Strengthen the competitiveness of Chalmers and industry
- Support and strengthen new businesses such as spin outs
- Contribute to the Grand Challenges outlined in H2020

Goals
- In the field of microwaves and antennas, among the top three leading centres in the world
- 30-50 company partners
- Turnover 50 MSEK/yr, on the long run 100 MSEK/yr with at least 1/3 from industry and 50% from external funding (in competition)
- Measure impact from the centre among partners: Research papers, PhDs, transfer of results to industry

Strategy
- Critical mass of actors with a long-term vision (10 years)
- A global centre based upon multi-lateral collaboration involving the most competent actors in the field
- Ideas from academy, guiding by industry
- Profiling and focus
- Foster a new generation of researchers for the 2020’s
- Support from several funding bodies including EU
- Efficient outreach of our results

During Stage 4, the new boards for GHz Centre and CHASE will at their first meeting decide upon a new task force mandate and continue to formulate the plan outlined above. A crucial point will be to follow up on VINNOVA’s plans for new Research Excellence Centres and how to apply for these from the new common platform in microwave and antennas.
9 Staff
Pending. This will be filled in the last version when the budget and person-planning has been approved by the new Board for Stage 4.

10 Financing and resource allocation

If not stated otherwise, all contributions below are given in kSEK.
One Full-Time Equivalent (FTE) = one working year = 1680 h = 140 h/month

10.1 Assumptions made for calculation of contributions inkind

For all partners, the contribution is divided between cash, and inkind. In kind is categorized as either work contribution in hours by specified personnel (name, position) or material contribution. Work is calculated (according to VINNOVA standards) as 800 SEK/hour for all partners including Chalmers. Material can be lab resources, components, foundry runs etc. This inkind must be specified in the project plan and given a specific value approved by the partners. Note that all inkind belongs to the GHz Centre under the same formal conditions as the cash contributed part.

10.2 Calculation of Chalmers contribution

Chalmers is doing a considerable investment in GHz Centre Stage 4 of 15,802,880 kSEK.

- Chalmers invests 5,100 kSEK cash per year from the central administration (750 kSEK/year), the MC2 Department (900 kSEK/year) and the three ingoing divisions MEL (500 kSEK/year), TML (200 kSEK/year) and Communication Systems (200 kSEK/year).
- Chalmers allocates three office spaces for external GHz Centre partners at MC2, floor B6 (MEL+TML) at full time with fully equipped EDA tools for industrial partners. This cost corresponds to the overhead cost at Chalmers for three full-time employees in keeping up the infrastructure for research. The cost also includes full access to copy machines, Chalmers library and full administrative and technical support.
- Chalmers offers the microwave measurement infrastructure at 50% usage time for GHz Centre staff in all projects. This is one of Northern Europe’s best equipped microwave laboratories with equipment worth around 70 MSEK. Large investments are made during Stage 4 for new measurement equipment.
- Chalmers offers industry access to the Microwave Process Line at the cleanroom at MC2 in the INTHEL project. This facility is strongly subsidized by Chalmers Foundation with around 10,000 kSEK per year. GHz Centre can use the facility at 100% cleanroom time for one person in the INTHEL project.
- Two individual researchers at Chalmers (Thomas Eriksson and Jan Grahn) offer their projects from Swedish Research Council (VR) as in kind contribution in the SITRA project and INTHEL project, respectively, provided the PhD student give their approval in the internal agreement for Chalmers’ GHz Centre employees.
- Chalmers spends an estimated 414 kSEK during Stage 4 by involving MC2 administrative personnel (MoM support at Steering Board meetings, practical arrangements, economical administration, communication functions such as web page support, folder and poster material, and press releases).
The Chalmers contribution:

<table>
<thead>
<tr>
<th>Contribution Stage 4</th>
<th>SEK/h</th>
<th>SEK/yr</th>
<th>Hours</th>
<th>SEK total</th>
<th>SEK/yr</th>
<th>Anm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inkind material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office spaces 300% usage</td>
<td>267</td>
<td>448560</td>
<td>10080</td>
<td>2691360</td>
<td>1345680</td>
<td>3 places full time</td>
</tr>
<tr>
<td>Measurement lab 50% usage</td>
<td>600</td>
<td>1008000</td>
<td>1680</td>
<td>1008000</td>
<td>504000</td>
<td>0.5 FTE</td>
</tr>
<tr>
<td>Cleanroom 100% usage</td>
<td>1000</td>
<td>1680000</td>
<td>3360</td>
<td>3360000</td>
<td>1680000</td>
<td>1.0 FTE</td>
</tr>
<tr>
<td>Sum in kind material Chalmers</td>
<td></td>
<td></td>
<td></td>
<td>7059360</td>
<td>3529680</td>
<td></td>
</tr>
<tr>
<td>In kind work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR inkind 2015-2016 (2 grants)</td>
<td>400</td>
<td>1108.8</td>
<td></td>
<td>443520</td>
<td>221760</td>
<td>Grahn (INTHEL), Eriksson (SITRA)</td>
</tr>
<tr>
<td>Sum in kind work Chalmers</td>
<td></td>
<td></td>
<td></td>
<td>3643520</td>
<td>1821760</td>
<td></td>
</tr>
<tr>
<td>Sum in kind Chalmers</td>
<td></td>
<td></td>
<td></td>
<td>10702880</td>
<td>5351440</td>
<td></td>
</tr>
<tr>
<td>Cash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalmers central</td>
<td>150000</td>
<td>750000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC2</td>
<td>180000</td>
<td>900000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML/M2</td>
<td>100000</td>
<td>500000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TML/M2</td>
<td>40000</td>
<td>200000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comesys/S2</td>
<td>40000</td>
<td>200000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum cash Chalmers</td>
<td>5 100 000</td>
<td>2550000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 10.3 Contributions from industry, Chalmers, and VINNOVA

Stage 4 is a large GHz Centre investment from ingoing partners with a total budget of 66.1 MSEK (29.6 MSEK cash). Here the financing from all partners are described per category, partner and project. The requirement from VINNOVA of at least equal amount of investment from both industry and academia is fulfilled.

<table>
<thead>
<tr>
<th>Cash contribution GHz Stage 4 (SEK)</th>
<th>2015</th>
<th>2016</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>5 249 999</td>
<td>5 249 999</td>
<td>10 499 998</td>
<td>35%</td>
</tr>
<tr>
<td>Chalmers</td>
<td>2 550 000</td>
<td>2 550 000</td>
<td>5 100 000</td>
<td>17%</td>
</tr>
<tr>
<td>VINNOVA</td>
<td>7 000 000</td>
<td>7 000 000</td>
<td>14 000 000</td>
<td>47%</td>
</tr>
<tr>
<td>Sum</td>
<td>14 799 999</td>
<td>14 799 999</td>
<td>29 599 998</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total contribution GHz Stage 4 (SEK)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>18 269 145</td>
<td>18 069 145</td>
<td>36 338 290</td>
<td>55%</td>
</tr>
<tr>
<td>Chalmers</td>
<td>7 901 440</td>
<td>7 901 440</td>
<td>15 802 880</td>
<td>24%</td>
</tr>
<tr>
<td>VINNOVA</td>
<td>7 000 000</td>
<td>7 000 000</td>
<td>14 000 000</td>
<td>21%</td>
</tr>
<tr>
<td>Sum</td>
<td>33 170 585</td>
<td>32 970 585</td>
<td>66 141 170</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contribution GHz Stage 4 (SEK)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>In kind work</td>
<td>11 323 786</td>
<td>11 323 786</td>
<td>22 647 572</td>
<td>34%</td>
</tr>
<tr>
<td>In kind material</td>
<td>7 046 800</td>
<td>6 846 800</td>
<td>13 893 600</td>
<td>21%</td>
</tr>
<tr>
<td>Cash</td>
<td>14 799 999</td>
<td>14 799 999</td>
<td>29 599 998</td>
<td>45%</td>
</tr>
<tr>
<td>Sum</td>
<td>33 170 585</td>
<td>32 970 585</td>
<td>66 141 170</td>
<td>100%</td>
</tr>
</tbody>
</table>

SPs contributions are included in industry. Pie charts are shown below.
### 10.4 Allocation per project

The proposed allocation per project:

<table>
<thead>
<tr>
<th>Project</th>
<th>Director</th>
<th>SITRA</th>
<th>TOPGAN</th>
<th>GANOSC+</th>
<th>INTHEL</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>0 3 716 666</td>
<td>3 950 000</td>
<td>1 333 333</td>
<td>2 000 000</td>
<td>10 999 998</td>
<td></td>
</tr>
<tr>
<td>Chalmers</td>
<td>1 100 000</td>
<td>1 000 000</td>
<td>1 000 000</td>
<td>1 000 000</td>
<td>5 100 000</td>
<td></td>
</tr>
<tr>
<td>VINNOVA</td>
<td>1 700 000</td>
<td>3 000 000</td>
<td>3 300 000</td>
<td>3 000 000</td>
<td>14 000 000</td>
<td></td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>2 800 000</strong></td>
<td><strong>7 716 666</strong></td>
<td><strong>8 250 000</strong></td>
<td><strong>5 333 333</strong></td>
<td><strong>30 099 998</strong></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>9%</td>
<td>26%</td>
<td>27%</td>
<td>18%</td>
<td>20%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project</th>
<th>Director</th>
<th>SITRA</th>
<th>TOPGAN</th>
<th>GANOSC+</th>
<th>INTHEL</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>0 9 828 667</td>
<td>7 522 827</td>
<td>4 213 333</td>
<td>4 273 466</td>
<td>25 838 292</td>
<td></td>
</tr>
<tr>
<td>Chalmers</td>
<td>443 520</td>
<td>2 600 000</td>
<td>1 900 000</td>
<td>1 500 000</td>
<td>10 702 880</td>
<td></td>
</tr>
<tr>
<td>VINNOVA</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
<td></td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>443 520</strong></td>
<td><strong>12 428 667</strong></td>
<td><strong>9 422 827</strong></td>
<td><strong>5 713 333</strong></td>
<td><strong>36 541 172</strong></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>1%</td>
<td>34%</td>
<td>26%</td>
<td>16%</td>
<td>23%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project</th>
<th>Director</th>
<th>SITRA</th>
<th>TOPGAN</th>
<th>GANOSC+</th>
<th>INTHEL</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>0 13 545 332</td>
<td>11 472 826</td>
<td>5 546 665</td>
<td>4 273 466</td>
<td>36 838 290</td>
<td></td>
</tr>
<tr>
<td>Chalmers</td>
<td>1 543 520</td>
<td>3 600 000</td>
<td>2 900 000</td>
<td>2 500 000</td>
<td>15 802 880</td>
<td></td>
</tr>
<tr>
<td>VINNOVA</td>
<td>1 700 000</td>
<td>3 000 000</td>
<td>3 300 000</td>
<td>3 000 000</td>
<td>14 000 000</td>
<td></td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>3 243 520</strong></td>
<td><strong>20 145 332</strong></td>
<td><strong>17 672 826</strong></td>
<td><strong>11 046 665</strong></td>
<td><strong>66 641 170</strong></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>5%</td>
<td>30%</td>
<td>27%</td>
<td>17%</td>
<td>22%</td>
<td>100%</td>
</tr>
</tbody>
</table>

### 10.5 Spending budget per year and project

The spending cash budget (kSEK) is mainly used for salaries for Chalmers employees in the GHz Centre including OH costs.

#### Cash spending budget / project

| Payroll costs | 1 300 000 | 4 500 000 | 4 240 000 | 3 000 000 | 3 000 000 | 16 040 000 |
| Computer costs | 50 000 | 100 000 | 110 000 | 75 000 | 75 000 | 410 000 |
| Equipment | 0 | 500 000 | 805 000 | 210 000 | 140 000 | 1 655 000 |
| Materials, running costs etc | 0 | 100 000 | 500 000 | 375 000 | 250 000 | 1 225 000 |
| Travel | 100 000 | 166 666 | 75 000 | 73 333 | 75 000 | 489 999 |
| Consultancy expenses | 0 | 0 | 300 000 | 0 | 300 000 | 600 000 |
| Lab costs | 0 | 0 | 0 | 0 | 960 000 | 960 000 |
| Other costs (specify) | 700 000 | 0 | 0 | 0 | 0 | 700 000 |
| Total direct project cost | 2 150 000 | 5 366 666 | 6 030 000 | 3 733 333 | 4 800 000 | 22 079 999 |
| Indirect costs | 650 000 | 2 250 000 | 2 120 000 | 1 500 000 | 1 500 000 | 8 020 000 |
| **Total** | **2 800 000** | **7 616 666** | **8 150 000** | **5 233 333** | **6 300 000** | **30 099 999** |
The cash spending posts per year in the Table follow the specifications from VINNOVA.

<table>
<thead>
<tr>
<th>Spending budget / year</th>
<th>2015</th>
<th>2016</th>
<th>Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries</td>
<td>8 020 000</td>
<td>8 020 000</td>
<td>16 040 000</td>
</tr>
<tr>
<td>External services</td>
<td>300 000</td>
<td>300 000</td>
<td>600 000</td>
</tr>
<tr>
<td>Equipment</td>
<td>1 032 500</td>
<td>1 032 500</td>
<td>2 065 000</td>
</tr>
<tr>
<td>Material, running costs</td>
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<td>612 500</td>
<td>1 225 000</td>
</tr>
<tr>
<td>Travel</td>
<td>245 000</td>
<td>245 000</td>
<td>489 999</td>
</tr>
<tr>
<td>Other</td>
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<td>830 000</td>
<td>1 660 000</td>
</tr>
<tr>
<td>OH costs</td>
<td>4 010 000</td>
<td>4 010 000</td>
<td>8 020 000</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>15 050 000</td>
<td>15 050 000</td>
<td>30 099 999</td>
</tr>
</tbody>
</table>