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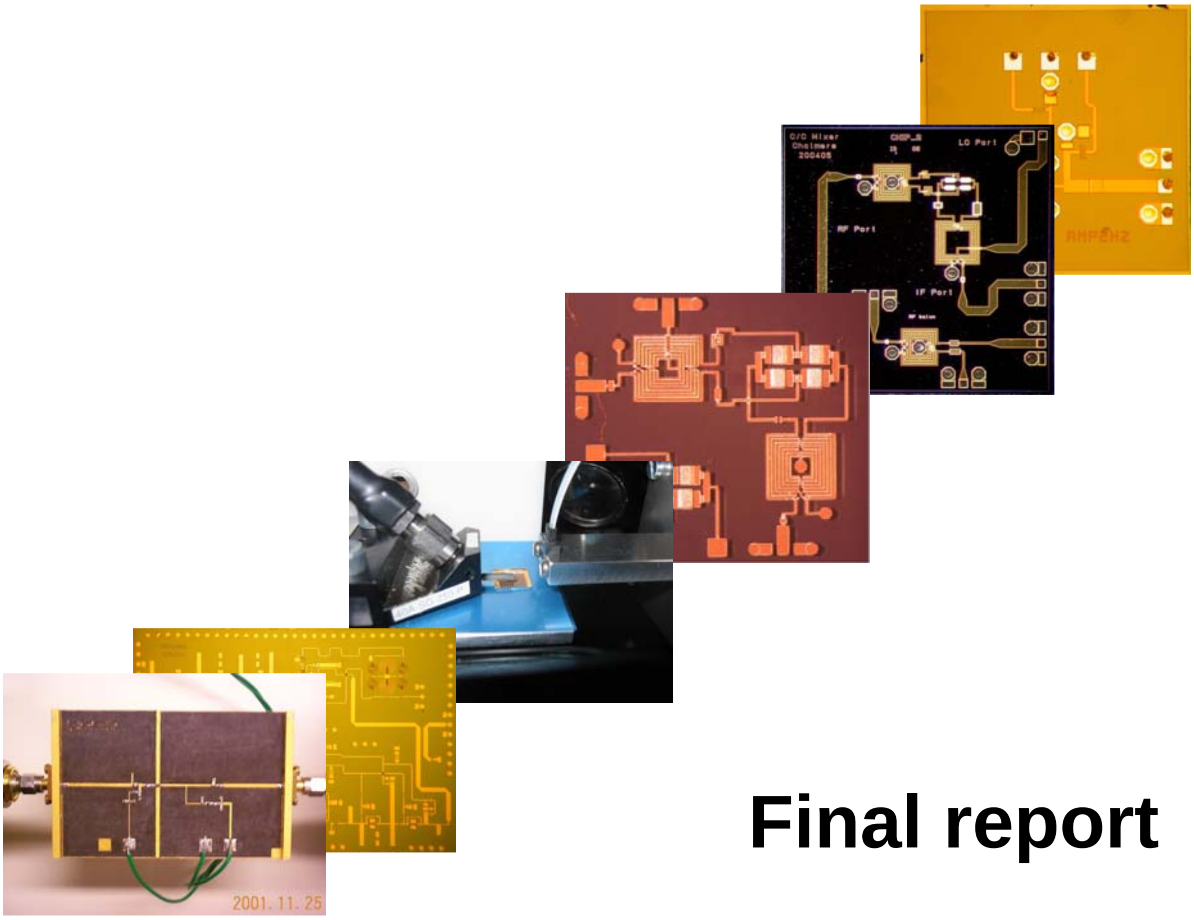
Chalmers Center for High-Speed Technology – CHACH



Final report

April 1, 1995 – Dec 31, 2006

Göteborg, October 2007

Chalmers Center for High-Speed Technology

A Competence Center hosted by Chalmers University of Technology

www.chach.chalmers.se

CHACH
high speed
technology

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Executive Summary CHACH 1995 - 2006

Chalmers Center for High-Speed Technology (CHACH) was a Competence Center in high-speed electronics and photonics between Chalmers University of Technology, industrial partners and Swedish Governmental Agencies (Swedish National Board for Industrial and Technical Development (NUTEK) 1995-2000, Swedish Governmental Agency for Innovation Systems (VINNOVA) 2000-2005). CHACH was run 1995.04.01 - 2006.12.31 in six consecutive Stages, each one from 6 to 36 months in duration. For each Stage, a Consortium Agreement was signed between the partners defining the management, legal structure and a joint research program.

CHACH's original mission was to conduct research for the long-term competitiveness of its partners. The research program encompassed fiberoptic communication, optoelectronics, high-frequency circuit design, emerging microwave devices, microwave power (devices), and electro-magnetic modeling. The mission was later changed to: "To bring academic advances in microwave-based components faster to industrial development and system prototyping by taking full advantage of the common infrastructure established by Chalmers and its industrial partners through CHACH."

14 enterprises (six small- or medium-sized) and one industrial research institute joined as company members in CHACH. 173 persons (18 women) participated in research projects, steering boards and administration. Of these, 66 persons (8 women) were from Chalmers. Around 50% of the engaged researchers from industry partners was from Ericsson companies. In total, 239 MSEK (75 MSEK cash) was invested in the center by the partners in CHACH.

The total academic output from CHACH was 174 journal papers and 290 conference contributions (37 invited). 22 Ph.D.s and 30 licentiates were examined at Chalmers. Eight of the Ph.D.s were later employed in industry.

Eight success stories of industrial testing and transfer of results have been identified of which three had a commercial impact at company partners. It is expected that at least two to three of the other success stories will become commercially viable in coming years. A total of 47 patents were registered, almost all owned by Ericson. The number of spin off companies was three plus one in an advanced planning stage. Other CHACH research which turned out to have a long way to market has been transferred to verification projects or EU framework programs.

CHACH was part of a large research environment at Department of Microtechnology and Nanoscience (MC2) at Chalmers. CHACH has during almost twelve years developed from a traditional center of excellence within engineering science to a Competence Center where company partners, academia and society benefit from impact. International evaluations by NUTEK/VINNOVA, an international advisory board, and support from university management have constituted essential factors in developing CHACH. Key issues have been to strongly increase industrial involvement including cash contributions from company partners, to profile the research program after industrial long-term needs, to clarify CHACH projects and results in relation to other activities at university, to settle the agreement and in particular solve IPR issues, and to clarify the added value of CHACH in relation to other research at Chalmers. This strategy helped Chalmers to transform CHACH into the second generation Competence Center, GigaHertz Centre, which was launched by Chalmers and industrial partners in January 2007 and is expected to operate at least until December 2016 within VINNOVA's VINN Excellence Program.

Sammanfattning CHACH 1995 - 2006

Chalmers Centrum för Höghastighetsteknologi (CHACH) var ett kompetenscentrum i höghastighetselektronik och fotonik mellan Chalmers tekniska högskola, näringslivspartners och svenska myndigheter (Närings- och Teknikutvecklingsverket (NUTEK) 1995-2000, Verket för Innovationssystem (VINNOVA) 2000-2005). CHACH verkade 1995.04.01 - 2006.12.31 i sex på varandra följande etapper, var och en med en längd av 6 till 36 månader. För varje etapp tecknades ett konsortialavtal mellan parterna som fastslog styrning, legala strukturer samt ett gemensamt forskningsprogram.

CHACHs ursprungliga uppdrag var att utföra forskning för sina parters långsiktiga konkurrenskraft. Forskningsprogrammet innefattade fiberoptisk kommunikation, optoelektronik, högfrekvent kretsdesign, framtida mikrovågskomponenter, mikrovågseffekt(komponenter) och elektromagnetisk modellering. Uppdraget kom sedan att ändras till: "Att föra akademiska framsteg inom mikrovågsbaserade komponenter fortare ut till industriell utveckling och systemprototyper genom att fullt ut utnyttja den gemensamma infrastrukturen etablerad av Chalmers och näringslivsparter via CHACH."

14 företag (varav sex små- eller medelstora) och ett industriforskningsinstitut deltog som industriella parter i CHACH. 173 personer (18 kvinnor) deltog i forskningsprojekt, styrelser och administration. Av dessa var 66 personer (8 kvinnor) från Chalmers. Omkring 50 % av de engagerade forskarna från industrin var från Ericssonföretag. Total investerades 239 MSEK (75 MSEK kontant) i centret av CHACHs parter.

Den totala akademiska produktionen från CHACH var 174 uppsatser i vetenskapliga tidskrifter och 290 konferensbidrag (37 inbjudna). 22 tekniska doktorer och 30 tekniska licenciater examinerades vid Chalmers. 8 av doktorerna anställdes sedemera i industrin.

Åtta framgångshistorier inom industriell testning och överföring av resultat har identifierats varav tre haft en kommersiell inverkan hos företagsparter. Det förväntas att åtminstone två till tre av de övriga framgångshistorierna kommer bli kommersiellt gångbara de kommande åren. Totalt 47 patent har registrerats, nästan samtliga ägda av Ericsson. Antalet företagsavknoppningar var tre plus en i ett långt framskridet planeringsstadium. Övrig CHACH forskning som visade sig ha en lång väg till marknaden har överförts till verifieringsprojekt eller EUs ramprogram.

CHACH var del av en stor forskningsmiljö på Institutionen för mikroteknologi och nanovetenskap (MC2) på Chalmers. CHACH har under nästan tolv år utvecklats från ett traditionellt excellenscentrum inom teknikvetenskap till ett kompetenscentrum där näringslivsparter, akademi och samhälle drar nytta av dess inverkan. Internationella utvärderingar av NUTEK/VINNOVA, ett internationellt vetenskapligt råd och stöd från universitetsledningen har utgjort väsentliga ingredienser i att utveckla CHACH. Nyckelpunkter har varit att starkt öka det industriella engagemanget inklusive kontanta bidrag från företagsparter, att profilera forskningsprogrammet efter industrins långsiktiga behovsbild, att tydliggöra CHACH projekt och resultat i relation till annan verksamhet på universitet, att teckna avtal och i synnerhet lösa IPR frågor, och att klargöra mervärdet av CHACH i relation till övrig forskning på Chalmers. Denna strategi hjälpte Chalmers att transformera CHACH till andra generationens kompetenscentrum, GigaHertz Centrum, vilket sjösattes av Chalmers och industriparter i januari 2007 och förväntas drivas till åtminstone december 2016 inom VINNOVAs VINN Excellence program.

Preface

This final report by Chalmers Center for High-Speed Technology (CHACH) constitutes the end point for a first generation Competence Center. CHACH was operated during six consecutive stages 1995-2006 between Chalmers University of Technology, industrial partners and Swedish Governmental Agency for Innovation Systems (VINNOVA). CHACH was one of 28 Competence Centers in Sweden started during mid-1990 in the largest national research program (5 BSEK) between universities and industry initiated by former Swedish National Board for Industrial and Technical Development (NUTEK).

This report is also an attempt to summarize the people, projects and achievements and their impact. CHACH utilized *the competence* from Sweden's strongest research academic and industrial constellations in microwave electronics, photonics and fiberoptic communication. This report describes the research subjects where Chalmers and companies found it advantageous to join forces in high-speed technology targeted for future communication and sensor systems, and how we organized and carried it out.

A story like this will always be biased. Since I had the pleasure to lead CHACH during almost half of its existence (2001-2006), it is of course not fair by me to claim the correct overall picture of an almost twelve-year journey. Fortunately, CHACH is well documented through reports, documents, and minutes which together with all academic theses and publications had helped me in writing this report. All faults in this report are on my full responsibility.

A number of people have helped me in guiding CHACH to its final end and I would like to take the opportunity to acknowledge these. First, I would like to thank Professor Erik Kollberg, Chalmers, Board Chairman Arne Filipsson, Ericsson Microwave Systems, and the Center Director Anders Karlström, CIT, who recruited me for position as CHACH Director in 2001 during Stage 3. My research colleagues at Chalmers, Professors Herbert Zirath, Anders Larsson, Peter Andrekson, Spartak Gevorgian, and Dr. Niklas Rorsman have all been key players at the faculty in building CHACH research during the twelve years. Moreover, the support from Chalmers Presidency, Vice President Johan Carlsten and former President's Advisor to the President, Roger Johansson, and former Department Head at MC2, now Vice President Professor Stefan Bengtsson, was of utmost importance for the development of CHACH. Furthermore, I am very grateful to Catharina Forssén for assisting me in minutes of all board meetings, financial details and many other practical issues with a joint center.

At industry, I and Chalmers faculty have been very fortunate to have established the networking and trust with industrial key players in the field which let us built fruitful long-term collaborations with a range of Swedish companies in different high-speed technology sectors. I thank all the industry people and companies for their support which now continues in a second generation of Competence Center, GigaHertz Centre. In particular, former Chairmen and all Board members have been central in how we developed CHACH towards something which both Chalmers and industry came to believe in. I am particular grateful to Stage 4 Board Chairman Anna Aspgren (former Johannison) at Ericsson Microwave Systems (now at Aspgren Ledarresurs AB) and Stage 4+ and 4++ Board Chairman Fredrik Wising, Saab Microwave Systems, and Board Member Dr. Peter Olanders, Ericsson. A special thanks for valuable advise from our International Advisory Board during Stage 4, 4+ and 4++, Professor Jussi Tuovinen, VTT and Dr. Michael Schlechtweg , Fraunhofer IAF.

I am grateful to Dr. Henric Rhedin at Chalmers Industrial Technologies (CIT) for allowing me to have an extraction from his VINNOVA report in Chapter 9, "CHACH as Verification Source" based upon interviews of former CHACH staff.

Finally, I would like to acknowledge involved VINNOVA co-workers for their far-sighted vision and engagement in long-term research between Swedish universities and industry which still continues to inspire Chalmers and our company partners despite the somewhat harsh international evaluations. In particular, I would like to thank former Program Manager at VINNOVA for the Competence Center program, Staffan Hjorth, for all his assistance and advice to me and former Directors during the CHACH years. Without him, the Competence Center program would never have become what it is today which we now utilize to build the second generation of Competence Centers.

Göteborg
October 2007

Jan Grahn
CHACH Center Director 2001-2006

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Appendix

1 Introduction

Chalmers Center for High-Speed Technology (CHACH) was an almost 12 year university-governmental- industrial project carried out year 1995 to 2006 between Chalmers University of Technology (Chalmers), company partners and public authorities. The overall objective of CHACH was to define and carry out integrated research projects between Chalmers and industry in high-speed electronics and photonics.

CHACH was initiated and proposed by Professor Erik Kollberg and colleagues at Chalmers in the official call April 1993 for national Competence Centers announced by the Swedish National Board for Industrial and Technical Development (NUTEK). The proposal for CHACH was filed at NUTEK on 1994.01.31. The application was approved and following negotiations between Chalmers, NUTEK and industrial partners, CHACH formally started on 1995.04.01. During 1995-2005, CHACH was part of the ten-year Competence Center program organized by NUTEK, transferred from 2000.06.01 to the Swedish Governmental Agency for Innovation Systems (VINNOVA), and the Swedish Energy Agency (STEM, previously Swedish National Energy Administration). The total Competence Center program headed by NUTEK /VINNOVA included 28 centers, each one with a Swedish university acting as a host partner. CHACH was one out of eight Swedish Competence Centers related to Information- and Communication Technology, and the only one of its kind at Chalmers where the remaining five Competence Centers all were dedicated to energy, transport and environmental technology.[1]

According to VINNOVA's criteria, a Competence Center had to face two major challenges:

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[1] The NUTEK Competence Centre Programme - An effort to build bridges between science and indsutry in Sweden, Staffan Hjorth, NUTEK Report, October 1998.

I. To be a cross-disciplinary center of excellence, *i.e*. a dynamic, productive, and internationally renowned academic research environment.
II. To promote the implementation of new technology and to strengthen the technical competence in Swedish industry, mainly through its industrial partners.

Originally inspired by the NSF Engineering Research Centers in US, the Competence Center program became the single largest public-industrial-university investment for research carried out in Sweden 1995-2005. Numerous international reviews of the 28 centers have testified that the Swedish Competence Center program was very efficient in its way of creating university-industrial partnerships with lasting value and large impact for involved academic and industrial partners. As a result, several agencies and foundations have launched programs during the 00's inspired by the concepts behind the Competence Center program.

A Competence Center is co-financed by its in-going partners and shall primarily be driven by the long-term needs from industry. Research tasks shall be guided (but not dictated) from the company partners to the involved university faculty staff. A Competence Center is thus neither a governmental-sponsored source for bi-lateral industrial contract research at a technical university, nor an added base funding for the normal engineering scientific work carried out at the faculty.

This report summarizes the history of the Competence Center CHACH during its full period year 1995-2006. The report tells the basic concept and idea of the center, its organization and management as well as ingoing partners and staff. The research program and its evolution are briefly given; for details, it is referred to annual reports and publications. Center activities and financing are described. The academic and industrial achievements and their impact are paid special attention. Finally, the report is concluded with recommendations for future academic-industrial joint research programs co-sponsored by governmental agencies.

2 The Center CHACH

CHACH was approved by NUTEK in late 1994 following an open call for Competence Centers by NUTEK the year before.[2] Professor Erik Kollberg, Chalmers, was the main applicant. The first negotiation between the original partners forming CHACH was finalized 1995.04.01.

Competence centers were run in consecutive stages. CHACH has been run in six stages during 11 years and 9 months. For definitions of the Stages, see Table I.

Table I. Definitions of CHACH Stage 1, 2, 3, 4, 4+ and 4++ during 1995 - 2006.

Stage	Start date – End date	Period in months	Public agency
1	1995.04.01– 1997.06.30	27	NUTEK
2	1997.07.01 – 2000.06.30	36	NUTEK
3	2000.07.01 – 2003.06.30	36	VINNOVA
4	2003.07.01 – 2005.06.30	24	VINNOVA
4+	2005.07.01 – 2006.06.30	12	None
4++	2006.07.01 – 2006.12.31	6	None
Total	**1995.04.01 – 2006.12.31**	**141**	

The two last CHACH Stages 4+ and 4++ were run without any governmental agency being part of the Center.

2.1 Mission and strategy

The overall objective of CHACH was to carry out research in high-speed electronic components and photonics between Chalmers and involved company partners. However, the mission of the center has changed during the years. This was related to the position of CHACH in relation to other adjacent funding in high-speed electronics and photonics at Chalmers.

[2] www.chach.chalmers.se

A Competence Center should be strongly driven by its defined tasks. Originally, the mission of CHACH was formulated very technically: *"To conduct research on components and packaging for high data rates and high frequencies for future electro-magnetic communications and sensor systems."* A new mission, taking into account the industrial partners, was formulated during early Stage 3: "*To perform research in high-speed electronics and photonics for communication and sensing to explore new technologies for the benefit of the long-term competitiveness of its partners."* Nonetheless, the mission never resulted in any new thoughts and directions about the added values which a joint research center could pursue. As a result, CHACH was considered a source of extra funding, albeit with some extra industrial involvement. The type of activity went perfect hand-and-hand with the large projects financed by other sources.

Following the evaluation by VINNOVA at the end of Stage 3, it was clear that a revised center concept and strategy was urgently needed and consequently, a new statement was formulated for the three last stages: "*To bring academic advances in microwave-based components faster to industrial development and system prototyping by taking full advantage of the common infrastructure established by Chalmers and its industrial partners through CHACH."* This new mission enabled new thoughts, new projects and, most important, much more involvement from industry on all levels.

The strategy of CHACH was rather vague during the first three stages which resulted in that several research topics were more driven by the need from the faculty than the need from the industry. In Stage 4 and beyond, a strategic plan guided by the new mission was adopted. The plan turned out efficient in identifying and selecting projects. The new strategy and mission meant that the added value of the Centre at the university could be much more easily identified than for the early Stages. It also helped Chalmers in selecting the best industrial partners for CHACH.

It is obvious that the center during 12 years has shifted its attitude and strategy from being faculty oriented to being customer oriented. With customer, it is here meant the company partners. The driving force to transfer knowledge, technology and trained people from university to industry constitutes the central issue of a Competence Center.

As a result from the refining of center mission and strategy, the research subjects in CHACH were also changed during the 12 years. The broad multi-disciplinary profile from the beginning of CHACH suffered from fragmentation. Eventually, the research program evolved into more focused projects with clear goals set up by the partners together. Simultaneously, the industrial contributions significantly increased.

2.2 Organization

Competence centers are joint constructions involving people from various partners, including university departments, research institutes and companies, all differing in tasks, size and geographical location. It is therefore essential to establish a clear structure for the leadership and research organization of a centre. Throughout the years, CHACH has taken advantage of an organizational model with a board, management, reference groups, and research programs. In Figure 1, a typical centre organization (from Stage 4) used in CHACH is presented with two research programs on Devices and Circuits and Systems.

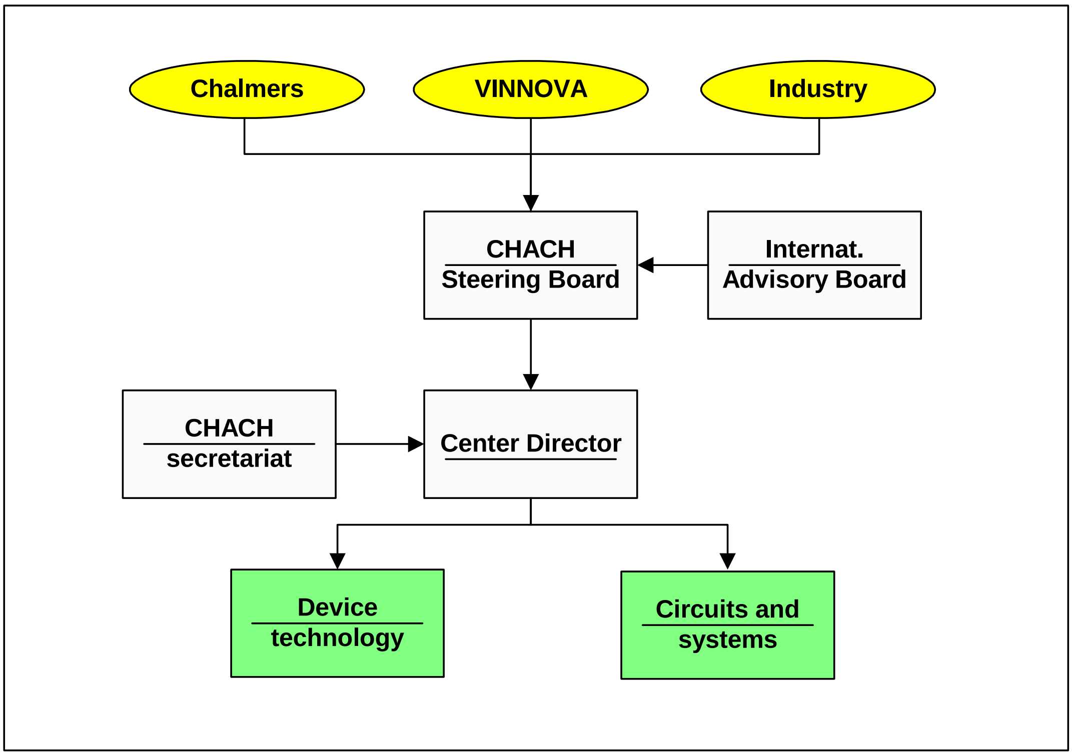

Figure 1. CHACH organization Stage 4.

The research programs in CHACH were broken down into individual projects involving one or several company partners. The content of the research projects during the 12 years are described in Chapter 3. Typically seven to ten projects were run for each Stage 1, 2, 3 and 4. Since the total cash budget at Chalmers during these years was only around 6-8 MSEK per year, the average cash sum allocated for each project was rather small. In particular, Stage 2 and 3 suffered from large fragmentation which was possible to deal with by co-financing (in kind) with external funding at Chalmers from Swedish Foundation for Strategic Research (SSF), more precisely the SSF programs in High-Frequency Electronics (HFE) and High-Speed Electronics and Photonics (HSEP) during Stage 2 and 3, respectively. This mixing of VINNOVA and SSF funding in CHACH projects strengthened the projects economically but also resulted in identification problems for the Competence Center and consequently, reduced efficiency in technology transfer. As a result, a more distinct mission and strategy of CHACH were introduced when entering Stage 4 (see Par. 2.1). When VINNOVA eventually stepped off in Stage 4+ and 4++, the number of projects was further reduced and a profiling occurred.

A challenge for every Competence Center direction is to manage research organization in relation to changes among industrial partners. Research projects normally have a long-term perspective. Companies may however change internal strategies quickly, *e.g.* because of re-organization. Being focused on technologies for wired and wireless communication, CHACH had to undergo some dramatic changes after Stage 3. For example, the largest project during Stage 2 (Fiber Optics) vanished when entering Stage 4. The simple reason was the cancellation in Ericsson's business of wired networks year 2002-2003. This was painstaking for involved faculty scientists at Chalmers, in particular since the research also involved Ph.D. students. However, keeping Competence Center projects alive without the driving force from companies in testing and eventually exploiting results is to ask for problems in the future. An active leadership and communication on several levels between Chalmers and partner companies turned out essential to prepare for necessary redirections in the center research profile. CHACH found it therefore suitable to hire a relatively large portion of senior researchers at Chalmers who were more flexible to handle than a center mainly sponsoring Ph.D. students.

2.3 Steering Board and Direction

The Steering Board of CHACH constituted the highest decision power in the center. The essential role of the Steering Board was to approve the activity plan and budget for each stage. The Competence Center board could actively influence and decide over the research program. This was a stronger mandate compared to the advisory role of external boards in traditional centers of excellence at the university, *e.g.* the Strategic Research Centers funded by SSF.

CHACH formalized one new board for each stage approved by the President of Chalmers. The 19 steering board members are shown in below. Four Chairmen (one woman) lead the board during the 12 years. Three of the chairmen were from Ericsson Microwave Systems (now Saab Microwave Systems, Saab AB) whereas the first Chairman during the start up of CHACH was hired from a small consult firm (not being partner in CHACH). This solution was far from optimal and it soon became essential to have a chairman in CHACH coming from one of the major industrial stakeholders. Chalmers was represented in the board by one or two Professors from the faculty. No Department Heads or Vice Presidents from Chalmers were board members. This turned out to be a disadvantage for the latter stages (4 and beyond) when the preparation for strategies after CHACH was initiated.

In total, 47 board meetings were held in CHACH making an average of four board meetings every year.

Table II. The steering board members of CHACH year 1995-2006. During Stage 4, four deputy members from CHACH companies were also part of the board (not shown below).

Steering Board	G	CHACH Partner	Stage 4++	Stage 4+	Stage 4	Stage 3	Stage 2	Stage 1
Year			2006	2005-2006	2003-2005	2000-2003	1997-2000	1995-1997
Anders Emrich	M	Omnisys Instruments	X	X	X	X	X	
Anders Larsson	M	Chalmers			X	X	X	X
Anna Aspgren (Johannison)	F	Ericsson Microwave Systems			X			
Arne Filipsson	M	Ericsson Microwave Systems				X	X	
Erik Kollberg	M	Chalmers				X	X	X
Fredrik Wising	M	Ericsson Microwave Systems	X	X				
Gottfrid Strindlund	M	SaabTech	X	X				
Herbert Zirath	M	Chalmers	X	X	X			
Håkan Janson	M	Saab Ericsson Space		X	X			
Ivan Öfverholm	M	Saab Ericsson Space						X*
Johan Norén	M	Ericsson Microwave Systems						X
Klas-Håkan Eklund	M	Comheat Microwave	X	X				
Marco Ghisoni	M	Zarlink Semiconductor			X	X		
Pennti Kölhi	M	CelsiusTech Electronics						X
Ulf Larsson	M	CelsiusTech Electronics					X*	X
Peter Olanders	M	Ericsson	X	X				
Peter Sohtell	M	Saab Ericsson Space					X	X*
Pontus de Laval	M	SaabTech / CelsiusTech Electronics				X	X*	
Sigvard Brodén	M	SaabTech			X			
Sven G. Gustafsson	M	Cirrus Consulting						X
Chairman								

* Appointed during part of Stage.

CHACH had four Center Directors during the twelve years, see Table III. Only Göran Lövestam and Jan Grahn planned and lead CHACH through full stages.

Table III. Center Directors in CHACH in chronological order.

Director	Title	Year / Stage
Erik Kollberg	Professor	1995-1996 / Stage 1
Göran Lövestam	Associate Professor	1996-2000 / Stage 1, 2
Anders Karlström	Associate Professor	2000-2001 / Stage 3
Jan Grahn	Associate Professor	2001-2006 / Stage 3, 4, 4+ ,4++

Figure 2. Steering Board meeting CHACH Stage 4.

2.4 Reference groups and advisory board

Several Competence Centers took advantage of reference groups and advisory boards. CHACH appointed one scientific review board and one technical advisory board consisting of faculty members at Chalmers during Stage 1 and 2. This turned out not efficient simply because internal reviewing of own activities more or less was doomed to fail. Following criticism from VINNOVA international evaluation reports of Stage

2 and 3, an International Advisory Board (IAB) consisting of established microwave experts from highly-ranked research institutes was assigned for Stage 4, 4+ and 4++. The IAB members appointed by the board were:

- Dr. Michael Schlechtweg, Fraunhofer Institute for Applied Physics (IAF), Freiburg, Germany
- Dr Jussi Tuovinen, VTT Millilab, Espoo, Finland

The main task of the IAB was to review and advise the center from a technical and scientific viewpoint and its industrial impact. The IAB participated at the annual technical review meetings and delivered one written report after Stage 4. This review and discussion with the IAB was very valuable not only because it focused on details in the research progress in the centre projects but also for the ideas and strategy of the long-term future of the Chalmers-industry collaboration. Indeed, many of the recommendations from the IAB inspired the proposal texts of the next generation Competence Center carried out 2005-2006.

2.5 Partners

2.5.1 VINNOVA

VINNOVA has been the governmental agency for funding the center after the approval process in an open call procedure. VINNOVA (until June 2000 NUTEK) has been participating by an observatory member in the Steering Board. The following VINNOVA / NUTEK co-workers were assigned to follow CHACH during the 12 years. (Note that VINNOVA / NUTEK was not a partner in Stage 4+ and 4++).

Table IV. Representatives from governmental agency NUTEK (Stage 1 and 2) or VINNOVA (Stage 3, 4, 4+, 4++).

VINNOVA (NUTEK)	G	Stage 4++	Stage 4+	Stage 4	Stage 3	Stage 2	Stage 1
Year		2006	2005-2006	2003-2005	2000-2003	1997-2000	1995-1997
Anders Hedin	M			X			
Anders Sjölund	M						X
Håkan Håkanson	M				X	X	

Each observer also played the role of contact person at the agency when CHACH wanted to discuss center issues with VINNOVA, *e.g.* legal aspects. During the whole CHACH period, one essential part was the extensive communication between Chalmers and the Program Manager for the full VINNOVA/NUTEK Competence Center Program, Staffan Hjorth. In addition, VINNOVA arranged one annual Competence Center day plus one evening event for Center Directors and Chairmen. CHACH personnel participated in almost all these meetings. This was in particular important for sharing the leadership challenges and experiences among Board members, Chairmen and Directors.

Finally, VINNOVA, in its role as agency, also arranged and executed formal international reviewing events during three occasions. The performance of CHACH was then scrutinized not only with respect to technical results but also with regard to management and organization of a joint university-industry center. See Chapter 7 for further details.

2.5.2 Chalmers

The following Departments and laboratories were active in CHACH. (The names of Departments have been changed during the years. Hence several permanent Chalmers employees, in particular Professors, have remained in CHACH but under new Department organizations).

Table V. Departments at Chalmers involved in CHACH.

Department (number of groups)	**Stage 4++**	**Stage 4+**	**Stage 4**	**Stage 3**	**Stage 2**	**Stage 1**
	2006	**2005-2006**	**2003-2005**	**2000-2003**	**1997-2000**	**1995-1997**
Microwave Technology						**1**
Optical Electronics & Electrical Measurement Technology						**2**
Applied Solid State Physics					**1**	**1**
Microelectronics				**4**	**3**	
Electromagnetics				**1**	**1**	
Microtechnology and Nanoscience (MC2)	**1**	**1**	**3**			
Sum number of research groups	**1**	**1**	**3**	**5**	**5**	**4**

What is clear from the Table above is that CHACH has been strongly reduced in the number of participating groups. Eventually, when VINNOVA stepped off after Stage

4, only one group attracted sufficient interest from industry in motivating a joint Centre.

2.5.3 Industry

Totally 14 companies of which six small-or medium sized enterprises[3] (SMEs) have been partners in CHACH. Also one research institute was partner during one year in Stage 3. Several company names have been changing and here the organization name is given at the time for the last formal agreement in CHACH. Former and/or present company names used in agreements are given within parentheses.

Table VI. Company and institute partners in CHACH.

CHACH company	Place	Stage 4++	Stage 4+	Stage 4	Stage 3	Stage 2	Stage 1
		2006	2005-2006	2003-2005	2000-2003	1997-2000	1995-1997
Comheat Microwave AB* (former Eklund Innovation)	Sollentuna	X	X	X	X		
Ericsson AB (part of former Ericsson Microwave Systems, Ericsson Telecom)	Mölndal, Kista	X	X	X	X	X	X
Ericsson Microwave Systems AB (present name: Saab Microwave Systems, B.U. in Saab AB)	Mölndal	X	X	X	X	X	X
Infineon Wireless Solutions Sweden AB (present name: Infineon Technologies Nordic AB) (Ericsson Microelectronics, Ericsson Components)	Kista			X	X	X	X
Omnisys Instruments AB*	Göteborg	X	X	X	X	X	X
Saab Ericsson Space AB (present name: Saab Space AB)	Göteborg		X	X	X	X	X
Saab AB (Saab Avitronics, SaabTech, CelsiusTech Electronics, Ericsson Saab Avionics)	Järfälla	X	X	X	X	X	X
Saab Marine Electronics AB (present name: Rosemount Tank Radar AB, (Saab Rosemount)	Göteborg		X	X	X		
Zarlink Semiconductor AB (Mitel Semiconductor)	Järfälla			X	X		
Allgon Systems AB (present name: Powerwave Technologies AB, former LGP Allgon AB)	Täby				X	X	
Radians Innova AB* (later acquired by Thorlabs AB)	Göteborg				X		
Optillion AB* (liquidated)	Stockholm				X		
SP Technical Research Institute of Sweden**	Borås				X		
Gigatech AB* (later acquired by BeVe, then Miteq)	Växjö					X	X
Ranatech AB*	Mölndal					X	X
Number of companies		**5**	**7**	**9**	**13**	**9**	**8**

*Small- or medium enterprise ** Research institute

[3] SME is defined as company with less than 250 employees.

It is clear from the Table that the number of industrial partners experienced a peak during Stage 3. As a result of higher demands on industrial partnership, *e.g.* contributions of in kind and cash, the number of companies decreased in the latter stages.

2.6 Staff

The staff of CHACH during the six Stages is given in Appendix A and B. Totally, 173 persons of which 18 women participated in the research, steering boards and/or management and administration.

The staff from Chalmers (Appendix A) was 66 people (8 women). It is seen that slightly less than 10% of the Chalmers' staff participated in four Stages or more. This pinpoints one of the challenges with a Competence Center: To keep the long-term continuity with at least some key researchers and leaders during a period where the industrial landscape is constantly changing.

The staff from industrial partners (Appendix B, sorted per company) was 107 persons (10 women). The dominance from Ericsson companies is obvious, representing 49% of the staff among CHACH partners. However, several business units including Ericsson Research are represented. There is also a spread in the geography with both Kista and Mölndal units from Ericsson involved. Nonetheless, during the 12 years CHACH was heavily dominated by the Ericsson and Saab partners. This is not surprising given the Swedish industrial profile where these large companies lead much of the industrial development of advanced high-speed technologies for communication and sensor systems.

2.7 Legal structure

The basic legal steering functions and rules of financing for CHACH were stipulated in the consortium agreement. This contract was originally formulated in a template by NUTEK/VINNOVA for all 28 Swedish Competence Centers. All partners including VINNOVA were expected to sign the agreement prior to each Stage. Even though the agreement was subject to some revision and updating, the basic legal rules of CHACH remained essentially the same during all twelve years. An important exception is rules for handling intellectual property issues, see below.

The signing of consortium agreements in CHACH involving up to 14 participating organizations (Stage 3) was not always straightforward. An inherent weakness was that signing was carried out after the Stage had been started. Chalmers and VINNOVA's signatures were in fact sufficient for enabling governmental funding. For example, the agreement for Stage 3 in CHACH was signed by all industrial partners after more than half of the period had passed. This meant in reality missed opportunities for Chalmers in negotiating larger resources from industrial partners to the CHACH projects.

2.7.1 IPR agreement

The consortium agreement did not regulate intellectual property rights (IPRs) in the Competence Center projects. Since a Swedish university faculty researcher has the right to ownership of his/her own inventions regardless of financing body, an IPR agreement must be signed not only by all incoming legal organizations in the Competence Center but also for each individual faculty staff member involved at the university. This is a complex process which Swedish university administrations have difficulties in handling. CHACH was no exception and consequently, no IPR agreement was employed during Stage 1, 2, and 3 (an attempt was made during Stage 2 but failed). The absence of an IPR agreement in CHACH was heavily criticized in the international review carried out by VINNOVA at end of Stage 3. As a result, an IPR agreement for Stage 4 was formulated, negotiated and signed by all legal partners including faculty members at Chalmers involved in CHACH. This agreement was also used for Stage 4+ and 4++.

The experiences from CHACH with regard to IPR was that industry is prepared to invest more resources, in particular cash, in the center provided IPR was regulated on a fair basis for all partners (including faculty scientists) *prior* to the start of the Stage. Indeed, budget negotiations among partners only became efficient provided IPR issues had been resolved. Chalmers learned that serious handling of intellectual property helped the faculty scientists to have companies more involved in the projects.

Having a seriously engaged industrial partner from the beginning was the best way to further commercialize promising CHACH results emanating from Chalmers.

2.8 Collaborative forms academia - industry

The basic idea of the Competence Center was to collaborate between university and industry. Thus the form of the collaboration must be a top priority for any center management. In practice, the task was challenging because of all surrounding activities at the university and the shifting prerequisites and way of working among different company partners in a Competence Center project.

During CHACH Stage 1, 2 and most of Stage 3, Chalmers-industry collaborations were mostly carried out in the form of common workshops, information exchange and board meetings between university and industry people. Personal contacts were thus very important, even crucial, for a successful collaboration. The part employment of two Chalmers professors at Ericsson also meant much for the initial collaborations.

From Stage 3, the lack of efficient project steering became highlighted and project plans were employed, in particular to better follow up Chalmers' employees. From Stage 4, this was extended to joint project plans where the industry and academic contributions were specified and jointly followed up. These project plans were essential both for project leader training in CHACH and having company partners aware of their commitments (where Competence Center projects are much more of a peripheral activity than at a university faculty). Event though the project plans became efficient, there was always room for updating and changing of priorities thus leaving room for academic creativity and some flexibility in the common activities. Moreover, two industrial project leaders including one adjunct professor from a company partner were recruited to Chalmers and CHACH.

2.9 *Relation to Chalmers outside the Centre*

2.9.1 Line organization and facilities

A Competence Center at the university gathers individual scientists across Departments, research groups and laboratories. Hence it is not part of the line organization (Departments, laboratories) at the university. At Chalmers, Competence Centers sorted directly under Vice President for industrial relations. In practice, however, the most involved university department acted as a kind of host for the center.

Since CHACH neither could employ its own staff, nor gain its own legal status (signing of contract), the relation to the university line organization became essential. This meant internal negotiating with Department Heads, in reality the Head of Microtechnology and Nanoscience (MC2): The amount of support, the trading of the center in relation to the marketing of the normal department activities and the usage of facilities.

The relation to Chalmers was gradually strengthened during the Stages. After Stage 3, CHACH Director became part of the executive group at MC2. This meant that CHACH issues became more active in the Department agenda. Also the center became visible in Department annual reports and on the Department web page.

During Stage 1 and 2, CHACH had in its organizational structure a responsibility for a process laboratory infrastructure dedicated for microwave electronics. When the new Microtechnology Center at Chalmers[4] was opened year 2000, the CHACH office and most of its Chalmers' employees were moved to the new building. The former process laboratory became part of the new cleanroom organization at the Microtechnology Center at Chalmers. In reality, this meant that industrial partners in CHACH could use the new cleanroom facility and measurement laboratories at Chalmers within the framework of the projects.

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[4] *N.b.*: Not a Competence Center. This was a center at Chalmers with no formal industrial partners.

2.9.2 Other external funding

A challenge for every Competence Center is to define its relation to all other activities at the university faculty. Here large variations can be found in how center management describes its center.

CHACH was part of a very successful research environment at Chalmers year 1995-2006 which attracted large external funding in microwave electronics and photonics. The most important funding sources were Swedish Research Council (VR), Swedish Foundation for Strategic Research (SSF), European Space Agency (ESA), various EU projects from FP5 and FP6 and contract research from industry. In addition, equipment funding was granted by Knut and Alice Wallenberg Foundation.

In CHACH, the center walls in relation to adjacent external funding were defined along two routes. First, it was found very difficult to have other projects bound up by contracts to external partners related to CHACH. This meant that EU, and ESA projects, and industrial contract research were strictly carried out outside the center. Second, the relation to SSF funding which was arranged in three programs of large relevance to CHACH: Microwave-Photonics-Nanoscience Program (MFN), High-Frequency Electronics Program (HFE) and Strategic Research Center in High-Speed Electronics and Photonics (HSEP). In addition, framework programs were funded by SSF in microwave & photonics component technologies 2003-2007.

In CHACH, funding with SSF was more or less mixed during Stage 1, 2, and 3. No clear borders were obvious and co-funding was the normal situation. This became impossible when IPR agreements were settled in Stage 4. As a consequence, from Stage 4, CHACH developed its own agenda more and more independent of the SSF projects and funding. The trend of distinguishing the SSF and VINNOVA programs has been strengthened during the last years and turned out to be rather important for developing the CHACH concept and its identity. As a result, both programs worked better. The coordination and co-financing of workshops and foundry runs has however been successfully utilized during the whole twelve year period.

In the Table below, the difference between the funding sources are described.

Table VII. Differences between a Competence Center (NUTEK/VINNOVA) and a Strategic Research Program, later Strategic Research Center (SSF).

	CHACH	MFN & HFE & HSEP
Funding source	VINNOVA, Chalmers and company partners	SSF
Form	Research partnership on formal basis between Chalmers and industrial partners	Strategic research programs in microwave electronics & photonics at Chalmers
Existence	1995-2006	1995 - 2007 in three programs
Vision	To bring academic advances in microwave-based components closer to industrial development and system prototyping by taking full advantage of the common infrastructure established by Chalmers and industrial partners through CHACH.	To maintain and develop an international outstanding research environment at Chalmers in high-speed electronics and photonics
Main objective	A. To create industrial impact: - New circuit designs for testing and evaluation in industrial microwave systems - Testing of non-established microwave components from university at industrial partners B. To produce academic results: Ph.D.s, papers.	To fulfill long term needs of Swedish industry and academia in high-speed electronics and photonics research and educated Ph.D.s
Steering board	Decision power. Industry majority.	Advisory board to Director
Agreement	Between Chalmers, its involved researchers, industrial partners, and VINNOVA including IPR sub-agreement	Agreement between Chalmers and SSF. Neither agreements with industry nor with Chalmers researcher
Research profile	More short term focused and top-down. Demonstrator and innovation focus. General risk-taking in projects: Medium to high	More long term, much broader and bottom-up Emerging technologies. General risk-taking in projects: High
Industry engagement	Direct support in cash and involvement. Accurate definition of in kind contribution. Large and small companies. Minor interaction with institutes Joint project plans. Industrial project leaders may be used.	To establish and maintain close interaction with Swedish industry. No cash or formalized in kind contribution. Partners: Mainly large companies. Institutes.

3 Research program

CHACH had during its twelve years six different research subjects all related to component and/or fiber optics for either high-speed wired/wireless communication or sensing. Some of the subjects were carried out in a multi-disciplinary approach. Each subject was broken down into projects with an assigned project leader either from industry or Chalmers.

In this Chapter, a brief summary is given of the six major areas and ingoing projects during the existence of CHACH. This does not claim to be a stringent technical summary of the research program but rather a reflection on the major results as well as the impact seen in a decade-long perspective. All these projects have produced publications, conference presentations, examinations and patents. All references are numbered according to listings in Appendix C, D, and E.

3.1 Fiberoptic communication

3.1.1 40 Gbps transceivers (Stage 1)

Principal investigator: Dr. Thomas Swahn, Ericsson Microwave Systems

Company: Ericsson Microwave Systems

Ph.D. theses: None

Licentiate theses: None

Journal articles: None

Invited conferences papers: 2

Conference papers: 3, 6, 12, 13, 19

Technical reports, book chapters: None

Patents: None

A complete 40 Gbps fiber-optical communication chipset was designed in InP HBT mixed-signal technology made available through collaboration with Hughes Research Laboratories. The project was carried out by Ericsson Microwave Systems (Ericsson Research) and Royal Institute of Technology (KTH).

This project resulted in state-of-the-art transceivers for 40 Gbps. The lack of high-speed mixed-signal and digital activities at Chalmers was later on issued as a concern in several strategic reports of CHACH. This expertise eventually returned to Chalmers in the project with Optillion in Stage 3, see Par. 3.1.2.

The exploitation of these results has taken a long road and today, 40 Gbps is available at the commercial market. At the time of Stage 1, 40 Gbps wired communication was too long-term. Optillion AB later on hired people who had been working in the CHACH project. As seen below, this competence returned to Chalmers in Stage 3. At present, some of the people and associated competence seem eventually to return to Ericsson for the present development of 100 Gbps Ethernet.

3.1.2 100 Gbps transceivers (Stage 3)

Principal investigator: Dr. Thomas Swahn, Optillion

Company: Optillion

Ph.D. theses: None

Licentiate theses: None

Journal articles: None

Invited conferences papers: 197

Conference papers: None

Technical reports, book chapters: None

Patents: None

The company Optillion closed their R&D unit in Göteborg Summer 2002. By a direct request from VINNOVA and its Director General, it was suggested to transfer industrial R&D personnel at the Optillion office in Göteborg to Chalmers. In favor, CHACH (or more correctly Chalmers) was approved a dedicated VINNOVA funding of 5 MSEK per year for supporting the former Optillion personnel at Chalmers in a demonstrator project on future fiber-optic 100 Gbps transceivers. The project was run together with KTH.[5]

[5] KTH also obtained the same funding as Chalmers from VINNOVA used for KTH own photonics staff.

This project was initiated in CHACH Stage 3. Later on, outstanding circuit designs using InP DHBT technology was reported, *e.g.* a 4:1 multiplexers at 165 Gbps and a 94-Gbps 2^9-1 PRBS generator. Also advanced packaging was tested. All these results were however obtained after Stage 3 when the project had transferred from a CHACH project to a Chalmers project (still financed by VINNOVA). The project could not qualify for CHACH Stage 4 since the company interest was too weak. Optillion later on closed their business.

The outcome from this project has partly been exploited in contract R&D by Chalmers Industrial Technologies (CIT).

Figure 3. The Xenpak transceiver from Optillion for the 10 Gbps Ethernet market.

3.1.3 High-speed fiberoptic communication (Stage 1, 2, 3)

Principal investigators: Prof. Peter Andrekson, Dr. Per-Olof Hedekvist

Company: Ericsson, Radians Innova, Allgon Systems

Ph.D. theses: 2, 4, 8, 9, 18

Licentiate theses: 6, 7, 24

Journal articles: 2, 4, 5, 14, 21, 31, 32, 33, 34, 35, 41, 42, 43, 49, 51, 52, 60, 62, 63, 67, 68, 69, 75, 76, 77, 78, 80, 81, 82, 86, 87, 105, 107, 108, 119, 132, 141, 142

Invited conferences papers: 9, 10, 13, 20, 21, 22, 23, 26, 29, 30, 32

Conference papers: 2, 4, 5, 14, 36, 37, 38, 39, 40, 41, 52, 53, 54, 66, 67, 71, 79, 91, 92, 104, 106, 129, 130, 124, 131, 132, 139, 149, 158, 168, 169, 170, 173, 179, 192, 193, 194, 195

Technical reports, book chapters: None

Patents: None

The fiberoptic group at Chalmers collaborated with Ericsson (Component and Telecom divisions) during Stage 1, 2 and 3. The academic output of this theoretical and experimental research was outstanding with a large production of Ph.D.s and journal papers.

The efforts at Chalmers were focused on the design and construction of a fiberoptic link for data transmission. Optical transmission experiments were performed in a test bed at 10 Gbps, later on extended to 40 Gbps during Stage 2. Research encompassed a number of issues such as signal sources, dispersion, and associated measurement methods. Field trials at 40 Gbps based on solitons were highly successful during Stage 2 and were internationally recognized as witnessed by numerous invited talks. The research during Stage 3 was focused on polarization-mode dispersion, fiberoptic parametric amplifiers, and new pulse sources.

Ericsson (Ericsson Telecom) closed their fiberoptic activities in 2002 which stopped this research to continue in Stage 4. Results from this research are now exploited in one spin off from Chalmers (PicoSolve AB - optical sampling oscilloscope) and by Ericsson in their 100 Gbps Ethernet project at Ericson Research. Another spin off company, Accilon Photonics AB (survey equipment for fiberoptic networks), had to shut down its business 2005.

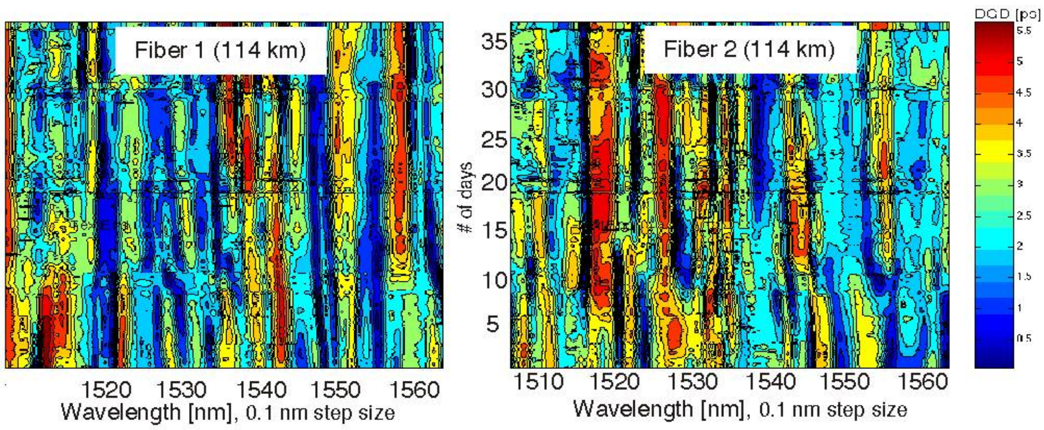

Figure 4. Example on long-term measurements of polarization-mode dispersion on installed optical fiber.

3.1.4 Nonlinear optical pulse phenomena in fibers (Stage 3)

Principal investigator: Prof. Dan Anderson

Company: Ericsson

Ph.D. theses: None

Licentiate theses: 19, 20

Journal articles: 19, 37, 38, 44, 56, 74, 79, 93, 103, 114, 115, 117, 120, 121, 134, 136

Invited conferences papers: 16, 19, 31

Conference papers: 20, 97, 101, 123, 126, 135, 137, 140, 141, 153, 154, 155, 171, 172

Technical reports, book chapters: None

Patents: None

The project concerned theoretical modeling on manipulating light by light made possible by non-linear effects in fibers. Optical pulse splitting was demonstrated by "the optical axe". This project was also terminated after Ericsson's closure of its fiberoptic business. No exploitation routes are known from this project.

3.2 Optoelectronic components

3.2.1 High-speed optoelectronics for optical interconnects (Stage 2, 3)

Principal investigator: Prof. Anders Larsson

Company: Zarlink Semiconductor, Ericsson Microwave Systems, Ericsson

Ph.D. theses: 12, 17

Licentiate theses: 11, 14, 15, 23, 27

Journal articles: 110, 111, 145, 167

Invited conferences papers: None

Conference papers: 82, 93, 99, 121, 136, 151, 167

Technical reports, book chapters: 2, 3, 4, 6

Patents: 40

The idea was to develop a demonstrator for > 100 Gbps optical inter-chip interconnect networks for future communication and radar systems. Short distance optical interconnects were here targeted as a replacement for future electrical on-chip wiring. The project involved four different groups representing VCSEL technology, high-speed electronics using MMICs, diffractive optics for planar free space optics and computer architectures (involving Halmstad University).

This project is an example where Chalmers attracts companies to do "blue sky" research in CHACH. The industrial interest in this project was very high in the beginning. The project was high risk and a successful demo could not be realized at the relatively modest budget made available. The project, with its relatively challenging multi-disciplinary approach, was managed in an excellent way. One CHACH workshop was also initiated by the project.

A comprehensive time-domain model for VCSELs accounting for the interdependent electrical, optical and thermal effects in a self-consistent manner was developed by Chalmers. The model was transferred to Zarlink Semiconductor.

3.2.2 Integrated optical sources for microwave photonic links (Stage 4)

Principal investigator: Prof. Anders Larsson

Company: Zarlink Semiconductor, Ericsson Microwave Systems

Ph.D. theses: None

Licentiate theses: None

Journal articles: 168

Invited conferences papers: None

Conference papers: 224

Technical reports, book chapters: None

Patents: 34

Cascade arrays of vertical cavity surface emitting lasers (VCSELs) fabricated at Chalmers were used together with matching parallel detector arrays fabricated at Zarlink Semiconductor to assemble a photonic link using a parallel fiber ribbon supplied by Zarlink. Ericsson Microwave Systems fabricated impedance matching circuits. In a demonstrator experiment, a differential current gain exceeding unity was obtained which clearly demonstrated the potential of the technology for the development of low loss and low noise fiber optic RF links. No further exploitation is known from this project.

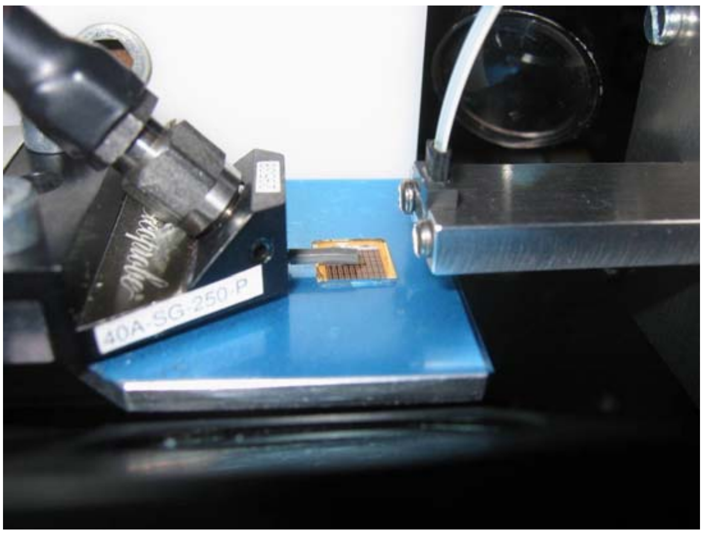

Figure 5. Measurement on linear cascade 4x VCSEL array (850 nm). High frequency probe to the left, fiber ribbon to the right.

3.3 High-frequency circuit design

3.3.1 Oscillators (Stage 1, 3)

Principal investigator: Prof. Herbert Zirath

Company: CelsiusTech Electronics, Saab Rosemount, Ericsson

Ph.D. theses: None

Licentiate theses: 5

Journal articles: 84

Invited conferences papers: None

Conference papers: 134, 198, 201, 202, 205, 222

Technical reports, book chapters: 1

Patents: 30

This component project was run in two periods. The first during Stage 1 with CelsiusTech Electronics discussed critical definitions on phase noise and its sources. The targeted application was an automotive radar system (in collaboration with Volvo) which later was abandoned when CelsiusTech re-directed its business to only defense technologies.

During Stage 3, MMIC-based VCOs in PHEMT processes up to 24 GHz were designed and fabricated at external foundry. This activity was later transferred to two independent projects in Stage 4, namely 60 GHz wireless communication and the synthesizer detector chip for tank radars, see Par. 3.3.2 and 3.3.6, respectively. After closure of CHACH, this activity was revitalized in GigaHertz Centre Stage 1 (2007-2009) based on a new company constellation.

3.3.2 60 GHz Communication Broadband Wireless Communication (Stage 4)

Principal investigator: Prof. Herbert Zirath

Company: Ericsson

Ph.D. theses: 21

Licentiate theses: 28

Journal articles: 148, 157, 160, 165, 166, 167, 174

Invited conferences papers: 24, 28, 33

Conference papers: 100, 178, 207, 212, 225, 230, 235, 236, 237, 242, 243, 245, 246, 247, 251, 252, 253

Technical reports, book chapters: 7, 8, 9, 10, 11

Patents: 41

This project was based upon a solid background at Chalmers from SSF programs (HFE, HSEP). By launching a CHACH project in Stage 4 under the leadership from Ericsson Research (Dr. Arne Alping), the project was further speeded up. (SSF HSEP still co-financed the project, e.g. through foundry runs). Ericsson assisted in building demonstrators based on 60 GHz MMICs designed at Chalmers. The project successfully demonstrated multifunctional 60 GHz Rx-Tx chips in GaAs PHEMT and MHEMT technology. A test bench was set up for data transmission demonstrating 200 Mbps 16-QAM in link experiments. Furthermore, new state-of-art values for phase noise in VCOs were achieved using an InGaP HBT technology. Flip-chip of MMIC amplifiers for packaging was demonstrated. Finally, 60 GHz antenna design and propagation experiments at Ericsson were carried out.

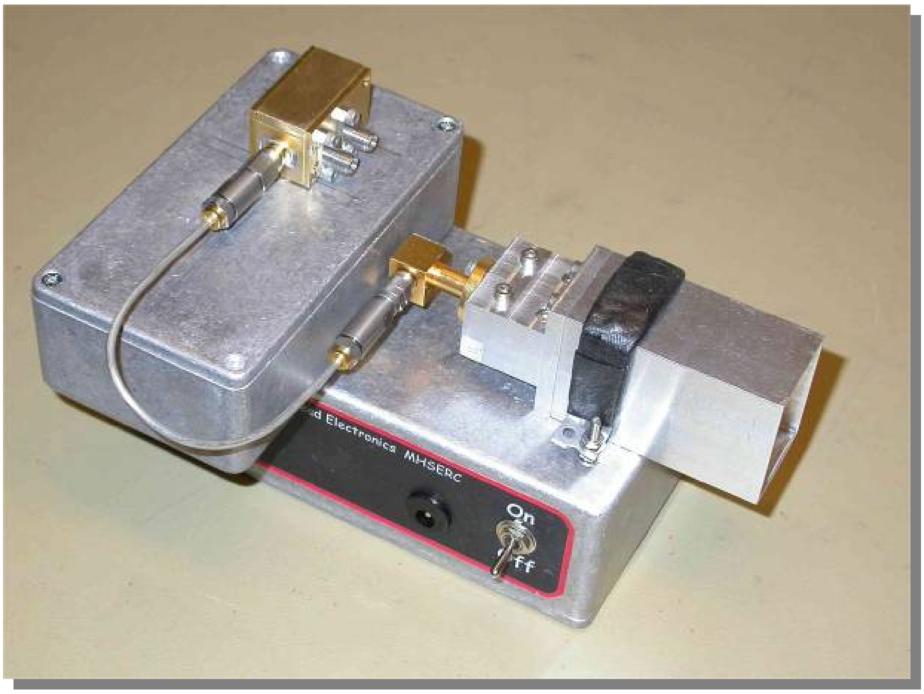

Figure 6. Part of 60 GHz radio link demonstrator tested at Ericsson Research.

The project demonstrated the feasibility to design highly integrated low-cost solutions in mm-wave transceivers. The interest for exploiting mm-wave communication has not been high among Swedish actors and the project was not continued in subsequent stages. However, entrepreneurial activities in US now soar for mm-wave links at 70, 80 and 90 GHz as well as 60 GHz WLAN. After closure of CHACH, this Chalmers activity has during 2007 been approved verification funding from VINNOVA. A spin off company is planned to take off during 2008.

Another spin-off from this project is in mm-wave sensors for space radiometers at 53, 118 and 183 GHz with Omnisys Instruments. A pre-study was conducted in Stage 4++ and later transferred into a full project in GHz Centre 2007-2008.

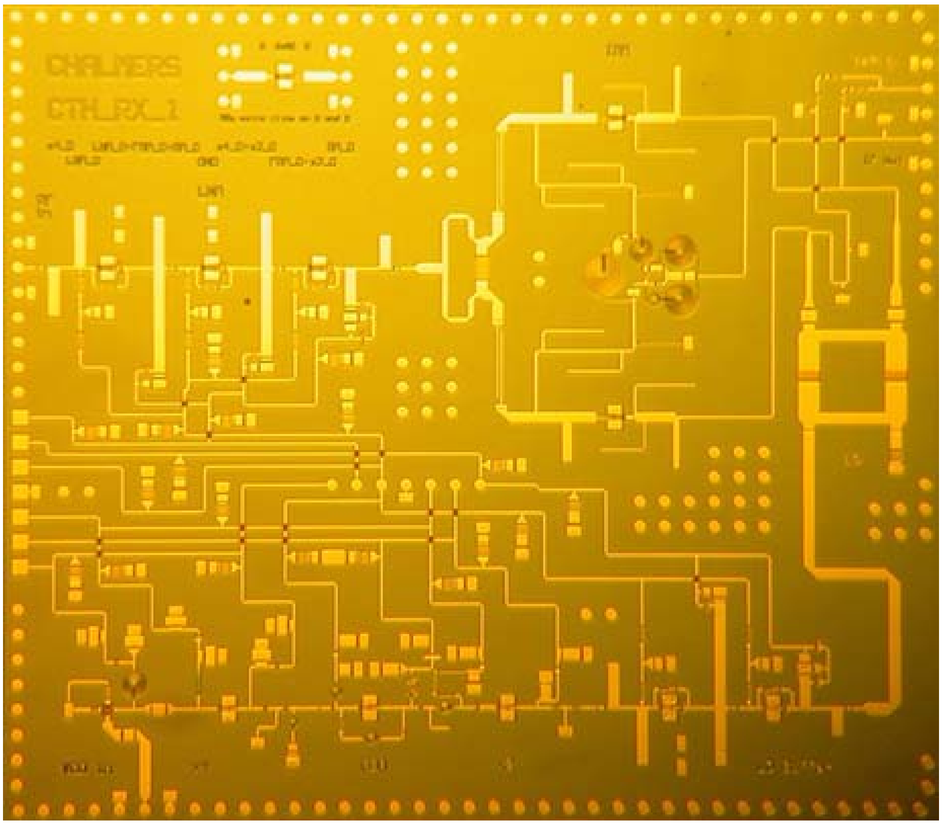

Figure 7. The highly integrated 60 GHz Rx MMIC chip (5.7 x 5.0 mm).

3.3.3 Mixers and multipliers for satellite communication (Stage 2, 4)

Principal investigator: Prof. Herbert Zirath

Company: Ericsson Microwave Systems, Saab Ericsson Space

Ph.D. theses: 6

Licentiate theses: 4, 10, 30

Journal articles: 1, 59, 112

Invited conferences papers: 4, 5, 6

Conference papers: 1, 22, 23, 31, 44, 46, 55, 69, 86, 88, 112, 203, 223, 232, 234, 249

Technical reports, book chapters: None

Patents: 16, 19, 20, 22

During Stage 2, MMIC balanced resistive FET mixers were developed in a microstrip process. This design proved useful in several subsequent projects. A FET transceiver was also developed for a FMCW radar.

In Stage 4, Saab Ericson Space initiated a project where a series of HEMT mixers were realized based on a zero-bias diode concept invented by the P.I. and owned by Ericsson. The advantage with the concept was that the mixer permitted reduced power consumption and higher reliability than competing solutions, This is important for frequency converters used for uplink and downlink in satellite communication. In addition, MMIC multipliers were designed in the same HEMT process.

This project worked excellent in that the work was carried out in a balanced manner between the company and Chalmers. Joint papers were published, one licentiate examination was achieved and the results were transferred to the company. The chip designs are now used in the latest generation of space-qualified frequency converter products. These have now been successfully sold by Saab Space to international customers and will be used in commercial space satellites.

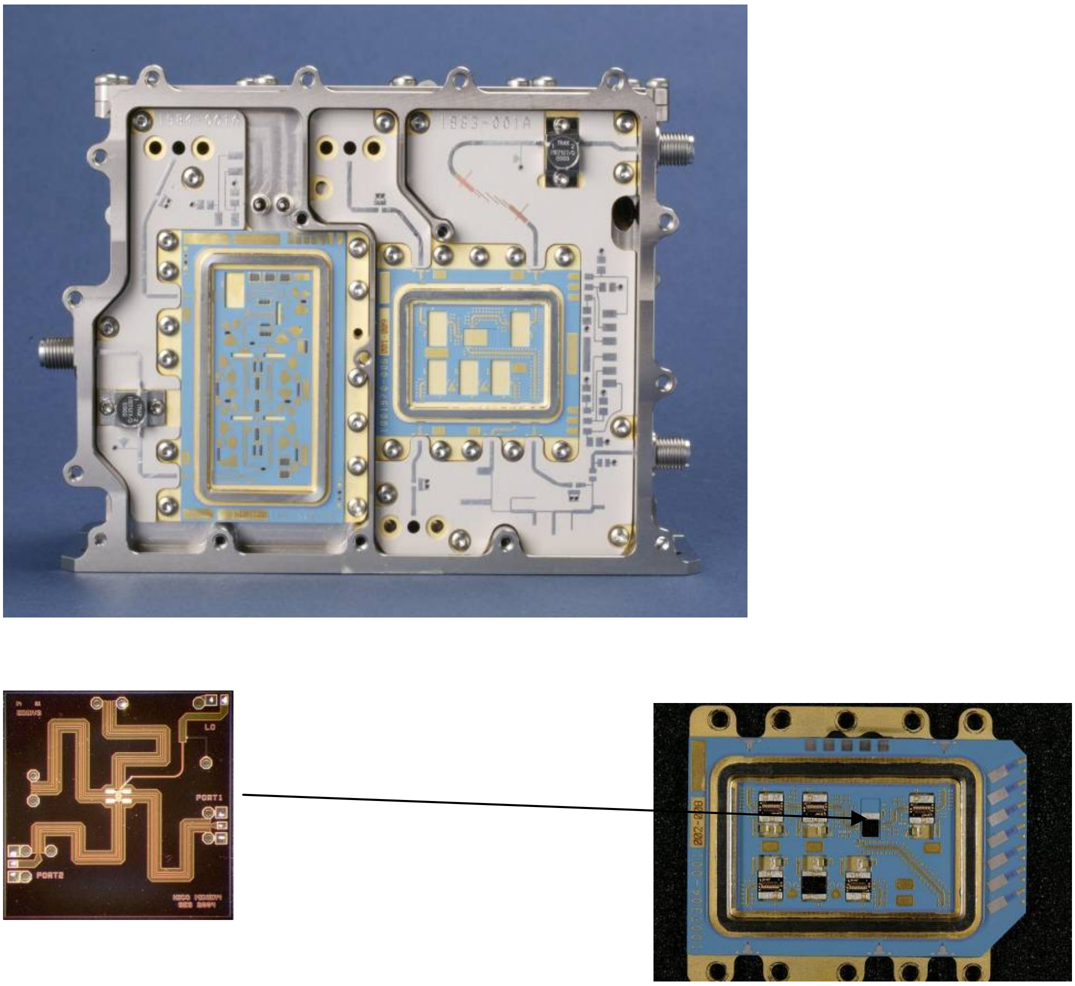

Figure 8. CHACH mixer chip from Chalmers in industrial module together with final integrated frequency converter product above manufactured by Saab Space for up-link/ down-link satellite communication.

3.3.4 Microwave device modeling (Stage 1, 2, 4)

Principal investigators: Prof. Herbert Zirath, Dr. Iltcho Angelov

Company: Ericsson Microwave Systems, Ericsson, Saab Ericsson Space

Ph.D. theses: 3, 7, 11

Licentiate theses: 1, 3

Journal articles: 3, 12, 13, 23, 24, 47, 50, 109

Invited conferences papers: 3, 7, 8, 18, 25

Conference papers: 11, 27, 43, 56, 58, 59, 85, 105, 133, 148, 163, 214

Technical reports, book chapters: 13, 14

Patents: None

Chalmers has developed small- and large-signal (nonlinear) models of both HBTs and HEMTs. In addition, FET noise models have been developed. The model work has been of large interest for Ericsson and Saab Ericsson Space. In the beginning of CHACH, these model projects had a large academic output with highly cited papers pioneering an empirical table-based FET model approach. In later Stages, the academic impact was reduced in favor of transferring the knowledge to Ericsson. Nonetheless, the models are today in industrial utilization in the design of circuits for microwave radios up to 40 GHz (Ericsson Minilink system).

3.3.5 Integrated microwave and high-speed digital designs (Stage 1, 3, 4)

Principal investigator: Prof. Herbert Zirath

Company: Omnisys Instruments

Ph.D. theses: None

Licentiate theses: 13

Journal articles: None

Invited conferences papers: None

Conference papers: None

Technical reports, book chapters: 22

Patents: None

The project is an illustrating example of the challenge in involving SMEs in a Competence Center. Omnisys Instruments is a leading actor in correlator-based spectrometers for space applications with high spectral bandwidth aimed for radiometer systems 50-500 GHz. The project in CHACH aimed for a low-power consumption single-chip solution. In Stage 1, a 0.5 G sample/s solution was targeted. At the end of Stage 4, an 8 G sample/s, 1.5 bit ADC was taped out in a 0.18 μm SiGe BICMOS process. Subsequently, a bug in the chip was discovered during measurements. A second tape out for a revised version is now planned by the company. The project turned out challenging for Chalmers since it was a rather specified request from an SME to the university constituting one part of a relatively complex industrial system design. The project helped Omnisys to strengthen its commitments towards European Space Agency (ESA).

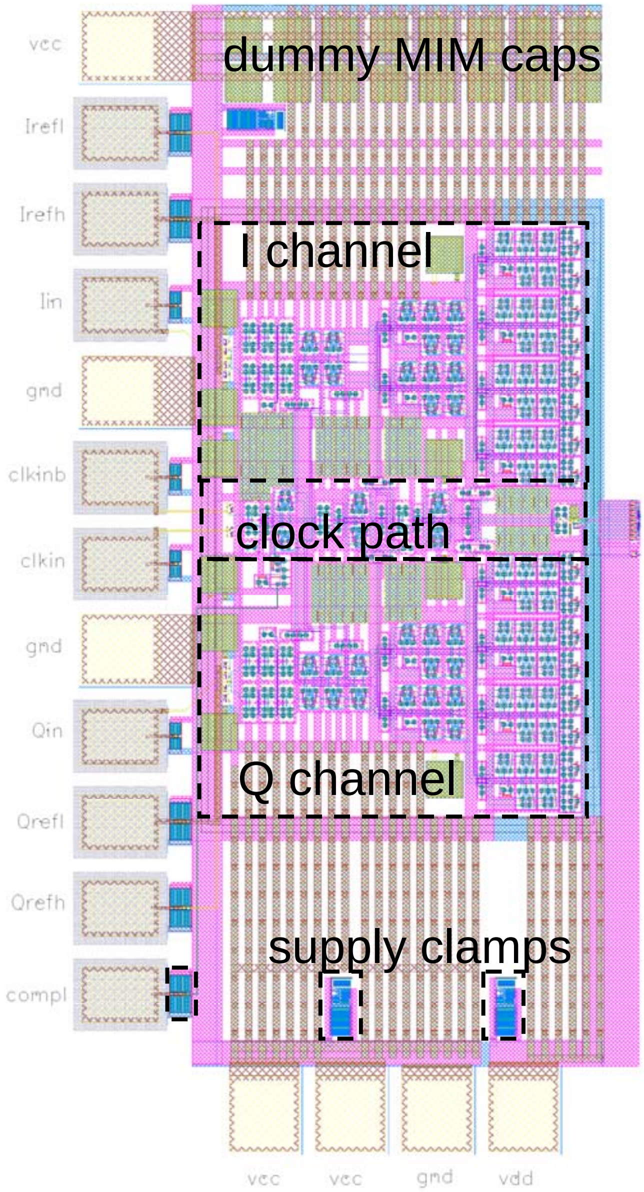

Figure 9. ADC layout in the IBM SiGe 0.18 BiCMOS 7WL process (chip size 0.8 x 2.0 mm)

3.3.6 MMIC frequency synthesizer (Stage 4)

Principal investigator: Prof. Herbert Zirath

Company: Saab Rosemount

Ph.D. theses: None

Licentiate theses: None

Journal articles: None

Invited conferences papers: None

Conference papers: 250

Technical reports, book chapters: None

Patents: None

The project was a spin out from the oscillator activities during Stage 1 and 3; see above. As a result, the industrial involvement from Saab Rosemount was heavily enhanced. MMIC VCO designs operating at 23-25 GHz based on LO, mixer and power divider were realized and tested in an industrial tank radar demonstrator. Even though this concept was not directly pursued by the company, it gave Saab Rosemount essential information of the pros and cons using an integrated microwave circuit technology in their microwave hybrid-based products.

Figure 10. Single-chip 24 GHz GaAs MHEMT synthesizer chip (3.8 x 2.0 mm) designed at Chalmers glued and bonded by Saab Rosemount on a soft substrate and mounted into the industrial radar gauge demonstrator (above).

3.3.7 Microwave CMOS (Stage 4)

Principal investigator: Adjunct Prof. Andrej Litwin

Company: Infineon Technologies Sweden

Ph.D. theses: None

Licentiate theses: None

Journal articles: None

Invited conferences papers: None

Conference papers: None

Technical reports, book chapters: 16, 17, 18, 19, 20

Patents: None

The project was a pre-study of the microwave properties up to 23 GHz of a 130 nm CMOS process provided by Infineon. Integrated power amplifiers, variable-gain amplifiers and mixers were designed and taped out. Because of the small size of the project, the academic output was very small. However, the project was continued in a MEDEA+ project, HI-MISSION, focusing on integrated CMOS PAs for microwave radios at 23 GHz (involving Ericsson, Ericsson Microwave Systems and Infineon). This is an example how one VINNOVA project is continued into another one.

3.4 Emerging microwave components

3.4.1 MMIC line in-house for high-speed electronics (Stage 1, 2)

Principal investigator: Prof. Herbert Zirath

Company: CelsiusTech Electronics

Ph.D. theses: 1

Licentiate theses: None

Journal articles: 15, 16, 53, 57, 70

Invited conferences papers: 1, 14

Conference papers: 7, 8, 10, 18, 28, 45, 49, 50, 68, 72, 73, 74, 87

Technical reports, book chapters: None

Patents: None

This activity was of an infrastructural character. Process modules, components and a model library were developed for an InP HEMT MMIC process in the old clean room at School of Electrical and Computer Engineering at Chalmers. The project was based upon excellent results from mm-wave InP HEMTs and MMIC during the first half of the 1990's. Nonetheless, it turned out not successful to transfer this into a CHACH project. The main reasons were two: At first, the company interest among the present actors in Stage 1 was not sufficient to motivate the support of a high-performance mm-wave process in CHACH. It is probable that this interest could have been substantially raised with a more active search for international partner companies. Secondly, this type of project is much more suitable for an institute-like organization focused on customers. Unfortunately, the opportunity for using this CHACH activity in the new Microtechnology Centre at Chalmers under planning during Stage 1-2 at Chalmers was not taken into consideration. The CHACH project was subsequently transformed into an SSF project. The project provided the emerging RF/microwave wide bandgap device activity with essential background knowledge and technology, see Par. 3.5.2.

3.4.2 Ferroelectric tunable components (Stage 1, 2, 3, 4)

Principal investigator: Prof. Spartak Gevorgian

Company: Ericsson Components, Ericsson Microwave Systems, Ericsson

Ph.D. theses: 5, 13, 14, 15, 20

Licentiate theses: 2, 12, 16, 18, 25

Journal articles: 6, 7, 8, 9, 10, 11, 17, 18, 26, 27, 28, 29, 30, 39, 40, 46, 61, 64, 66, 94, 96, 97, 72, 73, 85, 98, 99, 100, 101, 123, 125, 126, 127, 128, 131, 137, 139, 140, 144, 146, 147, 149, 153, 156

Invited conferences papers: 11, 12, 27, 34, 35

Conference papers: 17, 21, 30, 33, 34, 35, 47, 48, 51, 60, 70, 76, 80, 83, 84, 89, 95, 96, 98, 102, 103, 107, 108, 109, 110, 111, 114, 115, 118, 119, 120, 122, 125, 142, 143, 144, 145, 146, 147, 149, 160, 161, 162, 175, 176, 177, 180, 181, 186, 187, 188, 189, 190, 211, 213, 217, 219, 221, 227, 228, 229

Technical reports, book chapters: 12

Patents: 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 13, 14, 15, 17, 18, 23, 24, 25, 26, 27, 28, 29, 31, 33, 35, 36, 37, 38, 39, 42, 43, 44, 45, 46, 47

The project started with high T_c superconducting components integrated with ferroelectric films. Industrial disbelief in cryogenic applications made this project later to focus solely on ferroelectric-based components. The aim was to develop a range of electrically tunable microwave components such as varactors, phase shifters, modulators and filters for new frequency agile microwave systems in communication and sensing. A dedicated effort was also made during Stage 3 in the quest for optimizing passive microwave components in silicon-based technologies. The large scientific and patent productivity in this project, including both theory and experiment, has undoubtedly positioned the research at the international forefront. The project was however difficult to pursue when CHACH demanded increased support from companies, in particular when VINNOVA left the consortium. The project was only supported by industrial corporate research (here Ericsson Research). As a result, this CHACH activity was spun off to Eureka projects such as HI-MISSION in MEDEA+ and also an EU FP6 STREP project (Nanostar).

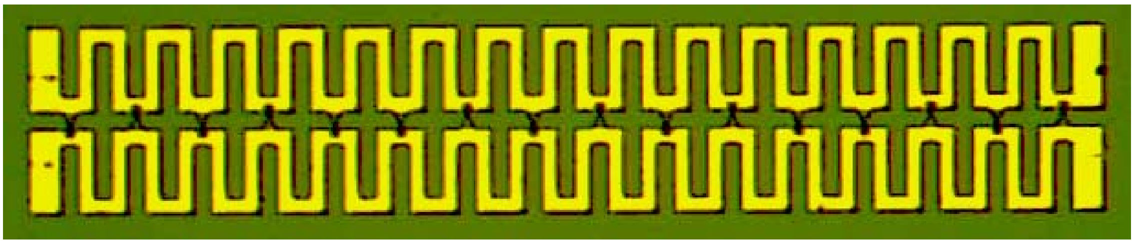

Figure 11. Ferroelectric-based delay line (2 mm long).

3.5 Microwave power devices and design

3.5.1 Power amplifiers (Stage 3, 4, 4+, 4++)

Principal investigator: Prof. Herbert Zirath, Dr. Christian Fager

Company: Eklund Innovation, Comheat Microwave, Ericsson

Ph.D. theses: None

Licentiate theses: None

Journal articles: 45, 104, 150

Invited conferences papers: 15, 36, 37

Conference papers: 57, 159, 218, 233, 239, 248

Technical reports, book chapters: 21

Patents: None

The project started on a small scale with an SME (Eklund Innovation, later on Comheat Microwave). The Chalmers background originated from Prof. Herbert Zirath's research initiated in the 1990's partly together with Prof. Rutledge at Caltech (journal paper 45). The purpose was to develop highly-efficiency class-E amplifiers based on LDMOS. Comheat Microwave developed fabrication with foundries of SOI LDMOS based on a patent owned by Comheat whereas Chalmers pursued research on large-signal device models for prediction of linearity and efficiency. Physical device simulations were carried out at Uppsala University. This project grew significantly in size the last year (4+, 4++) because of Ericsson's rising interest in high-efficient switched-mode amplifiers for output stages in 3G radio base stations. Such amplifiers have high peak efficiency but are inherently nonlinear which presents some interesting academic challenges. Also wide bandgap (GaN HEMT) transistors were started being considered as future replacement for LDMOS in amplifier stages.

This activity later on evolved into the largest project in GHz Centre Stage 1 (2007-2008) with five involved companies.

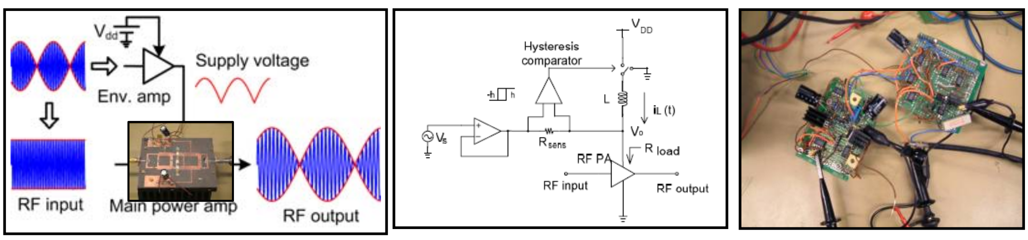

Figure 12. From left to right: Polar transmitter architecture, envelope amplifier topology and the prototype.

3.5.2 Wide bandgap devices and circuits (Stage 1, 2, 3, 4, 4+, 4++)

Principal investigator: Prof. Herbert Zirath, Dr. Niklas Rorsman

Company: Ranatec Instruments, Ericsson Microwave Systems, Saab Avionics, SaabTech

Ph.D. theses: 10, 16, 19, 22

Licentiate theses: 8, 17, 22, 26, 29

Journal articles: 48, 88, 89, 90, 106, 113. 124, 133, 155, 158, 162, 163, 164, 169, 170, 171, 172, 173

Invited conferences papers: 17

Conference papers: 24, 25, 62, 63, 64, 65, 165, 166, 182, 199, 200, 216, 238

Technical reports, book chapters: 5, 15

Patents: None

During the lifetime of CHACH, RF/microwave wide bandgap technology has gone from being an academic subject to gaining industrial acceptance. Research in wide bandgap devices started in Stage 1 with an SME (Ranatech Instruments) on SiC diodes for detection of high-energetic microwave pulses. From Stage 2, large companies joined the project. In parallel, many other sources granted funding to Chalmers in this subject because of the increasing industrial interest, *e.g.* a very large bi-lateral contract research on SiC MOSFETs at Chalmers for Philips Semiconductor year 2001-2006. Also new SSF and VINNOVA money were granted independent of CHACH, This multitude of RF wide bandgap projects at Chalmers presented a large challenge with respect to IPR which to some extent was straightforward to keep apart, in some cases not.

RF/microwave SiC diodes, SiC MESFETs, GaN HEMTs and circuit demonstrators with state-of-the-art performance were developed during the years in CHACH. A full MMIC process and scalable model library now exist. Industrial partners, in particular oriented versus defense applications such as electronic warfare and radar, have thus through CHACH been able to test RF/microwave wide bandgap technology long before it has appeared on the open market. As today, civil actors such as in wireless communication (Ericsson) are seriously considering the technology as an option for future product generations. It is worth mention that this project is by far the largest where Swedish system houses such as Saab and Ericsson still directly support cleanroom-based research in Sweden.

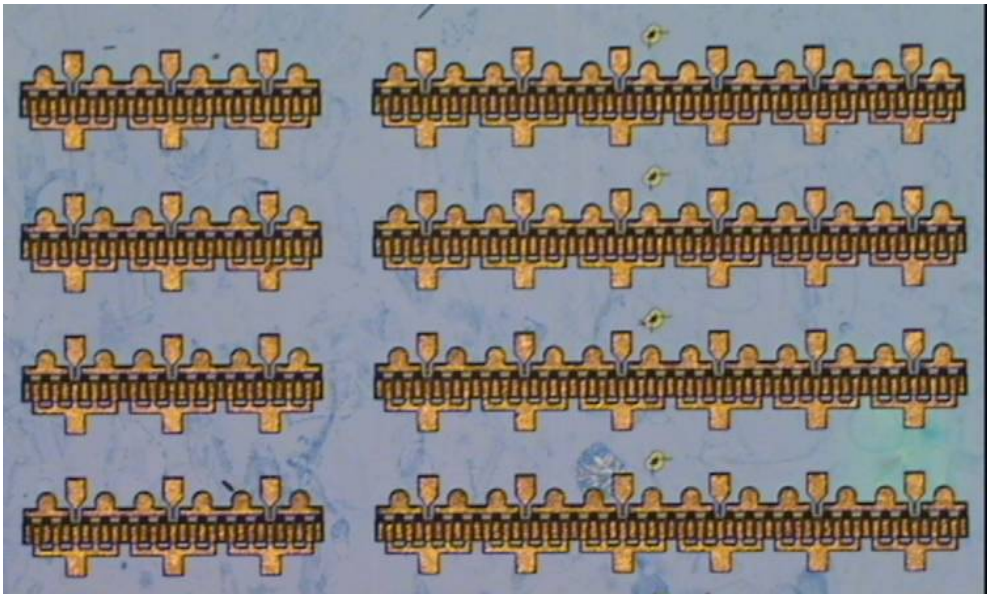

Figure 13. Via-hole grounded 3 mm and 6 mm SiC MESFETs using double-recessed field plated design. The SiC MESFET exhibited 7.8 W/mm at 3 GHz (f_{max} = 25 GHz).

A large project funded by VINNOVA, Swedish Energy Agency (STEM) and several industrial partners is now run year 2007-2011 at Chalmers (Dr. Niklas Rorsman). Wide bandgap technology at Chalmers thus has gained its own centre run in synergy with the more design-oriented GHz centre. One company, Norse Semiconductor Laboratories was spun out by Chalmers scientists already during Stage 2. However, this company did not have any larger prospects for growth during the years in CHACH and mainly served alternative customers to Chalmers on a consultant basis in process services.

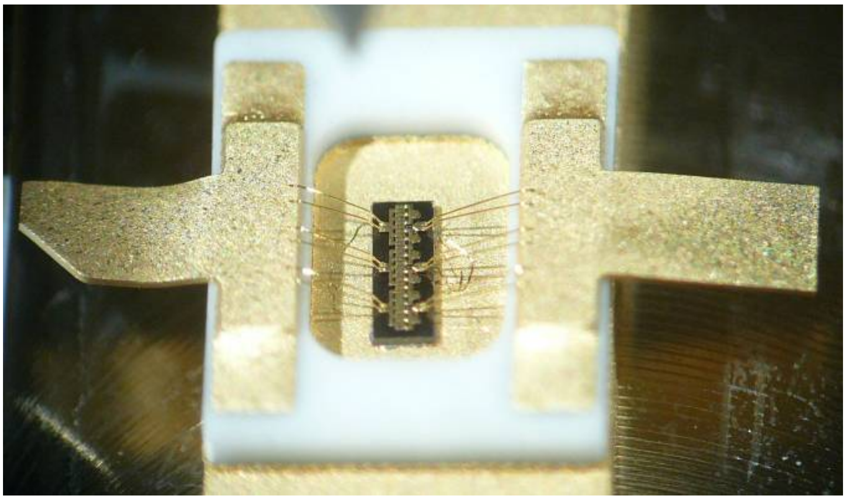

Figure 14. Packaged SiC MESFET (3 mm) in Kyocera A1510.

3.6 Electromagnetic modeling

3.6.1 Microwave-induced breakdown (Stage 2, 3)

Principal investigator: Prof. Dan Anderson

Company: Allgon Systems, Saab Ericsson Space

Ph.D. theses: None

Licentiate theses: 9, 21

Journal articles: 36, 65, 102, 118, 138, 143

Invited conferences papers: None

Conference papers: 20, 42, 61, 77, 78, 81, 116, 117, 150, 152, 156, 157

Technical reports, book chapters: None

Patents: None

Microwave breakdown in microwave resonators for mobile telephone communication systems was investigated theoretically, numerically and experimentally. Breakdown phenomenon presented problems in resonators and filters for companies such as Allgon because of more compact designs, complicated geometries and higher RF power levels. During Stage 2, the project produced some outstanding theoretical work and journal paper 36 was elected as the best scientific contribution year 1999 in IEEE

Trans. Microwave Theory Tech (Microwave Prize award). Moreover, the work from this group had an impact on the design of passive components in Allgon System's products. However, the company involvement was strongly reduced in Stage 3 meaning that this activity could not continue as a CHACH project. The project was therefore decided by the Board to be closed six months before Stage 3 was terminated.

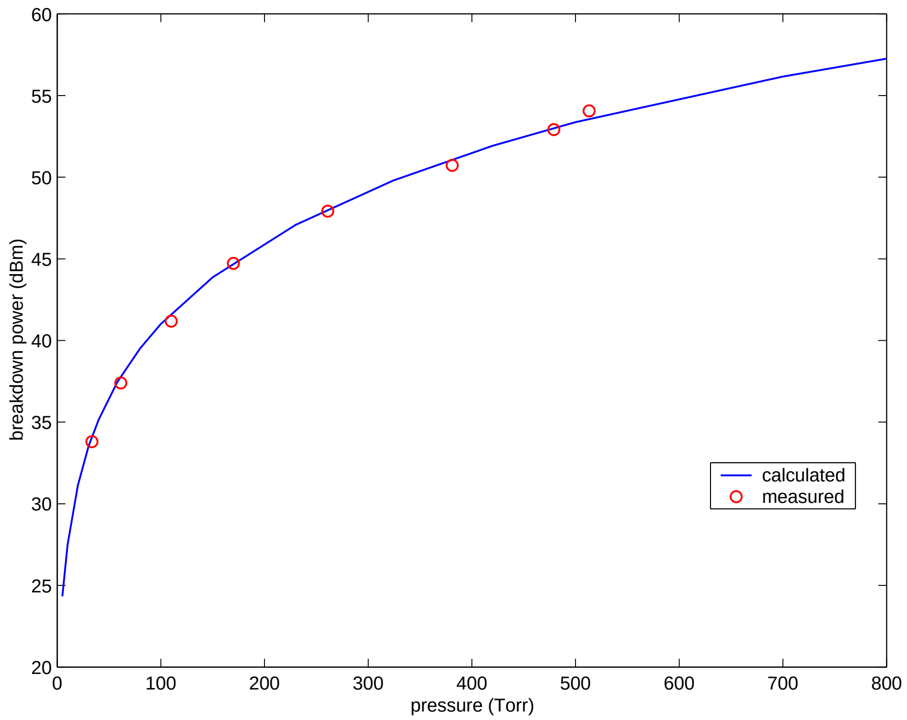

Figure 15. Breakdown power as a function of pressure for determination of breakdown thresholds in resonators demonstrating excellent agreement between theory and experiment. This model tool came later to use at Allgon Systems.

4 Center activities

One of the added values with a Competence Center shall be common activities enabling meetings and interactions between Departments, laboratories, and companies in various business areas. CHACH consisted of researchers geographically scattered among 5-10 companies and in addition, among several laboratories and departments at Chalmers campus. Common center activities consisted of workshops, conferences and center meetings. Center meetings were usually only reserved for center partners and involved researchers. In addition, VINNOVA's official reviews at the end of a Stage also served as a center activity. Not mentioned below are the numerous visits at Chalmers from companies or from Chalmers at companies to present CHACH and its opportunities.

4.1 Open technical workshops arranged by CHACH

Some of the workshops below have been co-arranged with the west Swedish cluster Microwave Road, the SSF Center HSEP at Chalmers or with EU Network of Excellence in FP6. At the workshops, a brief presentation of CHACH was normally given in poster or oral form.

1. Silicon MMICs in Microwave/Millimeterwave Communication Systems, November 5, 1998
2. Workshop on MMIC and Smart Antennas, 22-23 November, 1999
3. GigaHertz Symposium 2000, Göteborg, March 13-14, 2000
4. High-Speed Wide-Bandgap Devices, Chalmers Teknikpark, June 19, 2002
5. Swedish Microwave Photonics Workshop, Aspenäs Herrgård, May 28-29, 2002
6. Short Distance Optical Interconnects - From Backplanes to Intrachip Communication, Chalmers Teknikpark, March 7, 2003
7. MMIC Workshop, Säröhus, May 27-28, 2004
8. NEFERTITI Workshop on Photonics in Wireless Communication, Säröhus, June 1-3, 2005
9. European Semiconductor Laser Workshop, Säröhus, September 3-4, 2004

10. Microwaves for Growth - Future THz technologies, (with Microwave Road), Saab Ericsson Space, November 10, 2005

4.2 Official presentations of CHACH

These presentations were made by the Director.

1. GHz Symposium, Lund, November 2001 (poster)
2. VINNOVA Competence Center Day at Chalmers, Nov. 6, 2003 (oral)
3. GHz Symposium, Linköping, November 4-5, 2003 (poster)
4. Microwave Road, Kick-off, Ericsson Microwave Systems, December 5, 2003 (poster)
5. VINNOVA Competence Center Day, Stockholm, Nov 2, 2005 (oral)
6. GHz Symposium, Uppsala, November 8-9, 2005 (poster)

4.3 Internal CHACH meetings

These centre meetings or courses were only held for CHACH partners and involved faculty scientists at Chalmers. All meetings were held at Chalmers.

1. Annual CHACH Symposium, 1997
2. International Evaluation NUTEK, March 1997
3. Annual CHACH Symposium, 1998
4. Annual CHACH Symposium, 1999
5. International Evaluation, NUTEK, March 2000
6. Technical Review Meeting, March 6, 2002
7. International Evaluation, March 2003
8. Kick-off Stage 4, September 19, 2003
9. Technical Review Meeting April 29, 2004
10. Technical Review Meeting June 9, 2005
11. Technical Review Meeting Nov 23, 2006

4.4 Strategy meetings

Four dedicated strategy meetings were held mainly with the Steering Board and involved Professors at Chalmers

1. Steering Board and faculty researchers, Aspenäs, March 5-6, 1998
2. Steering Board, Hjortviken, November, 2001
3. Steering Board, Hjortviken, November, 2003
4. Steering Board, faculty researchers and industry representatives, Hjortviken, October 11-12, 2005

4.5 Courses

The following courses have been given for CHACH:

1. *Project Management Course,* Enator, 1996.
2. *Non-linear Microwave and RF Circuits,* Lecturer Dr. Steven Maas, 1997
3. *Electromagnetic Modelling using QuickWave-3D (QW-3D) Time-Domain Software and Modelling for Microwave Heating Applications*, Prof. Wojciech Gwarek, QWED, Warsaw, Poland), Chalmers, November 24-26, 1999
4. *Quickwave Semina*r, Lecturer Prof. Wojciech Gwarek and Dr. Malgorzata Celuch from Warsaw University and QWED Company, Chalmers, February 27, 2003
5. *Nonlinear Electronic Design Automation Tools for Microwave/Wireless Circuit Analysis*, Lecturer Prof. José Carlos Pedro from University Aveiro, Chalmers, November 2002
6. *Intermodulation Distortion Analysis and Linear Circuit Design*, Lecturer Prof. José Carlos Pedro from University Aveiro, Chalmers, November 2002

4.6 Seminars

No regular seminar series was given in CHACH. Seminars for CHACH partners were announced in the normal seminar series with 5-10 seminars each year given at the Department of Microelectronics, later on Department of Microtechnology and Nanoscience (MC2) at Chalmers.

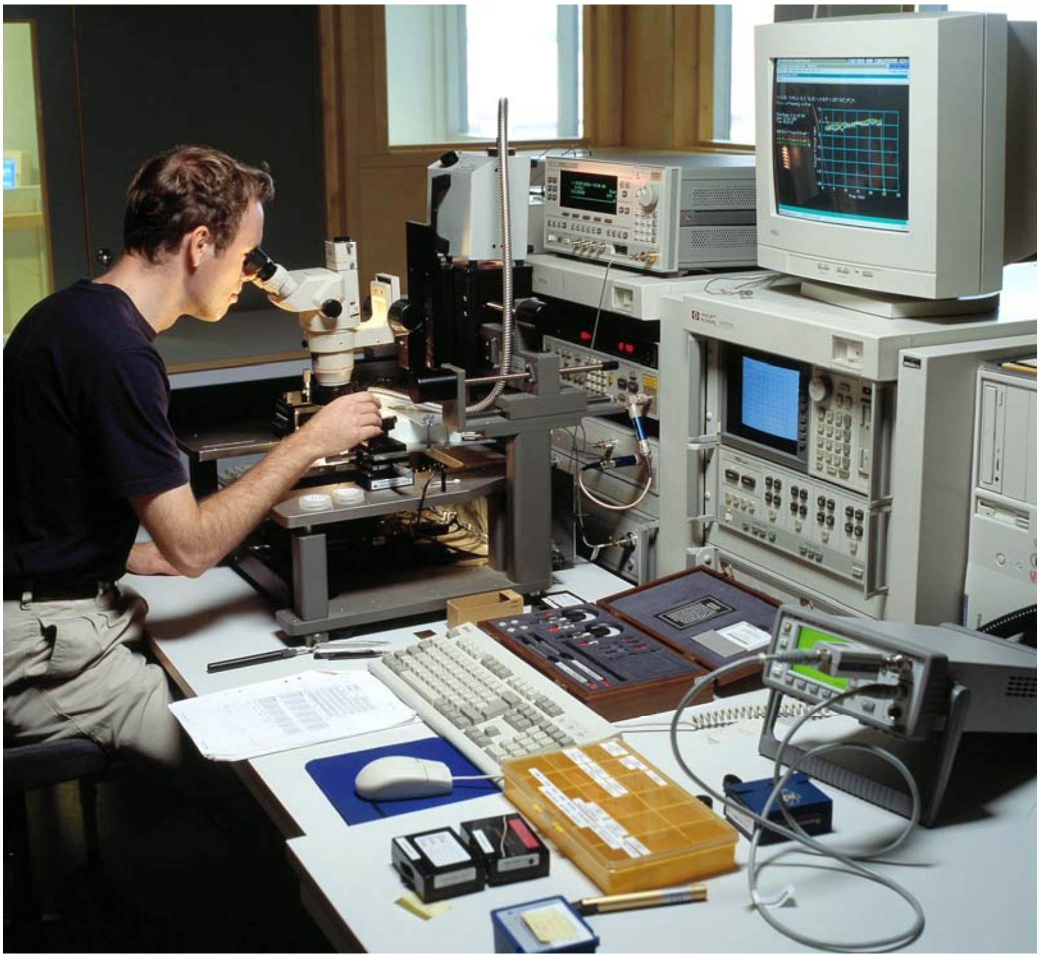

Figure 16. Mattias Ferndahl in the microwave characterization laboratory in CHACH.

5 Academic achievements

Academic achievements are quantitatively reported using traditional key numbers such as examinations, publications in journals and at conferences. The achievements per research program are summarized based on the identification of output per project in CHACH. The qualitative academic achievements are also further described in Chapter 3 for each one of the programs and projects carried out in CHACH.

5.1 Research programs

A summary of the achievements per research program is made in Table VIII.

Table VIII. Achievements per research program (ingoing projects, see Chapter 3).

Research program	Ph.D.	Lic.	Journals	Conf.	Reports	Patents	Spin-offs
Fiberoptic communication	5	5	54	79	0	0	2
Optoelectronic components	2	5	5	8	4	2	0
High-frequency circuit design	5	8	19	52	14	6	1
Emerging microwave devices	6	5	49	76	1	35	0
Microwave power	4	5	21	19	3	0	1
EM modeling	0	2	6	12	0	0	0

Because of the mixing between CHACH and SSF funding, it is meaningless to give funding per project; Programs in Fiberoptic Communication, High-Frequency Circuit Design and Emerging Microwave Devices were co-financed with SSF during Stages 1-3. In contrast, the low quantitative output from the program on Optoelectronic Components is simply due to the fact that these projects were strictly kept apart from the SSF funded research. Per SEK, this program was as productive as other activities.

The following conclusions from the three largest programs can be made from the Research Program in CHACH:

Two programs, Fiberoptic Communication and Emerging Microwave Devices, have been very productive. Both were strongly associated with Ericsson corporate research.

The CHACH projects were long-term and gave more of indirect benefits for the company. It turned out difficult to find concrete statements and evidence for company exploitation of project results. The large number of patents from one of the projects was simply due to the fact that the project leader had an employment at Ericsson Research and the patenting was a part of his working task at the company. This co-employment of Chalmers faculty scientists was a very efficient way of transferring IP(R) from Chalmers to the company.

High-frequency Circuit Design was much less academically productive despite relatively large funding. There are many reasons for this: A tradition of preferred publishing at conferences rather than in journals which indeed is nothing unique for Chalmers. Moreover, the collaboration landscape was scattered representing shifting different needs and sectors from SMEs to large system houses such as Ericsson and Saab companies. As a result, projects became more fragmented and differed vastly in how companies regarded the utilization of project results. Typically, SMEs preferred concrete results and hardware deliverables whereas the large companies, in particular their corporate research units, preferred to join forces with Chalmers for long-term issues. This activity was to some extent more similar to a research institute portfolio. On the other hand, some of the projects were the most successful in CHACH because of the targets set by industry to obtain a real output from their investment.

5.2 Examinations

List of all CHACH examinations during year 1995-2008 including titles of theses are given in Appendix C.

5.2.1 Ph.D. examinations

Students who had at least 50% of their work supported by CHACH and/or were counted as in kind contributions to CHACH are reported here. The number of Ph.D. students in CHACH during the years was 33. Of these, 22 were awarded a Ph.D. degree. The rest was either carrying out their Ph.D.s using other funding sources or left Chalmers with a licentiate alternatively in some case without any examination at all.

5.2.2 Licentiate examinations

Licentiate degree, *i.e.* approximately the requirements for 50% of a Swedish Ph.D., was reported at 30 circumstances. Of these, 19 later pursued towards their Ph.D. degree. 4 students completed their Ph.D.s using other funding than CHACH whereas 7 left Chalmers after their licentiate degree.

5.2.3 Diploma works

The number of reported diploma works corresponding to an equivalent M.Sc. thesis was 23. This number, however, is probably too low since students carrying out diploma works in industrial partners CHACH projects were not always reporting their achievements.

The number of Ph.D. and Licentiate theses is presented in Figure 17 for year 1995-2008.

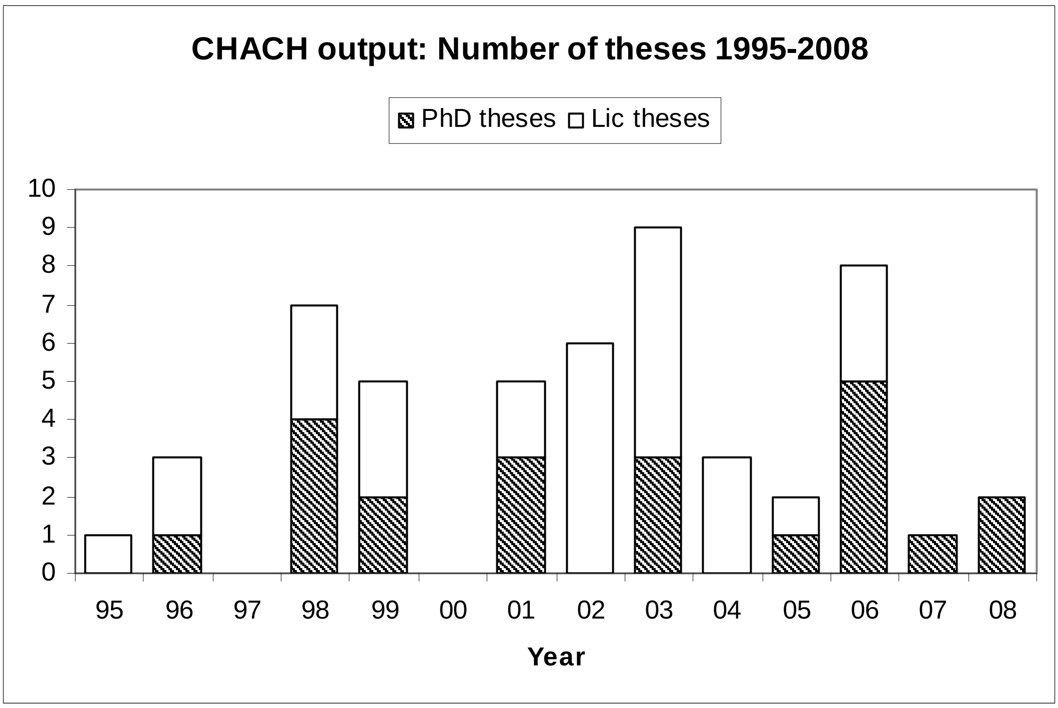

Figure 17. Number of Ph.D. and licentiate theses year 1995-2008.

5.3 Publications

Publications are reported year 1995-2007 for journals, invited conference papers, regular conference papers, technical reports and book chapters. In Appendix D, all publications including titles, authors and reference data are listed. As mention earlier, the funding for the research during year 1995-2003 was not only from CHACH; In particular, SSF funded much of the reported work. During this period, the number of publications in CHACH is therefore much higher than for most other Competence Centers.

The publications in Appendix D originate from the reporting carried out by responsible project leaders. A problem in reporting these figures is that CHACH and other funding sources were more or less completely mixed at Chalmers during Stage 1-3 in CHACH. Involved Professors had an incitement to report the whole bulk of their achievements including background, foreground and sideground results irrespective of funding source. When the new Centre mission and strategy coupled to the IPR issues was settled in Stage 4, the number of reported publications was also reduced. This is clearly seen in the statistics below

The total number of journal papers was 174. The total number of invited conference papers was 37 and the amount of regular conference contributions was 253 making a total of 290 reported conference contributions. Most of the conference papers were published in peer-reviewed proceedings at international conferences. Some of the conference papers were also presented at national events, in particular GigaHertz Symposium where the review assessment was less rigorous.

Also 20 technical reports by various CHACH projects and partners at Chalmers and companies were presented, see Appendix D. Finally, two book Chapters were also written and published.

In Figure 18, the number of journal, conference papers and patents is shown as a function per year in CHACH. The large reduction of total output in the last years is attributed to the new strategy in Stage 4 which meant a focus and separation from SSF funding.

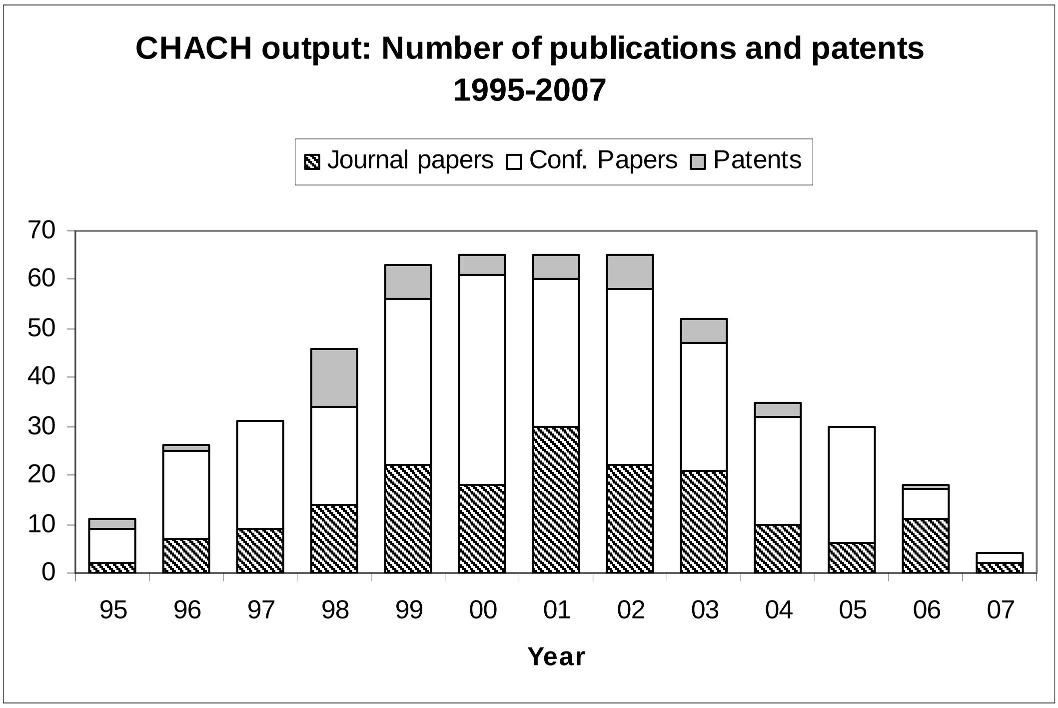

Figure 18. Number of journals, conference papers (including invited) and patents reported in CHACH year 1995-2007.

5.4 Undergraduate and graduate teaching

CHACH as a center was not involved in any undergraduate teaching at Chalmers. Centers at a university are often not directly involved in this type of engagement since it presents more of a threat than an opportunity for the line organization of a university. Rather the involvement from CHACH in the undergraduate teaching came from the CHACH faculty teachers who shared their research experiences from company collaboration.

It should also be mentioned that laboratories at Chalmers involved in CHACH also had (and still have) a very small undergraduate teaching volume. The education in CHACH was mainly carried out at the graduate level.

The Director of CHACH had during 2004-2006 given an annual lecture of Academic Project Leadership in the Ph.D. student course *Project Management* at Department of Technology Management and Economics, Chalmers (examiner Prof. M. Lundqvist).

6 Industrial achievements

Industrial achievements in a Competence Center are generally more difficult to quantify than academic achievements. Transfer of knowledge and technology from Chalmers to industry via CHACH occurred via several routes and is inherently a non-linear process. We here use indicators such as patents, spin off companies and transfer of educated people and technology.

6.1 Patents

A total number of 47 patents were generated in CHACH during year 1995-2006. See the reported patents as a function of year in Figure 18. Almost all patents were registered and owned by Ericsson. The large majority of patents were reported in the research program on Emerging Microwave Devices under the project leadership of Professor Spartak Gevorgian. The patents are listed in Enclosure E. As mentioned previously, the number of patents rather reflects the co-employment of Professor's at Ericsson and Chalmers where their Ericsson activities were reported as CHACH results. The Ericsson corporate research patent policy stimulated large patent productivity among its employees during the late 90's and early 00's. As a result, CHACH exhibited a relatively large production of patents.

6.2 Spin off companies

The following spin off companies listed in Table VIII can be attributed to CHACH programs and projects:

- Accilon AB 2002 - 2005
  Fiberoptic measurements
- Norse Semiconductor AB 2000-
  Process services for microwave wide bandgap devices and circuits
- PicoSolve AB 2004-
  (Founded after CHACH projects ended in Stage 3)
  All-optical sampling oscilloscopes

- New MMIC-based company 2008-
  Planning based on a verification project from the 60 GHz broadband wireless communication program. Decision 2008.

Four spin off companies is a pretty low number. This is rather symptomatic for Göteborg with its existing large base of technically-oriented companies. At Chalmers, networking to entrepreneurial competence and business actors is not very strong. Chalmers itself has not abandoned its main task as serving the large companies with engineers and Ph.D.s. There is an evident lack of "strong entrepreneurial push" because of the lack of culture, entrepreneurs and seed funding. Things are changing in faculty but this is inherently a slow process which appears to take longer time compared to other places such as Kista. For example, the most successful company today spun out from Chalmers in high-frequency technology, FoodRadar Systems AB, is not a result of CHACH but really a product of pure entrepreneurial push.

6.3 Transfer of knowledge and technology

Knowledge and technology transfer from Chalmers to companies is a complex process. We here describe it in terms of people and project results.

6.3.1 People

An efficient way of transferring knowledge is to hire people from Chalmers to industry. The pie chart in Figure 19 shows the distribution of CHACH alumni (22 Ph.D.s). Around 36% has been employed by industry. It is seen that surprisingly few of the Ph.D.s have been hired at the companies they collaborated with in CHACH. One of the reasons was the crisis at Ericsson during the early 2000'. Another one is that industrial partners really did not regard the Competence Center as a recruitment source. Indeed, no real strategy from Chalmers was seen here and CHACH students were not considered in this role as potential future personnel with a roadmap outlined from Chalmers via CHACH to the company. A major portion of the Ph.D.s has remained in public sector in academia, research institutes or public authority.

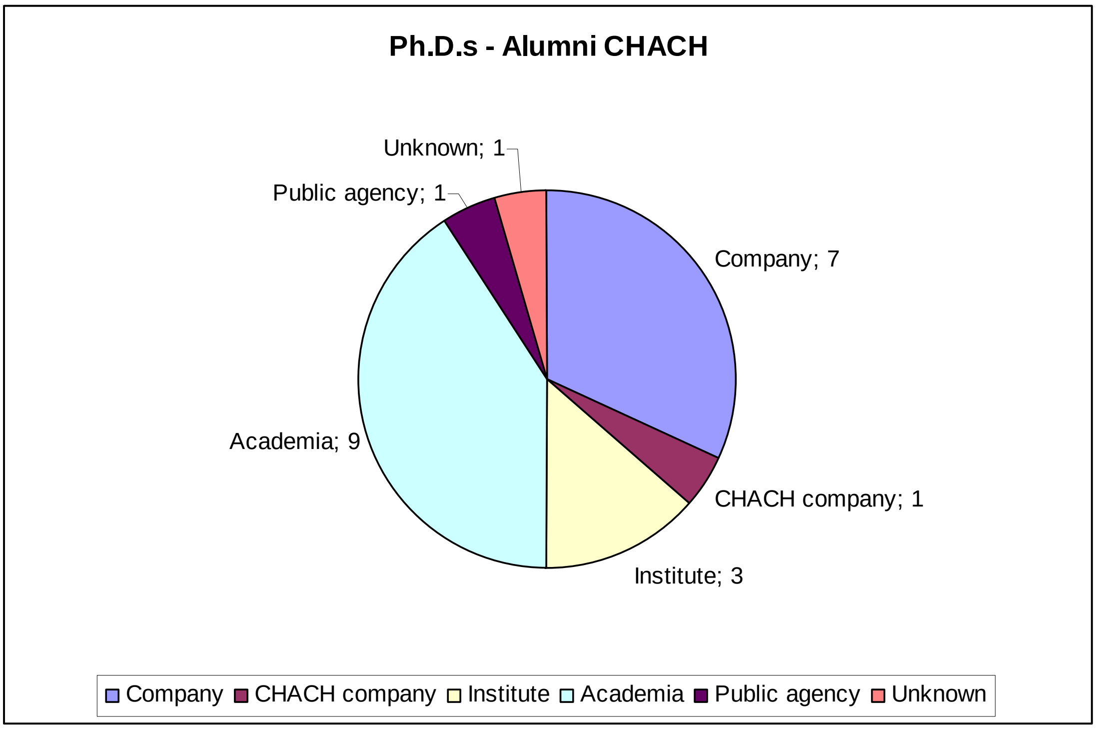

Figure 19. Pie chart showing CHACH alumni (22 Ph.D.s).

6.3.2 Technology transfer

Transfer of knowledge and technology from Chalmers to companies is not always easy to distinguish in a long-term research centre. The more interaction and involvement from company/companies at Chalmers, the larger the possibility to gain valuable transfer of knowledge and technology from Chalmers to industrial partners. Some CHACH projects in chip design and modeling were focused on deliverables from Chalmers to companies similar to conditions in contract research. This type of projects possessed certain disadvantages, in particular the risk for being more of development engineering character than by creative advancements in science. On the other hand, CHACH projects too deeply focused on scientific issues risked to loose company engagement. These were typically trade-off issues in CHACH.

Another essential type of knowledge transfer often witnessed by company partners in CHACH was the ability for industrial partners to test new and high-risk technology. This could result in the decision from companies to postpone transfer of emerging technologies from research into the industrial development phase. Chalmers transferred here essential know-how based in CHACH research results permitting the companies to make a sound decision relative their own roadmaps.

In Table IX below, some of the most important CHACH achievements are listed in knowledge and technology transfer Chalmers to partner companies.

One observation from Table IX is that for the largest CHACH projects in Fiberoptic Communication (Par. 3.1), Tunable Ferroelectric Microwave Components (Par. 3.4.2) and 60 GHz Broadband Wireless Communication (Par. 3.3.2), no direct evidence is seen for *direct* technology transfer from Chalmers to partner companies. The common issue for this type of projects is that corporate research divisions at company business units were involved. In this respect, CHACH projects more became outsourced research from companies to Chalmers. Another common aspect for the three projects was that the in kind contribution from company to Chalmers was large whereas cash contribution was virtually zero. This type of CHACH long-term projects were academically successful and the benefits for company much more indirect and thus difficult to follow up.

Finally, it is also essential to state that much of the technology transfer is not easy to measure by measurable impact factors. One good example is the knowledge of technologies for compound semiconductor wafer runs at foundries world-wide built up at Chalmers during many years. Several industrial partners saw this type of knowledge sharing as important as actual technology transfer. In return, Chalmers scientists learned from industry requirements on semiconductor components. This type of knowledge transfer continuously communicated between partners characterized a significant part of the added value with CHACH.

Table IX. Technology transfer in CHACH.

No	Program / project in CHACH (see Chapter 3)	Company /companies	Knowledge and/or technology transfer
1.	High-speed optoelectronics (Par. 3.2.1)	Zarlink Semiconductor	VCSEL laser model used at company
2.	Microwave device modeling (Par. 3.3.4)	Saab Ericsson Space Ericsson	Models used in today's circuit development at companies, e.g. in Ericsson's Minilink system.
3.	MMIC frequency synthesizer (Par. 3.3.6)	Saab Rosemount	Testing of MMIC as alternative to traditional microwave hybrid design
4.	Mixers and multipliers for satellite communication (Par. 3.3.3)	Saab Ericsson Space	Chip designs to be applied in future frequency converter product generations. Now sold to international customers.
5.	Integrated microwave and high-speed digital designs (Par. 3.3.5)	Omnisys Instruments	ASIC design making Omnisys more competitive in ESA projects.
6.	Power amplifiers (Par. 3.5.1)	Eklund Innovation	Large-signal model for exploitation of innovative power components
7.	Wide bandgap devices and circuits (Par. 3.5.2)	Ericsson Microwave Systems SaabTech/Saab Avionics	Allowing Swedish system companies to test a new semiconductor technology not available on the market, and to participate in European collaborations
8.	Microwave-induced Breakdown (Par. 3.6.1)	Allgon Systems	New filter design applied in companies products

7 Evaluations

Six international evaluations were carried out of the Centre CHACH. Three of these were part of the NUTEK/VINNOVA official evaluation series carried out for all 28 Competence Centers hosted by Swedish universities. The three other evaluations were arranged by the Steering Board and Centre Director using specially invited experts.

As research environment, CHACH was by far the most scrutinized at MC2. It is probably also one of the most evaluated singular research centers at Chalmers. The evaluations aimed at giving both technical and recommendations with respect to organization and management. The evaluations were mostly focused on the general direction and rarely suggested to stop individual projects except for some rare cases. (In practice, projects were cancelled because of changes among company partners and not due to reviewer's recommendations.) Nonetheless, the evaluations did help the Direction to take much more active decision on how to dynamically re-direct center projects and programs compared to adjacent research environments at MC2.

CHACH also actively contributed to the general overall review about impact from the Swedish Competence Center Program 1995-2003 carried out by the company TechnoPolis Ltd.[6]

The evaluations resulted in shifting impact on management and researchers. The evaluation 2003 did have a major impact on the research agenda also accelerated by the large changes in Ericsson taking part 2002-2003. Without doubt, the evaluations helped to change CHACH both with respect how to manage the center and to re-organize its research program. As a result, CHACH was able to be relatively dynamic and responsive compared to other programs at the university.

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[6] Impacts of the Swedish Competence Centres Programme 1995-2003, Erik Arnold, John Clark, Sophie Bussilet, VINNOVA Analysis VA 2004:03, ISBN 91-85084- 10-7, August 2004.

7.1 Summary of reviews in CHACH 1997 - 2004

1. March 1997 Evaluation CHACH Stage 1 by NUTEK[7]

Prof. John S. Baras, University of Maryland (generalist)
Prof. Tom M. Husband, University of Salford (generalist)
Dr. Marshall M. Lih, NSF, Arlington (generalist)
Director Egil Eike, Research Council of Norway (generalist)

This first evaluation conducted by generalist reviewers of Competence Centers was aimed for assessment of the start-up of CHACH after two years of operation. In particular, the role of Chalmers (more than companies) in starting up CHACH was reviewed. Overall, the picture of the Competence Center was reported to be in a good state. The lack of common Centre visions, goals and strategy were pointed out by the review panel. Also it was strongly recommended to make an objective assessment of the research in CHACH.

NUTEK followed up this evaluation at several meetings with CHACH management prior to the approval of funding for Stage 2.

2. September 1998, Evaluation CHACH Stage 2 - Internal

Prof. Manfred Berroth, University of Stuttgart (specialist)
Prof. Palle Jeppesen, Denmark Technical University (specialist)

This internal evaluation was initiated by the Board as a direct result from the criticism in the NUTEK evaluation regarding lack of methods for assessing the competitive status of CHACH. The review was focused on the technical output of CHACH in an international context. Several of the research projects obtained a very high ranking, *e.g.* fiberoptic communication. The international connections and collaborations in CHACH, in particular through EU projects, were considered too weak.

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[7] The NUTEK Competence Centre Programme, First International Evaluation Group 1 (12 Centres). John S. Baras *et al.*, NUTEK Report R 1997:18, ISSN 1102-2574. March 1997.

3. March 2000, Evaluation CHACH Stage 2 by NUTEK[8]

Prof. John S. Baras, University of Maryland (generalist)

Prof. Tom M. Husband, University of Salford (generalist)

Dr. Marshall M. Lih, NSF, Arlington (generalist)

Prof. Dr.-Ing. Manfred Berroth, University of Stuttgart (specialist)

Prof. Antti Räisänen, Helsinki University of Technology (specialist)

Compared to the first official evaluation, the second evaluation (carried out by VINNOVA) was more focused on the industrial collaboration part. The collaborative thinking between industrial partners and Chalmers in CHACH was considered not to be sufficiently developed. The necessity of a common framework and plan with industry was highlighted. Many of the scientific results from Chalmers were found world-class. The project reporting as well as academic reporting was found not satisfactory.

4. March 2002, Evaluation CHACH Stage 3 - Internal

Prof. Giovanni Ghione, University Turin (specialist)

Prof. Olle Nilsson, Royal Institute of Technology (specialist)

Prof. Staffan Rudner, Swedish Defence Research Agency (specialist)

An internal evaluation was carried out for benchmarking CHACH versus VINNOVA's criteria. Here two Swedish reviewers with large insight in the national research system pointed out the benefits but also problems in mixing various funding sources from SSF and VINNOVA. It was again concluded that the scientific production was of very high class whereas the industrial impact could be substantially improved.

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[8] The NUTEK Competence Centre Programme, Second, Mid-Term, International Evaluation Group 1 (7 Centres), John S. Baras *et al.*, NUTEK Report R 2000:9, ISSN 1102-2574. March 2000.

5. March 2003, Evaluation CHACH Stage 3 by VINNOVA[9]

Prof. John S. Baras, University of Maryland (generalist)

Prof. Gabriel M. Crean, NMRC, Cork (specialist)

Prof. Cesar Dopazo, Research Centre for Energy, Madrid (generalist)

Prof. Markus Pessa, Tampere University of Technology (specialist)

Prof. Per Stenius, Helsinki University of Technology (generalist)

The third and last official VINNOVA evaluation again addressed strong criticism to CHACH on the lack of a common vision and strategic plan between Chalmers and industry. According to the review team, an international advisory board was urgently needed. Also large concerns were aimed at the lack of IPR agreement in CHACH.

6. April 2004, Evaluation CHACH Stage 4 - Internal

Dr. Michael Schlechtweg, Fraunhofer Institut IAF, Freiburg (specialist)

Prof. Jussi Tuovinen, VTT Information Technology, Espoo (specialist)

This internal evaluation was carried out by the Stage 4 appointed members of the International Advisory Board in CHACH. Suggestions were given on improving the exploitation, visibility and project organization in CHACH. Several of these proposals were later on adapted in the application and start-up of the next-generation Competence Center, GigaHertz Centre.

[9] The Competence Centres Programme: Third International Evaluation. Group 1 (8 Centres). John S. Baras *et al.*, VINNOVA Information VI 2003:4, ISSN 1650-3120, September 2003.

8 Impact of CHACH

The academic and industrial achievements are already documented in Chapter 5 and 6, respectively. In this Chapter, comments are given on second order effects in relation to CHACH's partners including the host Chalmers University of Technology.

8.1 International context

CHACH was part of a national Competence Center program. CHACH's *direct* impact on the international scene was rather limited which partly was related to the branding strategy, see Par. 8.2. Indeed, there was no mission or vision statement formulated by the Steering Board to take advantage of CHACH from an international viewpoint. Another important fact keeping the international ambitions low for CHACH was that Competence Centers generally were regarded by both scholars and industrialists as promoters of *Swedish* growth. In fact, non-Swedish company partners were not even considered during Stage 1-3 in CHACH. VINNOVA clarified during the 00's that such commercial actors were indeed allowed as partners in Competence Centers but such new perspectives take time to alter in established consortia.

Even though CHACH was listed and described in international reviews such as Institute of Physics report on *Commercial Applications for mm-wave MMICs,*[10] the direct international contact for CHACH was through its International Advisory Board and official evaluations where the general and technical center content was described.

8.2 Branding

Competence Centers such as CHACH were given a mission from VINNOVA to market themselves as cross-disciplinary creative environments for research and innovation between host university and company partners. This constituted an important strategy to attract new company partners. In addition, a successful branding could be an essential ingredient in keeping the center together both for researchers at industry and for the faculty where scientists were scattered at their departments. The

[10] Commercial Applications for Millimetre-wave MMICs, Jeff Powell and Dave Bannister, ISBN 0 7503 1028 6, Qinteiq and IOP Publishing 2004.

center name CHACH would also create some sort of international brand for high-speed technologies in electronics and photonics where industry and Chalmers joined for research.

CHACH was marketed through a dedicated website, in Chalmers annual reports and by its own printed material such as folders. Seven colored folders, 4 large and 3 small-sized, were printed and distributed presenting the research and partnerships in CHACH for Stage 1, 2, 3, and 4.

For CHACH, branding presented somewhat of a problem not unknown for centers. In fact, one of the main points in several reviews for criticism was the low visibility of CHACH. The reasons for the difficulty in branding for CHACH were several:

- CHACH was not used as affiliation when disseminating research results, e.g. at international conferences or in scientific journals. CHACH was more considered as a funding agency or sponsor by ingoing researchers; Chalmers or the company was the important affiliation. This was characteristic for projects where the company-industry interaction was weak or more working as information exchange. In Stage 4, it was clearly told by the Board that CHACH and its partners should be acknowledged explicitly in publications presenting CHACH results.
- At Chalmers, CHACH was a center "without walls". The identity for a center mixed in a much larger research environment made CHACH and its branding unclear for many, in particular for people having mixed financing. In particular, this was a problem during Stage 2 and 3 when SSF provided large in kind to CHACH.
- Professors at Chalmers participating in CHACH had their own laboratories and departments to think of. For many, a center which only partly sponsored their research activities was often second to their own group or laboratory when it came to branding. In addition, the establishment of the Microtechnology Center at Chalmers during 1996-2004, the largest investment made in Chalmers history, made it even more difficult to have CHACH highlighted.

8.3 Networking and mobility between Chalmers and industry

One of the most important effects experienced from CHACH was its ability to create networks between industry and Chalmers. In the beginning, industrial partners regarded CHACH as a university center of excellence and company presence was low at center meetings. However, industry appeared more and more frequently and during the second half of CHACH, meetings displayed a large industrial presence (>40%). In addition, CHACH also created new networking between company partners. Some of the strategies for creating networks and improving mobility between partners were:

- Common and regular center activities in an open manner permitting meetings and interactions between delegates (See Chapter 4)
- Project hardware demonstrators requiring competence and resources from more than one partner
- Adjunct Professorships
- Industrial project leaders

Industrial Ph.D. students were also tested in a few cases but never became significant in CHACH for increased mobility between Chalmers and industrial partners.

8.4 Impact on hosting university

The impact from CHACH on Chalmers line organization was minor in the beginning but grew with time. The reason for the minor impact in the beginning was the strong internal force to regard CHACH as any VINNOVA funding source guided by industrial collaboration. The economy was focused on having in kind contributions from Chalmers and partners to match VINNOVA's cash funding, see Chapter 10. The confusion in internal branding (Paragraph 8.2) and keeping funding sources apart also weakened the impact from CHACH on Chalmers. Moreover, CHACH did not have any major impact in the set up of the cleanroom constructed in the new MC2 building year 1998-2000. Looking in the rear mirror, this was a missed opportunity since CHACH activities in wide bandgap later became the largest cleanroom-based project involving major key Swedish system industries Ericsson and Saab.

Locally at the Department of Microtechnology and Nanoscience (MC2), the Directors of CHACH after Stage 1 also were active in other funding efforts, in particular SSF, which meant that CHACH both directly and indirectly became important, in some cases essential, in attracting further funding to Chalmers, in particular at the laboratory level.

Compared to other Swedish universities hosting Competence Centers, the management at Chalmers was relatively involved and supportive in favor of its six VINNOVA / STEM Competence Centers, one of them CHACH. Center Directors at Chalmers were hired by the Vice President and not by the Department Heads. The success with several of Chalmers Competence Centers during the period created an asset for the university and an inspiring model for other research environments. Consequently, the number of "centers of excellence" during CHACH increased strongly at Chalmers to an extent where it became difficult for external observers to understand the difference between center and center, in particular what "industrial collaboration" really signified.

Centers and its Directors were often made visible in Chalmers' agenda, e.g. at visits or in working groups. Also Chalmers management engaged heavily in the applications for second generation of Competence Centers in the call 2003-2004 in VINNOVA's VINN Excellence program.

A final remark is the impact on the Department level. It turned out efficient to have the Director as member of the Executive Group at the MC2 Department. Usually, the Executive Group consisted of laboratory and administrative managers at MC2. By having the Center Director as part of this management group, the added value of CHACH also at the Department level became more obvious to the rest of the faculty. This turned out very important when CHACH was without VINNOVA funding and only relied on Chalmers and industrial sponsoring.

8.5 Impact on industrial partners

The impact on the industry is here given by statements from four important company partners in CHACH.

The telecom infrastructure market is today very competitive, in terms of e.g. price and performance. Ericsson maintains its position as the technology leader with in-house research and active collaboration with key universities and research institutes. CHACH proved to be an excellent centre for collaboration, with high competence and active partners. The research efficiency has been very high: Our investments in CHACH (knowledge, funding) has been multiplied in the centre.

Dr. Peter Olanders
Technology Strategist
Research Management
Ericsson AB, Kista
CHACH Stage 4++

Collaborative advanced research programs between university and industry, such as CHACH, are essential for smaller and medium sized high technology companies. Companies benefit from these programs in many ways, technology development, risk reduction, competence development, networking, etc. All these are factors that significantly contribute to give us the global competitive edge we need to grow and develop products for the future.

Dr. Mats Nordlund (Director - Engineering)
Emerson Process Management
Rosemount Tank Radar AB, Göteborg
CHACH Stage 4+

Saab Space has been engaged in the competence centre CHACH since the start more than ten years ago. Several different circuits and processes have in cooperation with Chalmers been explored during the years. CHACH offered the possibility for Saab Space to start up the first MMIC design activities made in the company. During the last two years some of the MMICs have been implemented in demonstrators and prototypes at Saab Space, and are now integrated as key components in the new product generation for the telecom market. CHACH has offered an important possibility to start early research and selection of technology for microwave products. CHACH has also strengthened the contacts between Saab Space and Chalmers MC2.

Paul Häyhänen
Antenna & Microwave Department Manager
Saab Space AB, Göteborg
CHACH Stage 4+

CHACH provides the ideal mechanism for strengthening industry-university links which is of long-term benefit to both parties, as well as the individuals involved. We believe CHACH provides and will continue to provide, the ideal link between industry and academia. In the future the need for a center such as CHACH to support industry in medium to long term research will become ever more important.

Marco Ghisoni
R&D manager
Zarlink Semiconductor AB, Järfälla
CHACH Stage 3

9 CHACH as a verification source

This study and Chapter was conducted and written by Henric Rhedin, Chalmers Industrial Technologies (CIT).

The text is an extract of opinions and conclusion that have emerged from the VINNOVA project “Verification of research project originating from Chalmers center of excellence” (Henric Rhedin) specific for Chalmers Center for High-Speed Technology (CHACH). Within the framework of the project, interviews were carried out with persons who had been active in CHACH. The interviews and other additional work and material formed the basis for this text. University researchers, employee's at large companies and SMEs, members of the Board and Center Directors have been interviewed.

9.1 CHACH and verification

The answers from the university researches clearly showed that there are a number of potential verification ideas that were not of direct interest to the member companies. The reason, according to the university researchers, was that the ideas were not in the core business of the company.

Another question of interest was the process of how projects were initiated, either ideas from the industrial partners (technology pull) or ideas from the university researchers (technology push). The answers did not give a clear picture and in general divided the interest groups (industry and university) in two parts where both claimed they did most of the initiation. One researcher had the (presumably correct) hypothesis that it varied over time and from his own experience, the center started as a university-driven research platform that developed into an arena for university-industry interchange on more equal conditions.

9.2 Expectations on the outcome of the center

The largest difference, both internal and external, was found in the expectations on the outcome of the cooperation within the center. The expectation differed widely between those of large companies and those of SMEs. Of course the university also had other expectations compared to those of the companies.

SMEs expected results to lead to new innovations, the founding of new companies in the area and to establish business relations to other companies within the center. SMEs were more dependent on the research made within the center, since they often did not have the resources for in-house research. In addition, this also meant that the research had to be closer to application. Furthermore, business relations and network established through the center were often crucial for the survival and development of small and newly founded companies.

Large companies expected verification of results, education of present and future personnel, and to gain deeper insight in research at the scientific-frontier. Large companies have well established in-house research and development (with an extreme emphasis on development). Large companies were thus not depending on the research made within the center, but consider the results as an indicator in which way they should focus their own research, and as verification of their own results.

The university expected good education of their students and research with a higher degree of industrial relevance. The researchers at the university also saw the ability to establish contact with the companies (especially the larger ones), for future projects or expanded studies as vertical projects (contract work) outside the center, which will generate financial support to their research. The researchers also hoped that the activity within the center should to some extent contribute to the starting of new companies or lead to new innovations.

Another interesting opinion was expectations from the SMEs and the university on the large companies. Both the SMEs and the university had high demands on the larger companies to steer the center strategy and direction, a role not always welcomed by the larger companies. The universities and SMEs had an accentuated belief that large companies “know the future or create the future”.

9.3 Meeting of the expectations

Both companies and university felt that their expectations were well met, with one exception; the expectation that the activity within the center should result in spin off companies within the technology area. The reason for this given in the interviews was the lack of funding for spin-off ideas. Other reasons were the handling of IPR and competition between companies involved in the center. Hence if a project resulted in a good idea that fell outside the business focus of the companies involved in the project, it was difficult to motivate the center to financially support verification of the idea and to further investigate its business potential.

During the interviews it also was suggested that the university should develop some platform or organization connected to the center of excellences where these issues could be handled and internal funding could be raised for the new project. It is concluded that researchers at the universities did not engage themselves too much in verification projects from CHACH. The reasons were:

- Lack of competence, time and acceptance from the university
- Large companies rarely showed an interest in ideas not in line with their core business.
- SMEs were even more restricted to short time to market ideas and hence had neither desire nor strategy for dealing with general verification projects.

9.4 University as a commercial research and development department

The discussion on whether or not the university could be an effective R&D department for the industry gave different answers whether the person interviewed worked within industry or the academic world. In general, personnel from the university answered yes, and personnel from the industry answered no.

The large enterprises stated that it was not possible in practice since the university is too public. They also stated that the companies should do the product development and the university should perform basic studies and free science sponsored by the government and not the industry.

SMEs also had the opinion that the basic studies and free science should be conducted at the universities with funding from the government. However, they did not see this as an obstacle for placing some part of their R&D activity at the university. It is concluded that SMEs attached to a center were often dependent on the R&D work made in the center since their own R&D capability was inadequate mostly due to financial limitations.

Both the university and industry said that it could be possible if and only if the right balance between the industry relevance and the fundamental research could be found and maintained. Another barrier that had to be solved is the handling of IPR. Both small and large enterprises state that a more expanded cooperation between university and industry was a better option, either by contract work or by expanding the work within the centers. They agreed on that one of the major barriers for expanding cooperation between companies and the university, and also between companies within the same center of excellence, was the handling of IPR.

9.5 Handling of results with high potential

Here the answers differed between the large companies and SMEs. The large companies stated that if a result with high potential was in their area of interest, they would "take it home" meaning continue the expanded study or verification of the results at their own research and development department. An alternative was to create a bi-lateral project outside the center, in cooperation with the university Department. It is concluded that the large companies were not dependent on cooperation with the other companies or the university.

The SMEs stated that a verification fund connected to the centers or the university could increase the number of spin-off projects that would lead to new products or companies. They also requested a platform or organization within the center or university that provided the "know how" and an interdisciplinary network. The SMEs do not have the required resources to continue a project in-house. They are dependent on continuous cooperation with both the university and larger companies which have the needs and financials strength to support the development process.

9.6 Generalities about the center

The participants, both small and large companies as well as the researchers at the university, were pleased with the results and benefits they derived from the center of excellence. This conclusion is also verified by E. Arnold *et al*.[11] The participants considered the chain of feedback working well in most projects. However, it mainly depended on the engagement and interest shown by the industrial representatives in each project. Another factor was the time. The longer the participants had known each other and worked together, the more efficient was the joint research work. As a result, a certain trust between the participants was formed over time, which contributed to a more open atmosphere.

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[11] Impacts of the Swedish Competence Centres Programme 1995-2003, Erik Arnold, John Clark, Sophie Bussilet, VINNOVA Analysis VA 2004:03, ISBN 91-85084- 10-7, August 2004.

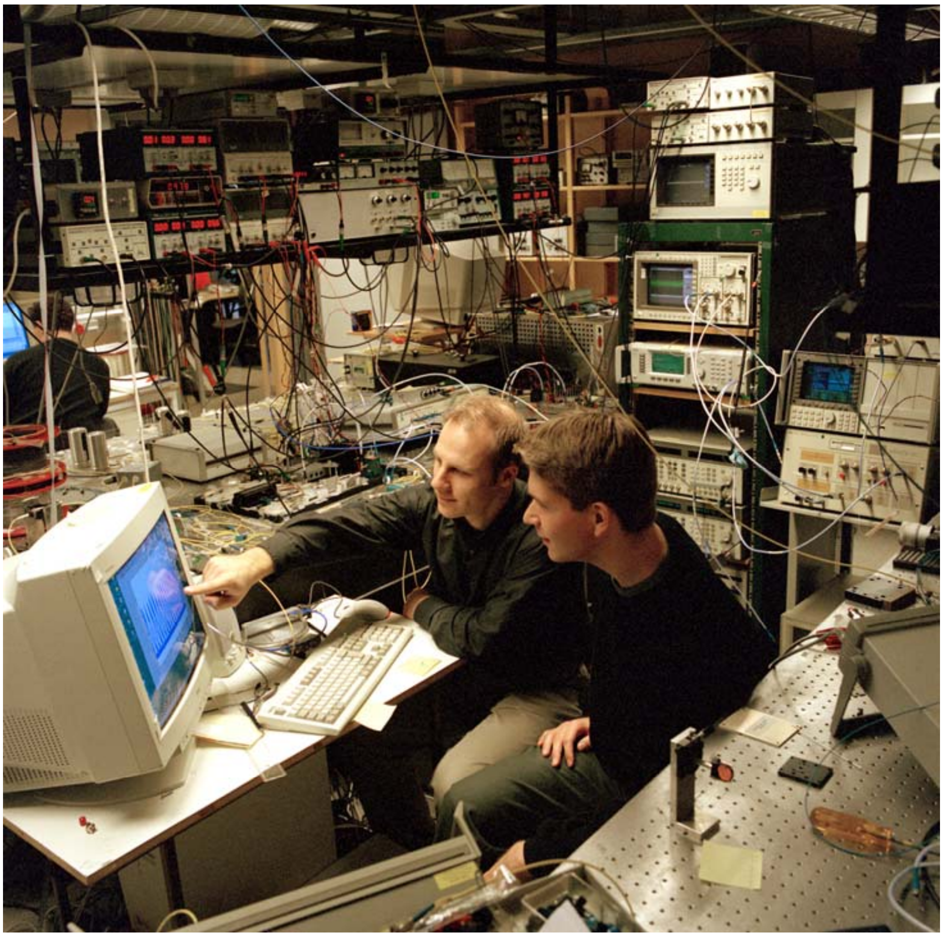


Figure 20. Henrik Sunnerud and Per Kylemark in the fiberoptic measurement lab at Chalmers, (CHACH project described in Par. 3.1.3).

10 Financing of CHACH

The financing of a Competence Center relied on model where the governmental agency, industrial partners and the university host were expected to share costs in an equal manner. NUTEK, later VINNOVA, provided 6,000 kSEK per year. Hence the total annual budget was expected to be 6,000+6,000+6,000 = 18,000 kSEK from VINNOVA, companies and Chalmers, respectively. In reality, the real cash budget was substantially lower.

While VINNOVA supported CHACH in cash, Chalmers and industrial partners, in order to match the governmental contribution, contributed to the CHACH activities with a combination of cash money and in kind contributions. In kind contributions were either own work (man hours) or laboratory resources (access to equipment and facilities) and material costs (foundry runs, wafers etc).

For calculation of in kind work, the VINNOVA standard of 650 SEK/hour was used for industrial partners. In kind costs at Chalmers were accounted using a pre-determined cost factor for Ph.D. students and senior scientists.[12] The material and resources provided by Chalmers were contributions from usage of MC2 cleanroom, measurement and test laboratories calculated according to a cost model. In general, all in kind work numbers reported below possess a certain element of uncertainty since no time reporting neither at Chalmers nor at company partners were used in CHACH.

In Figure 21, the CHACH financing for year 1995-2006 between VINNOVA/NUTEK, Chalmers and industry is shown both for the cash contribution and the total contribution. Chalmers and industry were able to fulfill the minimum 67% requirement with good margin.

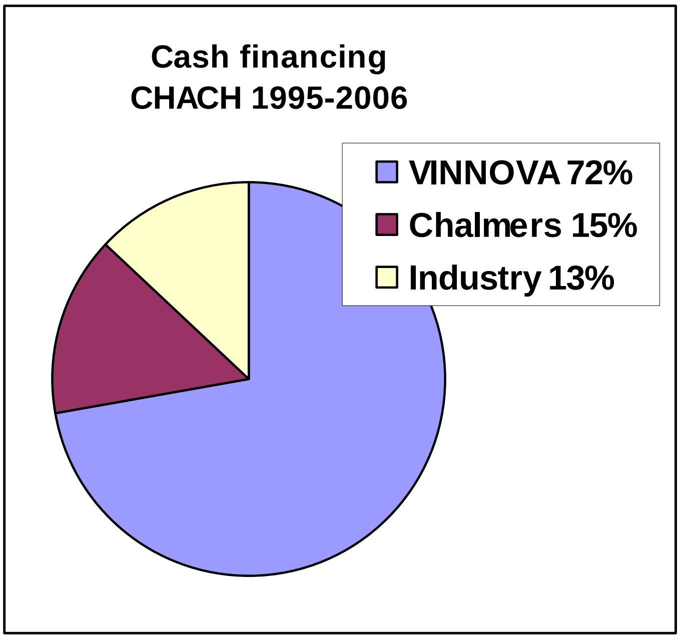
All detailed contributions for the financing of CHACH during all six Stages 1995-2006 are given in Table X including individual contributions for all company partners. The total cash financing was 75,311 kSEK whereas total financing ended up in 238,704 kSEK.

[12] President's Decision, DNr C858-02, Chalmers University of Technology.

The following central observations are drawn from the table:

- The cash constituted only about 32% of the total financing with VINNOVA as major cash contributor.
- The large in kind contribution originated from Chalmers, corporate research departments at Ericsson and one SME, Omnisys Instruments.
- Chalmers large in kind contributions during Stage 2 and 3 was totally dominated by the co-financing with SSF programs. When the IPR agreement was signed for Stage 4, the in kind contribution from Chalmers was heavily reduced. From Stage 2 to Stage 4, the in kind contribution from Chalmers was reduced with more than 50%.
- Because of the new strategy in Stage 4, the financing per Chalmers employee involved in CHACH increased with a factor of 2-2.5.

In general, the projects with cash and in kind contribution partners showed the best scientific results and exploitation output for Chalmers and the company partners, respectively. This made the Steering Board in Stage 4 to raise requirements for cash contributions from company partners. In Figure 22, cash evolution (normalized per year) in CHACH 1995-2006 is shown per Stage. It is seen that the company partners increased their contributions substantially in the later Stages. Also shown is the budget for Stage 1 of GigaHertz Centre year 2007-2008 which here represents the second generation of Competence Center, see Chapter 12.



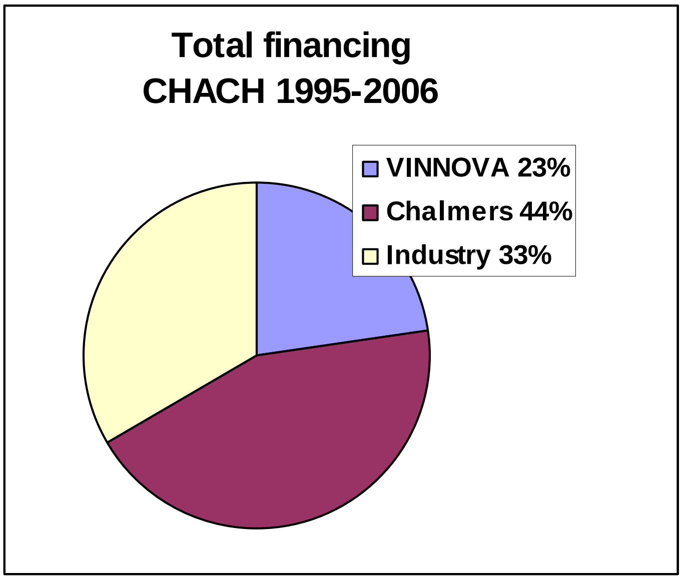


Figure 21. CHACH financing distribution 1995-2006 in pie charts: Cash and total (cash + in kind) financing. Cash financing was 75,311 kSEK. Total financing was 238,704 kSEK.

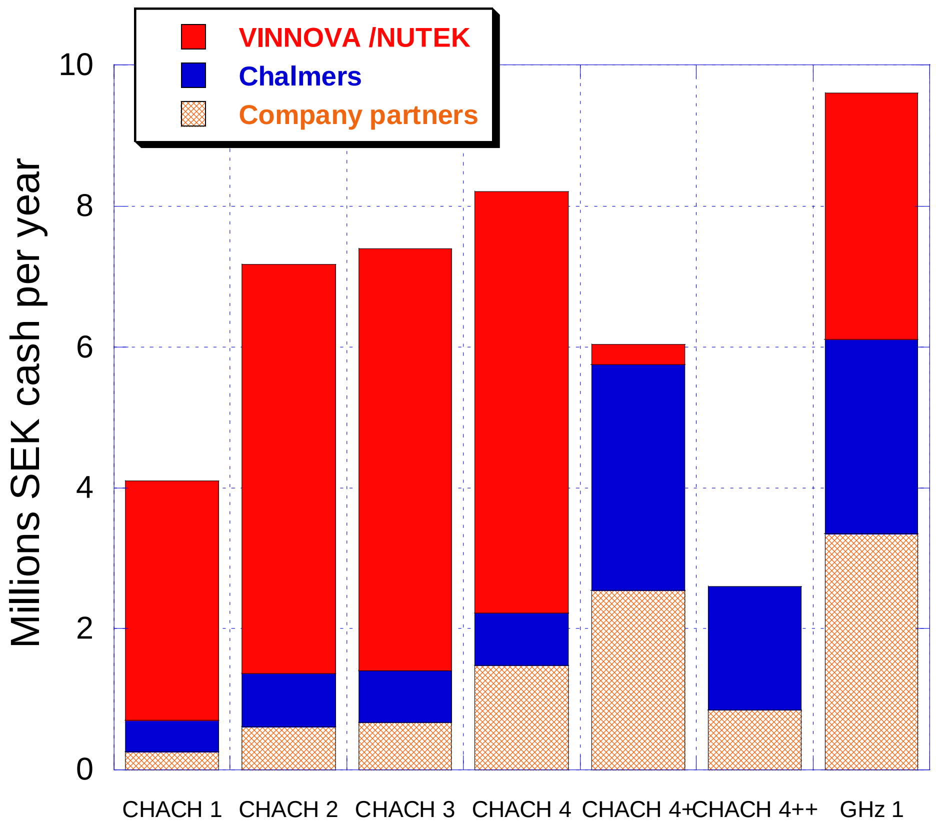


Figure 22. CHACH financing in cash 1995-2006 normalized to MSEK per year from the three financing bodies VINNOVA/NUTEK, Chalmers, and industry per Stage (for definition and length of Stages, see Table I). The column to the right illustrates GigaHertz Centre funding Stage 1 year 2007-2009 (second generation of Competence Center)

Table X. CHACH financing 1995-2006 divided for all partners and Stages

CHACH total financing 11.75 yrs	**Stage 4++ (0.5yr)**		**Stage 4+ (1 yr)**		**Stage 4 (2 yrs)**		**Stage 3 (3 yrs)**		**Stage 2 (3 yrs)**		**Stage 1 (2.25 yrs)**			**All**	**Stages**
All costs in kSEK	**2006**		**2005-2006**		**2003-2005**		**2000-2003**		**1997-2000**		**1995-1997**			**1995 -**	**2006**
	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	**Total**
VINNOVA (NUTEK)	**0**	**0**	**250**	**0**	**12000**	**0**	**18000**	**0**	**17400**	**0**	**6800**	**0**	**54450**	**0**	**54450**
Chalmers	**875**	**885**	**3175**	**2660**	**1500**	**12618**	**2250**	**32350**	**2250**	**39255**	**882**	**5774**	**10932**	**93542**	**104474**
Industry	**425**	**2117**	**2300**	**6465**	**2850**	**12779**	**2020**	**24200**	**1819**	**17248**	**515**	**7042**	**9929**	**69851**	**79780**
Ericsson AB (Ericsson Microwave + Ericsson Telecom)	0	117	500	442	150	4263	0	5445	0	0	0	0	650	10267	**10917**
Infineon (Ericsson Microelectronics, Ericsson Components, Ericsson Telecom)	0	0	0	0	0	1223	0	330	200	6051	215	585	415	8189	**8604**
Ericsson Microwave Systems	200	200	300	442	1000	920	0	5760	0	5779	0	3995	1500	17096	**18596**
Ericsson Saab Avionics AB	0	0	0	0	0	0	0	0	0	167	0	0	0	167	**167**
Comheat Microwave (Eklund Innovation)	125	1300	250	760	200	868	225	870	0	0	0	0	800	3798	**4598**
Omnisys Instruments	0	400	550	3910	0	2315	0	1650	555	1139	0	787	1105	10201	**11306**
Saab Ericsson Space	0	0	400	525	800	650	0	1200	0	1180	0	766	1200	4321	**5521**
SaabTech AB (Saab Avionics, CelsiusTech)	100	100	200	200	400	400	645	1500	440	458	300	700	2085	3358	**5443**
Saab Rosemount (Saab Marine Electronics AB)	0	0	100	186	300	200	450	1200	0	0	0	0	850	1586	**2436**
Zarlink Semiconductor AB (Mitel Semiconductor)	0	0	0	0	0	1940	650	1240	0	315	0	0	650	3495	**4145**
Allgon Systems	0	0	0	0	0	0	0	1500	90	663	0	0	90	2163	**2253**
Radians Innova	0	0	0	0	0	0	0	660	0	0	0	0	0	660	**660**
Optillion	0	0	0	0	0	0	0	2845	0	0	0	0	0	2845	**2845**
Swedish National Testing & Research Institute (SP)	0	0	0	0	0	0	50	0	0	0	0	0	50	0	**50**
Gigatech	0	0	0	0	0	0	0	0	534	1116	0	0	534	1116	**1650**
Ranatech	0	0	0	0	0	0	0	0	0	380	0	209	0	589	**589**
VINNOVA + Chalmers + Industry	**1300**	**3002**	**5725**	**9125**	**16350**	**25397**	**22270**	**56550**	**21469**	**56503**	**8197**	**12816**	**75311**	**163393**	**238704**
	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	Cash	In kind	**Total**

11 Conclusions of CHACH 1995-2006

A Competence Center had to face two major challenges. Did CHACH meet these two?

I. To be a cross-disciplinary center of excellence, *i.e.* a dynamic, productive, and internationally renowned academic research environment.

Overall, the academic achievements with regard to productivity and quality (Chapter 3 and 5) were outstanding in CHACH, although somewhat unevenly distributed among the research programs. Many of the research groups reported world-class results. An observation is that CHACH during its first Stages 1-3 co-financed research, in particular together with SSF, in high-speed technology at Chalmers which already was rather strong. It was thus "more of the same". As a result, CHACH helped to produce more of high-quality research and Ph.D.s at Chalmers.

When demands for industrial participation were increased from Stage 4, some research groups could not meet the new requirements and were consequently phased out. Moreover, an IPR agreement was introduced which made mixing with SSF funding not longer possible. The research profile became more focused towards microwave technology with a clearer mission of transferring competence and results from Chalmers to the industrial partners. The number of publications was also reduced. There were no signs that the quality of the scientific papers degraded.

Nonetheless, it is important to point out that the total research environment is crucial. A Competence Center i small and can not stand by itself. The Center must be surrounded by a much larger body of strategic, high-risk research where industry is not necessarily active or involved. Hence the Competence Center shall work as a kind of channel for transferring results from university to industry as soon as a "market window" opens up which here is spelled industrial involvement, see further below. This window of opportunity can be quite different from company to company.

II. **To promote the implementation of new technology and to strengthen the technical competence in Swedish industry, mainly through its industrial partners.**

Several stories of successful implementation or testing of CHACH results at industrial partners have been demonstrated in this report (Chapter 6). Some conclusions can be made from this:

- The joint industry-Chalmers work was rather weak during Stage 1, 2 and 3. From Stage 4, this became more efficient because of a new mission and an IPR agreement meaning much larger involvement and financing from industry in CHACH.
- Testing of a new technology was essential for companies. A decision of postponing the introduction of an emerging technology from university research to industrial development was also an important result for commercial partners.
- Corporate research organizations were best suited for the long-term research collaborations in CHACH. The industrial impact was however much lower compared to collaborations between Chalmers and industrial development teams closer to production environments at the companies.
- It was important to have some action of "pull" from industry in the CHACH projects.
- The international trend in research was one very essential factor in the strategic decisions for the companies to join the center.

11.1 Recommendations

Some concluding remarks and recommendations are given to the three partners:

11.1.1 Industry

Industry must be prepared to be seriously involved. In practice, this means that industry must be prepared to pay a combination of cash and in kind to Competence Center projects. Sharing risks can however return much IPR for a small investment.

Important research for companies should not be carried out in Competence Centers. Such company requests shall be carried out in contract research, at institutes or at the companies themselves.

11.1.2 University

University management

In analogy to the company involvement mentioned above, a large university involvement will increase probability for success. University management must be prepared to invest resources in a Competence Center. In return, Competence Centers can be a most efficient channel for commercializing research for the university.

University management shall not regard Competence Centers as an external funding source. The leadership of the center is a sensitive point depending upon the Chairman and Director and a few committed project leaders. Centers are often leading the way for new initiatives at the university. It is highly recommended to adjunct the center leader to executives groups at the department so that the role and identity of the center can be utilized in an optimal manner in relation to the Department.

Faculty

- The mission of the Competence Center implies a more customer-oriented research in the faculty. A direction is pointed out for transferring results from university to industry. The incitement for transfer of results becomes strongest when the involved companies are paying a non-negligible part of the salary for the faculty scientist and providing industrial knowledge and facilities to Chalmers.
- Competence centers can create much more focused research than the ordinary faculty centers of excellence where the tendency of fragmenting funding is strong.
- IPR awareness and the signature by the individual researcher him/herself at a Swedish university is an important incitement for the individual researcher to understand the difference of doing research in a Competence Center compared to a traditional center of excellence.

11.1.3 VINNOVA

VINNOVA created the most successful Swedish program for university-industry collaboration so far. Three important reasons were (1) long-term funding (2) rigid international evaluations and internal follow-ups, e.g. regular Competence Centre days (3) excellent leadership at VINNOVA.

The Competence Center program resulted in a serious boundary condition for the expansion of the center. It turned out very difficult to add further funding to CHACH during the twelve years because of VINNOVA's lack of coordination of its own programs. As a result, companies working with Chalmers through VINNOVA's programs had completely different conditions in their agreements depending on whether companies were positioned inside or outside CHACH. This probably reduced research efficiency and innovation power at Chalmers. The inclusion of Optillion in Stage 3 was one attempt to expand CHACH but turned out not successful since the interest and involvement from the company was far too low.

One may also argue about branding of the centers. The branding is emphasized by VINNOVA. However, branding takes a lot of energy. If the center is allowed to embrace a larger research environment at the host university, branding can be justified. It is up to each university to settle a strategy how it wishes to take advantage of building up a brand name for its research and innovation environments carried out together with industry. Such a strategy is normally lacking at Swedish technical universities including Chalmers.

12 Second generation of Competence Centers: VINN Excellence program

During the writing of this report year 2007, Chalmers had the favor of starting up the second generation of Competence Centers in the VINN Excellence program initiated by VINNOVA. GigaHertz Centre (GHz Centre) was one of the fifteen winners in June 2006 in the national competition (169 proposed consortia) following the official call 2004 of the VINN Excellence program. Similar to the Competence Center program, the VINN Excellence program supports the approved centers with governmental funding for ten years. The transformation of CHACH to the GigaHertz Centre[13] started already during the final years of CHACH (Stage 4 and later). With the launch of VINN Excellence Centers, new progress and renewal of the research and innovation system can be progressed further by Chalmers and industry together.

The list in Table XI highlights essential differences between the first and second generation Competence Center with reference to CHACH (prior to Stage 4) and GigaHertz Centre, respectively.

[13] www.chalmers.se/ghz

Table XI. Comparison between CHACH and GigaHertz Centre.

Center	CHACH	GigaHertz Centre
Funding Program	Competence Center Program	VINN Excellence Center Program
Governmental Agency	NUTEK (1995 - 2000) VINNOVA (2000 - 2006)	VINNOVA (2007-2016)
Legal agreement	University has a status as non-commercial actor. Governmental agency is part of the Consortium Agreement. Governmental payment executed after university and agency have signed.	University and industrial partners share similar legal rights. Consortium Agreement between the university and industrial partners (leaving governmental agency out). Governmental payment executed after university and all industrial partners have signed.
Industry involvement and contribution	Small or negligible cash contribution, large in kind	Substantial cash contribution *and* in kind, see Figure 22.
University Department	Regarded as an external funding source similar to other research centers ("more of the same"). Little or no involvement from university department and management. Provides negligible added industrial cash and no IPR to university.	Center is an enabler of new policies and research directions at the departments. Involvement from university departments and management. Centre generates industrial cash and IPR to the university.
Centre employees at partners	Fuzzy	Clear
Range of Center	National Center	International Center
Center location and boundary	Without walls - fuzzy location	Clear physical location at host university but still integrated in the academic environment.
Innovation system at host university	Unclear or no role for center.	Clear role for the center.
Innovation and IPR	No or unfavorable IPR arrangement for university meaning poor incitements for faculty to innovate. No particular spin-off strategy.	University has the ownership and a responsibility to utilize the ownership for the benefit of the partners and the society. Incitements for faculty to do innovation. Spin-off strategy
Center identity and trading	Vague at university since background, sideground and foreground results normally are not kept apart.	Foreground results clear at university because of IPR yet trading difficult externally because Centers are too small.
Interdisciplinary	Several component platforms	Components and systems
Steering Board	Surveying of research projects	Enabling of new policies, lobbying and initiatives inside and outside the university.
Research	Faculty controlled. Focused on the individual researcher. Fragmented research program.	Guided by shared university-industry centre vision. Focused research program

Appendix

A. CHACH staff at Chalmers

B. CHACH staff at industrial partners

C. CHACH examinations

D. CHACH publications

E. Patents

A. CHACH staff at Chalmers

Chalmers employee in CHACH	**G**	**Department Laboratory**	**Position**	**Stage 4++**	**Stage 4+**	**Stage 4**	**Stage 3**	**Stage 2**	**Stage 1**
				2006	**2005-2006**	**2003-2005**	**2000-2003**	**1997-2000**	**1995-1997**
Alex Kryachev	M	Physics	Ph.D. student					**X**	
Anders Eriksson	M	Microwave	Ph.D. student			**X**	**X**	**X**	
Anders Karlström	M	CIT	Center Director				**X**		
Anders Larsson	M	Photonics	Professor			**X**	**X**	**X**	**X**
Anders Magnusson	M	Photonics	Ph.D. student			**X**	**X**	**X**	
Andreas Ådahl	M	Microwave	Ph.D. student		**X**	**X**			
Bahar Mahmoudian	F	Microwave	Ph.D. student			**X**			
Bengt-Erik Olsson	M	Photonics	Sr. researcher				**X**		
Björn Hall	M		Ph.D. student				**X**	**X**	
Camilla Kärnfelt	F	Microwave	Res engineer			**X**	**X**		
Catharina Forssén	F	Microwave	Administrator			**X**	**X**	**X**	
Christer Karlsson	M	Microwave	Ph.D. student / Sr. researcher						**X**
Christian Fager	M	Microwave	Ph.D. student / Sr. researcher	**X**	**X**	**X**	**X**	**X**	
Dan Anderson	M	Electromagn	Professor				**X**	**X**	
Elisabeth Ericsson	F		Administrator						**X**
Erik Carlsson	M	Microwave	Ph.D. student						**X**
Erik Kollberg	M	Microwave	Professor				**X**	**X**	**X**
Göran Lövestam	M	Microwave	Center Director					**X**	**X**
Henrik Sunnerud	M	Photonics	Ph.D. student / Sr. researcher				**X**	**X**	**X**
Herbert Zirath	M	Microwave	Professor	**X**	**X**	**X**	**X**	**X**	**X**
Håkan Berg	M	Microwave	Ph.D. student				**X**	**X**	
Håkan Forsberg	M		Ph.D. student					**X**	
Iltcho Angelov	M	Microwave	Sr. researcher			**X**	**X**	**X**	
Jan Grahn	M	Microwave	Docent	**X**	**X**	**X**	**X**		
Joakim Eriksson	M	Microwave	Ph.D. student / Sr. researcher				**X**	**X**	**X**
Joakim Hallin	M	Microwave	Sr. researcher				**X**		
Johan Gustavsson	M	Photonics	Ph.D. student			**X**	**X**	**X**	
John Halonen	M	Photonics	Res engineer					**X**	
Jonas Brentel	M		Ph.D. student					**X**	
Katharina Back	F		Administrator						**X**
Klas Yhland	M	Microwave	Ph.D. student						**X**
Kristina Dynefors	F	Microwave	Ph.D. student				**X**		
Kristoffer Andersson	M	Microwave	Ph.D. student		**X**	**X**			
Lars Bengtson	M	Microwave	Ph.D. student						**X**
Lars Landén	M	Microwave	Ph.D. student			**X**	**X**	**X**	

Lukas Helczynski	M	Electromagn	Ph.D. student				X	X	
Magnus Andersson	M	Microwave	Ph.D. student				X	X	
Magnus Karlsson	M	Photonics	Professor				X		
Magnus Persson	M	Microwave	Sr. researcher						X
Manolis Choumas	M	Microwave	Res engineer					X	X
Mattias Ferndahl	M	Microwave	Ph.D. student			X	X		
Mattias Sudow	M	Microwave	Ph.D. student	X	X	X			
Mietek Lisak	M	Electromagn	Professor				X	X	
Niklas Rorsman	M	Microwave	Sr. researcher	X	X	X	X	X	X
Niklas Wadefalk	M	Microwave	Engineer	X	X				
Per-Olof Hedekvist	M	Photonics	Sr. researcher				X		X
Peter Andrekson	M	Photonics	Professor				X	X	X
Peter Modh	M	Photonics	Sr. researcher			X			
Pär Rundqvist	M	Microwave	Ph.D. student				X		
Rickard Larsson	M		Res engineer					X	
Rumen Kozhuharov	M	Microwave	Sr. researcher		X	X	X		
Saaed Abadei	M	Microwave	Ph.D. student			X	X	X	
Sheila Galt	F	Photonics	Ass. Professor			X	X		
Spartak Gevorgian	M	Microwave	Professor			X	X	X	X
Stefan Andersson	M	Microwave	Ph.D. student						X
Stefan Davidsson	M	Microwave	Ph.D. student				X		
Sten Gunnarsson	M	Microwave	Ph.D. student		X	X			
Sverker Hård	M	Photonics	Professor			X	X	X	
Thomas Torounidis	M	Photonics	Ph.D. student				X		
Thorvald Andersson	M	Physics	Professor				X		
Tord Claeson	M	Nanoscience	Professor					X	X
Torgil Kjellberg	M	Microwave	Sr. researcher		X		X		
Ulf Jordan	M	Electromagn	Ph.D. student				X	X	
Vincent Desmaris	M	Microwave	Ph.D. student			X	X	X	
Zdravko Ivanov	M	Nanoscience	Professor					X	
Åsa Haglund	F	Photonics	Ph.D. student			X	X	X	

B. CHACH staff at industrial partners

CHACH company	G	Position	Stage 4++	Stage 4+	Stage 4	Stage 3	Stage 2	Stage 1
Year			2006	2005-2006	2003-2005	2000-2003	1997-2000	1995-1997
Comheat Microwave AB (Eklund Innovation)								
Klas-Håkan Eklund	M	Manager	X	X	X	X		
Lars Vestling	M	Engineer	X					
Ericsson AB (part of former Ericsson Microwave Systems, Ericsson Telecom)								
Anders Berndson	M	Engineer				X	X	
Anders Djupsjöbacka	M	Engineer				X		
Arne Alping	M	Proj.leader			X	X	X	
Arne Filipsson	M	Manager				X	X	
Bertil Hansson	M	Engineer			X			
Bo Berglund	M	Manager	X	X				
Charlotta Hedenäs	F	Engineer					X	X
Fredrik Harryson	M	Engineer			X			
Georg de Laval	M	Engineer					X	
Harald Jacobsson	M	Engineer			X	X	X	
Herbert Zirath	M	Engineer			X			
Ingmar Andersson	M	Manager						X
Ingmar Karlsson	M	Engineer					X	
Jie Li	M	Engineer				X		
Joakim Een	M	Engineer			X	X		
Jonas Mårtensson	M	Engineer				X		
Jonas Noreus	M	WP leader			X	X		
Katharina Boustedt	F	Engineer					X	
Lars Ridell Virtanen	M	Engineer	X	X				
Leif Bergstedt	M	Engineer					X	
Martin Emanuelsson	M	Engineer			X			
Martin Johansson	M	Engineer			X	X		
Mats Gustavsson	M	Engineer					X	
Mikael Öhberg	M	Manager			X	X		
Mingquan Bao	M	Engineer			X			
Olof Sahlén	M	Engineer					X	
Paul Hallbjörner	M	Engineer			X			
Per Ligander	M	Engineer			X			
Per Lövenvik	M	Engineer			X			
Per O. Andersson	M	Manager				X	X	
Peter Olanders	M	Manager	X	X				
Richard Larsson	M	Engineer					X	

Spartak Gevorgian	M	Proj.leader			X			
Torgil Kjellberg	M	Engineer						X
Thomas Lewin	M	Manager			X	X	X	X
Thomas Swahn	M	Engineer						X
Tomas Lejon	M	Engineer	X	X				
Torgil Kjellberg	M	Engineer						X
Ulrika Johansson	F	Engineer			X			
Yinggang Li	M	Engineer			X			
Ericsson Microwave Systems AB (present name: Saab Microwave Systems, Saab AB)								
Anna Aspgren (Johannison)	F	General manager			X			
Arne Filipsson	M	Manager				X	X	
Gabriel Gitye	M	Engineer			X			
Ivan Öfverholm	M	Engineer						X
Johan Norén	M	Manager						X
Joakim Nilsson	M	Engineer	X	X	X			
Johan Fält	M	Engineer	X	X				
Johan Ståhl	M	Manager	X		X	X		
Karin Gabrielsson	F	Manager		X				
Morgan Andersson	M	Engineer			X			
Sverker Sander	M	Engineer		X				
Ola Tageman	M	Engineer				X		
Infineon Wireless Solutions Sweden AB (present name: Infineon Technologies Nordic AB) (Ericsson Microelectronics, Ericsson Components)								
Andrej Litwin	M	Proj.leader			X			
Erland Wikborg	M	Proj leader				X	X	X
Gunnar Björklund	M	Manager			X			
Omnisys Instruments AB								
Anders Emrich	M	Proj.leader	X	X	X	X	X	X
Christina Tegnander	F	Engineer	X	X	X			
Johan Dahlberg	M	Engineer		X	X			
Lars Landén	M	Eng., Ph.D. stud			X			
Stefan Andersson	M	Engineer	X	X	X	X	X	
Mikael Krus	M	Engineer	X	X				
Saab Ericsson Space AB (present name: Saab Space AB)								
Denis Kleen	M	Engineer		X	X	X	X	
Hans Grönkvist	M	Engineer					X	
Hans-Olof Vickes	M	Engineer					X	X

Håkan Janson	M	Manager		X	X			
Jock Bhumbra	M	Engineer					X	
Marino Poppeé	M	Engineer		X	X			
Per Ingmarsson	M	Manager				X		
Pentti Kölhi	M	Manager						X
Peter Sohtell	M	Manager			X	X	X	X
Saab AB (Saab Avitronics, SaabTech, CelsiusTech Electronics, Ericsson Saab Avionics)								
Andreas Karlsson	M	Engineer					X	
Gottfrid Strindlund	M	Manager	X	X				
Ingemar Bäck	M	Engineer					X	X
Jan Grabs	M	Engineer	X	X	X			
Magnus Sterner	M	Engineer			X	X	X	
Maria van Zijl	F	Manager	X	X	X	X	X	
Pontus de Laval	M	CTO			X	X	X	
Sigvard Brodén	M	Manager		X	X			
Ulf Larsson	M	Manager					X	X
Vola Abri	F	Engineer					X	
Saab Marine Electronics AB (present name: Rosemount Tank Radar AB, (Saab Rosemount))								
Anders Jirskog	M	Engineer		X	X	X		
Mats Nordlund	M	Manager		X	X	X		
Mikael Eriksson	M	Engineer			X			
Niklas Penndal	M	Engineer		X	X	X		
Jan Westerling	M	Manager						
Olle Edvardsson	M	Engineer				X		
Zarlink Semiconductor AB (Mitel Semiconductor)								
Jeanette Sveijer	F	Manager			X			
Lars Dillner	M	Engineer			X	X		
Marco Ghisoni	M	Manager			X	X		
Richard Marx	M	Engineer				X		
Thomas Aggerstam	M	Engineer				X		
Allgon Systems AB (present name: Powerwave Technologies AB, former LGP Allgon AB)								
Torbjörn Olsson	M	Manager				X	X	
Radians Innova AB (later acquired by Thorlabs AB)								
Michael Larsson	M	Engineer				X		
Trajan Badju	M	Engineer				X		

Optillion AB (liquidated)								
Patrik Evaldsson	M	Manager				**X**		
Thomas Swahn	M	Res. manager				**X**		
SP Technical Research Institute of Sweden*								
Håkan Nilsson	M	Manager				**X**		
Klas Yhland	M	Engineer				**X**		
Leslie Pendrill	M	Engineer				**X**		
Gigatech AB (later acquired by BeVe, then Miteq)								
Christer Stoij	M	Engineer					**X**	**X**
Kjell Jarl	M	Engineer					**X**	
Weronica Sjögren	F	Engineer					**X**	
Ranatech AB								
Lars Hanson	M	Engineer					**X**	**X**
Mats Wiliander	M	Engineer						**X**
Sven Lindfors	M	Manager					**X**	

*Industrial research institute

C. CHACH examinations[+]

Ph.D. theses

1. **Heterostructure field-effect transistors for millimeter wave applications**
   Christer Karlsson
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1996

2. **Nonlinear Pulse Propagation in Optical Fibres**
   Anders Berntsson
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1998

3. **Experimentally Based HFET Modelling for Microwave and Millimeterwave Applications**
   Mikael Garcia
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1998

4. **Optical Phase Conjugation and All-Optical Demultiplexing using Four-Wave Mixing in Dispersion Shifted Fibers**
   Per-Olof Hedekvist
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1998

5. **High Temperature Superconducting and Tunable Ferroelectric Microwave Devices**
   Erik Carlsson
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1998

6. **Resistive FET Mixers**
   Klas Yhland
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

7. **Large-Signal Modelling of Microwave Transistors**
   Lars Bengtsson
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

8. **Ultrahigh Capacity Fiber-Optic Transmission Systems**
   Jonas Hansryd
   School of Electrical and Computer Engineering, Chalmers University of Technology, 2001

9. **Polarization-Mode Dispersion in Optical Fibers: Characterization, Transmission, Impairments and Compensation**
   Henrik Sunnerud
   School of Electrical and Computer Engineering, Chalmers University of Technology, 2001

10. **Silicon Carbide Microwave Device**
    Joakim Eriksson
    School of Electrical and Computer Engineering, Chalmers University of Technology, 2001

[+] For all examinations in this section, the publication year of the thesis is given, not the actual year of the formal examination which may occur later.

11. **Microwave FET Modeling and Applications**
Christian Fager
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2003

12. **Model Dynamics of VCSELs**
Johan S. Gustavsson
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2003

13. **Ferroelectric thin films on Si substrate for tunable microwave applications**
Saeed Abadei
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2003

14. **Tunable Filters based on Ferroelectrics and Semiconductor Varactors**
Anders Eriksson
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2005

15. **Characterization of (Ba,Sr)TiO_3 thin films for multiplier applications**
Pär Rundqvist
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

16. **Process, Characterization and Modeling of AlGaN/GaN HEMTs**
Vincent Desmaris
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

17. **Mode and Polarization Control in VCSELs using Surface Structures**
Åsa Haglund
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

18. **Fiber Optic Parametric Amplifiers in Singel- and Multi-Wavelength Applications**
Thomas Torounidis
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

19. **Microwave power device characterization and wide band gap mixer circuits**
Kristoffer Andersson
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

20. **Integrated Lumped Element and Ferroelectrically Tunable Microwave Components**
Dan Kuylenstierna
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2007

21. **Millimeter Wave Mixer and Multifunctional MMICs**
Sten E. Gunnarsson
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2008

22. **Wide Bandgap MMIC Technology**
Mattias Südow
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2008

Licentiate theses

Licentiates who later pursued a Ph.D thesis in CHACH are marked with a star (*)
Licentiates who later pursued a Ph.D thesis outside CHACH are marked with two stars (**)

1. **Small-Signal, Large-Signal and Noise Modelling of HEMTs**
   Mikael Garcia*
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1995

2. **Study of High Temperature Superconducting Circuits for Microwave Applications**
   Erik Carlsson*
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1996

3. **Nonlinear Transistor Models for Microwave and Millimeterwave Circuits**
   Lars Bengtsson*
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1996

4. **FET Mixers and Nonlinear FET Models for Intermodulation Analysis**
   Klas Yhland*
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1998

5. **Low Phase Noise Voltage Controlled Micro- and Millimetre Wave Oscillators**
   Stefan Andersson
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1998

6. **Polarisation-mode dispersion in optical fibres and its implications on signal transmission**
   Henrik Sunnerud*
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1998

7. **Pre-scaled clock recovery and ultra-high bit-rate soliton transmission over installed optical fibre**
   Jonas Hansryd*
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

8. **Silicon Carbide Microwave Schottky Diodes and MESFETs**
   Joakim Eriksson*
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

9. **Investigations of Microwave Breakdown in Transmit - Receive switches and in Air**
   Kent Madsen
   School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

10. **MMIC FET Frequency Doublers and FMCW Radar Transcievers**
    Christian Fager*
    School of Electrical and Computer Engineering, Chalmers University of Technology, 2001

11. **Parallel computer architectures using optical interconnects**
    Hans Forsberg**
    School of Computer Engineering, Chalmers University of Technology, 2001

12. **Ferroelectric $Na_{0.5}K_{0.5}NbO_3$ Varactor for Microwave Applications**
    Saeed Abadei*
    School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

13. **Microwave Integrated Circuits for Frequency Generation and Power Spectrum Measurements**
Lars Landén
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

14. **Modeling the Modal Dynamics of VCSEL**
Johan S. Gustavsson*
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

15. **Diffractive Optics Applications**
Anders Magnusson
School of Electrical and Computer Engineering, Chalmers University of Technology 2002

16. **Tunable Resonators and Filters Based on Bulk Single Crystal Incipient Ferroelectrics**
Anders Eriksson*
School of Electrical and Computer Engineering, Chalmers University of Technology 2002

17. **Initial growth of GaN on sapphire and growth of AlGaN on GaN by molecular beam epitaxy**
Stefan Davidsson*
School of Electrical and Computer Engineering, Chalmers University of Technology 2002

18. **Passive Microwave Components for Silicon MMICs: Design, Modeling, and Measurements**
Håkan Berg
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2003

19. **Influence of frequency chirp and partial incoherence on non-linear light propagation**
Lukas Helczynski**
School of Electrical and Computer Engineering, Chalmers University of Technology 2003

20. **Nonlinear impairment in strongly dispersion-managed optical systems**
Pontus Johannisson**
School of Electrical and Computer Engineering, Chalmers University of Technology 2003

21. **Microwave breakdown; physics and application**
Ulf Jordan**
School of Electrical and Computer Engineering, Chalmers University of Technology 2003

22. **Processing and Characterization of AlGaN/GaN HEMTs on Sapphire**
Vincent Desmaris*
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2003

23. **VCSELs for High-Speed Interconnects**
Åsa Haglund*
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2003

24. **Applications of fiber optic parametric amplifiers**
Thomas Torounidis*
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2004

25. **Perovskite Oxides for Parallel Plate Ferroelectric Varactors**
Pär Rundqvist*
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2004

26. **Wide bandgap resistive FET mixers and statistical estimation of small-signal model parameters**
Kristoffer Andersson*
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2004

27. **Integrated Receiver for Fiber Optical Communications**
Magnus Andersson
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2005

28. **60 GHz Mixer and Multifunctional MMICs in GaAs pHEMT and mHEMT Technologies**
Sten E. Gunnarsson*
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

29. **Developement of SiC MESFET Based MMIC Technology**
Mattias Südow*
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

30. **Reliable and Efficient Microwave Circuits for Space Applications**
Andreas Ådahl
Department of Microtechnology and Nanoscience, Chalmers University of Technology, 2006

Diploma works

1. **Ferroelectric Tuning of Dielectric Resonators**
D. Åkesson
School of Electrical and Computer Engineering, Chalmers University of Technology, 1997

2. **Numerical simulation of 40 Gb/s dispersion-managed transmission systems**
J. Mårtensson and M. Westerlund
School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

3. **Modelling of bidirectionally pumped Raman amplifiers in optical communication systems**
L. Helczynski
School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

4. **A numerical and analytical analysis of breakdown phenomena in air filled cavities with circular symmetry**
M. Åhlander
School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

5. **Microwave breakdown in air-filled resonators for mobile telephone**
U. Jordan
School of Electrical and Computer Engineering, Chalmers University of Technology, 1999

6. **Analysis of a Generalised nonlinear Schroedinger equation with nonlinear memory**
F. Hulth and D. Nesbö
School of Electrical and Computer Engineering, Chalmers University of Technology, 2000

7. **Multidimensional optical vector solitons**
A. Carlsson and J. Malmberg
School of Electrical and Computer Engineering, Chalmers University of Technology, 2000

8. **Perturbational analysis of the generation of ghost pulses in 40 Gbit/s fibre-optic communication systems**
P. Johannisson
School of Electrical and Computer Engineering, Chalmers University of Technology, 2000

9. **A study of balanced oscillators**
M. Ferndahl
School of Electrical and Computer Engineering, Chalmers University of Technology, 2001

10. **SiC MESFET Transistors for Power Amplifiers at Microwave Frequencies**
S. Saghafi
School of Electrical and Computer Engineering, Chalmers University of Technology, 2001

11. **Two-Tire Two-Line De-embedding of Pad Parasitics in On-Wafer Device Measurements**
N. Najmi
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

12. **Resistive SiC-MESFET Mixer**
K. Andersson
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

13. **Design and Fabrication of a SiC Static Induction Transistor**
K. Dynefors
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

14. **Dispersion-Managed Solitons; Theory and Applications**
A. Johansson and P. Johansson
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

15. **Threshold level determination of multicarrier multipaction and AM suppression of multipaction in resonant cavity**
G. Li and R. Udiljak
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

16. **SiC MESFET Class E Power Amplifier**
A. Ådahl
School of Electrical and Computer Engineering, Chalmers University of Technology, 2002

17. **Cascade VCSEL Array for Analog Photonic Link**
M. Ekholm
Department of Microtechnology and Nanoscience, Chalmers University of Technology 2003

18. **Robust Microwave Amplifier Based on a Low-Noise Matched Wide-Bandgap Semiconductor Device**
R. Eriksson
Department of Microtechnology and Nanoscience, Chalmers University of Technology 2004

19. **Planar SiC Schottky Microwave Diodes**
M. Südow
Department of Microtechnology and Nanoscience, Chalmers University of Technology 2004

20. **Design and simulation of a 60 GHz MMIC downconverting double balanced Gilbert mixer using mHEMT technology**
M. Gavell
Department of Microtechnology and Nanoscience, Chalmers University of Technology 2005

21. **Design and layout of a 60 GHz MMIC power amplifier in a mHEMT technology**
N. Nöther
Department of Microtechnology and Nanoscience, Chalmers University of Technology 2005

22. **Design, Implementation, and Evaluation of a Current Mode Class-D Power Amplifier**
H. M. Nemati
Department of Microtechnology and Nanoscience, Chalmers University of Technology 2006

23. **Design and layout of a 60 GHz MMIC SSB Modulator in an mHEMT technology**
M. Abassi
Department of Microtechnology and Nanoscience, Chalmers University of Technology 2007

D. CHACH publications

Articles in refereed international journals

1. **Novel Single Device Balanced Resistive HEMT Mixers**
   K. Yhland, N. Rorsman, H. Zirath
   IEEE Trans. Microwave Theory Techn., 43, 2863 -2867, 1995
2. **Impact of spectral inverter fiber length on four-wave mixing efficiency and signal distortion**
   P.O. Hedekvist, P.A. Andrekson, K. Bertilsson
   J. Lightwave Technol., 13, 1815-1819, 1995
3. **Accurate small-signal modeling of HFET's for millimeter-wave applications**
   N. Rorsman, M. Garcia, C. Karlsson, H. Zirath
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4. **Demonstration of fiber four-wave mixing optical demultiplexing with 19 dB parametric amplification**
   P.O. Hedekvist, P.A. Andrekson
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6. **CAD Model of a Gap in a Coplanar Waveguide**
   S. Gevorgian, A. Deleniv, T. Martinsson, S, Gal'chenko, P. Linnér, I. Vendik
   Int. Journ. Microwave and Millimeter-Wave Computer-Aided Engin., 6(5), 369-377, 1996
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13. **A direct extraction formula for the FET temperature noise model**
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14. **Fiber four-wave mixing with inherent parametric amplification**
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15. **Growth and characterization of Metamorphic $In_xGa_{1-x}As$ $(0.57<x<1)$ on GaAs using InAlAs graded buffer**
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46. **Conformal Mapping of the Field and Charge Distributions in Multilayered Substrate CPWs**
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4. **Modeling and design of resistive HEMT-mixers**
H. Zirath
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5. **Millimeterwave mixers with focus on resistive FET-mixers**
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H. Zirath
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9. **Soliton transmission in PMD perturbed transmission systems**
M. Karlsson, X. Zhang, P.A. Andrekson
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10. **Fibre-based OTDM techniques**
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14. **Microwave components and circuits activity at Chalmers**
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15. **Simulation and verification of a VHF class E power amplifier based on MRF 183 LDMOS-transistor**
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16. **A variational approach to nonlinear evolution equations**
D.Anderson, M.Lisak
Nonlinear Science Festival II, Risö, Denmark, December 1-4, 1999

17. **SiC-component research**
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