



Evaluation of Mathematics, ICT and Technology (EVALMIT) 2023-2024

Self-assessment for research groups

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Institution (name and short name): University of Oslo (UiO)
Administrative unit (name and short name): Department of Informatics (IFI)
Research group (name and short name): Nanoelectronics research group (NANO)
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1. Organisation and strategy

1.1 Research group's organisation

With a staff of more than 400, The UiO Department of Informatics (IFI) is a “powerhouse” for informatics training and research in Northern Europe. It is the largest such unit in Norway and the one with the strongest international rankings. Around a comprehensive core in computer science, IFI interprets informatics in substantial breadth: from microelectronics or signal processing to participatory design or digital innovation. In 2023, IFI hosts five BSc and eight MSc study programmes, with close to 2500 students. The department is organized in four thematic sections, each of which comprising 2–5 research groups. Our group, Nanoelectronics (NANO), is part of the section for Machine Learning (MLS).

NANO originates from the research group Digitalteknikk established in 1981. Since the inception, research activity has been focused on integrated circuits and systems. In the early phase, digital microelectronics and computer architecture were dominating but over the years the research has expanded towards analog/mixed- and radio frequency (RF) systems including wireless sensing.

The group aim for an international research front in strategically selected subfields within ultra-low power and low supply voltage integrated circuits and systems design in state-of-the-art technologies. Typical application fields are biomedical engineering and wireless sensor systems. The individual staff members have a steady publication rate in international journals and conferences and an excellent track record spanning vital parts of the micro-/nanoelectronics field. The common research effort and interaction is organized as a research group to join and strengthen the individual core competences. The group is headed by an elected group leader, whereas the research projects are led by the participating staff members. State-of-the-art laboratory facilities enable advanced research at an international level and the education of highly qualified candidates for research and industry. Since 2018, 5 PhD students have graduated from the group along with 33 MSc students.

The NANO **permanent staff members** included in the evaluation are:

- **Yngvar Berg, Professor:** Returned to the group in 2018 after serving as head for microsystems department at USN. Research activity within low-power high-speed CMOS circuits and didactics within electrical engineering.
- **Philipp Häfliger, Professor:** Research focus within biomedical and space exploration instrumentation, image sensors, implantable systems, and neuromorphic electronics.
- **Kristian Gjertsen Kjelgård, Associate Professor:** Started in 2020. Research focus within RF circuit and systems design including antennas and RF filters. Ultra-wideband radar systems.
- **Tor Sverre Lande, Professor Emeritus:** Retired in 2020 after being with the group since its inception, but still active within the group in selected projects. Research focus within analog / RF CMOS focusing on ultra-wideband radar and biomedical engineering.
- **Olav Stanly Kyrvestad, Chief Engineer:** Responsible for the group advanced laboratories, EDA tools and semiconductor foundry handling (Partly on-leave in the evaluation period).
- **Dag T. Wisland, Professor,** also serving as head of the NANO research group: Returned to the group in 2017 after heading the NANO spin-off company Novelda. Research activity is focused on analog/RF CMOS particularly towards ultra-wideband radar systems and low-power time-based data converters.

Adjunct positions: Snorre Aunet (NTNU), Sumit Bagga (Novelda AS), Jørgen A. Michaelsen (Novelda AS), Sigbjørn Næss (Telenor ASA), Trygve Willassen (Sony Europe AS), Joar M. Østby (Ideas AS)

PhD-students: Mathias Tømmer, Girish Subbarao, Tohid Khanshan, Mozhdeh Nematzadeh, Steffen Nøvik, Adrian Llop Recha, Candice Quinn, Habibur Rahman, Pål Gunnar Hogganvik, Tonny Do, Kaspar Moulin (joined 2023), Farnaz Salarkia (joined 2023)

Permanent staff and PhD students have abroad stays at a regular basis at collaborating international universities like UCSD, Imperial College, Polytechnique Montreal, Michigan State University and EPFL.

Table 1. List of number of personnel by categories (end 2022)

	Position by category	No. of researcher per category	Share of women per category (%)	No. of researchers who are part of multiple (other) research groups at the admin unit	No. of temporary positions
No. of Personnel by position	Professor (1013)	3	0%	-	-
	Assoc. Prof (1011)	1	0%	-	-
	Chief Engineer (1088)	1	0%	-	-
	Adjunct Professor (20%)	1	0%	-	1
	Adjunct Associate Professor (20%) (1013)	5	0%	-	5
	Doctoral Research Fellow (1017)	10	20%	-	10

1.2 Research group's strategy

a) Describe the research group's main goals, objectives and strategies to obtain these

Following the last evaluation, the group is continuously addressing strategic goals and measures to keep a strong international position within the research field. The main goals and objectives are:

- Deliver **research beyond state-of-the art in microelectronics circuits and systems** documented in internationally recognized publication channels.
- Secure **international collaboration and visibility**.
- Enable **research-driven innovation and value-creation** in collaboration with national microelectronics industry.
- **Educate and train MSc and PhD students** for research and development relevant for microelectronics industry.

Strategies applied to address above goals and objectives:

Research beyond SotA in microelectronics circuits and systems: The group has a clear strategy and track-record in delivering novel and conceptual research. Biomedical circuits and systems is a common focus area within the group involving sensors, implants, data-converters, transceivers and ultra-low power processing. Inspired by the human nerve system, time-domain coding has been applied across several research concepts to enable differentiating robust and energy-efficient solutions. In the evaluation period, novel methods from the research group have pioneered UWB radar transceivers internationally demonstrated through a high number of publications and product innovations.

International collaboration and visibility: The group strives to explore synergies and provide visibility of research through extensive collaborations with international universities and research communities. Abroad stays and sabbaticals are utilized to establish and strengthen international relations. In the period, the group has been involved in the SUURPh program in close collaboration with UCSD where two PhDs have completed their degrees. Involvement in the UK Dementia Research Center (DRI) through providing prototypes and expertise on UWB radar sensor technology is another example. Several of the group members are actively involved in IEEE and have held several elected positions. The group also hosted IEEE NORCAS in 2020, 2021 and 2022. Coordination of the EU project 3D-MUSE can also be mentioned.

Research-driven innovation and value-creation: In the evaluation period, collaboration with national microelectronics industry has been significant and the group has been partner in several RCN-funded innovation projects with companies like Sony, Equanostic, Novelda, Onio, WellID, Rottefella, Skiplukkern. Some of these are direct or indirect spin-offs from the NANO group and to a large extent technology utilized origins from the research group. The group also coordinated an SFI application on IoT/wireless technologies in 2019 involving several microelectronics companies like Nordic Semiconductor, Omnivision, IDEAS, Novelda and Onio as partners. The application was very close to get funding, and a new application with similar topic but expanded more towards AI and sustainability is currently in preparation together with NTNU and industry partners. Professors Lande and Wisland received the Univ. of Oslo Innovation award in 2022 as a recognition of significant research-driven innovation.

Educate and train MSc and PhD students: According to a recent report ordered by RCN (<https://www.menon.no/wp-content/uploads/2023-97-The-semiconductor-industry-in-Norway.pdf>), Norwegian microelectronics industry has the second highest value-creation per employee after the oil industry. The NANO group has defined study programs and courses based on strong interaction with local industry to support the demand for competence. Several new courses have been developed during the period to adapt to such needs and most MSc/PhD students ends up in the industry after completion. Still a great challenge is recruitment to study programs significantly limiting number of graduated candidates.

b) Please describe the benchmark of the research group.

Benchmark 1: Innovation and industrial collaboration: In the past evaluation, industrial collaboration was mentioned as one of the strengths of the research group. This is also among the explicit benchmarks from the department and a pillar in the UiO strategy. In the current period, the goal has been to further strengthen research driven innovation and national visibility which has resulted in several new collaborations and increased funding through Norwegian industry. The group has directly contributed to commercialized product innovations and was awarded UiO Innovation award for 2022. Prof. Wisland has also been elected for the IEEE Circuit and Systems Society (CASS) Industrial Pioneer Award Committee. The group also coordinated an SFI application ("Centre for Wireless Technology") with industry in the period.

Benchmark 2: Research quality and internationalization: The research group is internationally recognized as a pioneer within biomedical circuits and systems among other through initiating the IEEE BioCAS conference and IEEE Transactions of Biomedical Circuits and Systems, the key journal for the community (Level 2). In the past evaluation it was recommended to direct the publication channels from conferences to journals to increase impact, in the current period the number of journal papers per faculty member per year has increased and also several publications in prestigious channels like IEEE ISSCC, IEEE JSSC and IEEE TBioCAS have been accepted. The group has further strengthened its international focus through coordination of an EU project, participation in the SUURPh program, activity within IEEE and contributions to the UK DRI center (with Imperial College) among others.

c) Describe the research group contribution to education (master's degree and/or PhD).

Norway has a strong and highly internationally recognized microelectronics industry. The need for candidates is much higher than the number of graduates demonstrating the importance of relevant education within the field. The NANO group is among very few groups in Norway offering BSc, MSc and PhD education within the field of microelectronics integrated circuit and systems design. In the evaluation period the group has been involved in four different study programs.

2018-2022: The study program **Electronics, Informatics and Technology (ELITE)** is a joint program between Informatics- and Physics depts. The NANO group recruits students from the Microelectronics and Sensors focus area and most of these students target analog-/mixed/RF integrated circuits design for their master-study. The program gives students the required background in mathematics, physics and informatics and specialization within microelectronics circuit design through specialized master- and PhD courses. It is a goal that most students do full-cycle from design, circuit prototyping and test/characterization to prepare for the industry. The challenge with the ELITE program from a microelectronics point-of-view is very limited visibility towards potential students. The program **Informatics:Robotics and intelligent Systems (I:RIS)** is mainly targeting candidates interested in robotics, machine learning (ML), FPGA- and digital circuit design. The program is shared with the Robin and DSB groups and currently most students focus on robotics and ML, with very few students targeting digital microelectronics.

2012-2018: The group recruited students from the programs ELDAT and I:NOR generally very similar to the ELITE and I:RIS programs described above, with the major difference that microelectronics was directly visible towards candidate students ensuring better recruitment

Courses: The group offers full syllabus within circuit design and microelectronics at B.Sc, M.Sc and PhD level (IN1020, IN1080, IN3170, IN5180, IN5220, IN5230, IN5240, IN5260, IN5350). Many courses are taught by adjunct staff from the industry to ensure the highest relevance and hands-on experience.

Since 2018 33 MSc-students (6.6 per year) and 5 PhD students have graduated from the NANO group.

d) Describe the support the host institution provides to the research group (i.e., research infrastructure, access to databases, administrative support etc.).

The group receives good support from the host institution related to general research and teaching activities (Project applications/reporting, IT-support/servers, PhD/study administration, HR/recruitment etc.). As Nanoelectronics research is highly experimental, the host institution has also provided the following dedicated resources managed and maintained by the research group: 1) Anechoic chamber for RF with instrumentation, 2) Faraday cage for low noise measurements, 3) General purpose microelectronics characterization labs, 4) Dedicated servers for EDA tools.

1.3 Relevance to the institutions

Describe the role of the research group within the organisation. Consider the group's contribution towards the institutional strategies and objectives and relate the group's benchmark to these.

The NANO group targets to deliver state-of-the-art research within micro-/nanoelectronics supporting overall goals of UiO, MN and IFI (Host institution). IFI strategic frameworks have been addressed as follows:

Strategy 2014-2017: Overall research goal is to deliver research of high quality at an international level documented through major international grants or SFI/SFF coordination. This is well aligned with the group strategy and benchmark **"Research quality and internationalization"** which the group has addressed through several means: 1) Publication in highly recognized journals within the field, 2) Coordination of an EU-project (3d-muse), 3) Research collaboration with leading international universities (Imperial College, UCSD, Lund University, EPFL), 4) Involvement in IEEE and organization / TPC of several conferences (ISCAS, BioCAS, NORCAS). Innovation and collaboration with business is a separate pillar and goal in the strategy which is in good alignment with the research group benchmark **"Innovation and industrial collaboration"** exemplified by 1) Partner in several industry-owned innovation projects (RCN BIA/IPN), 2) Increased direct funding from industry, 3) Direct contributions to products launched in high-volume products, 4) Awarded UiO Innovation award for 2022, 5) Coordinated an SFI application on wireless technology (Grade 6 out of 7). The strategy also identifies Medicine and Health as a priority application area which has been applied by the research group in its research activities (Biomedical circuits and systems, medical sensors, implants, welfare technology).

Strategy 2019-2021: This strategy brought forward the same fundamental goals as the previous strategy meaning that the group benchmarks are still well aligned, but in addition identified some priority subject areas. Among these Machine Learning and Artificial Intelligence was identified as the most relevant for the NANO group especially in the context of providing enabling technology and circuit designs for energy efficient edge processing. The group research within neuromorphic circuits including asynchronous spike processing techniques, applied machine learning and ultra-low voltage circuits can be mentioned.

1.4 Research group's resources

Describe the funding portfolio of the research group the last five years (2018-2022).

The group has actively worked to attract external funding through funding from international and national funding schemes. In addition, part of the strategy has been to increase collaboration and funding from industry. Examples of granted R&D projects are 1) EU project 3d-muse coordinated by Prof. Häfliger at the NANO group with CEA/LETI, ST microelectronics, Lund University, INP Grenoble/IMEP and Ideas AS as partners addressing advanced 3d packaging techniques for microelectronics, 2) RCN/NANO-2021 project WellSafe coordinated by Novelda AS addressing miniaturized radar sensors in low-cost material, 3) RCN/Petromax project GeoEnlight with WellID AS as project owner focusing on UWB radar technology in oil-/energy wells, 4) RCN/IKTPLUSS project SUPRE with Sunnaas hospital as coordinator focusing on implantable microsensors, 5) RCN/IPN project Skidx with Skiplukkern AS as coordinator focusing on sensor technology for cross-country skis. 6) RCN/NANO-2021 project Photosense with University of Southeast Norway as coordinator focusing on developing an artificial retina.

The group has also received funding through the SUURPh collaboration program with UCSD and Simula Research where three PhD projects have been funded.

The resources also include direct funding from industry (Sony AS, ONIO AS, Novelda AS, Equanostic AS)

The group has also been involved in UiO strategic programs LATTICE, CINPLA, MEDIMA, 4DSpace and LabonChip funding several PhD students.

Table 2. Describe the sources of R&D funding for the research group in the period 2018-2022.

	2018 (kNOK)	2019(kNOK)	2020 (kNOK)	2021(kNOK)	2022(kNOK)
Basic funding	5201	5751	4631	5172	5337
Funding from industry and other private sector sources	150	183	200	350	816
Commissioned research for public sector					
Research Council of Norway	1219	1467	1317	68	1250
Grant funding from other national sources	1050	1100	1150	1200	1250
International funding e.g. NIH, NSF, EU framework programmes	1335	1335	1335	1335	1335
Other					

1.5 Research group's infrastructures

a) *Describe which national infrastructures the research group manages or co-manages.*

The NANO group manages highly specialized electronics laboratories part of NORFAB network widely used by external users:

- Anechoic chamber with related instrumentation for test and characterization of antennas and radio modules. Covers frequency range up to 26 GHz with high dynamic range.
- Faraday cage for low-noise measurements including probe station and vibration damping.
- LPKF laser for microelectronics device manipulation.

The labs are easily available to external users through the UiO BookitLab system and NANO group engineer(s) and faculty members are directly involved to ensure quality, but also to catalyze wider collaboration in research projects. According to users, our labs are the best equipped for this purpose in Norway. Examples of users/projects:

- FFI – Drone antenna research
- FFI – Norsat/AISSat Antenna development
- Novelda AS – Miniaturized UWB antennas
- WellID AS – Oil well mud characterization
- UiO/The Hybrid Hub center – Organ-on-a-chip

- VitalThings AS – Sleep / patient monitor
- Equanostic AS – UWB sensor systems
- Skiplukkern AS – Cross-country ski adaption sensor system

b) Describe the most important research infrastructures used by the group.

Microelectronic research requires high-cost infrastructures. In addition to the group managed national resources described above, the group also has several other electronics laboratories managed by the group which are critical for conducting the research.

As a mean to support microelectronics research in Europe, the European Commission funds low-cost and easy access infrastructure through Europractice to support EDA-tools for integrated circuit design, Multi-Project Wafers (MPW) for prototype manufacturing and specialized courses for researcher training. This infrastructure is critical for NANO research activities. The group also uses clean-room facilities at MiNaLab and MEMS fabrication through NorFAB. Some projects also rely on animal trials and the IBV “Dyrestall” has been used for such research.

1.6 Research group’s cooperations

Table 3. Reflect on the current interactions of the research group with other disciplines, non-academic stakeholders and the potential importance of these for the research (e.g. informing research questions, access to competence, data and infrastructure, broadening the perspectives, short/long-term relations).

Interdisciplinary (within and beyond the group)	Microelectronics systems design serves as enabling technology for a large variety of applications supporting important society needs. The group considers interdisciplinary research of high importance to push state-of-the-art and define research questions. NANO has been involved in several UiO strategic programs: Organ on Chip and Nano-Devices (2017-2020), Cinpla – Neural recording (2014-2019), 4d-space – Space technology (2014-2023), Medima – Medical imaging (2015-2020), Lattice – Earth science (2016-2021). These programs have financed several PostDocs and PhDs with shared supervision across disciplines and contributed to co-authored publications and new relations nurturing further collaboration. The group has also collaborated with hospitals (Sunnaas and OUS) bringing forward new sensor technology addressing health challenges like heart diseases, diabetes and lack of bladder control. Another area of collaboration has been within the geo/oil-sector where a 4D-caliper for oilwells have been developed utilizing UWB radar expertise from the group (WellID). Within this area a collaboration with University of Pavia has also been established for snow assessment.
Collaboration with other research sectors e.g. higher education, research institutes, health trusts and industry.	As described under section 2.2, the research group has an extensive collaboration with industry documented by tangible results. This is considered critical for motivating research and contribute to value creation. The group also considers collaboration with other national universities and research institutes (NTNU, USN, SINTEF, FFI, Simula) as important to support addressing larger research challenges and to strengthen Norwegian impact within the research field.

	International collaboration is considered crucial for our research activity to get access to the top researchers, to explore and new research opportunities and ensure a high international level of the research. The group has prioritized to establish long-lasting relations with a few leading institutions where exchange of researchers is also considered important. Key collaborators are Imperial College, UCSD, Lund university, CEA-Leti.
<u>Transdisciplinary</u> (including non-academic stakeholders) <i>Transdisciplinary research involves the integration of knowledge from different science disciplines and (non-academic) stakeholder communities with the aim to help address complex societal challenges.</i>	Over several years, the NANO group has brought forward unique UWB radar sensor technology applied for different applications. The group had performed significant research on applying such technology within healthcare. Through collaboration with Imperial College, the NANO radar sensors has been included as one of the key sensing platforms applied in the UK Dementia Research Institute collecting more than 800 researchers distributed across transdisciplinary research centres all targeting to improve the lives of people with dementia. Link to the Care Research & Technology lab within DRI: https://ukdri.ac.uk/team/timothy-constandinou . Link to entire centre: https://ukdri.ac.uk .

2. Research quality

2.1 Research group's scientific quality

Describe the research profile of the group and the activities that contribute to the research group's scientific quality. Consider how the group's work contributes to the wider research within the group's field nationally and internationally.

The group has evolved to an international level within several disciplines. During the evaluation period, widely recognized contributions have been made within (but not limited to) the following research fields:

- Novel solutions for impulse radio resulting in successful commercialization of CMOS UWB radar sensors in high-volume products. The concepts brought forward through this research has pioneered UWB sensors internationally and published at the prestigious IEEE ISSCC-conference (2017 and 2024). This research also includes biomedical applications and system / antenna design.
- Low-power, low-voltage digital system design exploring novel fault-tolerant design principles targeting energy-harvesting IoT applications.
- Biomedical instrumentation for glucose monitoring including neuromorphic silicon system design.
- Novel solutions for sensor interfacing exploring frequency coding. One of the lowest power analog-to-digital converters available has been reported.

Ultra-Wideband Impulse Radio and Impulse Radar (Lande, Wisland, Kjelgård, Bagga)

We pursue novel integrated radio solutions in standard nanoelectronics that facilitate inexpensive wireless systems and are easily combined with sensors and/or microprocessors. The Continuous-Time Binary-Value (CTBV) design paradigm is explored for implementing impulse radio ultra-wideband (IR-UWB) systems. As a related field, short-range radar with precise localization and electromagnetic cameras using beamforming are under investigation. The first single-chip CMOS UWB radar reported in the literature is exploring CTBV design.

Energy-efficient, low-voltage sensor interfaces and processing logic CMOS (Wisland, Berg, Aunet, Michaelsen)

The research is focused on ultra-low voltage analog and digital CMOS circuits. Analog-to-digital converters utilizing time-domain signal coding to allow for ultra-low supply voltages based on the Frequency Delta-sigma Modulator (FDSM) concept developed by the NANO group. Digital logic styles and analog circuits are also explored for mixed signal design operating at supply voltages down to sub-100mV. The target is to enable IoT nodes operating on harvested energy.

Neuromorphic Electronics and Biomedical Implants (Häfliger, Lande, Østby)

Neuromorphic electronics mimics operation principles of the nervous system, resulting in very different characteristics compared to more traditional electronics: e.g. sub-threshold operation inspired by the energy efficiency of biological organisms, and biocompatible signaling, which also suggests using them in implants. The project GlucoSense/SenseCell concerned itself with a micro-implant for continuous blood glucose monitoring, with a tremendous potential impact for millions of diabetes patients worldwide.

CMOS Image sensors (Häfliger, Willassen)

Since the triumph of CMOS 'active pixel sensors' (APS) at the company Photobit, Oslo has hosted research centers at the forefront of CMOS Image Sensor (CIS) innovation, and today the world's biggest (SONY) and 3rd biggest (OmniVision) suppliers of CIS maintain R&D centers in Oslo with close ties to the NANO-electronics group. NANO complements the industrial R&D of the world's leading consumer products with more daring and experimental developments of bio-inspired vision sensors, providing some basic image processing functions already in the pixels and event-based read-out.

NANO research contributions have been recognized through two best paper awards (IEEE BioCAS-2016, IET LAPC-2016), one technology innovation award (IEEE ISSCC-2018) and the University of Oslo Innovation Award in 2022. Professors Berg and Häfliger are also listed in the Stanford Elsevier list of the 2% most cited scientists globally.

Part of the group strategy is a strong international engagement and exposure in the IEEE Circuits and Systems (CAS) society, where several staff members serve in central positions. IEEE Fellow Prof. Lande has been on the CAS society's board of governors and IEEE CAS Vice-President of Conferences. Prof. Häfliger has chaired IEEE CAS Biomedical Circuits and Systems technical committee. Prof. Wisland is member of IEEE CAS Industrial Pioneer Committee, IEEE CAS ASP-TC and BioCAS-TC. He has also contributed significantly to IEEE and ETSI UWB standards and is a BoD member of UWB Alliance.

The group has been and is involved in several research projects funded by EU and the Research Council of Norway (RCN) and is actively participating in several new proposals including an SFI. Scientific quality is also documented through the group publication list including several high-quality channels.

Please add a link to the research group's publication list at the research group's website

<https://www.mn.uio.no/ifi/english/about/strategy/evalmit/nano.html>

Table 4. List of projects

Instructions: Please select 5-10 projects you consider to be representative/the best of the work in the period 1 January 2012 – 31 December 2022. The list may include projects lead by other institutions nationally or internationally. Please delete tables that are not used.

Project 1: <i>RCN: PhotoSense: The interaction of photosensitive proteins with microfabricated sensor arrays (2022 – 2026)</i>	Project owner(s) (project leaders organisation)	University of Southeast Norway (USN)
	Total budget and share allocated to research group	12M NOK / 3.6M NOK
	Objectives and outcomes (planned or actual) and link to website	Photosense will seek to develop a novel artificial retina, built around the photosensitive protein, bacteriorhodopsin, which represents the utmost example of a «bottom-up» approach and the ideal design of modern nanotechnology. This project will seek to develop technology that may restore vision and thereby benefit millions of people worldwide that are suffering from retinal degenerative diseases. https://www.usn.no/english/research/our-research-centres-and-groups/technology/biomems/the-interaction-of-photosensitive-proteins-with-microfabricated-sensor-arrays-photosense
Project 2: <i>EU: 3D-MUSE: System-in-Cube' (SinC) 3D integrated circuit design in emerging ultra dense sequential/monolithic 3D CMOS technology. (2018 – 2022)</i>	Project owner(s) (project leaders organisation)	University of Oslo (UiO)

	Total budget and share allocated to research group	3.8M EUR / 590k EUR
	Objectives and outcomes (planned or actual) and link to website	See www.3dmuse.eu for details on objectives and outcomes.
Project 3: <i>RCN: WellSafe: Home wellness and safety sensor utilizing new material technology for condensed. MIMO antenna implementation (2017 – 2023)</i>	Project owner(s) (project leaders organisation)	Novelda AS
	Total budget and share allocated to research group	20M NOK / 3.2M NOK
	Objectives and outcomes (planned or actual) and link to website	The primary objective was a new material technology enabled fully integrated electromagnetic MIMO sensor for monitoring presence, location, and vital signs of people. The outcome was fully functional prototypes later resulting in high-volume products.
Project 4: RCN: SKidx: Platform for classification and characterization of ski properties for cross-country skis (2022 – 2025)	Project owner(s) (project leaders organisation)	Skiplukkern AS
	Total budget and share allocated to research group	21M NOK / 3M NOK
	Objectives and outcomes (planned or actual) and link to website	The project aims to develop new methodology and technology for personalization of cross-country skis. The research will focus on the development of measurement techniques and sensors for better

		characterization of skis when they are to be selected for the individual skier.
Project 5: <i>RCN: Supre: Novel health services using implantable sensors connected to wireless applications (2015-2022)</i>	Project owner(s) (project leaders organisation)	Sunnaas hospital
	Total budget and share allocated to research group	11.2 MNOK / 1.2 MNOK
	Objectives and outcomes (planned or actual) and link to website	The main objective is to develop novel health services for patients with dysfunctional urinary bladder. The new service will provide for improved patient health and quality of life. The outcome of the project was implantable sensors tested in human trials.
Project 6: <i>RCN: GeoEnlight Pilot</i>	Project owner(s) (project leaders organisation)	WellID AS
	Total budget and share allocated to research group	3.7 MNOK / 600k NOK
	Objectives and outcomes (planned or actual) and link to website	Caliper for 4D oil-well imaging. The objective of the GeoEnlight Pilot is developing and piloting a corescanner that can accurately identify lithology, fractures and oil saturation. See https://wellid.no/technology for resulting product.

Project 7: <i>RCN: Ventricorder: Cardiac Monitoring – The Ventricorder Product (2014 – 2017)</i>		Project owner(s) (project leaders organisation)	Novelda AS
	Total budget and share allocated to research group	37MNOK / 1.4MNOK	
	Objectives and outcomes (planned or actual) and link to website	The primary objective is a new medical device, Ventricorder , which can be used by patients with cardiovascular diseases (CVD) to perform cardiac self-monitoring anywhere and anytime. The outcome was a sensor prototype tested and characterized against gold standards.	

Table 5. Research group's contribution to publications

Publication 1: "3D Printed Wideband Microwave Absorbers using Composite Graphite/PLA Filament,"	Authors (Please highlight group members)	Kjelgard K.G., Wisland D.T., Lande T.S.
<i>48th European Microwave Conference (EuMC)</i> , Madrid, Spain, 2018, pp. 859-862, doi: 10.23919/EuMC.2018.8541699.	Short description	In this paper we present a method for designing microwave absorbers using 3D printing of conductive plastic. The principle is demonstrated with design and characterization of absorber structures using NANO laboratory facilities.

	Research group's contribution	The entire project / paper originates from the NANO group.
Publication 2: “Vital sign monitoring through the back using an UWB impulse radar with body coupled antennas”, <i>IEEE Transactions on Biomedical Circuits and Systems</i> , vol. 12, no. 2, pp. 292-302, April 2018, doi: 10.1109/TBCAS.2018.2799322.	Authors (Please highlight group members)	Schires E., Georgiou P., Lande T.S.
	Short description	Early publication of successful body-coupled radar vital sign sensing using UWB technology developed and prototyped at our group. T.S. Lande contributed with conceptualization, method, supervision, validation and Writing – review & editing.
	Research group's contribution	Conceptualization on measuring radar instrument and applied sensing method.
Publication 3: “A Miniaturized Two-Axis Ultra Low Latency and Low-Power Sun Sensor for Attitude Determination of Micro Space Probes” <i>IEEE Transactions on Circuits and Systems I: Regular Papers</i> , vol. 65, no. 5, pp. 1543-1554, May 2018, doi: 10.1109/TCSI.2017.2763990.	Authors (Please highlight group members)	Farian L., Häfliger P., Leñero-Bardallo J.A.
	Short description	The paper presents a sun sensor with novel (bio-inspired) operation principle. Sun sensors are used for attitude determination on space vehicles by pinpointing the position of the sun as a reference. Particular for this realization is a high degree of miniaturization, low power, high speed and extremely low latency. Commercialization is underway by the company Eidel (https://eidel.no/en/product/miniaturized-sun-sensor/)

	Research group's contribution	The entire project has been conducted at the NANO group, L. Farian has been a PhD, and J.A. Leñero-Bardallo a postdoc. P. Häfliger is a professor at the group. A related patent has later been licenced to Eidel.
Publication 4: Combining biophysical modeling and deep learning for multielectrode array neuron localization and classification, <i>Journal of Neurophysiology</i> , 120 (3), pp. 1212 – 1232.	Authors (Please highlight group members)	Buccino A.P. , Kordovan M., Ness T.V., Merkt B., Häfliger P.D. , Fyhn M., Cauwenberghs G., Rotter S., Einevoll G.T.
	Short description	The paper proposes a method of using extracellular multi electrode array recordings in the brain to localize individual neurons.
	Research group's contribution	A. P. Buccino has been a Phd student at the group in the SUURPH collaborative program between UiO, the SIMULA research centre and UCSD (USA). He has been the main contributor to the paper. P. Häfliger has been a supervisor and has been substantially involved in conceptualization and methodology, as well as funding acquisition, project administration and reviewing and editing.
Publication 5: A CMOS Multi-Electrode Array for Four-Electrode Bioimpedance Measurements, <i>IEEE Transactions on Biomedical Circuits and Systems</i> , vol. 16, no. 6, pp. 1276-1286, Dec. 2022, doi: 10.1109/TBCAS.2022.3214243	Authors (Please highlight group members)	Nøvik S., Drageseth M.F., Grøndalen M.B. , Nilsen O., Krauss S.J.K., Martinsen Ø.G., Häfliger P.D.

	Short description	The paper presents a micro-electrode array specifically tailored for 4-electrode measurements of bio-impedance, for cell cultures and organs-on-chip.
	Research group's contribution	Conceptualization by S. Nøvik (PhD candidate), P. Häfliger (prof.), and Ø.G. Martinsen (prof.). S. Nøvik and M. F. Drageseth (MSc candidate) have been the main responsible for the system implementation and initial verification. S. Nøvik and M.B. Grøndahlen have taken on more detailed system characterization later on. S.J. K. Krauss has been the main responsible for funding acquisition. Supervision by P. Häfliger, Ø. G. Marinsen, and O. Nilsen. Everybody has been involved in review and editing. Main author has been S. Nøvik.

Publication 6: Dynamic Microwave Imaging of the Cardiovascular System Using Ultra-Wideband Radar-on-Chip Devices.	Authors (Please highlight group members)	Lauteslager, Timo; Tømmer, Mathias; Lande, Tor Sverre & Constandinou, Timothy G. (2022).
IEEE Transactions on Biomedical Engineering. ISSN 0018-9294. 69(9), s. 2935–2946. doi: 10.1109/TBME.2022.3158251.	Short description	Early report of dynamic in-body radar imaging using MIMO UWB radar with high efficiency body-coupled antennas.
	Research group's contribution	The results are ground-breaking exploring blood vessel dilation for improved image quality. Tømmer contributed with resources (instrumentation) and Lande with conceptualization, method, supervision and Writing – review & editing.

Publication 7: A 118-mW pulse-based radar SoC in 55-nm CMOS for non-contact human vital signs detection	Authors (Please highlight group members)	Nikolaj Andersen, Kristian Granhaug, Jørgen Andreas Michaelsen, Sumit Bagga, Håkon A Hjortland, Mats Risopatron Knutsen, Tor Sverre Lande, Dag T Wisland
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IEEE Journal of Solid-State Circuits, vol. 52, no. 12, pp. 3421-3433, Dec. 2017, doi: 10.1109/JSSC.2017.2764051.	Short description	First published fully self-contained CMOS UWB radar System-on-Chip
	Research group's contribution	The NANO group contributed with conceptualization, method, supervision, validation and writing – review & editing.

Publication 8: "ISFETs in CMOS and Emergent Trends in Instrumentation: A Review,"	Authors (Please highlight group members)	N. Moser, T. S. Lande , C. Toumazou and P. Georgiou,
<i>IEEE Sensors Journal</i> , vol. 16, no. 17, pp. 6496-6514, Sept.1, 2016, doi: 10.1109/JSEN.2016.2585920.	Short description	Review paper on ISFET chemical sensing technology for system-on-chip integration. The Imperial contribution in this review is the method developed enabling large chemical sensing arrays.
	Research group's contribution	T.S. Lande has contributed with conceptualization, method, supervision and Writing – review & editing.

Publication 9: Coherent UWB Radar-on-Chip for In-Body Measurement of Cardiovascular Dynamics	Authors (Please highlight group members)	Lauteslager T., Tømmer M. , Lande T.S. , Constandinou T.G.
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<i>IEEE Transactions on Biomedical Circuits and Systems</i> , vol. 13, no. 5, pp. 814-824, Oct. 2019, doi: 10.1109/TBCAS.2019.2922775	Short description	UWB Radar-on-Chip for In-Body Measurement of Cardiovascular Dynamics
	Research group's contribution	Tømmer contributed with conceptualization on antenna part + resources (instrumentation) and Lande with conceptualization, method, supervision.

Table 6. Please add a list with the research groups monographs/scientific books. Max 10 listed: title, first three authors et al and link to webpage (if any). Please delete lines which are not used.

1	James D. Taylor, Dag T. Wisland , “Novelda Nanoscale Impulse Radar”. Book chapter in James D. Taylor, “Ultrawideband Radar – Applications and Design”, CRC Press, 2012/2017, https://doi.org/10.1201/b12356
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2.2 Research group’s societal contribution

Describe the societal impact of the group’s research. Consider contribution to education, economic, societal and cultural development in Norway and internationally.

The NANO group has a long-lasting and strong relation to Norwegian semiconductor and technology industry also formalized through several industry funded projects. The collaboration has led to commercialization of ideas with later market deployment. Below are examples of collaborators and impact:

Industrial collaboration / Innovation

- Onio: Battery-less IoT tag based on energy harvesting – Founded by past NANO M.Sc student.
- WellID: 4D caliper for oil wells based on UWB radar technology originating from the NANO group.
- Novelda: International pioneer and leader on UWB radar sensors and modules – NANO spin-off
- Equanostic: UWB radar and ultrasound sensor modules – Novelda spin-off
- Sony / Omnivision: CMOS image sensors – several projects with NANO group
- IDEAS: Advanced space electronics – originally UiO spin-off. Several projects
- Eidel: Developing sun sensor for space missions as a product, licensed from UiO.
- Lambdavis Inc.: Developing retina implant through RCN project.

Addressing health challenges

- University of Southeast Norway: Development of artificial vision based on NANO research on neuromorphic circuits.
- Sunnaas hospital: Implantable bladder pressure sensor interface.
- Imperial College/UK Dementia Research Institute (DRI): Improving quality of life of dementia patients through using UWB radar technology originating from NANO

Table 7. The research group's societal contribution, including user-oriented publications, products (including patents, software or process innovations

Instructions: Please select 5–10 of your most important user-oriented publications or other products from the last 5–10 years with emphasis on recent publications/products. For each item, please use the following formatting: Please delete lines which are not used.

No.	Name of publication/product	Date of publication/product	Link to the document
1	Novelda X7 radar SoC, accepted for publication in: IEEE ISSCC-2024 N. Andersen, S. Bagga, J.A. Michaelsen, H.A. Hjortland, L. Leene, T. Skår, E. Stenersen, and D.T. Wisland, "A 79.7μW Two-Transceiver Direct-RF 7.875GHz UWB Radar SoC in 40nm CMOS", 2024 IEEE International Solid-State Circuits Conference (ISSCC), San Francisco, CA, USA, 2024, Accepted for publication.	Product released for pilot customers in 2023.	https://www.prnewswire.com/news-releases/novelda-introduces-new-ultra-low-power-uw-b-proximity-sensor-featuring-100w-power-consumption-making-it-the-worlds-lowest-power-radar-301850423.html https://www.prnewswire.com/news-releases/novelda-announces-new-ultra-wideband-child-presence-detection-cpd-sensor-enabling-lifesaving-sensing-for-automotive-and-iot-markets-302007549.html http://submissions.mirasmart.com/ISSCC2024/PDF/ISSCC2024AdvanceProgram.pdf
2	Novelda X4 radar SoC, published in: IEEE JSSCC-2017, IEEE ISSCC-2017 N. Andersen, K. Granhaug, J.A. Michaelsen, S. Bagga, H.A. Hjortland, M.R. Knutsen, T.S.Lande, and D.T. Wisland, "A 118-mW Pulse-Based Radar SoC in 55-nm CMOS for Non-Contact Human Vital Signs Detection," in IEEE Journal of Solid-State Circuits, vol. 52, no. 12, pp. 3421-3433, Dec. 2017, doi: 10.1109/JSSC.2017.2764051.	Product released in 2018 and later incorporated in radar modules and industrial / consumer products (Steinel True Presence sensor, Miku babymonitor, Lenovo laptops etc.). Scientific papers were published in 2017. The X4 radar SoC also received the "Technology Innovation Award" at ISSCC-2018.	https://ieeexplore.ieee.org/document/8106658 https://ieeexplore.ieee.org/document/7870299

	N. Andersen, K. Granhaug, J.A. Michaelsen, S. Bagga , H.A. Hjortland, M.R. Knutsen, T.S.Lande, and D.T. Wisland. , "A 118-mW 23.3-GS/s dual-band 7.3-GHz and 8.7-GHz impulse-based direct RF sampling radar SoC in 55-nm CMOS," 2017 IEEE International Solid-State Circuits Conference (ISSCC), San Francisco, CA, USA, 2017, pp. 138-139, doi: 10.1109/ISSCC.2017.7870299.		
3	Eidel Patent Solsensor	Product development ongoing, licence agreement between UiO and Eidel in June 2018. Patent application in March 2018.	https://eidel.no/en/product/miniaturized-sun-sensor/ UK patent application 'light source position sensor', GB1803670.7, https://www.ipo.gov.uk/pro-types/pro-patent/pro-p-os/pro-p-journal/p-pi?startYear=2018&startMonth=April&startDay=25th+-+6727&endYear=2018&endMonth=April&endDay=25th+-+6727&filter=GB1803670.7&perPage=10&sort=Date+Lodged
4	Antenna Laptop HPD modules	Antennas developed during WellSafe project enabled world's smallest UWB module	https://medium.com/novelda-news/two-new-lenovo-laptops-with-the-novelda-hpd-sensor-launched-at-ces-2021-c82fc67f3ee7
5	Novelda X2 radar SoC, published in: D. T. Wisland , K. Granhaug, J. R. Pleyrn, N. Andersen, S. Støa and H. A. Hjortland, "Remote monitoring of vital signs using a CMOS UWB radar transceiver", Proc. NEWCAS, pp. 1-4, Jun. 2016.	Product released in 2016 and later deployed in 4D caliper for oil drilling among other	https://wellid.no/technology https://ieeexplore.ieee.org/document/7604841

3. Challenges and opportunities

Information about the strengths and weaknesses of the research group is obtained through the questions above. In this chapter, please reflect on what might be the challenges and opportunities for developing and strengthening the research and the position of the group.

The NANO group is well established and internationally recognized within its key research areas. The group has also documented strong contributions to innovation through establishing spin-offs and significant collaboration with Norwegian microelectronics industry. At the same time, the group is about the same size now as it was in the start of the evaluation period and has limited national visibility beyond the microelectronics industry. The number of MSc students has also been reduced the last years. Part of this can probably be explained by a wider trend where hardware related studies are less popular compared to for instance machine learning (ML) and artificial intelligence (AI). Until recently ML/AI researchers have only to a limited degree recognized the fact that microelectronics research is among the most important enablers for ML/AI. This is however in the phase of change partly driven by sustainability goals where energy efficiency and carbon footprint are fundamental constraints to address moving forward. This also drives the need for distributed AI processing in IoT nodes utilizing edge processing where all aspects of microelectronics and sensor research becomes key especially in the framework of battery-less systems utilizing energy harvesting. These requirements will challenge and disrupt microelectronics research in the time to come and represents a huge opportunity for the NANO group in particular given its expertise on energy-efficient circuits and systems and neural processing techniques. The strong link to Norwegian microelectronics industry is also a good opportunity to convey such research into products and position Norway as a leading nation within this field.

There is however also a large threat potentially undermining this opportunity, which is lack of students pursuing studies within this field. For several years, number of graduated students pursuing microelectronics has been going down only marginally supporting industry needs. Although the Norwegian microelectronics industry has the second largest value creation per employee after oil-industry, general visibility is low. For UiO, this is even more severe as the latest revision of study-programs in 2018 resulted in microelectronic research at UiO is no longer visible towards relevant candidates but hidden within broader programs with naming not conveying this possibility of study. This is important to address nationally and particularly within UiO. Researchers at the NANO group is now working together with researchers at NTNU in Trondheim and Norwegian microelectronics industry with a common SFI proposal to bring forward enabling technology for AI/ML and to secure better national visibility.

Norway also has a strong industry and research community on material science and sensor technology complementary to microelectronics offering obvious synergies. EU and US are investing heavily in microelectronics research and infrastructure to strengthen their position internationally and to be more robust towards geopolitical threats ("Chip Act"). This is also a great opportunity for Norway to position its research activities and industry, but it requires actions and resources to secure education of sufficient number of good candidates.