Application

2015-03-31

2015-04294 **Dabrowski, Jerzy** **NT-14**

Information about applicant

Name: Jerzy Dabrowski

Doctorial degree: 1987-03-17

Birthdate: 19521016

Academic title: Docent

Gender: Male

Employer: No current employer

Administrating organisation: Linköpings universitet

Project site: Institutionen för systemteknik (ISY)

Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): Hardware impairments-aware optimization of Massive MIMO systems

Project start: 2016-01-01

Project end: 2019-12-31

Review panel applied for: NT-14, NT-13

Classification code: 20203. Kommunikationssystem

Keywords: massive MIMO, hardware impairments, performance optimization, nonlinear distortion, noise and phase noise

Funds applied for

Year:	2016	2017	2018	2019
Amount:	1,124,000	1,144,000	1,173,000	1,214,000

Descriptive data

Project info

Project title (Swedish)*

Hårdvarunedsättningar-medveten optimering av Massiv MIMO system

Project title (English)*

Hardware impairments-aware optimization of Massive MIMO systems

Abstract (English)*

The emerging next generation communication systems (5G) is expected to rely on large-scale multiple-input multiple-output technology, also referred to as Massive MIMO. This technology unlike widely exploited conventional MIMO makes use of large antenna arrays at base stations (BS) and thereby it can serve many users concurrently. By exploiting antenna diversity and spatial multiplexing technique (beamforming) it can provide data throughputs that largely surpass those of the contemporary cellular systems both on the forward and reverse link. The beamforming technique allows for significant power savings at BS that results in high power efficiency since power can be transmitted in spatial directions. Also the transmit power in the reverse link can be scaled down by a factor O(sqrt(M)) owing to antenna diversity where M is the number of base station antennas. The information capacity of a massive MIMO system scales with M due to channel state information and ideally it is only limited by so called pilot contamination (due to noise and inherent interference). In reality the system performance can be largely limited by impairments in transceivers at BS and user terminals. The project aims to explore physical models of the system building blocks to capture the possible impairments like nonlinear distortion, intermodulation, noise, phase noise, and their effect on the system performance. Diverse modeling and simulation techniques will be employed to handle the system using different abstraction levels. Expertise in information theory, optimization algorithms, and RF front-end design will be combined in the project to devise optimal Massive MIMO solutions. The project will start with identification of physical models of the critical RF building blocks of the system. In the following two years various transceiver impairments will be investigated and the physical models will be adopted for system level simulation. Impact of the respective impairments on the overall performance will be analyzed to identify the tradeoffs. Beginning from the second half of the third year a systematic design methodology for Massive MIMO transceivers will be developed and verified by simulation of practical systems. The proposed research may have an impact on future Massive MIMO systems both theoretically and practically. Theoretically, we hope to identify the existing tradeoffs and physical limitations of those systems evoked by non-idealities in the RF system blocks. Practically, we aim to develop a methodology for designing the RF front-ends suitable for this kind of applications.

Popular scientific description (Swedish)*

Nästa generation av kommunikationssystem (5G) förväntas förlita sig på storskalig flerantenn-teknologi, som vanligen brukar benämnas Massiv MIMO (multiple-in multiple-out). Till skillnad från konventionell MIMO, så använder denna teknologi stora antenn-arrayer på basstationer och kan på det viset betjäna många användare samtidigt. Genom att utnyttja antenn-diversitet och spatial multiplex så kan tekniken tillhandahålla datatakter som vida överskrider dagens cellulära system både i upplänk och i nerlänk. Lobformning möjliggör en betydande effektbesparing i bassationerna som resulterar i effektivt utnyttjande av sändareffekt eftersom denna effekt kan transmitteras i spatiala riktningar. Vidare kan effekten i upplänken skalas ner med en faktor O(sqrt(M)) pga antenndiversitet, där M är antalet antenner i basstationen. Informationskapaciteten av ett massivt MIMO-system skalar med M på grund av kanaltillståndet, och idealt begränsas det bara av så kallad pilot-kontaminering (pga. brus och inbyggd störning). I verkligheten kan systemets uppförande kraftigt begränsas av hårdvarudefekter i både basstation och användarnas terminaler. Projektet avser att undersöka fysikaliska modeller av systemets byggblock för att fånga in möjliga defekter, som t.ex. olinjär distorsion, intermodulation, brus, fasbrus och deras inverkan på systemets uppförande. Diverse modellerings- och simuleringstekniker kommer att användas för att hantera systemet i olika abstraktionsnivåer. Expertis inom informationsteori, optimering och design av RF front-ends kommer att kombineras för att konstruera optimala lösningar för massiv MIMO.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*	2. Teknik > 202. Elektroteknik och elektronik > 20203. Kommunikationssystem

Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

massive MIMO

Keyword 2*

hardware impairments

Keyword 3*

performance optimization

Keyword 4

nonlinear distortion

Keyword 5

noise and phase noise

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

The applicant declares that the project work will be carried out according to the acknowledged university practices. The available funds will be spent to achieve the best possible research results. The PhD students will be supervised and guided appropriately, and will be shown how to perform research in a decent way.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Hardware impairments-aware optimization of Massive MIMO systems

Purpose and aims

The objective of this project is to investigate Massive MIMO systems in terms of various limiting factors that originate from physical impairments in the system hardware. Massive MIMO is considered as a key technology for the next generation communication systems. The project will be focused on effects of RF transceivers impairments (non-idealities) which directly decide the quality of the provided wireless links. By introducing realistic models of the transceivers it will be possible to derive reliable performance estimates of the system such as data throughput and power efficiency, find tradeoffs among critical factors, and finally develop design methodology for transceivers operating the Massive MIMO systems.

Survey of the field

The emerging next generation communication systems (5G) is expected to rely on large-scale multiple-input multiple-output technology, also referred to as *Massive MIMO* or *large multi-user* (*MU*) *MIMO* [6-8]. Massive MIMO unlike widely exploited conventional MIMO systems [1,2] makes use of large antenna arrays at base stations (BS) and thereby it can serve many users concurrently. By exploiting antenna diversity and spatial multiplexing technique (beamforming) it can provide data throughputs that largely surpass those of the contemporary cellular systems both on the forward and reverse link. The beamforming technique allows for significant power savings at BS that results in high power efficiency since power can be transmitted in spatial directions. Also the transmit power in the reverse link can be scaled down owing to antenna diversity. In particular, in [5] the authors show that the total power from the user terminals can be reduced by a factor $O(\sqrt{M})$ without sacrificing per-user data rate when the number of BS antennas is increased from 1 to M. Clearly, interference at the user terminals can be reduced in this way as well.

The information capacity of a massive MIMO system scales with the number of antennas at BS but the corresponding number of users it serves must be much less in order to acquire and process the channel state information (CSI) on line. In a fast-fading environment the system coherence-time can be a limiter in this case. In the time-division duplex (TDD) scenario the CSI can be derived from reverse-link *pilots* and the related training overhead scales linearly with the number of user terminals. For the system operation the pilots are essential since they provide a BS with an estimate of the forward channel owing to the *channel reciprocity*. It has been shown that with increased number of BS antennas the effects of Gaussian noise and uncorrelated intra- and inter-cell interference tend to disappear asymptotically, and the remaining predominant impairment is the correlated inter-cell interference due to *pilot contamination* [3,4], i.e., the correlated interference due to reusing the same pilot signals in other cells (that is similar to “pilot pollution” in CDMA systems).

This effect creates a challenge for the reverse-link capacity that is exacerbated by the demand for wideband and high mobility communication. Another challenge is in the complexity of scheduling procedure to select a group of user terminals which can be served concurrently. The related overhead of the corresponding search algorithms scales exponentially with the group size [1].

The particular objective in this case is to maximize a practical performance index such as *sum-rate* in the broadcast channel while minimizing the transmitted power. Alternatively an upper bound placed on the transmitted power can be considered as a design constraint. To attain optimum design various pre-coding and feedback schemes relying on CSI have been proposed; most of them adopted from the conventional MIMO technology. The most popular pre-coding schemes are: minimum mean square error (MMSE), zero forcing (ZF), dirty page coding (DPC) or Tomlinson-Harashima algorithm, all having their pros and cons [1,6-8]. The popular feedback techniques include vector quantization, dimension reduction, adaptive feedback, and opportunistic spatial division multiple access.

Most of the results in Massive MIMO have been achieved by employing information theory supported by simple simulation models. Practical experiments using test-bed setups have begun to emerge as well [24,25]. As of today, both the experimental work and the underlying theory are far away from being considered mature. Rather they pave a way for an extensive research in this field to provide practical design solutions for the next generation communication systems.

Even though the Massive MIMO as a research topic has intensively been investigated, not much attention has been paid to the physical layer models accounting for possible impairments in the BS and user terminal transceivers. The related work is briefly summarized below.

In [19] the phase noise (PN) effect in a single-carrier Massive MIMO system is analyzed in synchronous and asynchronous BS scenario. Using the time-reversal maximum-ratio combining strategy (TR-MRC) the achievable sum-rates are shown to suffer from PN for typical SNR values while for low SNR they benefit from the number of BS antennas with a factor $O(\sqrt{M})$ like for the PN-free system [3]. Additionally, the authors demonstrate a tradeoff between the length of the time interval spent on data transmission and the sum-rate performance.

In [22] a noise-like aggregate model of hardware impairments is considered (noise+distortion+IQ imbalance). Its effect on the channel estimate accuracy and system capacity is shown to diminish when the number of BS antennas is increased, but the attained performance limits are inferior compared to the ideal hardware case. It means that unlike the channel noise and inter- or intra-cell interference the effect of transceiver impairments cannot be cancelled by increasing the antenna array size; it can only be mitigated.

In [21] a pre-coding scheme to reduce the peak-to-average-power ratio (PAR) in Massive MIMO OFDM systems is proposed that only affects processing at the BS and not at user terminals. As OFDM is known of large PAR it requires linear power amplifiers and additionally operation with significant back-off that results in poor power efficiency. The authors demonstrate significant PAR reduction that allows to alleviate the respective tradeoff. However, other tradeoffs among PAR, symbol error rate, and out-of-band radiation turn up as well. In this case, the out-of-band radiation occurs due to nonlinearity evoked by a truncation procedure used in pre-coding that seems a secondary effect compared to the actual amplifier nonlinearity that is omitted in this work.

In [20] pre-coding aimed at constant envelope (CE) transmission per-antenna in forward link was proposed to prove that non-linear power-efficient amplifiers can be used in the BSs. It is shown that by 2 dB higher power is required to maintain the same data rate (ergodic sum-rate) with CE pre-coding compared to conventional pre-coding in a typical case. This result is achieved by multi-user interference (MUI) suppression when using a sufficient number of BS antennas and assuming a slow-fading Gaussian channel. It is also shown that for a fixed sum-rate and fixed number of user terminals the required total transmit power reduces linearly with the increasing number of BS antennas.

Extension of this work in presented in [23] where the power consumption of low-PAR pre-coding is compared to conventional schemes such as maximum-ratio and zero-forcing. Unlike [20] nonlinear in-band distortion by PAs using a simple Rapp model [15] is taken into account. In particular, it is shown that for OFDM system there is no real power savings due to low-PAR pre-coding compared to zero-forcing. Moreover since the in-band distortions add-up non-coherently at the user terminals they do not limit the performance of Massive MIMO.

In [12-14] mutual antenna coupling has been analyzed. A tradeoff between the spatial correlation and antenna array gain was demonstrated in terms of antenna spacing and the system capacity. For maximum capacity a search for an optimum spacing in the antenna array is advocated [14].

The cited work addresses the physical impairments (non-idealities) usually using simplistic models. In effect, the results are mostly of qualitative value and also many problems remain open for further research.

References

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Project description

The cited publications provide a valuable insight into the problem of physical impairments in the MIMO transceivers. Also proposed are useful algorithms for control and correction to enhance the performance of the Massive MIMO systems. On the other hand, a study of the reported work gives rise to several questions that seem to be fundamental especially in terms of design and as such need to be answered.

In particular, what is the practical size of an antenna array (number of its elements) which can provide satisfactory improvement of the system performance (otherwise) adversely affected by various transceiver impairments? Realistic physical models must be applied in this case. Moreover, how this estimate depends on the system setup, i.e. modulation scheme, coding technique, channel reuse, blocking profile, power control, etc.

Consequently, other more detailed questions follow.

- What is the effect of antenna mutual coupling and the resulting back-scattering on the system performance in terms of PAs' nonlinearity (i.e. nonlinear PA impedance "seen" by the antennas)? How this effect depends on a filter between PA and antenna? Usually those filters are non-symmetric for the input and output port.
- What is the joint effect of in-band interference and phase noise in BS? Referred to as the reciprocal mixing, it is known as the SNR limiter of receivers in all conventional systems with a high blocking profile. It is likely to be such in the Massive MIMO case, too.
- Is it really possible to enhance the Massive MIMO system performance by using PAs with higher efficiency, e.g. class C or D instead of AB, assuming a low-PAR pre-coding is applied? In other words, will the low-PAR pre-coding be good enough when exposed to significant nonlinearities? What is the real tradeoff between power efficiency and the sum-rate in this case? Besides, how much power can be saved (if any) in various Massive MIMO variants (OFDM, single carrier) with different PAs?
- Can we effectively control emission to the adjacent channels (due to 3^{rd} or 5^{th} order intermodulation products) by pre-coding while high-efficiency non-linear PAs are used? What are the related tradeoffs? In fact, power radiation to the adjacent channels is a largely limiting factor (ACPR) for conventional systems and most likely it is such for the Massive MIMO, too.
- What are the real requirements for linearity (IP2, IP3) and noise figure for the BS receivers in terms of SNDR, the antenna array size, and MRC?

- The number of BS antennas and user terminals entails proportional computational overhead at baseband (BB) processors and it is increased when more sophisticated pre-coding schemes are employed e.g. to combat high PAR or to filter-out in-band blockers that are only partly suppressed in the analog RF front-end. The problem is exacerbated by the available processing time resulting in high clock frequency with proportional power consumption in the BB processors. In effect, while the system throughput is increased in proportion to the antenna array size and the RF front-end power is reduced accordingly, the power consumed by the high speed BB processors scales up in a similar proportion. What is the balance between those two power components and what is the total BS power?

The formulated questions can be considered a preliminary framework for the proposed project. While the previous theoretical work supported by a variety of algorithms provides a solid background for the further study on Massive MIMO, achieving realistic performance estimates necessitates physical RF front-end models and the related expertise especially when moving towards design issues. Then also the system needs to be defined in a more detail (physical layer perspective) to use such models and perform relevant analyses of data throughput, power consumption, are other related metrics of the system.

Mixed simulation techniques must be employed to capture the analog RF impairments and next incorporate them into the system level simulator to using realistic conditions (such as blocking profiles, adjacent channel interference or mutual antenna coupling). For the abstraction level of RF circuits/blocks, both Spectre SPICE and ADS software is suitable. The latter along with PTOLEMY might be used for system-level simulations as well unless MATLAB or similar software is employed.

Among RF front-end blocks the power amplifier models (class AB, C, D, …) need special attention for their nonlinear transmission- and scattering characteristics; the latter considered in terms of mutual antenna coupling. In this case also the characteristics of a filter between PA and antenna should be taken into account. Spectrum "leakage" to the adjacent channel, mostly evoked by the third order nonlinearities is of paramount importance.

Non-idealities (physical impairments) in BS transceivers must be accepted in this case unavoidably, driven by the economy behind Massive MIMO with one hundred or more antennas and the same number of the corresponding transceiver blocks in the BSs. This creates an extra challenge since expensive solutions which can guarantee high performance building blocks will not be accepted.

Project time line

The project will start with identification of physical models of the critical RF building blocks of the system. In the following two years various transceiver impairments will be investigated and the physical models will be adopted for system level simulation. Impact of the respective impairments on the overall performance will be analyzed to identify the tradeoffs. Beginning from the second half of the third year a systematic design methodology for Massive MIMO transceivers will be developed and verified by simulation of practical systems.

Significance

Massive MIMO is a hot topic nowadays. The proposed research may have an impact on future Massive MIMO systems both theoretically and practically. Theoretically, we hope to identify the existing tradeoffs and physical limitations of those systems evoked by non-idealities in the RF system blocks. Practically, we aim to develop a methodology for designing the RF front-ends suitable for this kind of applications.

Preliminary work and collaboration

The applicant has several years of experience in RF front-end chip design and design for testability documented by research activity. Besides, he has been teaching courses on RF design, both at circuit and system level where professional tools such as SPICE and ADS have been extensively used. This provides a solid foundation for the project from the RF transceiver perspective. The complementary expertise in information-, communication theory and algorithms will be secured by the potential of the research group that the applicant is a member of. The group of Communication Systems at the Linköping University lead by Prof. Erik G. Larsson has an impressive record of achievements in the Massive MIMO field. The group has also wide national and international collaboration of which Lund University with their Massive MIMO testbed is of particular interest for this project.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Jerzy Dabrowski	20
2	Other personnel without doctoral degree	1st PhD student	80
3	Other personnel without doctoral degree	2nd PhD student	40

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Jerzy Dabrowski	20	240,000	244,000	250,000	257,000	991,000
2	Other personnel without doctoral degree	1st PhD student	80	516,000	527,000	542,000	555,000	2,140,000
3	Other personnel without doctoral degree	2nd PhD student	40	258,000	263,000	271,000	277,000	1,069,000
	Total			1,014,000	1,034,000	1,063,000	1,089,000	4,200,000

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Rental fee	20,000	20,000	20,000	20,000	80,000
	Total	20,000	20,000	20,000	20,000	80,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Licences	software	20,000	20,000	20,000	20,000	80,000
2	Admin		10,000	10,000	10,000	10,000	40,000
3	PC	laptop	20,000				20,000
4	Conference, travel		40,000	60,000	60,000	60,000	220,000
	Total		90,000	90,000	90,000	90,000	360,000

Depreciation costs

	Depreciation cost	Description	2016	2017	2018	2019	Total
1	PC	laptop				15,000	15,000
	Total		0	0	0	15,000	15,000

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	1,014,000	1,034,000	1,063,000	1,089,000	4,200,000		4,200,000
Running costs	90,000	90,000	90,000	90,000	360,000		360,000
Depreciation costs	0	0	0	15,000	15,000		15,000
Premises	20,000	20,000	20,000	20,000	80,000		80,000
Subtotal	1,124,000	1,144,000	1,173,000	1,214,000	4,655,000	0	4,655,000
Indirect costs					0		0
Total project cost	1,124,000	1,144,000	1,173,000	1,214,000	4,655,000	0	4,655,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

The staff salaries seem to display a reasonable balance between the involvement of the senior researcher and the students. The second student will be involved in another project as well that reflects his % workload. Other costs reflect publication activity related to the project, costs of the infrastructure maintenance and chip manufacturing in submicron CMOS technology. The budget assumes 2.5% increase of salary per year, LKP of 53%, and overhead of 35%.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019

CV and publications

CV

Curriculum Vitae of Jerzy J. Dąbrowski

Education: DSc. (Dr hab.) "Piecewise linear approach to functional-level macrosimulation of analogue and mixed A/D systems", Silesian University of Technology (SUT), Gliwice, Poland, 2001

PhD. (Dr) "Analog integrated circuits macromodeling in the time domain", SUT, Poland, 1987

Officer in Communication Forces at Polish Army, 1978

MSc. in Electronics from SUT, Poland, 1976

Present position: Associate Professor / Docent
Department of Electrical Engineering
Linköping University, SE-581 83 Linköping, Sweden

Experience: 2001- Assoc. Professor in VLSI Design at Linköping University (LiU)

2001-2006 Assoc. Professor in CAD at Institute of Electronics, SUT

1987-2000 Assistant Professor at Institute of Electronics, SUT

1986 D&R engineer at Research Center"EMAG", Poland (6 months)

1978-1986 Research & Teaching Assistant at SUT

Supervised PhDs R. Ramzan, "Flexible Wireless Receivers: On-Chip Testing Techniques and Design for Testability", defended at LiU, 2009

S. Ahmad, "Stimuli Generation Techniques for On-Chip Mixed-Signal Test", defended at LiU, 2010

F. Qazi, "Selected Applications od Switched Capacitor Circuits: RF N-Path Filters and ΔΣ Modulators", defended at LiU, 2015

Research interests: Mixed-signal/RF wireless systems, High-level and behavioral modelling of mixed-signal /RF systems, RF IC design for testability, Built-in-self-test, Software defined radio, Flexible RF front-end design

Publications: 100+ papers published in international conference proceedings and journals, two monographs, two book chapters, and 12 patents (as co-author) in switched-mode power supplies and electronic instrumentation

Invited talks: more than 10 invited talks /lectures at international conferences and at industry

Assignments: **Referee** for: Journal of Electronic Testing (Springer)
Journal of Analog Integrated Circuits and Signal Processing (Springer)
Microelectronics Journal C&S (Elsevier), Integration, the VLSI Journal (Elsevier), IEEE Trans. on Circuits and Systems I, Trans. on Circuits and Systems II, IEEE Trans. on VLSI Systems, IEE Proc. Circuits Devices & Systems, IEEE Trans. on CAD, IEEE Trans. on Wireless Communication, Intl. Journal of Circuit Theory and Applications (Wiley), Cambridge Univ. Press (review of book proposals)

Referee to several international conferences (ISCAS, ITC, ECCTD, ICSES, VLSI-SoC, ETS)

Chair session: SSoCC, IEEE ICECS'2002, ECCTD'2003, 2007, ICSES'2006, 2008, 2010, VLSI-SoC 2011, ETS 2011

Special session organizer: ECCTD'2007

Conference organizer: NCCTES'1990, ICSES'2000, SSoCC'2010, SSoCC'2014, ECCTD'2011

General chair: ECCTD'2011 (with L.Wanhammar)

Leadership in research projects and grants
"Mixed-mode simulation for A/D circuits" by KBN, Poland (1990-92), "Functional-level PWL macrosimulation of A/D systems" by KBN, Poland (1997-99), "Testability-oriented Design Techniques for Mixed-Signal/ RF Integrated Circuits" by CENIIT LiU (2003-2008), "Direct RF Sampling for Flexible Radio Architectures" by VR (2009-2011)

Teaching: **Undergraduate** courses: Circuit & Signal Theory, Foundations of Electronics, Analog Circuit Design, CAD for Analog ICs, Programmable Analog Devices, Introduction to VLSI Design, VLSI Design Project, Digital Integrated Circuits, Introduction to Radioelectronics, RF Integrated Circuits, RF Transceiver Design, Analog and Discrete-Time Integrated Circuits, Wireless Systems.

Graduate courses: Selected Problems in Analog Design (2003), Introduction to RF Front-End Design (2006), Analog/Mixed-signal/RF Test (2007), DfT and BiST Techniques for RF Integrated Circuits, ENSICAEN/ NXP, Caen, France, (2007-2009), Advanced RF IC Design (2012 - 13), Test and testability of ICs (2014)

Supervision to about 20 MSc and BSc projects at SUT and 10 MSc at LiU.

Collaboration: Philips Research, Eindhoven, NL (2004-05),
NXP Semiconductors Caen, France under NDA (2005 - 08),
Silesian Technical University, PL (2003-),
University of Twente, NL (2005 - 06),
Acreo, Norrköping, SE (2006 - 08),
ST-Ericsson Lund (2011 - 12)

Membership to scientific societies: Polish Society of Electrical Engineering (PTETiS), Committee of Electronics of the Polish Academy of Sciences (PAN), Institution of Electrical and Electronics Engineers (IEEE), vice-chair of IEEE Swedish SSCS chapter (2009 - 12), Swedish Network of Design for Testability (SNDFT)

Publication list

Publications of Jerzy Dąbrowski (2007-)

Citations according to Google-Scholar (Feb 2015)
(*) publication most important for application

Books and chapters in books

Dąbrowski J., *Radioelectronics*, LiU-Tryck, Linköpings universitet, 2008,2009,2010 (220 pp)

(*) Dąbrowski J., *A/D and D/A data conversion for wireless communications transceivers*, in Digital Front-End in Wireless Communications and Broadcasting: Circuits and Signal Processing, Fa-Long Luo (Ed.) Cambridge University Press 2011, Ch.13.

Papers in reviewed journals

Ramzan R., Andersson S., Dąbrowski J., Svensson C., *Multiband RF-Sampling Receiver Front-End with On-Chip Testability in 0.13µm CMOS,* J. Analog Integrated Circuits and Signal Processing, Nov. 2009. pp. 115-127, **Number of citations: 8**

(*) Dąbrowski J., Ramzan R., *Built-in Loopback Test for IC RF Transceivers*, IEEE Trans. VLSI Systems, DOI:10.1109/TVLSI.2009.2019085, Dec.2009, (14 pp).
Number of citations: 22

Ramzan R., Ahsan N., and Dąbrowski J., *On-Chip Stimulus Generator for Gain, Linearity, and Blocking Profile Test of Wideband RF Front Ends*, Trans. Instrumentation and Measurement, Vol.59, Nov. 2010, pp. 2870-2876. **Number of citations: 2**

Ramzan R., Fritzin J., Dąbrowski J., and Svensson C., *Wideband Low Reflection Transmission Line for Bare Chip on Multilayer PCB*, in ETRI Journal, vol. 33, no. 3, June 2011, pp. 335-343. **Number of citations: 2**

Ahsan N., Svensson C., Ramzan R., Dąbrowski J., and Samuelsson C., *A 1.1 V 6.2 mW, wideband RF Front-end for 0 dBm Blocker Tolerant Receivers in 90 nm CMOS,* in Analog Integrated Circuits and Signal Processing, vol. 70, No. 1, 2012, pp. 79-90.
Number of citations: 2

Duong Q-T, Dąbrowski J., Alvandpour A., *Design and Analysis of High Speed Capacitive Pipeline DACs*, in Analog Integrated Circuits and Signal Processing, DOI 10.1007/s10470-014-0350-9, 2014.

Ramzan R., Dąbrowski J., *RF Calibration of On-Chip DfT Chain by DC Stimuli and Statistical Multivariate Regression Technique*, in Integration, the VLSI Journal, 10pp., DOI: 10.1016/j.vlsi.2014.11.006, 2014

(*) Qazi F., Duong Q-T, and Dąbrowski J., *Two-Stage Highly Selective Receiver Front-End Based on Impedance Transformation Filtering*, in IEEE Trans. on Circuits and Systems II, 5pp., DOI: 10.1109/TCSII.2014.2385213, 2014

Reviewed conference papers

Ahsan N., Ouacha A., Dąbrowski J., and Samuelsson C., *Dual band Tunable LNA for Flexible RF Front-End*, Proc.of IBCAST Conf., Islamabad, PK, 8-11 Jan. 2007, (4 pp)

Ramzan R., Andersson S., Dąbrowski J., and Svensson C., *A 1.4V, 25mW Inductorless Wideband LNA in 0.13um CMOS*, Proc.of ISSCC'07, San Francisco, USA, Feb.2007 (2 pp) **Number of citations: 88**

Dąbrowski J., Ramzan R., *Boosting SER Test for RF Transceivers by Simple DSP Technique*, Proc.of DATE Conf., Nice, France, 16-20 April 2007 (6 pp.) **Number of citations: 5**

Andersson S., Ramzan R., Dąbrowski J., Svensson C., *Multiband Direct RF Sampling ReceiverFront-End for WLAN in 0.13um CMOS*, Proc. of ECCTD, Seville, Spain, 27-29 August 2007, pp.168-171 **Number of citations: 3**

Ramzan R. and Dąbrowski J, *On-chip Calibration of RF Detectors by DC Stimuli and Artificial Neural Networks*, IEEE RFIC Symposium, Atlanta, Georgia, 15-17 June 2008, (4 pp) **Number of citations: 3**

Ahmad S. and Dabrowski J., *ADC On-Chip Dynamic Test by PWM Technique*, International Conference on Signals and Electronic Systems, Krakow, Poland, 2008, pp. 15-18. **Number of citations: 2**

Ahsan N., Svensson C., and Dąbrowski J., *Highly Linear Wideband Low Power Current Mode LNA*, International Conference on Signals and Electronic Systems, Krakow, Poland, 2008, pp. 73-76. **Number of citations: 5**

(*) Ahsan N., Dąbrowski J., and Ouacha A., *A Self-Tuning Technique for Optimization of Dual Band LNA*, 38th IEEE European Microwave Conference (EuMC'08), Amsterdam, Netherlands, 2008, pp. 178-181. **Number of citations: 12**

Ahmad S., Ahsan N., Blad A., Ramzan R., Sundström T., Johannson H., Dąbrowski J., Svennson C.*Feasibility of Filter-less RF Receiver Front-end,* Proc.GigaHertz 2008 Symposium, Göteborg, 5-6 March 2008 (1p)

Ahmad S. and Dąbrowski J., *On-Chip Stimuli Generation for ADC Dynamic Test by Sigma-Delta Technique*, in Proc. European Conference on Circuit Theory & Design (ECCTD´09, Antalya, Turkey, 2009), pp. 105-108. **Number of citations: 2**

Dąbrowski J., *Fast BER Test for Digital RF Transceivers*, Proc. European Test Symposium, Seville, Spain, 2009, (4pp).

Ahmad S.and Dąbrowski J., *Cancellation of spurious spectral components in one-bit stimuli generator*, IEEE International Conference on Electronics, Circuits and Systems (ICECS), 2010, pp.393 - 396. **Number of citations: 2**

Ahmad S., Azizi K., Esmaeil Zadeh I., and Dabrowski J., *Two-Tone PLL for IP3 on-Chip Test*, Proc. IEEE International Symposium on Circuits and Systems (ISCAS), 2010, pp. 3549 – 3552. **Number of citations: 2**

Fazli Yeknami A., Qazi F., Dąbrowski J., and Alvandpour A., *Design of OTAs for ultra-lowpower sigma-delta ADCs in medical applications*, Proc. International Conf. on Signals and Electronic Systems (ICSES), 2010, pp. 229-232. **Number of citations: 8**

Qazi F. and Dąbrowski J., *IP2 calibration of ADC for SDR receiver*, Proc. International Conf. on Signals and Electronic Systems (ICSES), 2010, pp. 233-236.

Qazi F., Sundstrom T., Wikner J., Svensson C. and Dąbrowski J., *A/D conversion for software defined radio,* Proc. 6th Karlsruhe Workshop on Software Radios, 2010, pp. 70-76.

Ramzan R., Ahsan N., Dąbrowski J., and Svensson C., *A 0.5–6GHz low gain linear RF front-end in 90nm CMOS*, Proc. 17th International Conference Mixed Design of Integrated Circuits and Systems (MIXDES), 2010, pp. 168-171.

Qazi F., Sundstrom T., Wikner J., Svensson C. and Dąbrowski J., *A/D conversion for software defined radio,* Proc. GigaHerz Symposium 2010, Lund, 2010, (1 p).

Ahmad S., Dąbrowski J., *On-Chip Spectral Test for High-Speed ADCs by ΣΔ Technique*, in European Conference on Circuit Theory and Design (ECCTD), Sept. 2011 pp. 661 - 664

Duong Q-T. and Dąbrowski J., *Low Noise Transconductance Amplifier Design for Continuous-Time Delta Sigma Wideband Frontend*, in European Conference on Circuit Theory and Design (ECCTD), 2011, pp. 825 – 828 **Number of citations: 5**

Qazi F., Duong Q-T, and Dąbrowski J., *Wideband RF Frontend Design for Flexible Radio Receiver*, in International Symp. on Integrated Circuits (ISIC), 2011, pp. 220 - 223.

Duong Q-T. and Dąbrowski J., *Wideband RF Detector Design for High Performance On-Chip Test*, in Proc. IEEE Norchip, pp. 1-4, November 2012 **Number of citations: 2**

Qazi F., Duong Q-T, and Dąbrowski J., *Blocker and Image Reject Low-IF Frontend*, in European Conference on Circuit Theory and Design (ECCTD), pp. (1-4), 2013

Duong Q-T, and Dąbrowski J., *Focused Calibration for Advanced RF Test with Embedded RF Detectors*,in European Conference on Circuit Theory and Design (ECCTD), pp. (1-4), 2013

Duong Q-T, Dąbrowski J., Alvandpour A., *Highly Linear Open-loop Output Driver Design for High Speed Capacitive DACs*, in Proc. IEEE Norchip, pp. (1-4), 2013

Invited talks and lectures

Dąbrowski J., *Software Defined Radio – Challenges and Solutions in RF Front-end Design*, IBCAST Conf., Islamabad, PK, 8-11 Jan. 2007

Dąbrowski J., *RF IC Front-end Design for Testability*, IBCAST Conf., Islamabad, PK, 8-11 Jan. 2007

Dąbrowski J., *DfT and BiST Techniques for RF Integrated Circuits*, ENSICAEN/ NXP, Caen, France, April and Nov 2007, Dec 2008, Dec 2009 (series of invited lectures)

Dąbrowski J., *Software Defined Radio Challenges and Solutions in RF Front-End Design*, SDR-Europe'09 Conference, Paris, France, October 28th 2009 (tutorial)

Dąbrowski J., *On-chip test for RF IC transceivers*, Proc. EuMWIT Workshop, RF mmWave DfT/BiST, WHS03 pp.16-30, 2010.

Dąbrowski J., *On-chip Test for RF ASICs*, ST-Ericsson, Lund, 10 Nov. 2011

Most cited publications

Jakonis D, Folkesson K., Dąbrowski J., Eriksson P., Svensson C.: *A 2.4-GHz RF sampling receiver front-end in 0.18µm CMOS*, IEEE J. of Solid-State Circuits, Vol. 40, Issue 6, June 2005, pp. 1265-77. **Number of citations: 118**

Ramzan R., Andersson S., Dąbrowski J., and Svensson C., *A 1.4V, 25mW Inductorless Wideband LNA in 0.13um CMOS*, Proc.of ISSCC'07, San Francisco, USA, Feb.2007 (2 pp) **Number of citations: 88**

(*) Dąbrowski J., Gonzalez Bayon J., *Mixed Loopback BiST for RF Digital Transceivers*, in Proc. of DFT'04, Cannes, 11-13 Oct. 2004, pp. 220-228, **Number of citations: 47**

Dąbrowski J., *BiST Model for IC RF-Transceiver Front-End*, Proc of DFT'03, Cambridge, Mass., USA, Nov. 2003, pp.295-302. **Number of citations: 43**

Dąbrowski J., Ramzan R., *Built-in Loopback Test for IC RF Transceivers*, IEEE Trans. VLSI Systems, DOI:10.1109/TVLSI.2009.2019085, Dec.2009, (14 pp). **Number of citations: 22**

(*) Dąbrowski J. and Ramzan R., *Offset loopback Test for IC RF Transceivers*, Proc.of MIXDES Conf. 2006, Gdynia, Poland, 22-24 June, 2006, (4 pp), **Number of citations: 13**

Dąbrowski J., *Loopback BiST for RF Front-Ends in Digital Transceivers*, Proc.of ICSOC'03, Tampere, Finland, Nov. 2003, pp.143-46, **Number of citations: 12**

Andersson S., Konopacki J., Dąbrowski J., Svensson C., *SC Filter for RF Sampling and Downconversion with Wideband Image Rejection*, Int. J. Analog Integrated Circuits and Signal Processing, Kluwer-Springer, 2006, Vol. 49, pp. 115-122, **Number of citations: 12**

Ahsan N., Dąbrowski J., and Ouacha A., *A Self-Tuning Technique for Optimization of Dual Band LNA*, 38th IEEE European Microwave Conference (EuMC'08), Amsterdam, Netherlands, 2008, pp. 178-181. **Number of citations: 12**

Ramzan R. and Dąbrowski J., *CMOS RF/DC Voltage Detector for on-Chip Test*, Proc.of IEEE International Multitopic Conference (INMIC), Islamabad, Pakistan, December 2006, pp. 472-476 **Number of citations: 12**

Dąbrowski J., Gonzalez Bayon J., *Techniques for Sensitizing RF Path under SER Test,* Proc. IEEE ISCAS'05 Kobe, Japan, May 23-26, 2005, (4 pp) . **Number of citations: 11**

Ramzan R., Zou L., Dąbrowski J., *LNA Design for on-Chip RF Test*, Proc.- ISCAS'06, Island of Kos, Greece, 21-24 May 2006, (4 pp) . **Number of citations: 10**

CV

Name: Jerzy Dabrowski	**Doctorial degree:** 1987-03-17
Birthdate: 19521016	**Academic title:** Docent
Gender: Male	**Employer:** No current employer

Research education

Dissertation title (swe)

Dissertation title (en)

Macromodeling of analog integrated circuits in the time domain

Organisation	Unit	Supervisor
Silesian University of Technology, Poland Not Sweden - Higher Education institutes	Dept. of Elecrtical Engineering	Adam Macura

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20299. Annan elektroteknik och elektronik		1987-03-17

Publications

Name: Jerzy Dabrowski	**Doctorial degree:** 1987-03-17
Birthdate: 19521016	**Academic title:** Docent
Gender: Male	**Employer:** No current employer

Dabrowski, Jerzy has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.