NEWCOM

Network of Excellence for Wireless Communication

Contract No IST NoE 507325

DR3.1 – Report on the initial know how of participating partners

Contractual Date of Delivery to the CEC:	August 31, 2004
Actual Date of Delivery to the CEC:	October 31, 2004
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Participant(s):	Bilkent, Chalmers, CTTC, ISIK, POLITO, TUI, UoP, UU
Workpackage:	*WPR3 Research integration for Project 3 “Design, modelling and experimental characterisation of RF and microwave devices and subsystems”*
Estimated Person months:	3
Security level:	CO
Nature:	Report
Version:	0.6 (x.y : x = 0 for draft, x = 1 for approved document, x = 2 for revisions in case of non EC acceptance); y = minor changes
Total number of pages:	65

Abstract:

This report is the first deliverable of the Department 3. In the initial parts, it contains the ideas of partners on what they think the gaps are and what they should do to close these gaps. WPR3 participants are grouped in four clusters as a result of their research interests. The research plans for each the four clusters for the purpose of integrating their research activities are presented. In the last part of the document, the information on the initial know-how of the NEWCOM-WPR3 participants, such as published papers, their abstracts and completed projects of the participants in related areas are listed. This collection of information gives a thorough idea of present know-how and interests of each partner. The report also includes detailed information such as graduate level courses, measuring equipment, design and analysis software that they can share with their partners when graduate students visit each other’s premises.

Keyword list: Nonlinearity, power amplifier, phase noise, antenna, RFIC front-end

DOCUMENT REVISION HISTORY

Version	Date	Author	Summary of main changes
0.1	20-05-2004	A. Atalar	Blank formatted document
0.2	25-09-2004	A. Atalar	Integrated partner's contributions
0.3	12-10-2004	A. Atalar	Added UoP contribution
0.4	15-10-2004	A. Atalar	A number of additions in Section 1,2 and 4 with additions from Isik and Chalmers
0.5	17-10-2004	A. Atalar	Final form to be submitted to S. Sadler
0.6	24-11-2004	A. Atalar	Last 10 pages moved to front of document with corresponding changes in the rest of the document.

EXECUTIVE SUMMARY

WPR3 partners plan to do collaborative research that will lead to coauthored papers. The research will be done on the physical layer of wireless systems and in particular on the topics given below. The partners are grouped in four clusters to tackle these problems.

Power amplifiers are essential parts of wireless systems. The nonlinear behavior of these amplifiers has a large impact on the performance of many communication systems, especially for techniques where the communication signals has a large amplitude variation, such as OFDM and spread spectrum systems. The nonlinear distortions are created by transistors as well as by distributed effects due to the materials, metallic connections between devices or by high temperature superconductors. Usually there is a trade-off between linearity and efficiency/size or cost. At the design stage, it is important to be able to simulate the effect of these nonlinearities on the overall system performance to optimize the trade-off.

The adverse effect of a nonlinearity may be negligible, if the envelope of the signal applied to it is nearly constant. The characteristics of the signals such as peak to average power ratio play an important role in the performance of systems containing nonlinear components. It is desirable to find baseband signals with suitable characteristics for use with nonlinear components.

A nonlinearity and its adverse effects can be cancelled completely if a suitable nonlinear component precedes it. This is typically done by predistorters in front of power amplifiers. Predistorting the signal at the RF level is very advantageous, if low cost and efficient solutions for MMIC and hybrid circuits can be found. Fully integrated solutions are preferable, since a more accurate compensation is possible.

it++ is a public domain system level simulator that is developed by one of the WPR3 partners. It is a C++ library that can be used to simulate and determine the performance of communication systems at the system level. it++ library contains many different communication functions such as modulators and demodulators, channel encoders and decoders, spreading and de-spreading functions, channel classes and interleavers. The WPR3 partners plan to develop models of nonlinear components such as power amplifiers or high temperature superconducting filters at the system level to be integrated with this package. Consequently, this package can be used to simulate the effect of nonlinear components on the overall system performance. It would then be possible to determine the adverse effect of nonlinearities on system level properties such as bit-error-rate and optimize linearity cost trade-off properly. It would also be possible to test the performance of suitably designed baseband signals and predistorters for use with nonlinear components.

It is well known that the phase noise in oscillators used in wireless systems can be a severe limitation to overall system performance, especially in OFDM systems where carriers may be closely spaced. The phase noise in such systems can cause severe intercarrier interference. It is possible to build low noise oscillators at the expense of size and cost. Usually, low cost and small size implies a higher phase noise. it++ library does not contain classes which can simulate phase noise in oscillators. We plan to develop models of oscillator phase noise to be integrated with it++ library. With this addition, it would be possible to determine the effect of phase noise on the overall system performance and determine what level of phase noise is acceptable.

New analytic methods of circuit and matching network design can be applied to wireless systems when broad bandwidth is to be achieved. The new methods allow one to determine the equivalent circuits of active devices or antennas from measurement results. With such an equivalent circuit one can find matching networks with an optimal topology.

Fully integrated single chip transceivers are very advantageous in mobile systems from the cost point of view. At higher microwave frequencies antennas should also be part of the monolithic solution due to increased losses in transmission lines. While silicon germanium technology allows high frequency transistors on commercial CMOS processes, full integration of transceiver is becoming a reality. As micromachining silicon becomes more prevalent, it is also feasible to integrate low loss antennas on the same chip.

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1 INTRODUCTION

This report contains a collection of information related to eight partners of WPR3, namely, Bilkent, Chalmers, Telecommunication Technological Centre of Catalonia (CTTC), Isik University, Polytecnico di Torino (POLITO), Technical University of Ilmenau (TUI), University of Pisa (UoP) and University of Uppsala (UU). WPR3 partners are composed of able and established researchers in the field of RF electronics, antennas and systems for the communication applications. Naturally, the research areas and interests are in rather diverse directions. The aim of this report is to integrate these researchers for common goals that are of interest to all of them.

For the purpose of integrating research activities, four research clusters are formed. Each cluster is made up of three or more partners interested in the particular research field. Section 2 presents the ideas and perspectives of each partner on what they think should be the research goals.

Section 3 shows the identified gaps in the particular research fields that are of interest to participating partners. In the same section, research plans to encounter those gaps for each of the four clusters are given. These plans are decided among partners during the meetings that took place in Leuven and in Istanbul. Obviously, these plans can only provide an initial guidance. They can and will be modified as research progresses.

Finally, in Section 4 initial know-how of the partners are summarized. This summary is intended to give partners information about each other's capabilities and expertise. For this purpose, published papers of partners in related areas are given in Section 4.2 along with their abstracts. Completed and ongoing research projects are listed in Section 4.3 with their short descriptions. Graduate student exchange between partners is a good way of sharing information and combining forces. An inventory of measuring equipment and analysis and design software for each partner is given in Section 4.4 for the purpose of sharing and using those resources during exchange visits. Graduate level courses and their short descriptions are presented in Section 4.5. Since many institutions offer courses in English, these courses can be made available to exchange students easily.

2 REQUIRED KNOW HOW TO SUCCESSFULLY COMPLETE WPR3 OBJECTIVES

The activities of WPR3 are organized under four clusters whose main activities are given by the following keywords:

- Nonlinearities of power amplifiers
- Antennas
- Oscillator phase noise
- RFIC Front-ends

In order to reach the workpackage objectives under the cluster organization, the following know-how stated by the partners involved in WP3 is vital.

2.1.1 Bilkent

We believe that ability to simulate a communication system with its associated nonideal behavior is an important goal to achieve. At Bilkent we have the expertise of designing and building real life communication systems. We are aware of the limitations of the components and subsytems and the adverse effect of these on the performance of a communication system. Some of these, but not all can be simulated with presently available commercial simulators. Most commercial communication system simulators remain at the system level and they are suitable for making system level choices. On the other hand, circuit level simulators can simulate components accurately at the lower level. For example, a circuit level simulator can predict the third order intercept point of a nonlinear amplifier, but using this simulator it is impossible to predict the bit-error-rate degradation. Circuit level simulators fail to provide guidance to a communication system designer who works at a higher level.

According to our experience, in a modern communication system the performance degradation arising from the phase noise of the local oscillators and nonlinearities of power amplifiers is the most important. For most cases the resulting degradation can be measured experimentally when a fully implemented version of the communication system is available. It is possible to make design changes at that stage, but it is often very costly. If all such circuit level effects that real systems face can be included in a system level simulator that would be an important addition to a communication system designer’s toolbox. This will allow a realistic simulation of systems before they are actually implemented and hence changes can be made at the design stage. It will then be possible to answer questions such as

- Since it is possible to increase the efficiency of a power amplifier at the expense of its linearity, how much nonlinearity can be tolerated before it causes a significant loss in performance?
- Since long term frequency stability and phase noise of oscillators are closely related to cost and bandwidth of the oscillators, how much stability and phase noise in local oscillators is acceptable and in what form (including the spectrum, amplitude distribution, etc.)?

We are willing to contribute with our know-how in communication system design, in simulator design and with our graduate student workforce to achieve this goal.

2.1.2 Chalmers

We believe that the cooptimization of hardware components and system is of main importance to complete the WPR3 objectives. From Chalmers side, we offer knowledge of communication systems and of system modelling of components (oscillators, amplifiers), and we can contribute to WPR3 in these areas. We lack knowledge about hardware components, and we hope to gain knowledge about:

1. State-of-the-art in the linearity of power amplifiers.
2. What is the linearity/cost trade-off in hardware design?
3. State-of-the-art in oscillators with low phase noise.
4. The trade-off between low phase noise and low costs in oscillator design.
5. What are the tolerances in the design of e.g. an amplifier? How much can e.g. the linearity vary between two amplifiers? Must each amplifier be separately measured?
6. How much can the characteristics vary with time?

7. What are typical impulse response lengths of a power amplifier?

Together with the other participants of WPR3, we would like to find the best compromises between hardware costs and software complexity, and discuss methods to relax some constraints in the hardware design by designing more advanced algorithms, or vice versa.

2.1.3 CTTC

We have bridged the gap between the nonlinear parameters of the material or a single device with the nonlinear performance of the whole system when it is subject to wideband modulated signal has been done at CTTC considering the nonlinearities of the superconducting materials. To quantify the overall performance in dense electromagnetic environments we have developed numerical techniques based on Harmonic Balance to be able to consider nonlinear distributed effects with a driven signal with many frequency components. Moreover we also have obtain an approach for a nonlinear equivalent circuit of the HTS filter and assessing its nonlinear performance. In order to predict the feasibility of using this filter in a front-end receiver for wireless communication, where the filter is driven by wideband modulated signals, we perform a wide range of intermodulation distortion (IMD) measurements. Then we also predict the performance of the filter when it is subject to weak in-band and strong out-of-band wideband modulated signals.

A more elaborate approach to consider the nonlinear distortion created by amplifiers –provided by other partners of Dept.3 - or by distributed effects of material or metallic connections between devices, it is necessary to quantify the overall nonlinear effects as a function of system parameters.

2.1.4 ISIK

One of the major issues in wireless communications is appropriate design and modelling of wideband wireless-air interface RF and microwave subsytems. In order to ensure the success of the design algorithms for the transmitter and receiver units of wireless front-ends, accurate modelling of physical components is essential. This requires the development of simulation engines for physical implementation processes of linear and nonlinear components and subsystem characteristics. The main objective of the proposed research is to develop tools to accomplish accurate characterization and design of RF subsystems of future wireless communication systems, facilitating miniaturized designs with easy manufacturing and improved overall system performance to contribute to the achievement of the general objectives of NEWCOM WPR3.

Because of the need for miniaturization of large-scale microwave communication systems, there is a great deal of effort being directed towards the area of Microwave Integrated Circuits (MIC) in hybrid or monolithic form. MIC design of wideband RF communication subsystems, such as amplifiers, filters, matching networks, phase shifters, phase arrays, require that active and passive device models are fully developed and the circuit-design approach is through and well disciplined. In the design process, besides the active devices and passive components, refined models are needed for treatment of device to circuit medium interfaces incorporating parasitic effects and junction discontinuities. In this regard, utilization of lumped - distributed multidimensional circuit models to describe the interstage equalizers and interconnects of the wireless air interface subsystems, would appear to offer advantages for accurate simulation of MIC layouts, where the physical sizes, parasitics and discontinuities are naturally embedded in the design process. Another problem in the computer aided simulation of broadband communication sub-systems is the need of employing circuit models for the measured data obtained from physical devices or sub-systems. Specifically, accurate models need to be utilized for the behaviour characterization and the design of physical components such as antennas and active solid state devices.

In this project, characterization and design of active and passive RF subsystems will be based on multi-dimensional electrical network models and new computer aided tools will be developed to model one port immitance or scattering data by means of linear interpolation techniques. Depending on the application, modelling tools via linear interpolation techniques may present advantages over the existing interpolation techniques, non-linear curve fittings or regression methods. It is expected that the new modelling tools will be utilized to provide initial circuit topologies to the commercially available analysis/simulation and design packages. Results of the work will be useful for the assessment of the electrical behaviour such as gain-bandwidth limitations or attainable optimum performance of physical devices under consideration. The modelling tool will find practical applications in the behaviour characterization, simulation and design of high speed/high frequency analog/digital mobile communication sub-systems manufactured on VLSI and MMIC chips. The outcomes of the research program are expected to be toolboxes and program libraries for various classes of physical problems (including different interconnection geometries for VLSI/MMIC implementation, RF filters and matching equalizers, phase shifters, adaptive phase array systems, multistage low noise amplifiers, linear power amplifiers), as well as benchmark comparison with other techniques and tools.

2.1.5 POLITO

High efficiency and high linearity power amplifiers are the main research area where contribution of POLITO to WPR3 is important. In the research unit accurate nonlinear circuit models for active device and circuits have been developed and implemented in commercial circuit simulators. Behavioral models, limited to the narrow-band case, have been extracted and applied to incorporate the effect of nonlinearities of the power amplifier in a system level simulation of TX-RX links exploiting commercial system simulators and in house POLITO system simulators. Based on the accuracy of the behavioral model, an innovative linearization scheme for power amplifiers, which exploits RF predistortion, has been demonstrated and optimum design rules have been extracted in order to cancel third order intermodulation. The activity in WPR3 will concern the extension of the linearization scheme to broadband communication systems exploiting complex, non-constant envelope modulation schemes: this requires the identification of broadband nonlinear models of the active device or power amplifier circuit. These models must be simple enough to be implemented in system simulators. Such nonlinear models can be implemented in the system simulator provided by Chalmers University, therefore providing a unified platform in WPR3 capable of a complete system simulation including the effects of power amplifier nonlinearities. A possible extension of the collaboration may be linked to the noise simulations. Accurate yet simple mixer noise models are currently under study in the POLITO unit and might be implemented at a system level as well. Finally an ongoing work within am Italian national research program concerns noise in autonomous systems, such as oscillators. In WPR3 we are part of the phase noise cluster in the perspective of being able, on the long term, to provide accurate nonlinear models for oscillators from physics-based simulations and gain insight on the research achievements of the other partners. This research in unit POLITO is at the beginning, but if any nonlinear noise model for phase noise in oscillators will become available, this can be tested and compared to noise models and noise measurements currently done by the other research units.

2.1.6 TUI

One of the main strategic objectives of NEWCOM is the "strengthening, development and integration of research beyond 3G". Customer's needs, system aspects and technological achievements are tightly related to the technical and economic progress in this field. The network NEWCOM is layed out such that all its departments provide a basis for maximum synergy. The objectives of Dept. 3, in special, are focused on the physical layer, and are directed towards inter-departmental coordination. Market drivers and industrial strategy plans will define the specifications to be met by the HW components of the receivers and transmitters. On the other hand, from an academic point of view, the potential of existing and near-term technologies should be exploited as far as possible, to address the needs and enhance the variability of wireless communications.

The following key areas reflecting the trends and visions in this field are, therefore, considered to adequately describe the required know-how to successfully complete the WPR3 objectives:

1. Reconfigurability and adaptivity (filters, oscillators, amplifiers).
2. Linearity and efficiency (power amplifiers).
3. Bandwidth (ultra/wideband systems versus reconfigurable systems of narrower bandwidths).
4. Miniaturisation and integrability (passive and active devices, switches; analog/digital; DC/RF).
5. Performance and functional density (MIMO antennas; tunability, adaptivity; artificial materials).

Progress in these areas will rely on the development of new concepts, improved simulation tools (e.g., for linearised amplification), advanced technologies, and comprehensive control of materials. Most of the aspects listed above can be addressed competently by the partners of WPR3. Consequently, it will be important to merge and share the existing knowledge, facilities, and ideas. The gaps identified during this process may then be filled, and the challenges for future communication systems tackled.

2.1.7 UoP

The main objectives of our research group in the WPR3 of NEWCOM are related to the investigation fully integrated transceiver solutions for wireless systems on standard silicon technologies. The feasibility of a single chip transceiver on standard silicon process represents the most important aspect to explore. Particularly, the extension of the obtained results up to higher operating frequencies (up to 24 GHz or more) will be focused thanks to the possibility offered by the silicon-germanium technology in terms of gain and noise performances. Modelling, re-design and performance measurements on the primary RF sub-circuits of the RF transceiver interface will be taken into account accurately. Moreover, considering the opportunity offered by SiGe-CMOS technologies, for more sub-circuits, the introduction of digital calibration systems will be investigated. That will introduce additional “on-chip” functionalities or extend and optimize the circuit’s performance over the entire band of interest, or over process variations and operating conditions in order to improve reliability and yield.

2.1.8 UU

Objectives in RF and Microwave Front-End Design:

1. Design and fabrication of antennas compatible with RF MEMS circuits. Relevant research is: Micromachined microstrip patch antennas for 60 GHz, which has been designed using an H-slot for coupling between the microstripline. Using genetic algorithms together with a novel transmission line model for the H-slot a computational efficient procedure for the design of micromachined slot-coupled patch antennas, showing good agreement with measurements, has been derived. Presently, work is pursued on design and fabrication of 24 GHz antennas to be monolithically integrated into a commercial SiGe HBT.

2. Design, fabrication and analysis of silicon based active devices suitable for monolithic integration into RF MEMS fabrication processes. Relevant research are: Modelling of SiGe Heterojunction Bipolar Transistors (HBT) where physics based large-signal millimeterwave models and 1/f-noise models has been derived.. Present work is on the design and fabrication of SiGe HBT circuits for millimeterwave applications, such as oscillators, subharmonic pumped gilbert-cell mixers etc.

3. Fabrication of passive microwave components in combination with organic built-up technology is an alternative to monolithic integration. The technique is using on-top-of-chip lamination and wafer bonding of passive microwave components. By this direct integration of thick film polymer carriers with ultra-high density passive circuitry components can be achieved on Si or III-V SOC at wafer level integration in RF MEMS structures. The polymer carriers are suggested to not only be of planar types but also in replicated 3D structured multilayer structures.

4. Multilayer – multichip architecture and interconnect needs vertical interconnections to create signal lines arbitrarily up and down through the stack layers. At the Angström facilities multiconductor via's have been made in different configurations with IC technology.

3 IDENTIFICATION OF THE GAPS AMONG THE WPR3 PARTICIPANTS

The goal of this NoE is to integrate the existing knowledge of the participants in the field defined in the objectives of this NoE, especially in the field defined at WP3 such that the integration lasts well beyond the duration of the NoE. One of the main tools of integration is the identification of the gaps in the knowledge owned and created by the partners involved in this WP. If these gaps are filled in an organized manner making use of the NoE resources, the integrated presence of the NoE partners in the Scientific and Commercial Community will be much stronger. In this manner, the clusters formed at this WP have defined the following gaps and agreed to cover them through the work which will be carried out at this WP.

3.1 Gaps identified:

(1) Absence of a system level simulator that can simulate component and subsystem deficiencies with resulting system degradation. Multicarrier signals of modern telecommunication systems require highly linear amplifiers. Nonlinearities in amplifiers, especially in final stages of amplification generate adjacent channel interference and in-band interference in multicarrier systems which reduces the system performance considerably. However, there is no system level simulator that predicts the effect of those nonlinearities on the overall system performance.

(2) Absence of system level solutions to nonlinearities in analog circuitry. There are several ways of linearizing amplifiers, but the present solutions are at the expense of efficiency and cost. Currently, the most accepted solution is to provide an analog predistorter to cancel the effect of subsequent distortion in the amplifiers. Most people assume that a linear amplifier is the only way to design a good communication system. On the other hand, there may be ways to compensate nonlinearities by digital signal processing at the baseband before the signal is converted to analog. With such a method, it may be possible to cancel a higher degree of nonlinearity with a resulting increase in power efficiency. Potentially, such solutions will be not only cheaper but also they will be more efficient in terms of consumed electrical power. If system level simulators can predict the performance, it may be possible to optimize signals that will be applied to nonlinear components. Maybe some types of nonlinearities can be acceptable, while others must be avoided.

(3) Absence of a good and widely accepted measure for a signal's suitability for use in a nonlinear system. It is known that the peak power to average power ratio is not a good measure. With the definition of such a measure, it may be possible to design signals that are more appropriate for use in nonlinear systems.

(4) Absence of a system level simulator that can simulate the nonideal behavior of local oscillators. The long term stability and phase noise of local oscillators play an important role in the system performance. Wide band oscillators typically have more problems in terms of stability and they have a higher phase noise. With a proper co-optimized system level design, it might be possible to reduce the problems.

(5) Absence of commonly available analytical tools to help design and synthesize matching networks for components with measured S-parameters. Such tools may provide information on tradeoff between gain and the bandwidth. Currently, the matching networks are designed with numerical optimization methods, and often there is no guarantee that the chosen network topology is the optimum.

(6) Absence of an easy to implement and low cost predistorter for use with power amplifiers to reduce the nonlinearity of the amplifiers.

(7) Absence of well established techniques of phase noise compensation and common phase error estimation. Since phase noise in local oscillators is unavoidable, there is a need to develop new methods of reducing the adverse effects of this noise.

(8) Absence of fully integrated single chip transceiver built on silicon especially on higher operating frequencies. With the advances in silicon-germanium technology this is becoming feasible.

(9) Absence of integrated solutions of antennas on the same chip as transceivers. This is particularly important at very high frequencies where the losses in the transmission lines are very high.

(10)Absence of established methods of designing ultra wideband systems.

3.2 Plan for encountering the gaps

We believe that we can encounter the gaps listed above with a focused research effort. Expertise and experience of the partners can be combined to reach this aim. For this purpose it is important that the partners know each other very well. We plan to exchange graduate students on a short time basis. This report contains the list of regular courses and short courses that the partners can offer to exchange students from other partner institutions.

We defined the common interest areas and partners of the workpackage are grouped in four clusters to tackle the identified research problems together. Each cluster has an assigned cluster leader to organize the research activities. Below we list the clusters, and summarize the planned research activities:

3.2.1 Nonlinearity of power amplifiers:

Partners involved: Chalmers, POLITO, Bilkent, UoP, ISIK, CTTC

This cluster is lead by Chalmers and POLITO and the aim to encounter the gaps (1), (2), (3) and (6) listed above. Chalmers group has developed software libraries that can be used to simulate the communication systems. This library is available through a GNU license at http://itpp.sourceforge.net. We will incorporate nonlinearity models in this library. As a result, simulation of performance of systems in the presence of nonlinearities can be possible. The research plan agreed between participating partners is given below:

- Researchers will get an access to it++ and they will try to learn it with their best abilities to use it for typical communication systems. Thomas Eriksson of Chalmers made a presentation on it++ (September 6th, 2004) for the purpose of introducing it. There are a number of tutorials and example files to help learn it++. Graduate students can use those tutorials and files to get a quick start on the use of it++.
- When the researchers are sufficiently familiar with the use of it++, Chalmers is willing to host those researchers for a limited time for more detailed training on the use of it++.
- POLITO group is experienced in amplifier nonlinear characterization and modelling. Giovanni Ghione of POLITO made a presentation on nonlinearity characterization (September 6th, 2004). The aim is to incorporate the models of nonlinearities supplied by POLITO into it++ as new modules. If the models are not appropriate for programming, POLITO will suggest modifications in the models that are more suitable.
- The graduate students involved in learning it++ need to learn the nonlinear models supplied by POLITO. POLITO is ready to accept graduate students on a short time basis to teach them the nonlinearity modelling.
- With realistic nonlinearity models, it++ will be used to predict the performance degradation for example systems in which the simulation results can be verified by experimental measurements.
- Predistorters can be used in front of nonlinear amplifiers to cancel the adverse effect of nonlinearities. In many mobile systems this approach is not used for cost and power reasons. We will study feasibility of designing baseband signals suitable for systems containing nonlinear elements. Such an approach will save cost and power. The performance of designed signals will be tested using it++ containing models of nonlinear components.

- it++ models of nonlinear high temperature superconductors will be developed. CTTC will supply the realistic nonlinearity models of filters or other components using high temperature superconductors.
- We will study of linearity, efficiency and cost tradeoffs for RF power amplifiers and development of numerical design algorithms for highly linear power amplifiers.
- We will study predistortion methods, especially in RFIC's using the scaled down versions of power amplifiers as predistorters.
- We will produce and publish joint papers.

3.2.2 Antennas:

Partners involved: UU, TUI, CTTC, ISIK

The cluster is lead by UU to encounter the gap (5) and (10). The research plan is as follows:

- Partners plan to develop numerical modelling tools for physical passive and active components such as RF transistors and antenna units using the new interpolation techniques.
- Isik University has developed "real frequency" techniques for this purpose. Isik University will organize "A short course on designing wideband microwave circuits" to teach these techniques to interested researchers. See below for a syllabus of this short course.
- The techniques will be applied to measurement results on real devices such as antennas and RF transistors.
- The cluster partners will develop real frequency numerical design and simulation toolboxes for broadband matching equalizers, interconnects and multistage microwave amplifiers. We will implement scattering based and impedance based design and circuit synthesis algorithms employing single and multivariable approaches.

A SHORT COURSE ON
DESIGNING WIDEBAND MICROWAVE CIRCUITS

COURSE TITLE: Design of Broad Band Matching Networks and Wide Band Microwave Amplifiers Using Real Frequency Techniques

COURSE DURATION: 5 Days

COURSE DESCRIPTION:
One of the major issues in wide band communication systems is appropriate design and modelling of broadband RF/Microwave active and passive subsytems. This crash course covers the practical aspects of *Real Frequency Techniques* for designing *Broadband Matching Networks* and *Multistage Amplifiers*. The challenging aspect of the Real Frequency design approach is the direct utilization of the real experimental data for the subsystems to be matched. In the design process, the approach also does not require a fixed topology for the network to be designed and its analytic form of transfer function. Because of these advantages, the real frequency technique has turn out to be the most feasible approach for designing broadband matching networks and amplifiers. In this short course the fundamentals underlying the real frequency design approach will be covered and the use of various real frequency techniques for practical matching network and multistage amplifier design problems will be exercised. The course will be held in 5 Half-Day Lectures.

Lecture 1: Network theoretical fundamentals of Real Frequency Broad Band Matching (3 Hours)
This session is devoted to a general discussion of some network theoretic fundamentals relevant to the course content. Basic definitions and properties concerning the scattering description of two-ports are reviewed, and some fundamental properties of network functions associated with practical lossless lumped and distributed networks are summarized. Then, a general discussion of the available approaches in the broadband matching theory is presented. The analytic approaches to broad band

matching problem is pointed out, and the practical aspects of Real Frequency and commercially available CAD techniques are discussed. The available real frequency algorithms are scanned in a comparative manner.

Lecture 2: Design of Matching Networks and Multistage Amplifiers via
Simplified Real Frequency Technique (3 Hours)
The Simplified Real Frequency Technique is based on the canonic polynomial representation of the scattering matrix and is especially suitable for the design of matching equalizers in cascaded multistage amplifiers. In this section, the application of the scattering approach for single and double matching problems will be studied and then the extension of the technique to the design of multistage amplifiers will be illustrated.

Lecture 3: Design of matching networks with mixed lumped and distributed
elements (3 Hours)
Practical implementation requirements for microwave lumped elements and transmission lines will be discussed and the extension of the real frequency approach for the multivariable characterization of mixed element structures with lumped circuit elements and transmission line will be studied.

Lecture 4: Practical Circuit modelling for Numerical Data (3 Hours)
Based on the numerical measurement data, the development of circuit models via numerical interpolation techniques will be discussed. Practical antenna modelling exercises will be introduced.

Lecture 5: Real Frequency Design Workshop (3 Hours)
In this session, hands on design work will be conducted in a computer lab for different applications of Real frequency Designs. Practical Matching Network and Multistage Amplifier Design examples will be worked out by making use of the Real Frequency Design Software WMCD (Wide Band Microwave Circuit Designer). Also Antenna modelling from given numerical data will be exercised using the Circuit Modelling Toolbox.

3.2.3 Phase Noise:

Partners involved: Bilkent, Chalmers, POLITO

This cluster is lead by Bilkent to encounter the identified gap (4) and (7). The research plan is similar to the research plan of nonlinearity cluster. it++ is also chosen as a medium of integration.

- Researchers will download it++ and they will learn it using tutorials and example files provided.
- Using it++ simulation of a typical communication system containing oscillators will be performed.
- Chalmers group will help graduate students on the use of it++. If necessary, researchers may visit Chalmers for training on it++.
- Realistic phase noise models for oscillators will be developed that are consistent with experimental data.
- These noise models will be programmed into it++ as new modules in the library.
- With these noise models, it++ will be used to predict the performance degradation in a communication system that contains noisy local oscillators.
- Amount of phase noise that can be tolerated will be determined.
- New methods of compensating phase noise and estimating common phase error will be developed. The success of these methods can be tested using it++, which has local oscillator noise models in it.
- Joint papers will be published

3.2.4 RFIC Front-ends:

Partners involved: UoP, UU, TUI

This cluster is lead by UoP to encounter the gaps (8) and (9). The research topics within the objectives of the project can be classified as follows:

- Classification of wideband RF front-end subsystems and the study of corresponding design problems.
- Further development of single and multi-dimensional circuit modelling concept for passive and active component description. The use of immitance and scattering based interpolation techniques for component and sub-system modelling.
- Systematic construction of multi-dimensional circuit models for different applications with a through investigation of possible topologies and physical implementation parameters. Mixed lumped and distributed circuit characterization via multivariable scattering and impedance representations.
- Development of numerical design and simulation algorithms for phase shifters, adaptive phase arrays and antenna array systems.
- Development of toolboxes for the design and simulation of the classified application models, including the study of implementation technologies.
- Benchmarking of the developed techniques and toolboxes to compare with other available classical approaches.
- Design, implementation and characterization of building blocks for fully integrated RF transceiver for wireless applications
- Work will be pursued on design and fabrication of 24 GHz antennas to be monolithically integrated into a commercial SiGe HBT. The objective is to derive novel antenna solutions suitable for monolithic integration with a commercial solid-state fabrication process. The antennas can be arranged in the form of Reconfigurable RF-(sub)System modules where each block will be like the generic “Lego”-piece in the antenna-RF architecture.

4 STATE OF THE ART AND INITIAL KNOW-HOW OF WPR3 PARTICIPANTS

4.1 Major Areas of Expertise

4.1.1 BILKENT

The state of the art and the initial Know-How of the Bilkent Team covers the following areas:

Communication, Radar and EW Systems Design:

The members of the Bilkent Team have been involved at the some projects starting from the design phase including the system design. They have been involved at Radar systems design for land platforms and EW systems integrated into some air platforms. Some of them personally lead design teams in EW resistant radio-link and tactical radio systems.

RF and Microwave Communication Electronics Design:

Bilkent University team has a long-standing experience in radar and communication circuit design in the RF and Microwave bands at the frequency range 3 MHz to 10 GHz. The circuits designed, modified, specified or supervised both at the university and at the industry, range from, HF over the horizon radars to X Band radars, from communication circuits starting from the tactical range to the frequencies going up to the 3 GHz and including the ISM band. The circuits designed cover a wide range of specialty circuits, including RF and microwave frequency synthesizers, RF power amplifiers, LNA and receiver front-ends, different coupler circuits, etc.

The design expertise the Bilkent team also includes Gallium Arsenide MMIC design and analysis and the use of CAD tools for such a design.

Antenna Analysis and Design:

Both integral equation and differential equation based methods for design and analysis of antennas and arrays as well as scattering from these structures. Using these methods we have designed and analysed printed antennas and arrays mounted on planar and/or curved host platforms which can be used in commercial and military applications. We have also designed reconfigurable antennas for mobile applications. This know-how has been used in applications like; Mimo system antennas, different patch antenna arrays, wire antenna arrays for wireless LAN applications.

The antenna experience of the Bilkent group also covers the integration of EW and Radar antennas to different platforms including airborne and land vehicles.

Wireless LAN circuit and systems design:

The Bilkent Team has lately designed an Wireless LAN radio module making use of some RF integrated circuits. This design served as a platform to apply the communication circuit knowledge accumulated in mobile communications and provided insight on certain aspects of Wireless LAN designs such as PA intermodulation and RFI shielding of wireless systems.

Fast circuit level simulator development:

The Bilkent group has the experience of developing fast algorithms for circuit level simulators to solve very large linear or nonlinear circuits using asymptotic order reduction techniques. Graduates of Bilkent have developed a number of best selling commercial simulators such as StarRC-XT (owned by Avanti Corp.).

4.1.2 CHALMERS

In the Communications Systems group, Department of Signals and Systems, methods to analyze and design systems for information transmission are studied. The main application for the principles that we study is wireless communication systems, and in particular personal and mobile radio communication systems. Lately, we have been working together with the Microelectronic department at Chalmers, where MMIC circuits for a 60 GHz wireless communication system has been developed. Our cooperation has resulted in good experience of system modelling of amplifier nonlinearities and phase noise in oscillators, and with design of single- and multi-carrier communication systems to avoid distortion due to nonlinear devices and phase noise. We describe state-of-the-art and our contribution in these areas below.

AMPLIFIER NONLINEARITY

System modelling*:* A system nonlinearity model must be low-complex enough to allow simulations using millions of communication symbols, in order to get enough statistics in communication simulations. Therefore, the possible candidates are rather limited. With memoryless models, we get a low complexity, but the accuracy is not good for most nonlinear devices, where memory plays an important part. At the other hand, models with memory can be accurate, but the complexity limits us to short memory and weak nonlinearities.

- **Memoryless nonlinearity:** Here we find models such as power series models, different kind of limiters, the Rapp model, the Saleh Model, etc. The models are either used in a quadrature scheme, with separate models for the real and imaginary part of the baseband, or in AM/AM and AM/PM schemes. In most cases, a memoryless model is not accurate enough to model a nonlinear amplifier.
- **Nonlinearities with memory:** The simplest model of nonlinearities with memory consists of a memoryless nonlinearity, followed or preceded by a linear filter. These models are usually denoted Hammerstein or Wiener models, respectively. They can work very well as system models if the memory of the nonlinearity is short compared to the symbol time in the

communication system. An alternative is the Volterra filter, which consists of a multidimensional power series. The Volterra filter can in principle model any nonlinearity with memory, but the complexity grows exponentially with the memory length and model order, and in practice only weak nonlinearities with short memory can be accurately modelled.

Our research has largely been focused on Hammerstein models, which have been shown to accurately model the power amplifier in the systems we have studied. We have also developed Volterra models for the purpose of equalizing the nonlinearity.

Single carrier communication system design:

The main problems that occur in a communication system due to nonlinearity are 1) in-band distortion of the communication signals, leading to a degraded performance, and 2) spectral regrowth, resulting in out-of-band power that disturbs neighbor communication channels. There are many ways to solve the problems, and we classify state-of-the-art methods into major parts as follows.

- **Data predistortion:** With this method, we shape the input signal to the nonlinearity such that the output of nonlinearity is as close as possible to the original signal in the linear case. This can be done by a *predistorter*, either with or without memory. A common method is to design a nonlinear memoryless predistorter in the baseband processing stage (using the same structures as in the modelling discussion above), in order to cancel the effects of the RF nonlinear amplifier. This type of predistortion can only give a limited performance improvement, mainly due to the limitation to baseband. An alternative is to utilize a lookup table (LUT) to adjust the input signal by the inverse characteristic of the nonlinearity. The transmitted signal is multiplied by the LUT value corresponding to the amplitude and phase of the signal. In theory, a LUT can fully compensate any nonlinearity, but the necessary size of the LUT grows exponentially with the memory of the pulse shaping filter and the amplifier, so in practice the LUT method is limited to very small problems.
- **Nonlinear equalizer:** A nonlinear equalizer is a nonlinear operator with memory. It changes the received signal constellation to be as close to the original transmitted one as possible. There are two problems associated with a nonlinear equalizer. Firstly, since a nonlinear equalizer is at the receiver, the spectral regrowth at the transmitter remains unchanged and is not compensated. Secondly, an equalizer will amplify the noise, which degrades the end-to-end performance of the system. The complexity of a Volterra filter is a major limitation.
- **Maximum likelihood sequence detection (MLSD):** One of the solutions to the problem of channels with intersymbol interference (ISI) is to make the decision on a sequence of symbols instead of one symbol at the time. The same method can be used to overcome the ISI induced by nonlinearity. In this case, the decision on the current symbol is made by considering the previous K symbols. A problem with this method is its substantial complexity.
- **Nonlinear detection:** This method refers to any detection method that is based on function estimation model. The method may use training data or just have blind training to estimate the nonlinear function. Neural network methods are among the top candidates to solve complex nonlinear problems, and can therefore be used to find the model h. One detection method that is proposed recently is the use of support vector machine for the detection. This method requires a small training set, but at the same time a considerable amount of computation.
- **Optimum linear receiver filter:** When the transmitter or channel contains nonlinearity, the optimal receiver filter is not the one that is matched to the transmitter filter anymore. Therefore, it has been proposed to find the optimum filter to minimize the bit error, subject to the constraint that the filter is linear. A limitation is that a linear filter can not be the optimal receiver for a nonlinearly distorted signal, but this solution is attractive from the viewpoint of system complexity.

At Chalmers, we have been studying predistorters as the main track in our research, due to two reasons: 1) Theoretically, predistorters can completely remove the effects of the nonlinearity. This is not true for any method at the receiver. 2) Only predistorters can reduce the spectral regrowth.

One way to improve the performance of data predistortion is to oversample the transmitted signal, using two or more samples per transmitted symbol. We have achieved very good results with moderate oversampling factors of 2 or 4. The practical limitation for this method is the oversampling rate, both because of the complexity of the algorithm and also the implementation of the fast D/A converters.

An upcoming interest of Chalmers is to develop low-complexity solutions to the Volterra filter. A promising structure is the parallel-cascade structure, which utilizes several low-order Volterra filters in parallel.

Multicarrier system communication design:

A case of particular interest is the nonlinearity in a multicarrier communication scheme such as OFDM, where the problem is more severe due to the large dynamic range of a multicarrier signal, and the methods to mitigate the nonlinear distortion are different. In addition to the solutions already discussed for a single carrier system, there are different methods to avoid large dynamics of the signal, a problem which is referred to as the peak power problem. Various methods have been shown to reduce the peak to average power ratio (PAPR) of a signal. These methods are based either on coding and modulation or on detecting high peaks before transmission and applying signal processing to reduce the PAPR. We classify the PAPR reduction solutions into the following methods.

- **Clipping:** The simplest solution to the PAPR problem is to just clip the signal at the desired level. This method does not eliminate the nonlinearity distortion, but copes with the effects of it by correcting the errors introduced. Obviously if the peak clipping occurs often, this method introduces considerable interference and spectral widening. Filtering and windowing can be added to control the interference and spectral regrowth, and also to limit the error.
- **Rotating selected subcarriers:** If the amplitude of the signal exceeds a certain level, the phase of each of the QAM modulated carrier is changed by means of a fixed phasor transformation and new symbol is generated.
- **Selected mapping:** The idea here is to represent the same information by more than one symbol and the one with the lowest PAPR is chosen and transmitted.
- **Injecting artificial tones:** The simplest example of this method is to add extra non-information subcarriers between each consecutive subcarrier, where the phase difference between the consequent subcarriers is determined such that the PAPR is minimized. The phase differences can be found by a lookup table if the number of subcarriers is small, or by means of numerical optimization.
- **Coding:** The statement of the problem here is to choose the best set of time domain vectors that are maximally spaced in the receive domain, but which are restricted in the transmit domain such that each instantaneous sample is within the linear region of the amplifier. While the idea of coding to reduce PAPR is straightforward, it is difficult to find structured codes with high rates that are suitable for high number of subcarriers. However, some codes with good PAPR reduction capabilities have been found, such as the Golay complementary codes. A large problem is that no good codes for more than 64 subcarriers are known.

Naturally, the methods discussed for single carrier systems can be applied also for multicarrier systems. At Chalmers, we have studied the peak-to-average-power (PAPR) criterion, and shown that while PAPR is straightforward to compute, it does not describe the true effects of nonlinearity well. Therefore we have developed new criterions, both for the case of known and unknown nonlinearity. Another approach we follow is to study techniques normally employed for multi-user detection to reduce interference between the users, for example parallel interference cancellation (PIC) or serial interference cancellation (SIC). By changing the optimization criterion, interference cancellation techniques can be modified to reduce interference between carriers in a multicarrier signal, which is useful in cases where a nonlinearity has introduced such interference.

OSCILLATOR PHASE NOISE

System modelling*:* As with system models of amplifiers, an oscillator system model must be very simple to allow the massive computer simulations necessary to achieve enough statistics in our research. Therefore, the models are normally digital baseband models, with the assumption that the oscillator phase noise is narrowband compared to the bandwidth of the communication signal. The prevailing system model of a free-running oscillator is the discrete Wiener process, $\phi_n = \phi_{n-1} + u_n$, where u_n is a white Gaussian process. The variance, and sometimes also the spectrum, of u_n are model parameters, and must be matched to measurements on real oscillators. With phase-locked oscillators, it is common to use a filtered Gaussian process model with a spectrum fitted to a given mask.

At Chalmers, we have access to phase noise measurements of the oscillator designed for the aforementioned 60 GHz wireless communication system we have been working with, and our model can predict the behaviour of the real oscillator with reasonable accuracy.

Communication system design:

Phase noise has been identified as a key problem in multicarrier communication systems (e.g. OFDM systems), and we therefore concentrate our efforts to discussing multicarrier systems. A multicarrier signal is very sensitive to oscillator phase noise due to the close subcarrier spacing leading to severe intercarrier interference (ICI). The effect of phase noise is two-fold. First, each communication symbol is rotated by a common phase error (CPE), which affects equally all the subcarriers and thus rotates the received signal space. Second, since phase noise is a time varying process, it destroys the orthogonality of the subcarriers and produces ICI.

A significant effort has been spent to compensate the phase noise effect on OFDM systems. The major efforts have been spent on CPE reduction; the common phase error has a major effect on all carriers, and must be suppressed. Most research has been concentrated on traditional estimation methods, using pilots and decision directed estimation of the CPE. The effort to reduce ICI has been less significant, but some effort has been spent here as well. In self-cancellation coding, every second subcarrier is the negative of its neighbor. With the plausible assumption that the phase noise for two neighbor subcarriers is approximately equal, the phase noise is cancelled by simple subtraction of the carriers at the receiver side. Unfortunately, cancellation coding implies a large sacrifice in throughput.

At Chalmers, we study methods for estimating jointly the channel and the CPE in a first step, and in a second step removing ICI while maintaining a high throughput, at the cost of a comparatively higher complexity. The technique is based on a few pilots and decision directed coding in combination.

Another technique we work with is to use interference reduction algorithms from other research areas, for example parallel interference cancellation (PIC) or serial interference cancellation (SIC) as described in the nonlinear amplifier section above. Interference cancellation techniques can be modified to reduce interference between carriers due to phase noise.

4.1.3 CTTC

Microwave communication subsystem technology is essential to most equipment in wireless access for fixed and mobile terrestial networks (especially 3G and 4G), radar, satellite system up/down links, wireless local area networks and microwave sensor systems. The popularity of modern wireless communication systems and the increasing demand of multimedia applications will lead to many new broadband service. The performance of the overall system will be significantly impacted by the RF or microwave transmitter and receiver. From a system perspective, a typical front-end radio architecture is composed of many passive and active blocks such as antennas, filters, low noise amplifiers (LNA), oscillators, mixers, phase shifters, power amplifiers (PA) etc. Since the ability to bring high-quality microwave devices is crucial to enable a successful of communication system, CTTC has opened in January 2003 a research area in this field.

In this area CTTC is interested to research and develop new microwave components and techniques and from their outcomes systematically study the impacts on the subsystem and system level (improvements on the overall system performance, reduce the overall system cost, create new architectures). For the time being the specific Research line involved in this area is the development of High performance Front-End receivers for wireless applications.

With the rapid growth in the telecommunication wireless industry many new communication systems have emerged. As a consequence, the necessity of an efficient usage of the limited spectrum has increased. Besides, with large subscriber numbers the interference between different systems may increase. Hence, to avoid such interferences and achieve the system requirements, more selective filters are required for an efficient exploitation of the spectrum.

An ideal receiver front-end, should be able to isolate only those signals of interest and pass them on to the subsequent stages of the receiver without alteration. It consists of a RF stage containing an input filter and a low noise amplifier (LNA), a down converter stage, and a demodulator stage. The qualities of the RF stage can be quantified in terms of the selectivity and sensitivity of the front-end. These qualities are considerably improved by incorporating a cryogenic LNA with a HTS filter, and may increase the capacity (number of simultaneous handsets and data rates) and the coverage (range) of a base-station in a wireless communication system.

One of the most important features of superconductors is their small resistance to the flow of current, when they are cooled below a particular temperature, called the critical temperature. Besides, HTS materials exhibit this feature at temperatures above 77K (the boiling point of nitrogen), stirring up high interest in many fields, with special repercussion in electrical engineering, including microwave, power, electronic and computer engineering.

In microwave applications, HTS materials offer performance improvements of components and systems, providing high frequency selectivity, low loss, light weight and small volume. Among the most important applications of HTS thin film microwave technology are those involving planar resonators with extremely high values of quality factors, comparable with normal-metal microwave cavities of much larger volume. A high-performance band-pass filter with low insertion loss and very sharp frequency roll-off characteristic needs coupled resonators with high quality factors. An attractive approach to reducing the volume of high-performance filters can be achieved by using HTS planar resonators like microstrip or coplanar waveguide.

Currently, there are several companies over the world with wide experience in the marketplace, which have deployed nearly 2000 HTS filter subsystems for wireless applications with more than 23 millions of hours of cumulative operation. Furthermore, the planned third generation system for wireless communication, which requires high receiver performance to maintain high data rates, may be an excellent opportunity for HTS technology application.

On the other hand, the HTS surface impedance depends on the applied field, which leads to nonlinearities such as the generation of intermodulation products. Thus, HTS filters are mainly deployed in the base station-receivers, where the signals levels are low, and the nonlinear effects are less pronounced. HTS subsystems for the transmit side are far less common, being limited to 3D structures or to some planar structures where the field distribution is sufficiently uniform.

Therefore the nonlinear effects in superconducting devices are an important limitation to the widespread application of HTS microwave technology. To overcome this obstacle many efforts have been made to understand the origin of such nonlinearities. Nevertheless, this is still not fully understood and there is considerable interest in learning how to improve and understand the microwave properties of HTS materials, how to characterize the materials, and how to improve the design of HTS microwave circuits taking into account their nonlinearities.

Our work stems from a microwave group of a signal theory and communication department, which has been working in the nonlinear aspects of HTS materials, developing algorithms, formulating phenomenological models and doing measurements. Our purpose has been to fill the gap between the HTS nonlinear characterization on one side and the RF system engineering on the other side.

- We suggest a phenomenological description of the microwave nonlinear properties of HTS, being specially adequate for applications using HTS resonators.
- This description has been the base to develop different numerical methods for the nonlinear characterization of the material and for the prediction of the nonlinear effects in communication system transceivers containing HTS components. A final aim is the prediction of the nonlinear effects in HTS filters when they are subject to signals like the ones found in dense electromagnetic environments.
- We expand on the general formulation for resonators based on unpatterned and patterned HTS thin films.
- Several unpatterned resonators are studied; one is a TE_{011} dielectric loaded cylindrical cavity and the other resonator is based on a planar disk resonator operating at TM_{010} mode.

We verify the use of the phenomenological description on resonant patterned structures, like straight-line resonators and other novel resonant structures with folded lines, which are the basis of many commercial HTS filters. The results of the characterization in patterned structures are checked with measurements. In addition, the application of general formulation in novel planar patterned structures also allows us to find out how one can improve the design of HTS microwave circuits in order to minimize the nonlinear effects.

Although the analytical formulation shows to be a reliable method, it becomes harsh for complex structures, besides other restrictions - it does not take into account compression effects. We overcome these limitations by developing numerical methods based on Harmonic Balance (HB) algorithms. We present the Multiport Harmonic Balance (MHB) algorithm, which allows us to analyze the nonlinear performance of HTS devices when they are driven by one or two tone signals. This tool is used to analyze the nonlinear performance of straight line or folded resonators. Furthermore, this numerical method is checked with analytical expressions and is also used to adjust the measurements, which may present compression effects.

MHB shows to be adequate for the nonlinear effects caused by one or two tones. However, in some communication systems, one would like to characterize the nonlinear performance of the circuit when they are subject to broadband signals. We present an expansion of the MHB which performs the nonlinear response of devices when they are fed by an input signal with many frequency components, like the signals used in WCDMA wireless communication systems. We call this expansion Multiport Multitone Harmonic Balance (MMHB). Results of WCDMA communication system environment either through an HTS frontend receivers or transmitter shown the viability of such devices in the coming third generation wireless systems. In these predictions we also have take into account the effects of the nonlinearities produced by the amplifiers. More elaborate approach of the nolinearities of the amplifiers is necessary to consider.

4.1.4 ISIK

Işık University microwave research group has long years of experience in designing wideband microwave circuits such as matching networks, amplifiers and filters. The group members have developed novel design techniques on broadband matching networks and multistage amplifiers. The broadband matching problem was of serious concern in the literature over several decades. With the advent of microwave and millimetre wave integrated circuit technology, the new activities in the design and development of wideband communication systems stimulated a renewed interest on broadband matching of communication subsystems. Since the current analytic theory on the issue presents serious difficulties in solving complicated matching problems encountered in practical applications, several computer programs have been developed to meet the needs of industry. These computer aided design packages suffer from several deficiencies in handling microwave design problems, since they are based upon brute force methods. Based on these considerations, a new synthesis based approach called the Real Frequency Technique eliminated most of the problems associated with classical analytic methods and purely numerical CAD techniques, and has therefore activated and renewed research efforts in the field of broadband matching. The Işık group members have developed several variants of the real frequency method and introduced novel contributions to the literature on this new trend in matching problem studies. In these contributions on broadband circuit design, networks employing solely lumped circuit elements or distributed transmission line are elaborated and broadband design of practical antenna matching networks and broadband amplifiers are realized. On the other hand, in the microwave discrete, hybrid or monolithic integrated (MMIC) designs, the physical realization of ideal lumped and distributed network elements presents serious implementation problems. For a complete characterization of microwave integrated circuit (MIC) layouts, it is therefore essential to model all the physical parameters and the possible parasitic effects inherent to the implementation process, and to take them into account in the design procedure. This would in turn require the treatment of mixed, lumped and distributed elements in the network modelling and design. In this regard, based on multivariable network characterization we have developed extended real frequency technique to design generalized mixed element microwave circuits for MIC and MMIC implementations.

Another area of study for which Işik microwave group has been striving is immittance data modelling based on interpolation methods. Especially, with the commencement of a new technological era to produce new generation communication systems, immittance data modelling has regained its popularity. The circuit models constructed are utilized for behavioral characterization and simulation of physical devices or to design sub-systems with active and passive solid-state devices, that is to say, analyzing the electrical behavior of the physical devices such as gain bandwidth limitations, determining of the noise figure merits or power delivering capabilities. The developed modelling tools based on linear interpolation techniques present "computational and practical" advantages over the existing interpolation techniques, such as non-linear curve fittings or regression methods. Among the application areas of the developed circuit modelling methods, providing initial circuit topologies to the commercially available analysis/simulation and design packages comes first. Up to day, utilizing the immitance modelling techniques several circuit models for experimental measured data of different antennas have been developed and the technical description of the techniques have been presented to the literature.

Based on the expertise on the above mentioned areas, Işık team has newly developed a CAD tool; ***WMCD*** - the acronym standing for "*Wideband Microwave Circuit Designer"* - whose capabilities encapsulate all the relevant issues encountered in broadband design of passive and active networks such as double matching of passive source and load data, filters and multistage amplifiers.

"*Wideband Microwave Circuit Designer"*, is a Matlab based GUI supported software tool for designing broadband matching networks, and multistage microwave amplifiers for high frequency analogue/digital communication subsystems to be manufactured on VLSI and MMIC chips.
The underlying theory, namely, Real Frequency Techniques, incorporated in the design algorithms comes from the previous works of Carlin, Yarman and Aksen whose contributions to the computer aided design of broad band networks have opened a new direction in the field. In the package, these "Real Frequency Design Techniques", are collected together and the algorithms underpinning the theory are made user-friendly by plugging enhanced graphical interfaces into MATLAB m-files. The real frequency matching network design techniques incorporate directly the experimental measurement data for the generator, load and the active devices in the system. Also without any necessity of choosing a network topology and a transfer function form, the real frequency approach yields the optimum design. All of these advantages make the package a flexible microwave design suite. Amongst the different real frequency approaches, "*Wideband Microwave Circuit Designer* "*(WMCD)* includes the following;

- *Line Segment Technique* - matches a complex load to a resistive generator by generating optimum back end impedance of the equalizer representing its real part as number of straight line segments.
- *Direct Computational Technique* – similar to the Line Segment Technique but instead line segments here the real part of impedance is expressed as an even rational function whose coefficients to be optimised to obtain better gain performance.
- *Simplified Real Frequency Technique* – uses the scattering matrix of the lossless equalizer and optimises the transducer power gain which is a function of scattering parameters of the equalizer.
- *Parametrical Approach* - assumes the input impedance of the equalizer network as a minimum reactance impedance function and optimises directly the poles of this function to obtain the optimum power gain.

User can select freely three types of network design schemes;

- *Lumped element design* – includes inductors, capacitors, and chip inductors, chip capacitors manufactured in microstrip form for lossless ladder structures to be realized as low-pass, high-pass or band-pass matching networks and inter-stage equalizers for microwave amplifiers.
- *Distributed element design* – includes cascade connection of commensurate lengths of transmission lines to design matching networks and inter-stage equalizers for microwave amplifiers.
- *Mixed lumped & distributed network design* – includes both lumped and distributed lossless two-ports connected in cascade to design matching networks and inter-stage equalizers for microwave amplifiers.

With its flexible and user-friendly nature, *"Wideband Microwave Circuit Designer"* is a powerful tool for designing broadband microwave matching networks and multistage amplifiers. To say another priority of WMCD over other brute force design packages, it is a synthesis based design tool, which also incorporates lumped element extraction, and Richards' distributed circuit synthesis tools. It also bridges the gap in the development of interconnect modelling for MMIC chips -an important facet of the business that has been overlooked so far by the designers -, in order the parasitic and discontinuity effects of implementation to be embedded into the design process.

WMCD software presents MATLAB based environment with enhanced graphical interfaces, enables the microwave engineers to design wideband microwave circuits in an easy and user friendly manner bringing new horizons to the researchers in microwave area.

As a summary, major areas of expertise of Işık microwave research group can be collected under the following items:

- Analytic and computer aided design of broadband matching networks for Radio Frequency (RF) and microwave communication systems. (Wireless cellular systems, Antennas, RF-Amplifiers, Satellite Communications etc.)
- Analytic and computer aided design of broadband amplifiers for RF and wireless communication systems.
- Computer aided design tools for discrete, hybrid and monolithic Microwave Integrated Circuits (MIC)
- Design of digital phase shifters for RF-antenna arrays.
- Lumped, distributed and multivariable network characterization for MIC implementation.
- Construction of circuit models for collected RF data.

4.1.5 POLITO

The microwave research group in Politecnico di Torino, Italy has a well-established experience in the areas of high-frequency device modelling, device characterization and RF nonlinear circuit design. The activity of the group is demonstrated by several publications in the field and by an extended network of collaborations with academic and industrial partners both in Europe and in the USA. The research unit microwave laboratory has gained a leading position in the nonlinear device and system characterization especially through active load and source harmonic pull and is contributing a continuous measurement activity both for research purposes within the group and for consultancies. Recent research advances has been achieved in the field of power amplifier linearization in the K band by means of RF predistortion schemes suited for MMIC and hybrid implementation. Relevant activity for WPR3 include nonlinear high frequency device modelling, power amplifier design and linearization, noise analysis capabilities. In particular the main research areas of unit POLITO include:

a) Device modelling The research unit has gained a wide experience in linear and nonlinear device modelling at various levels, from physics-based to compact and black-box circuit models. In particular the group has a well-established research activity in the field of physics-based device noise modelling, both in the linear case and in the non-autonomous nonlinear case. At the circuit level, the research activity has been focused on device models for nonlinear RF and microwave analog applications. A circuit level PHEMT large-signal model, based on a modified Angelov model including thermal effects, has been proposed, while nonlinear models extracted from measurements have also been demonstrated. Recently a growing interest has been dedicated to the development of black-box and behavioural device and circuit nonlinear models, in conjunction with nonlinear characterization, and some achievements have been obtained in device modelling through neural networks. The modelling research activity has been brought forward in conjunction with the development of simulation techniques, especially through CAD tools. Simulation codes have been developed in house in order to demonstrate advanced device simulation techniques, especially for noise analysis, while commercial CAD tools are also exploited for accurate device simulations. In general simulation tools can be divided in three main areas: physics-based simulations, circuit simulation and system level analysis. In particular in the latter approach, nonlinear behavioural models can be included in telecom RX-TX links analysis in order to identify the effects of the active device nonlinearities on the system level performances such as the BER, ACPR etc. CAD tools capabilities in the POLITO unit include:
    - 1-2D physics-based device simulation with in-house codes allowing for linear and nonlinear noise analysis. PADRE from Bell Laboratories and standard commercial programs (Silvaco ATLAS, ISE Tcad).
    - Circuit simulators for microwave applications include Agilent ADS and AWR Microwave Office. Innovative circuit-level device models have been implemented within these tools,

such a PHEMT modified Angelov model including thermal effects, nonlinear coupled electro-thermal models and behavioural black-box models.

- System simulators include Agilent Ptolemy and AWR VSS. In particular user-defined nonlinear behavioural models can be linked in VSS though the MATLAB environment.

b) Microwave and RF circuit design. POLITO Unit has a well-established circuit design activity in the area of microwave integrated circuits on GaAs. In particular design of various front-end power amplifiers in the microwave frequency range (20-40 GHz) has been carried out in collaboration with AMS and exploiting AMS GaAs fab facilities. Recently the design activity has been devoted to high efficiency, high linearity power amplifiers which is becoming the most critical step in the project of the transmission front-end for next generation wireless communication systems. In fact the requirement for both high data rates and efficient spectrum utilization necessitates the simultaneous amplitude and phase modulation with a peak to average ratio greater than 6 dB. Distortion of the amplified signal can cause both AM-AM distortion and AM-PM conversion. The result is a spectral re-growth within adjacent channels. This calls for the design of high linear power amplifiers not only concerning the Pin-Pout behaviour but also regarding the in-band intermodulation products (IP). Among the various proposed linearization approaches, many are not suited for implementation at high frequency (above 10GHz) both because they require a too complex design and the unavailability of the required active and passive components. In the microwave frequency range one of the most effective linearization techniques is predistortion at RF level. The main concept of this technique involves the insertion of a nonlinear block prior to the RF power stage such that the combined transfer characteristic of the cascade is linear. An RF predistorter typically creates the expansive predistortion characteristic by subtracting a nonlinear compressive transfer characteristic from a linear one. Within our research unit a novel optimum predistortion scheme, suitable for MMIC and hybrid microwave power amplifiers, has been proposed and demonstrated through a prototype implementation and characterization. The new scheme includes two branches, which exploit scaled down (reduced periphery) amplifiers operating at different power levels in order to drive one in nonlinear condition and the other in linearity. The combined power of the two branches not only shows the required expansive behaviour but also has a harmonic content related to the compression behaviour of the high power amplifier to be linearized. By properly combining the power in the two predistortion branches with optimally designed attenuators third order intermodulation products of the linearized power amplifier can be completely cancelled and significant reduction of the fifth order intermodulation can simultaneously be achieved. The linearization scheme requires a nonlinear modelling for the active devices: simple models based on AM-AM and AM-PM measurements proved to be sufficiently accurate for narrow-band applications, even compared with more advanced large signal models including memory effects. The prototype demonstrating the capability of the linearization scheme has been realized in collaboration with SIAE Microelettronica in a hybrid technology while a MMIC higher frequency implementation has been designed at a circuit level within CAD tools (ADS). In order to exploit the predistortion scheme for wideband communication systems, more advanced nonlinear models including memory are required and are currently investigated.

c) System level analysis A system level simulation activity by exploiting VSS in conjunction with MATLAB has been initiated, by including power amplifier nonlinearities through behavioural models. At the time being, only simple memory-less models based an AM-AM and AM-PM characterization have been implemented, but the ongoing work is dedicated to models including memory. The difficulty is related to the need of accurate yet simple models, suited to be easily implemented in system level simulation. In fact, this kind of simulation tools requires simple and computationally efficient models, compared to standard circuit-level nonlinear models or behavioural models based on Volterra series.

d) Nonlinear characterization. Accurate power device modelling and amplifier design requires accurate nonlinear characterization capabilities. Conventional techniques are narrowband and include Pin-Pout at the fundamental and the harmonics with single and multitone excitation. In nonlinear operation, measurements with various load and source terminations are of paramount relevance, especially if extended to advanced characterization such as PAE and intermodulation. Measurement set-ups that allow changing the loading conditions are referred as load- and source-pull systems. To obtain a variable load, passive networks with manual or automatic variable

elements can be used (passive tuners). The alternatives are active loads, which electronically synthesize the required reflection coefficient. In the case of active load pull a portion of the input or output power is drawn, amplified, phase shifted and fed back to the amplifier. Typical high power devices present high input mismatch and highly reflective optimum power load: while with passive load-pull losses reduce the maximum achievable reflection coefficient below the optimum required for power applications, with active load-pull losses can be compensated and therefore a complete mapping of the source or load termination within the Smith chart can be easily obtained. Typical results of load/source pull characterization show the terminations on the Smith chart with constant values of power (at the fundamental and at the harmonics), efficiency and intermodulation, thus allowing a combined design with optimum compromise for high power, high efficiency and high linearity operation. A typical application of this technique is the power amplifier design for CDMA, WCDMA or other 3G/4G-telecommunication systems. Standard load pull measurements allow controlling the load at the fundamental with no control of the same load at the harmonic frequencies. This is usually enough for classical applications such as class A power amplifiers but for advanced amplifiers where both high linearity and high efficiency are sought for, the harmonic termination control is of paramount importance. Harmonic active load-pull extends load-pull characterization in order to set the source and load terminations in a discrete set of frequencies thus allowing harmonic tuning of power transistors.
The Microwave Laboratory of Unit 30 includes linear and nonlinear high-frequency on-wafer device and circuit characterization. This includes S-parameters up to 40 GHz, automated load-pull measurements up to 18 GHz and harmonic load-pull with highest (typically second) harmonic at 18 GHz. Intermodulation characterization can also be carried out by using two RF sources and a spectrum analyzer.

4.1.6 TUI

The department for RF & Microwave Techniques (HMT) at TUI has a long-standing tradition in the research and development of active and passive RF and microwave devices and circuits, namely in the areas "analog RF and microwave circuits", "antennas", "RADAR", and "sensors". In addition, following the call on a full chair in 2003, the new Head of the Department has amended this expertise by complementary knowledge on RF measurements and microwave device applications of novel materials, including superconducting and magnetic oxides and borides.

One of the present research foci at TUI concerns "mobile communications". It integrates the know-how of five departments - including RF & microwaves, communications research lab, electronic measurement techniques, integrated hard- and software systems etc. - covering almost all layers addressed by the OSI reference model. Furthermore, numerous links between the high-frequency aspects and related thin-film and packaging technologies (fabrication, periphery, characterisation) and microelectronics exist on campus. The available know-how, hence, is well suited to address the WPR3 Research integration for Project 3: “Design, modelling and experimental characterisation of RF and microwave devices and subsystems”. In the following, we describe selected areas of research, whose contents or methods are especially closely related to the NEWCOM work package WPR3 and related areas.

a) Integrated GaAs microwave filters

From 1993 until 1996, we performed an R&D-project (funded by the German Federal Government, 01 BT 308) dealing with the integration of coplanar microwave filters on GaAs. In cooperation with the Fraunhofer Institute for Applied Solid State Physics IAF (Freiburg, Germany), we developed, fabricated and tested frequency selective devices for frequencies around 10 and 20 GHz, respectively. Based on designs of fully planar integrated circuits developed at TUI, the chips were fabricated in Freiburg and subsequently measured in Ilmenau. The layouts involved lumped-element resonators and distributed elements for frequencies below and above 20 GHz, respectively. The design included specific field-theoretical modelling of the electromagnetic coupling, for example, between coils and transmission lines. The measurements were performed with our on-wafer coplanar microwave prober.

For the frequency range 10-13 GHz, a three-pole bandpass filter with a 3-dB-bandwidth of 900 MHz and a stopband rejection of 32 dB was developed. Due to the integrated design, the high insertion loss of about 21 dB of the passive circuits required the additional integration of GaAs amplifiers. Wider passbands would allow for lower insertion loss. For 19-23 GHz, we developed a coplanar coupled-line bandpass filter. We achieved a 3-dB-bandwidth of 1000 MHz, an insertion loss of 23 dB, and a stopband rejection of 49 dB. To demonstrate the potential of this technique for applications, we successfully fabricated stepped filter banks, employing LC as well as transmission line resonators.

The project provided valuable data and knowledge for the design and characterisation of integrated RF devices, especially in terms of the compatibility between circuit and field simulation tools, and physical models. We are ready to adopt our know-how to RF-components for future communication systems, where bandwidth, adaptivity, reconfigurability, and potentials for miniaturisation and monolithic integration present demanding challenges.

b) RFIC front-ends

The know-how and experience of the HMT group at TUI in the area of RFIC front-ends has been accumulated over more than 10 years. Different, application-specific, circuit solutions have been designed, fabricated, tested, and successfully applied. A few examples are sketched below.

We developed a power amplifier for “very small aperture” terminals that enable direct data transmission from and to satellites using mirrors of diameters below 1m. The amplifier delivered the required transmitted power of 4 W at 14 GHz. It allowed for online monitoring of the available power as well as automatic gain control based on a built-in detector.

For another application, the down-conversion of a very wide-band input signal (1.2 to 3 GHz) to a frequency range from 260 to 900 MHz was required. The spectrum of the input signal was devided into into three separate, 600 MHz wide, channels by means of microstrip filters. The super-heterodyne receiver offered an electronic channel selection (switching; > 60 dB out-of-band rejection). The external local oscillator switched synchronously with the tunable filter banks.

We also developed and fabricated a complete receiver for the simultaneous reception of GPS (1575.42 ± 1 MHz) and GLONASS (1609.5 ± 7.5 MHz) navigation signals, which included the entire electronic hardware and software for signal processing, like microcontrollers and FPGAs.

The examples illustrate our capability to develop a wide range of RFIC front-ends to given specifications. New design tools or increased functionality brought about by novel materials are thoroughly taken into account. Co-operation with our partners within WPR3, by synergy, will further enhance the range and quality of contributions to NEWCOM.

c) Antennas

Smart antennas are expected to significantly enhance the system performance of 3G and 4G mobile radio systems at both link ends. These multiple-input multiple-output (MIMO) systems are of great interest in the research community. Such systems can exploit the full spatial and temporal structure of the mobile radio channel. However, the development of suitable and robust space-time processing algorithms requires a profound knowledge of the behavior of the mobile radio channel. To attain this information, channel measurements are required, e.g., by using a MIMO channel sounder. Channel sounding is another area of expertise of TUI, addressed by WPR2 of NEWCOM.

We have designed, fabricated, and tested dual-polarised uniform rectangular antenna arrays (URA) for channel sounding applications. This application imposes challenging requirements for the antenna: The URAs have to be able to resolve the impinging wave fronts (propagation paths) in azimuth as well as in elevation to fully assess the mobile radio channel. Moreover, the URAs have to take into consideration the polarisation of the paths.

Two types of arrays, consisting of Vivaldi radiators and patch resonators, respectively, were compared. The Vivaldi array, which has the inherent potential for broadband capability, consisted of 64 elements. Simulations and measurements showed unexpected radiation patterns of a single antenna when its lateral dimensions were reduced below the usual values, due to currents on the antenna rim. This effect had to be accounted for by the arrangement of the radiating elements within the array. However, the frequency bandwidth of the optimized two-dimensional Vivaldi array decreased in comparison with the usual stand-alone Vivaldi antenna element. Within the frequency range of 1.8-2.2 GHz, the array achieved vertical and horizontal 3-dB beam-widths of 112° and 99°.

The limitations in beam-width, aperture angle, and the bulky construction of the Vivaldi array led us to design a second array, based on 32 dual-polarised patch antenna elements, each with two parasitic patches in the horizontal and vertical directions. The measured isolation between both polarisation planes was 16.5 dB, comparable to the 20 dB for the Vivaldi URA using separate radiators for each polarisation. The antenna elements of the patch array covered a frequency range of 1.9-2.2 GHz with average vertical and horizontal 3-dB beam-widths of 87° and 107°.

d) Microwave properties of novel materials

Part of the former research activities of the new Head of Department was devoted to high-temperature superconductors (HTS). Numerous projects since their discovery dealt with experimental and theoretical studies of the linear and nonlinear microwave response of epitaxial HTS films and passive devices for communication systems. The unusual properties of HTS, which lack from a consistent theoretical explanation until today, display dynamic effects that manifest themselves in unique dependencies of the electrical conductivity on temperature, frequency, and power. To access these properties experimentally, in cooperative efforts with international research groups, numerous sample-specific measurement systems were developed, measured data compared with the results of analytical calculations and numerical simulations of the surface impedance and the two-tone frequency intermodulation. This work, which forms an essential link between the physics of novel materials and the engineering of related devices, achieved a leading position, as reflected by various monographs, numerous publications, and contributions to tutorials and summer schools at international conferences.

Of special relevance for the development of HTS microwave devices are their nonlinear properties. These were investigated within the "International Research Initiative" (IRI), aiming at the "*Engagement of world-class, international researchers and application of their capabilities to address the objectives of the Research Interest described by the Air Force Office of Scientific Research"*. The focus of this research, conducted together with partners from the US and UK, was the study of third-order nonlinear effects like frequency intermodulation and harmonic generation. Such effects can be caused by the superconducting materials as well as by the dielectric substrates. It may be worth mentioning that our group was the first to discover a nonlinear loss-tangent of magnesium oxide, which strongly decreases for increasing microwave power. This phenomenon is caused by resonant absorption. It could occur as well in other dielectric, ferro-electric, or piezo-electric materials, and could grossly alter the performance of devices made thereof.

This area of research demonstrates how strongly the progress of innovative RF and microwave devices is linked to the invention, development, and exploitation of novel materials. It also illustrates the importance of a comprehensive characterisation of the high-frequency response of materials in the light of the specifications to be achieved by the devices based on these. Such a view is considered of high relevance for the future development of the hardware components within NEWCOM, as these, most likely, will be based on novel functional materials.

e) Novel devices

Following the rationale apparent from the previous sections, the HMT group at TUI has recently started two new research projects dealing with the development of novel RF and microwave devices. Both of them involve partners with expertise in technology.

One project aims at the development of innovative and inexpensive components for future applications in multimedia satellite communications. The rationale of the project is to exploit the possibility of integrating passive and active components in LTCC multi-layer structures, and by minimising the complexity of the semiconductor components. LTCC offers a number of benefits such as low-cost production and assembly, compact size, and hermetic sealing, which are of utmost importance for satellite-based applications. Three technological milestones for Ka-band satellite applications used for the downlink are under development in this German academic-industrial co-operation: solid-state amplifier, frequency synthesiser, and reconfigurable switch matrix. The concept of the project could be similarly well adapted to the modular layout of receivers for earth-based mobile communications.

The other project deals with the research and development of micro/nano-electromechanical RF sensors based on piezo-electric AlGaN-GaN heterostructures on Si substrates [9]. Miniature electromechanical resonators find a multiplicity of applications like sensors for micro-biology or chemistry, electro-optical couplers, or RF filters. Integrating the sensing elements with active semiconducting or passive RF components opens the potential for enhanced functionality in monolithic integrated circuits, including smart receivers for mobile communications.

4.1.7 UoP

In the Department of Information Engineering: Electronics, Computer Science, Telecommunications the first studies on radar were begun in early ’40. In 1961, one of the first master degree in Electronics in Italy was established, and in 1989, that in Telecommunications with curriculum dedicated to microwave engineering. The activities in the field of modern microwave circuits design started in 1992 with several courses in Microwave, Electronics for Telecommunications, Electromagnetic Compatibility, Electromagnetic Field Propagation.
Two research groups are currently applied, both for Mathematical Methods for Electromagnetic Field Propagation, Antennas and Passives design and Microwave Integrated Circuits with emphasis to RF ICs for mobile communications. Concerning the latter, our research group is mainly active on fully integrated transceiver solutions for wireless systems on standard silicon technologies. In order to research for the feasibility of a single chip transceiver on silicon standard process, a special focus was dedicated on proposal of novel circuit solutions capable to represent a valid opportunity to the traditional ones which use bulky and expensive external components. Particularly, the feasibility of high-Q voltage controlled inductors has been fully demonstrated. Novel primary blocks (as Low Noise Amplifiers, Mixers, RF antenna switches, Power Amplifiers, etc) have been designed on different standard process (Si, SiGe-CMOS) for several operating frequency ranges (up to 6 GHz) and applications (mobile telephony, WLAN, Bluetooth).

4.1.8 UU

The Division of Signal and Systems consists of 36 lecturers, research scientists and Ph.D. students. The division is pursuing research in applied physics, electrical engineering and information technology areas, mainly in microwave technology, signal processing, and non-destructive testing oriented towards industrial oriented applications. The group has three main spheres of interest namely: microwave and millimeterwave technology, telecommunication and nondestructive testing.
The Division Material Science consists of 48 lecturers, research scientists and Ph.D. students. The main areas of research are the development of novel processes and structures for microsystems and tribological applications, sensors and actuators, multifunctional system integration, bulk acoustic wave devices, microsystem mechanical modelling, miniaturisation of spacecraft's, and materials microanalyses. The Microsystem Materials and Processing group consists of 6 researchers . The group is involved in novel processes and devices for microsystems like quartz and AlN-based BAW resonators, 3-D magnetoresistive sensors by ion track lithography, optical MEMS with diamond and heterobonded InP-to-Si, membrane incorporated active III-V Schottky diodes for RF-MEMS, diamond based microreactors, and MEMS cold gas thrusters for space crafts.

4.2 Related Publications of partners

4.2.1 Bilkent

i. M.Celik, O. Ocali, M.A. Tan, A. Atalar, ``Pole-zero computation in High Frequency Circuits using Multipoint Pade Approximation,'' *IEEE Trans. Circuits and Systems I: Fund. Theory and Appl.* 42, pp. 6-13, (1995).

Abstract: A new method is proposed for dominant pole-zero (or pole-residue) analysis of large linear microwave circuits containing both lumped and distributed elements. The method is based on a multipoint Pade approximation. It finds a reduced-order rational s-domain transfer function using a data set obtained by solving the circuit at only a few frequency points. We propose two techniques in order to obtain the coefficients of the transfer function from the data set. The proposed method provides a more efficient computation of both transient and frequency domain responses than conventional simulators and more accurate results than the techniques based on single-point Pade approximation such as asymptotic waveform evaluation.

ii. M. Celik, A. Atalar, M.A. Tan, ``Transient Analysis of Nonlinear Circuits by Combining Asymptotic Waveform Evaluation with Volterra Series,'' *IEEE Trans. Circuits and Systems I: Fund. Theory and Appl.* **42**, pp. 470-473, (1995).

Abstract: A new method is proposed for the transient analysis of circuits with large number of linear lumped elements and lossy coupled transmission lines, and with few mildly nonlinear terminations. The method combines the Volterra-series technique with Asymptotic Waveform Evaluation approach and corresponds to recursive analysis of a linear equivalent circuit.

iii. O. Ocali, M. A. Tan, A. Atalar, ``A new method for nonlinear circuit simulation in time domain: NOWE,'' *IEEE Trans. on Computer Aided Design* **15**, pp. 368-374, (1996).

Abstract: A new method for the time-domain solution of general nonlinear dynamic circuits is presented. In this method, the solutions of the state variables are computed by using their time derivatives up to some order at the initial time instant. The computation of the higher order derivatives is equivalent to solving the same linear circuit for various sets of dc excitations. Once the time derivatives of the state variables are obtained, an approximation to the solution can be found as a polynomial rational function of time, The time derivatives of the approximation at the initial time instant are matched to those of the exact solution. This method is promising in terms of execution speed, since it can achieve the same accuracy as the trapezoidal approximation with much smaller number of matrix inversions.

iv. M. Celik, A. Atalar, M.A. Tan, ``A New Method for the Steady-State Analysis of Periodically Excited Nonlinear Circuits,'' *IEEE Trans. Circuits and Systems* **43**, pp. 964-972 (1996).

Abstract: We propose a new method for the steady state analysis of periodically excited nonlinear microwave circuits, It is a modified and more efficient form of Newton-Raphson iteration based harmonic balance (HB) technique. It solves the convergence problems of the HB technique at high drive levels. The proposed method makes use of the parametric dependence of the circuit responses on the excitation level. It first computes the derivatives of the complex amplitudes of the harmonics with respect to the excitation level efficiently and then finds the Fade approximants for the amplitudes of the harmonics using these derivatives.

v. S. Topcu, A. Atalar, M.A. Tan, ``Application of asymptotic waveform evaluation for time-domain analysis of nonlinear circuits", Int. J. of Electronics, vol. 83, pp. 351-361, (1997)

Abstract: A method is described to exploit asymptotic waveform evaluation (ATNE) in the time-domain analysis of nonlinear circuits by using SPICE models for nonlinear devices such as diodes, transistors, etc. Although AWE has been used for linearized circuits only, the aim is to enhance the accuracy of the simulation while preserving the computational efficiency obtained with AWE and to eliminate the piecewise-linear modelling problem. Practical examples are given to illustrate significant improvements in accuracy. For circuits containing weakly nonlinear devices, it is demonstrated that this method is typically at least one order of magnitude faster than SPICE.

vi. M. Sungur, A.S. Ekinci, A.. Atalar, "An efficient program for analysis of interconnect circuits", Int. J. of Electronics, vol. 82, pp. 641-654 (1997)

Abstract: A circuit simulation program using generalized asymptotic waveform evaluation techniques is introduced. The program analyses circuits with lumped and distributed components. It computes the moments at a few frequency points, and extracts the coefficients of an approximating rational by matching the moments simultaneously. The accuracy of the results and the execution times are compared with conventional simulators using several examples, indicating that our simulator provides a speed improvement without a significant loss of accuracy.

vii. A.S. Ekinci, A. Atalar, "An electrical circuit theoretical method for time- and frequency-domain solutions of the structural mechanics problems", Int. J. for Numerical Methods in Engineering, vol. 45, pp. 1485-1507 (1999)

Abstract: Shrinking device dimensions in integrated circuit technology made integrated circuits with millions of components a reality. As a result of this advance, electrical circuit simulators that can handle very large number of components have emerged. These programs use new circuit simulation techniques and can find solutions accurately and quickly. In this paper, we apply these techniques to structural mechanics problems by adopting electrical circuit equivalents. We first apply finite element formulation to the mechanical problem. The obtained sets of equations are treated as if they are sets of equations of an equivalent electrical circuit, which consists of linear circuit elements such as capacitors, inductors and controlled sources. The equivalent circuit is obtained in the form of a circuit netlist and solved using a general-purpose electrical circuit simulator. Several examples showing the advantages of the circuit simulation techniques are demonstrated. Asymptotic waveform evaluation technique, which is widely used for simulation of large electrical circuits, is also studied for the same examples and the speed-up advantage is shown.

viii. G.G. Yaralioglu, A. Atalar, "Noise analysis of geometrically complex mechanical structures using the analogy between electrical circuits and mechanical systems", Rev. of Scientific Instruments, vol. 70, pp. 2379-2383 (1999)

Abstract: Random fluctuations of displacement or velocity in mechanical systems can be calculated by using the analogy between electrical circuits and mechanical systems. The fluctuation-dissipation theorem expresses the relation between the generalized mechanical admittance and the noise in velocity. Similarly, correlation of mechanical noise can be calculated by using the generalized Nyquist theorem, which states that the current noise correlation between two ports in an electrical circuit is dictated by the real part of the transadmittance. In this article, we will present the determination of the mechanical transadmittance and we will use the mechanical transadmittance to calculate the noise correlation on geometrically complex structures where it is not possible to approximate the noise by using the simple harmonic oscillator model. We will apply our method to atomic force microscope cantilevers by means of finite element method tools. The application of the noise correlation calculation method to rectangular cantilever beams shows some interesting results. We found that on the resonance frequencies, the correlation coefficient takes values 1 (full correlation) and -1 (anti-correlation) along the cantilever axis depending on the mode shapes of the structure.

ix. E. Kocabas, A. Atalar, "Binary Sequences with Low Aperiodic Autocorrelation for Synchronization Purposes" *IEEE Communications Letters*, **7**, pp. 36-38 (2003).

Abstract: An evolutionary algorithm is used to find three sets of binary sequences of length 49-100 suitable for the rsynchronization of digital communication systems. Optimization of the sets are done by taking into consideration the type of preamble used in data frames and the phase-lock mechanism of the communication system. The preamble is assumed to be either a pseudonoise (PN) sequence or a sequence of 1's. There may or may not be phase ambiguity in detection. With this categorization, the first set of binary sequences is optimized with respect to aperiodic autocorrelation which corresponds to the random (PN) preamble without phase ambiguity case. The second and third sets are optimized with respect to a modified aperiodic autocorrelation for different figures of merit corresponding to the predetermined preamble (sequence of 1's) with and without phase ambiguity cases.

4.2.2 Chalmers

i. A. Behravan, T. Eriksson, "Analysis of distortion in a memoryless bandpass nonlinearity," in Proceedings of Nordic Radio Symposium, Oulu, Finland, Aug 2004.

Abstract: In this paper we study linear models for some nonlinear systems with random Gaussian input signals. The model consists of a linear deterministic gain plus an additive random distortion. The model is used for some typical nonlinearity in a digital communication link. The validity of the model in comparison with the most commonly used model for a scalar *quantizer is also studied. As an example of the application of the model we will look at the performance of an OFDM system with nonlinearity.*

ii. A. Behravan, T. Eriksson, A. Svensson, H. Zirath. "Adaptive predistorter design for nonlinear high power amplifiers," in Prodeedings of GHz 2003 Symposium, Linköping, Sweden, Nov 2003

Abstract: In this paper we present and compare several methods of compensating the nonlinearity of the RF front-end of a wireless system. The baseband compensation techniques have gained more attentions due to the simplicity of DSP implementation and also utilizing adaptive algorithms.Two baseband compensation techniques, namely predistortion and postdistortion (equalization) of the baseband signal are discussed and the problems associated with each one is addressed. Furthermore, a combination of a predistorter and a nonlinear equalizer is studied. It is shown that under realistic conditions with a frequently saturated amplifier and ISI channel, the latter methods is able to compensate the nonlinearity up to a good extent, while the first two methods can only operate under certain channel conditions and nonlinearity type.

iii. A. Behravan, T. Eriksson. "Baseband compensation techniques for bandpass nonlinearities" in Proceedings of the IEEE Vehicular technology conference fall 2003, Orlando, Florida, USA, Oct 2003.

Abstract: In this paper we present and compare several methods of compensating the nonlinearity of the RF front-end of a wireless system. Two baseband compensation techniques, namely predistortion and postdistortion (equalization) of the baseband signal are discussed and the problems associated with each one is addressed. Furthermore a combination of a predistorter and a nonlinear equalizer and also predistortion of oversampled baseband signal are analyzed. It will be shown that under realistic conditions with a frequently saturated amplifier and ISI channel, the latter two methods are able to compensate the nonlinearity up to a good extent, while the first two methods can only operate under certain assumptions for channel conditions and nonlinearity type.

iv. A. Behravan, T. Eriksson. "A model for bandpass nonlinearities based on Harmonic measurements" in Proceedings of the IEEE Radio and Wireless conference, Boston, MA, USA, Aug 2003

Abstract: This paper presents a model for a bandpass nonlinearity which is based on measurements on several harmonics of the output. The model has a quadrature structure, with a memoryless nonlinearity and a filter in each branch. The structure can describe AM/AM as well as AM/PM conversions. The parameters of the nonlinearity and the filter are jointly optimized to fit the measurements. Analytic expressions for the parameters of the model are found by means of the MMSE optimization. The method is applied to find a model for a 60GHz solid-state power amplifier based on a set of measurements on different harmonics of the output.

v. A. Behravan, T. Eriksson. "Harmonic-based model for bandpass nonlinearity and its application to RF predistorter design" in Proceedings of the 15th international conference on wireless communications, Calgary, Canada, July 2003

Abstract: Due to their large bandwidth of operation, RF predistorters are suitable for linearizing amplifier nonlinearity in high speed wireless applications. Unlike baseband linearization techniques, RF predistorters generate overtones which contribute to the first zone output of the bandpass high power amplifier. This paper presents a model for a bandpass nonlinearity that is based on measurements on several harmonics of the output. The model matches different harmonics of the output signal fairly well. The model is then used to design an RF predistorter. The advantage of the method compared to a design based on first zone of the output, is that the predistorter minimizes the total distortion power instead of reducing one specific intermodulation product.

vi. A. Behravan, T. Eriksson. "PAPR and other measures for OFDM systems with nonlinearity" in Proc of the 5th International Symposium on Wireless Personal Multimedia Communications, Honolulu, Hawaii, Oct 2002

Abstract: In this paper, we discuss the effects of nonlinearity on the performance in transmission of OFDM signals. Furthermore, we study measures related to nonlinearities, such as PAPR (Peak-to-Average-Power-Ratio), with respect to their ability to correctly predict the effect of a nonlinearity in an OFDM system. We also propose new measures for signal distortion in nonlinear systems. The performance of the measures is studied using several examples.

vii. A. Behravan, F. Munier, T. Svensson, M. Flament, T. Eriksson, A. Svensson, H. Zirath. "System implications in designing a 60 GHz WLAN RF front end" in Proceedings GHz 2001, Lund, Sweden, Nov 2001

Abstract: In this paper, we seek to evaluate the performance of a 60 GHz WLAN system taking into account RF circuitry imperfections and hardware requirements for various modulation techniques. A model of an RF front-end is developed, including physical imperfections of the circuitry such as power amplifier (PA) nonlinearity and voltage controlled oscillator VCO phase noise. Given the RF front-end model, several modulation techniques such as Orthogonal Frequency Division Multiplexing (OFDM) and Continuous Phase Modulation (CPM) are considered. The evaluation of the system performance in terms of bit error rate allows a better understanding of physical circuitry limitations, and optimal modulation parameters as well as circuit design recommendations can be derived.

viii. F. Munier, T. Eriksson, A. Svensson. "Receiver Algorithms for OFDM systems in Phase Noise and AWGN" in Proceedings IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications, Barcelona, Spain, Sep 2004. to appear

Abstract: In this paper we address the subject of reducing the impact of phase noise on a QAM-OFDM system transmitting over an AWGN channel. Phase noise is known to have two effects on OFDM systems, rotating each symbol by a different common phase rotation (CPR) and producing an intercarrier interference term (ICI) that adds to the channel noise. We present two novel algorithms that remove CPR and reduce the amount of ICI using different approaches to the ICI problem. Their performances in terms of bit error rate (BER) are evaluated by simulation using symbol by symbol or maximum likelihood sequence detection (MLSD). The results show that these algorithms can significantly reduce the BER floor of the system while still maintaining an acceptable throughput.

ix. F. Munier, E. Alpman, T. Eriksson, A. Svensson, H. Zirath. "Estimation of Phase Noise for QPSK Modulation over AWGN Channels" in Proceedings Gigahertz 2003 Symposium, Linköping, Sweden, Nov 2003

Abstract: Every oscillator used in bandpass communication suffers from an instability of their phase (a.k.a. phase noise) that, if left unaddressed, can lead to great degradation of the system performance. In this paper, we tackle the problem of minimising the effect of oscillator phase noise on the coherent detection of a quadrature phase shift keying (QPSK) modulation operating on an Additive White Gaussian Noise (AWGN) channel. The phase noise process is modelled as a Wiener-Levy (random walk) process. Our approach uses maximum likelihood (ML) estimation of phase noise. Thorough analysis and derivation for Decision Directed (DD), Non-Data Aided (NDA), used with and without symbol differential encoding, and pilot based estimators are presented. We compare these estimators with respect to their main features and evaluate their bit error rate (BER) performances through simulations. Results show that for low signal to noise ratio (SNR) applications, the use of differential encoding along with the proposed DD or NDA estimator yields performances with an SNR penalty below the two dB imposed by the non coherent detection methods, while pilot based estimation using wiener interpolation makes it possible to detect a QPSK modulation with SNR penalty around two dB.

4.2.3 CTTC

i. C. Collado, J. Mateu, J.M. O'Callaghan, "Analysis and Simulation of the Effects of Distributed Nonlinearities in Microwave Superconducting Devices", IEEE Trans. On Applied Superconductivity, To be published, 2004.

ii. J. Mateu, C. Collado, O. Menéndez, J.M. O'Callaghan, "Nonlinear performance characterization in a 8-pole quasi-elliptic bandpass filter", Superconductor Science and Technology 17, No 5, pp. S359-S362, 2004.

Abstract: In this work we predict the nonlinear behaviour of an eight-pole quasi-elliptic bandpass high temperature superconducting (HTS) filter with an equivalent circuit extracted from intermodulation measurements performed at the centre of the filter passband. We present measurements that show that the equivalent circuit is able to predict the intermodulation products produced by the filter when driven by two in-band or out-of-band sinusoidal signals. Numerical techniques based on harmonic balance are used to extract the elements of the equivalent circuit and to simulate its nonlinear performance.

iii. C. Collado, J. Mateu, J.M. O'Callaghan, "Comparison between nonlinear measurements in patterned and unpatterned thin films", Superconductor Science and Technology 17, No 7, pp. 876-880, 2004.

iv. J. Mateu, C. Collado, O. Menéndez, J.M. O'Callaghan, "Analysis of Dielectric-Loaded Cavities for Characterization of Nonlinear Properties of High Temperature superconductors". IEEE Tans. On Applied Superconductivity, Vol. 13, No. 2/ 332-335, 2003.

Abstract: This work describes and compares two alternative methods of analyzing dielectric-loaded cavities for measurement of intermodulation distortion in HTS films. One of them is based on assuming a specific type of HTS nonlinearities and developing theoretical equations based on them. The second is based on a numerical approach that can be applied to many types of nonlinearities. Both methods are shown to work on measured data of representative HTS films.

v. C.Collado, J.Mateu, R. Ferrus, J.M.O'Callaghan, "Prediction of Nonlinear Distortion in HTS Filters for CDMA Communication Systems". IEEE Trans. On Applied Superconductivity,Vol. 13, No. 2/ 328-331, 2003.

Abstract: HTS materials are known to produce intermodulation and other nonlinear effects, and this may restrict their use in wireless communication systems. While significant efforts are being done to measure and characterize nonlinear properties of HTS materials, there are very few works that relate these properties to system parameters. In this work we attempt to bridge this gap by using Harmonic Balance algorithms to analyze the nonlinear performance of superconducting filters subject to the WCDMA signals specified by 3GPP for the UNITS wireless system. This is a first step to predict compliance with system parameters like Adjacent Channel Leakage power Ratio (ACLR) or Error Vector Magnitude (EVM).

vi. J. Mateu, C. Collado, O. Menéndez, J.M. O'Callaghan, "Experiments and model of intermodulation distortion in a rutile resonator with YBCO", Journal of Superconductivity. Incorporating Novel Magnetism, Vol. 16, No 5 / 873-880, October 2003.

Abstract: We have derived general equations to calculate intermodulation distortion in resonators with high temperature superconducting (HTS) films which are not restricted to a specific resonator shape and may be used whenever the fields in a resonator generate currents on the surface of one or more HTS films. These equations are applied to rutile-loaded cavities with one or two 10 x 10 mm(2) Y-Ba-2-Cu-3-O7-delta endplates and are used to extract parameters characterizing the nonlinearities of these films from intermodulation measurements. Even though the films have similar small-signal performance, we have found large variation in the strength of their nonlinearities.

vii. J. Mateu, C. Collado, O. Menéndez, J.M. O'Callaghan, "A general approach for the calculation of intermodulation distortion in cavities with superconducting endplates', Applied Physics Letters 82, 97 (2003). Paper selected for January 1, 2003 issue of the Virtual Journal of Applications of Superconductivity.

Abstract: We report on a general procedure to calculate intermodulation distortion in cavities with superconducting endplates that is applicable to the dielectric-loaded cavities currently used for measurement of surface resistance in high-temperature superconductors. The procedure would enable the use such cavities for intermodulation characterization of unpatterned superconducting films, and would remove the uncertainty of measuring intermodulation on patterned devices, in which the effect of patterning damage might influence the outcome of the measurements. We have verified the calculation method by combining superconducting and copper endplates in a rutile-loaded cavity.

viii. J.Mateu, C. Collado, T.J.Shaw, J.M.O'Callaghan, "Nonlinear RF spurious in Cylindrical Cavity with a Superconducting Endplate", Physica C, Vol. 372-376, No. P-2, Pag 679-682, August 2002.

Abstract: We have developed a method to calculate the distribution of fundamental and spurious fields in a metallic cylindrical cavity with superconducting endplates in which signals at two different frequencies are injected. The nonlinearity in the superconductor produces the typical intermodulation effects if the frequencies of the injected signals are sufficiently close to each other and near a resonant mode. Our method uses harmonic balance to match the fields in the cavity with the currents on the endplates. The method can be used for a variety of nonlinear models of the superconducting endplate, and could be the base for a nondestructive procedure to extract the nonlinear parameters of an HTS sample from RF measurements. Our analysis is restricted to the TE011 mode, but the method can be applied to any propagating mode in the cylindrical cavity. Closed-form equations for the case of square-law nonlinearities in the superconductor are derived and used to check the validity of the harmonic balance calculation.

ix. C. Collado, J.Mateu, T.J.Shaw, J.M.O'Callaghan, "HTS nonlinearities in microwave disk resonators", Physica C, Vol. 372-376, No. P-1, Pag 566-570, August 2002.

Abstract: This article describes a procedure for the calculation of the intermodulation behavior of the TM010 mode in high temperature superconducting (HTS) disk resonators from a description of the local HTS nonlinearities. Successful cross-checks are performed by comparing the theoretical results with experimental measurements and simulations based on the multiport harmonic balance algorithm for a specific model of HTS nonlinearity. The application of this procedure to the determination of nonlinear material parameters from disk resonator measurements is illustrated and compared to theoretical predictions. (C) 2002 Elsevier Science B.V. All rights reserved.

x. J. Mateu, C.Collado, J.M. O'Callaghan, "Nonlinear Analysis of Disk Resonators. Application to Material Characteritzation and Filter Design", IEEE Trans. on Applied Superconductivity. Vol 11, No 1 March 2001, pp 135-138.

xi. C. Collado, J. Mateu, J.M. O'Callaghan, "Nonlinear Simulation and Characterization of HTS Devices using Harmonic Balance Algorithm", IEEE Trans. on Applied Superconductivity. Vol 11, No 1 March 2001, pp 1396-1399.

Abstract: This work presents the use of Harmonic Balance to simulate the nonlinear behavior of HTS transmission lines. Good agreement with theoretical cross-checks is found We also show the use of this algorithm to fa the model of HTS lines from experimental measurements. We illustrate this by fitting several types of experimental data, and discuss how to avoid ambiguity in this fitting.

xii. J. Parrón, C. Collado, J. Mateu, J.M. Rius, N. Duffo, J. O'Callaghan, "General Electromagnetic Simulation Tool to Predict the Microwave Non-Linear Response of Planar, Arbitrarily-Shaped HTS Structures", IEEE Trans. on Applied Superconductivity, Vol. 11, No. 1, March 2001, pp. 399-402.

Abstract: This work describes a simulation tool being developed at WC to predict the microwave nonlinear behavior of planar superconducting structures with very few restrictions on the geometry of the planar layout. The software is intended to be applicable to most structures used in planar HTS circuits, including line, patch, and quasi-lumped microstrip resonators.
The tool combines Method of Moments (MoM) algorithms for general electromagnetic simulation with Harmonic Balance algorithms to take into account the nonlinearites in the HTS material. The Method of Moments code is based on discretization of the Electric Field Integral Equation in Rao, Wilton and Glisson Basis Functions. The multilayer dyadic Green's function is used with Sommerfeld integral formulation. The Harmonic Balance algorithm has been adapted to this application where the nonlinearity is distributed and where compatibility with the MoM algorithm is required.
Tests of the algorithm in TM010 disk resonators agree with closed-form equations for both the fundamental and third-order intermodulation currents. Simulations of hairpin resonators show good qualitative agreement with previously published results, but it is found that a finer meshing would be necessary to get correct quantitative results. Possible improvements are suggested.

xiii. C. Collado, J. Mateu, J. Parrón, J. Pons, J.M. O'Callaghan, J.M. Rius, "Harmonic Balance Algorithms for the Nonlinear Simulation of HTS Devices," Journal of Superconductivity. pp. 57 - 64 (2001).

Abstract: This paper describes the application of Harmonic Balance algorithms to predict nonlinear effects in planar High Temperature Superconductors (HTS) microwave circuits. The resulting algorithms are fast and efficient and can be used both for the characterization of the nonlinearities in the HTS material, and for the prediction of the behavior of an HTS circuit given the parameters of these nonlinearities (such as a dependence of the surface impedance on the current density). Most previously published nonlinear HTS models can be used, because the algorithms are not restricted to a specific model of HTS nonlinearities. Two different types of algorithms are described: (1) algorithms specific for one-dimensional resonators (transmission lines and TM010 disk resonators) and (2) an algorithm based on the combination of Method of Moments and Harmonic Balance, applicable to 2D planar structures with few restrictions in their shape. Several cross-checks with theory and measurements are presented.

xiv. J. Mateu, C. Collado, O. Menendez, J.M. O'Callaghan "Nonlinear Distortion in a 8-pole Quasi-Elliptic Bandpass HTS Filter for CDMA" , IEEE Applied Superconductivity Conference (ASC), Jacksonville, Florida, USA, October 3-8 2004.

xv. J. Mateu, C. Collado, J.M. O'Callaghan "Nonlinear Models of Coupled Superconducting Lines", IEEE Applied Superconductivity Conference (ASC), Jacksonville, Florida, USA, October 3-8 2004.

4.2.4 ISIK

i. A. Aksen, H. Pınarbası, B. S. Yarman, "A Parametric Approach to Construct Two-Variable Positive Real Impedance Functions for the Real Frequency Design of Mixed Lumped-Distributed Matching Networks", *Proceedings of IEEE International Microwave Conference*, *IMS'2004,* pp. 1851-1854, Forth Worth, Texas, June 2004

Abstract: In this paper, a computer–aided real frequency technique is presented for treating the design of mixed lumped and distributed element equalizer networks in broadband microwave amplifiers for wireless communication systems. The work aims to bring together the available real frequency design techniques for wideband matching and the multidimensional modelling approach for accurate description of MIC realisations. The scattering based two-variable description of lossless equalizers with mixed lumped and distributed elements will be discussed and a practical two-stage microwave amplifier design example will be studied to exhibit the application and the potential benefits of the algorithm.

ii. A. Aksen, B.S. Yarman, "Scattering Based Parametric Description of Lossless Two-ports with Commensurate Lines and Lumped Discontinuity Elements for MMIC's", *Proceedings of*

European Conference on Circuit Theory and Design, ECCTD'2003, vol. 2, pp. 21-24, Cracow, Poland, September 2003

Abstract : In this paper, a semi-analytic method is presented to describe lossless networks formed with commensurate transmission lines and lumped discontinuity elements in cascade connection. For the computer aided design and the simulation of lossless distributed two-ports with lumped discontinuity models, a scattering based parametric approach is presented. It is expected that the proposed tool will find immediate usage in the design and simulation of RF subsytems for accurate representation of MMIC layouts. Application of the proposed tool in broadband matching network design is indicated.

iii. B.S. Yarman, A. Aksen, E.G. Cimen, "Design and simulation of miniaturized communication systems employing symmetrical lossless two-ports constructed with two kinds of elements" *Proceedings of the International Symposium on Circuits and Systems*, *ISCAS '03* vol. 2 , pp. 336 -339, Bangkok, Thailand, May 2003

Abstract: In this paper, a semi-analytic method is presented to describe symmetrical lossless networks with two-kinds of elements, namely, distributed and lumped elements in cascade connection. In terms of the independently chosen parameters, element values of the lossless symmetrical networks are given by explicit formulas up to nine elements. It is expected that the results presented in this paper will find imediate usage in performance assessment, design and simulation of analog/digital wireless communication systems put on MMICs or VLSI chips.

iv. A. Kilinc, H. Pinarbasi, B.S. Yarman, A. Aksen, "Microwave amplifier design for mobile communication via immittance modelling" *Proceedings of the International Symposium on Circuits and Systems, ISCAS '03*, vol. 4 , pp. 572 -575, Bangkok, Thailand, May 2003

Abstract: In this paper, a practical broadband microwave amplifier design algorithm based on immittance data modelling is presented. In the course of design, first, the optimum input and output terminations for the active device are produced employing the real frequency technique. Then these terminations are modelled using the new immittance modelling tool to synthesize the front-end and back-end matching networks. An example is included to exhibit the implementation of the proposed design algorithm to consctuct a single-stage wideband microwave amplifier over a wide frequency band. It is expected that the proposed design algorithm will fing applications in the design of microwave amplifiers put on MMIS for mobile communication.

v. B.S. Yarman, A. Aksen, A.Kilinc, "Immitance Data Modelling via Linear Interpolation Techniques", *Proceedings of IEEE International Symposium on Circuits and Systems, ISCAS'2002*, Phoenix, Arizona, vol 2, pp. 527-530, May 2002

Abstract: With the advancement of the manufacturing technologies to produce new generation analog/digital communication systems, immittance data modelling has gained renewed importance in the literature. Specifically, models are utilized for behavior characterization, simulation of physical devices or to design sub-systems with active and passive solid-state components. Therefore, in this paper new computer aided tools are presented to model one port immittance data by means of linear interpolation techniques. It is remarkable to observe that complex electrical behaviour of physical devices can be simulated with the models built utilizing the linear interpolation of a few properly selected measured immittance data. An antenna example is presented to exhibit the implementation of the proposed techniques. It is expected that the new modelling tools will be employed to provide initial circuit topologies to commercially available analysis/simulation and design packages.

vi. A. Aksen, B.S. Yarman, "A Real Frequency approach to describe lossless two-ports formed with mixed lumped and distributed elements", International Journal of Electronics and Communications (AEÜ), vol. 6, pp. 389-396, November 2001

Abstract: The design of microwave filters, matching networks, amplifiers, that is the ``Broadband Networks'' with mixed lossless lumped and distributed elements, has been a significant concern *of the circuit theoreticians of the field. Yet, there has been no complete practical solution introduced in the literature so far. In this paper, an attempt has been made to design broadband networks constructed with a cascade connection of low pass LC ladders connected with commensurate transmission lines. The new design procedure is based on the two-variable description of the Simplified Real Frequency Technique. Up to five mixed-elements explicit equations are given to describe some selected network topologies. In general, synthesis is carried out employing a decomposition technique first introduced by Alfred Fettweis. A ``Double Matching Design'' example is presented to exhibit the merits and the application of the new approach.*

vii. B.S. Yarman, A. Aksen, A.Kılınç, "An immitance based tool for modelling passive one-port devices by means of Darlington equivalents", International Journal of Electronics and Communications (AEÜ), vol. 6, pp. 443-451, November 2001

Abstract: An immitance-based method is presented to model measured or computed data, obtained from a ``passive one-port physical device'' by means of its Darlington equivalent. In other words, the given data is modelled as a lossless two port terminated in a unit resistor. The basis of the new modelling tool rests on the numerical decomposition of the given immitance data into its Foster and minimum parts. Therefore, the proposed technique does not require any choice for the circuit topology to build the model. Rather, the optimum circuit topology that characterises the given data is the natural consequence of the modelling process proposed in this paper. A main algorithm is presented to construct the model from the given data. It is expected that the proposed modelling tool will find practical applications in the behaviour characterisation, simulation, and design of high speed/high frequency analog/digital mobile communication sub-systems manufactured on VLSI chips. An antenna-modelling example is included to systematically exhibit the implementation of the modelling technique.

viii. A. Aksen, B.S. Yarman, "Cascade synthesis of two-variable lossless two-port networks with lumped elements and transmission lines", in *Multidimensional Signals, Circuits and Systems*, Editors: K. Galkowski and J. Wood, Chapter 12, pp.219-232, Taylor & Francis, New York, 2001, (ISBN0-415-25363-2 hbk)

Abstract: Two-variable characterization of cascades composed of lossless two-port networks with lumped elements and transmission lines is considered. The problems associated with the construction of scattering functions in two variables are discussed and for cascade synthesis of two-variable mixed element networks, a semi-analytic procedure utilizing the topologic restrictions is proposed. Some particular mixed lumped-distributed structures for which the proposed procedure ends up with explicit formulas are addressed and the application of the results in real frequency broadband matching is indicated.

ix. A. Aksen, B. S. Yarman, "A computer aided design technique for hybrid and monolithic microwave amplifiers employing distributed equalizers with lumped discontinuities", *Proceedings of IEEE International Microwave Symposium, IMS'2001*, Arizona, USA, May 2001

Abstract: This paper will addres the use of mixed lumped and distributed elements in the matching equalizers of microwave amplifers for hybrid and monolithic MIC realizations. In this work we show how the computer aided real frequency technique can be extended to design broadband amplifiers employing distributed equalizers with lumped discontinuities. The scattering based two-variable description of lossless equalizers with mixed lumped-distributed elements will be discussed and the potential benefits of the approach will be indicated by examples.

x. B.S. Yarman, A. Aksen, "A reflectance-based computer aided modelling tool for high speed/high frequency communication systems", *Proceedings of IEEE International Symposium on Circuits and Systems, ISCAS'2001*, Sydney, Australia, May 2001

Abstract: A reflectance-based method is presented to model the measured or computed data, obtained from a "passive one-port physical device" by means of its Darlington equivalent. The *basis of the new modelling tool rests on the numerical generation of the scattering parameters of the Darlington 2-port from the given reflectance employing the losslessness condition. The proposed technique does not require any choice for the circuit topology to build the model. The circuit topology is the natural consequence of the modelling process.*

xi. B.S. Yarman, "Broadband Networks", *Wiley Encyclopedia of Electrical and Electronics Engineering*, vol. 2, pp. 589-604, 1999

Abstract: The problem of Broadband Matching is one of the major concerns of the high frequency communication systems. All broadcasting networks such as radio & TV, all wireless communication networks such as cellular telephones and satellite networks are the most frequently encountered examples of such systems. A typical high frequency wireless communication system contains two major sites namely; a transmitter and a receiver (Fig. 1). On the transmitter site, the generated signal must be properly transferred to the antenna over a preferably non-dissipative (lossless) network so that maximum power of the generated signal is pumped into the antenna. Similarly, on the receiver site, the received signal of the antenna is transferred over a lossless matching network and dissipated at the user end. The user end may be a radio or a TV set or a headphone etc. In this case, again the role of the matching network is to provide the maximum power transfer of the received signal to the user end. In the literature, several terms are associated with the non-dissipative power transfer network such as "impedance matching network", "equaliser", "lossless two-port", "lossless network" or "interstage-equaliser". All being interchangeable. The classical broadband matching theory deals with the proper design of the lossless matching networks between prescribed terminations.

The purpose of this article is to review, from a practical viewpoint, analytic gain-bandwidth theory and commercially available CAD techniques as applied to matching problems. Modern approaches and so called real frequency techniques to gain bandwidth problems are summarized to provide the necessary background for the reader to gain easy access to the relevant literature.

xii. B.S. Yarman, A. Aksen, "An integrated design tool to construct lossless matching networks with mixed lumped and distributed elements", IEEE Trans. on Circuits and Systems, Fundamental Theory and Applications, CAS-39, Nr.9, pp.713-723, September 1992.

***Abstract:* In this paper, a new integrated design tool to construct practical lossless matching** *networks with mixed lumped and distributed elements is proposed. The new design tools gathers the simplified real frequency technique of broadbanding with an appropriate application of algebraic network decomposition and replacement techniques.The proposed design method naturally incorporates the outstanding merits of modern broadbanding techniques of single variable. That is, in the course of design algorithm, there is no need to choose a circuit topology with mixed elements in advance, nor it is necessary to invent a realizable transfer function in two variables to measure the system performance. Examples are presented to exhibit the application of the proposed design tool. It is expected that the new design tool will be useful to construct practical matching networks to be manufactured on the microwave monolithic integrated circuits (MMIC), since the fringing lumped element parasitics which arise due to the physical implementation can easily be absorbed the mixed element network structure.*

xiii. B.S. Yarman, A. Fettweis, "Computer Aided Double Matching via Parametric Representation of Brune Functions", IEEE Transactions on Circuits and Systems, vol. 37, pp. 2121-222, February, 1990.

Abstract: In this paper, a new computer-aided broad-band matching technique, the so-called parametric approach, is applied to double matching problems. The new technique takes less computation time and yields superior performance over the other available brute force CAD techniques. Examples are presented to exhibit the practical use of the parametric approach. The results obtained are compared with those via the real frequency-direct computational technique which is also qualitatively proven to offer superior design performance with simpler equalizer structures. It is recalled that the real frequency techniques of broad-banding are *implemented with several computational phases in which data fitting process, explicit factorization of real polynomials and solution of a set of linear equations are required. The proposed parametric approach reformulates the real frequency techniques in which the laborious numerical computation of real frequency techniques are simply omitted by using the parametric representation of Brune functions. In the present case, neither the use of explicit factorization of polynomials nor the solution of linear equation systems is necessary. Thus the parametric method of broad-band matching requires less computation with improved numerical stability*

xiv. H.J. Carlin, B.S. Yarman , " The Double Matching Problem: Analytic and Real Frequency Solutions," IEEE Transactions on Circuits and Systems, vol.30, pp. 15-28, January 1983.

Abstract: A new and simplified analytic solution is given for the double matching problem. That problem requires the matching of a complex generator impedance to a complex load over a frequency band. The analytic solution is fundamental to understanding theoretical gain-bandwidth performance of systems but introduces severe difficulties when employed in design practice. Following the analytic presentation a CAD technique [the Real Frequency method] which bypasses the analytic theory and its difficulties of implementation is discussed. Various examples comparing the Real Frequency method to the analytic procedure are examined. It is shown that for double matching problems (as for single matching problems) the analytic method generally yields sub-optimal performance characteristics. Thus just as in single matching problems, the Real Frequency method for double matching compared to the analytic procedure gives superior equalizer performance, simpler equalizer structures, and also is applicable to problems where the analytic method is virtually impossible to implement. As a final example the Real Frequency method is applied to the design of a two-stage microwave FET amplifier including input, output, and inter-stage equalizers.

xv. B.S. Yarman, H.J. Carlin, "A Simplified Real Frequency Technique Applied to Broadband Multistage Microwave Amplifiers", IEEE Trans. Microwave Theory and Techniques, vol. 30, pp. 2216-2222, (1982).

Abstract: A computer-aided design (CAD) procedure, which is a new and simplified "real frequency" technique, is introduced for treating the broad-band matching of an arbitrary load to a complex generator. The method can be applied to the design of interstage equalizers for microwave amplifiers. It utilizes the measured data obtained from the generator and the load networks. Neither an a priori choice of an equalizer topology, nor an analytic form of the system transfer function, is assumed. The optimization process of the design procedure is carried on directly in terms of a physically realizable, unit normalized reflection coefficient which describes the equalizer alone. Based on the load-generator matching technique, a sequential procedure to design multistage microwave amplifiers is presented. An example is given for a three-stage, FET amplifier proceeding matching from the measured scattering parameters of the FET devices. The example is in three parts and illustrates the sequential method that is, first a single-stage, then a two-stage, and finally the three-stage system is computed.

4.2.5 POLITO

i. G. P. Bava, S. Benedetto, E. Biglieri, F. Filicori, V. A. Monaco, C. Naldi, U. Pisani, and V. Pozzolo, "Modelling and performance simulation techniques of GaAs MESFET's for microwave power amplifiers", *ESA/ESTEC report*, contract 4043/79, Feb. 1982.

ii. P. Bianco, G. Ghione, and M. Pirola, "New simple proofs of the two-port stability criterium in terms of the single stability parameter μ_1 (μ_2)", *IEEE Trans. Microwave Theory Tech.*, Vol. 49, No. 6, pp. 1073–1076, Jun. 2001.

Abstract: The classical scattering-parameter stability criterium for a linear two-port makes use of two conditions involving the Rollet parameter K plus one additional parameter. A new stability criterium was developed by Edwards and Sinksky on the basis of a condition on a single parameter, i.e., mu (1) or mu (2). This paper presents a new simpler, and more straightforward set of proofs of the single-parameter stability criterium for a linear two-port, The first proof is

algebraic and shows the equivalence of the conditions K > 1, b(i) > 1 with the condition mu (1) > 1 (i = 1, 2), The second proof, which is geometrical, relies only on the classical stability circle concepts in an improved way with respect to the treatment by Edwards and Sinksky.

iii. G. Madonna, A. Ferrero, M. Pirola, and U. Pisani, “Testing microwave devices under different source impedance values -a novel technique for on-line measurement of source and device reflection coefficients”, *IEEE Trans. on Instrumentation and Measurement,* Vol. 49 , No. 2, pp. 285–289, Apr. 2000.

Abstract: This paper describes a new approach for fast and accurate determination of the source reflection coefficient in microwave source-pup measurements, To the authors' knowledge, this is the only technique that allows the simultaneous measurement of the source and the device-under-test input reflection coefficients, A traditional vector network analyzer is used as a four-channel receiver, The calibration procedure is based on a new reflectometer model that extends the traditional error box concept. Experimental results are presented and compared to data obtained with traditional techniques.

iv. D. E. Root, M. Pirola, S. Fan, W. J. Anklam and A. Cognata, “Measurement-based large-signal diode modelling system for circuit and device design”, *IEEE Trans. Microwave Theory Tech*, Vol. 41, No. 12, pp. 2211–2217, Dec. 1993.

v. P.Bianco, S.Donati, A. Ferrero, G. Ghione, M. Pirola, C.U. Naldi A.Cetronio, M.Calori, C.Lanzieri, M.Peroni, “Large-Signal Modelling of Power HFETs for K-Ka band applications”, GAAS2000, pp. 136-139, Paris, France, 2-3 Oct. 2000.

vi. P. Bianco, S. Donati Guerrieri, G. Ghione, M. Pirola, C. U. Naldi, C. Florian, G. Vannini, A. Santarelli, F. Filicori, L. Manfredi, “Optimum design of a new predistortion scheme for high linearity K-band MMIC power amplifiers”, **Best Paper Award** in *GAAS 2001*, pp. 689–692, London, United Kingdom, 24-25 Sept. 2001.

vii. G. P. Bava, U. Pisani and V. Pozzolo, “Active load technique for load-pull characterization at microwave frequencies”, *Electronics Lett.*, Vol. 18, pp. 178–180, 1982.

viii. B. Hughes, A. Ferrero and A. Cognata, “Accurate on-wafer power and harmonic measurements of mm wave amplifiers and devices”, in *IEEE MTT-S Intl. Microwave Symp. Dig.*, pp. 1019–1022, Albuquerque, NM, Jun. 1992.

ix. A. Ferrero, G. Madonna and U. Pisani, “Recent technological advances for modular active harmonic load-pull measurement systems”, in *GAAS99*, pp. 381–386, Munich, Germany, Oct. 1999.

4.2.6 TUI

i. M. A. Hein, "High-temperature Superconducting Films at Microwave Frequencies", Springer Tracts of Modern Physics, Vol. 155, ISBN 3-540-65646-4, Springer-Verlag, Heidelberg (1999).

Abstract: The book develops a comprehensive understanding of the surface impedance of the oxide high-temperature superconductors in comparison with the conventional superconductor Nb_3Sn. Linear and nonlinear microwave responses are treated separately, both in terms of models, theories or numerical approaches and in terms of experimental results. The theoretical treatment connects fundamental aspects of superconductivity to the specific high-frequency properties. The experimental data review the state of the art, as reported by many international groups. The book describes further the main features of appropriate preparation, handling, mounting, and refrigeration techniques, and finally discusses possible applications in passive and active microwave devices.

ii. R. Stephan, J. Möhring, H. Bosch, "Monolithic microwave filters in GaAs coplanar technology", XI. International Microwave Conference MIKON 96, Warschau 27.-30. Mai 1996.

Abstract: Monolithic filters at frequencies about 10 GHz based on lumped LC-structures and about 30 GHz in coplanar waveguide technology are presented. Both filter concepts need active components to compensate the insertion loss of the filters. The performance of these filters is investigated experimentally.

iii. R. Stephan and J. Möhring, "Practical investigations on monolithic integrated microwave filters", European Gallium Arsenide and Related III-V Compounds Applications Symposium GAAS'96, Paris, July 5-6, 1996.

Abstract: Filters at microwave frequencies today normally are built in hybrid technology. In this paper principles for the monolithic integration of frequencies about 10 GHz based on lumped LC-structures and about 30 GHz in coplanar waveguide technology are presented. Both filter concepts need active components are interconnected by coplanar lines without reverse metallization. The performance of these filters is investigated experimentally.

iv. S. Balling, M. Hein, M. Hennhöfer, G. Sommerkorn, R. Stephan, "Broadband dual polarized antenna arrays for mobile communication applications", 33[rd] European Microwave Conference, München, 7-9. Oktober 2003.

Abstract: This paper discusses design issues for uniform rectangular antenna arrays and the requirements for channel sounding applications. Two different array realizations are presented. The first array is based on Vivaldi antennas the second on patch antennas. The arrays consist of 32 dual polarization-sensitive radiators. Both arrays operate at 2 GHz, covering the uplink and downlink bands of the UMTS standard. The resulting performance of the arrays is compared and discussed.

v. M.A. Hein, T. Kaiser und G. Müller, "Surface resistance of epitaxial $YBa_2Cu_3O_{7-x}$ films on various substrates: Effects of pair condensation and quasiparticle scattering", Phys. Rev. B61, 640-647 (2000).

Abstract: The temperature dependent surface resistance $R_s(T)$ of eight high-quality epitaxial $YBa_2Cu_3O_{7-x}$ films on $LaAlO_3$ (Y/L), MgO (Y/M), and CeO_2-buffered sapphire (Y/S) substrates was investigated at 19 GHz with a resolution of 20 µΩ. The residual level $R_s(T\rightarrow 0)$ was (90–180) µΩ for all films. The slope $\partial R_s(T)/\partial T$ in the range (4–20) K decreased from (6–8) µΩ/K for Y/L to (0–2) µΩ/K for Y/M, and to slightly negative values for Y/S. This slope correlated with the transition temperature T_c, including published data of about (10–20) µΩ/K for high-purity $YBa_2Cu_3O_{7-x}$ single crystals. The increase of R_s from 4.2 showed power-law behaviour $\Delta R_s(T) \propto T^a$ up to 40 K with $a \approx 1.3$ for Y/L and Y/M. However, it was exponential for Y/S, $\Delta R_s(T) \propto \exp(-\delta X T_c/T)$ with $\delta \approx 0.8$. The results can be described with the two-fluid model in terms of the quasiparticle density $n_N(T)$ and the scattering time $\tau(T)$. The high and reproducible residual resistance implies (magnetic) impurity scattering at a rate $\tau^{-1}(0) \propto n_N(0)$, i.e., proportional to the density of quasiparticles. In crystals and unstrained films, the pair condensation is gapless, and the power-law temperature dependences of τ and n_N are reflected in that of R_s. In contrast, in strained films, $n_N(T)$ displays activated behaviour, and the low-temperature behaviour of R_s changes to exponential. The formation of an energy gap is attributed to the interaction between the Cu-O planes and the chains, which is affected by strain. The existence of an energy range with zero density of states limits possible interpretations of the order parameter of YbaCuO. A two-band scenario with magnetic pairbreaking and two different order parameters ($2\Delta/kT_c$=6-8 for the planes and $\geq$0 for the chains) with s-wave symmetry, at least in the chains, appears to be an adequate explanation.

vi. D.E.Oates, S.-H. Park, M.A. Hein, P.J. Hirst und R.G. Humphreys, "Intermodulation distortion and third-harmonic generation in YBCO films of varying oxygen content", IEEE Trans. Appl. Supercond. 13, 311-314 (2003).

Abstract: We have measured the nonlinear surface impedance, intermodulation distortion (IMD), and third-harmonic generation (THG) in a series of identically prepared YBaCuO films that have been carefully annealed to produce a controlled oxygen stoichiometry. These are also *compared with an unannealed film. The measurements were performed using a stripline-resonator techniques as a function of temperature at a fundamental frequency of 2.3 GHz; the IMD tone separation was 10 kHz. We have found that overdoping films with oxygen substantially lowers the IMD relative to optimally and underdoped films. We have also observed differences in the slopes of the THG and IMD, with IMD slope of close to 2:1 while the same film shows THG slope of 3:1. A possible explanation of the differences lies in the different time scales to which IMD and THG are sensitive.*

vii. M.A. Hein, D.E. Oates, P.J. Hirst, R.G. Humphreys und A.V. Velichko, "Nonlinear dielectric losses in MgO substrates", Appl. Phys. Lett. 80, 1007 (2002).

Abstract: We have investigated the nonlinear surface impedance and two-tone intermodulation distortion of ten epitaxial $YBa_2Cu_3O_{7-\delta}$ films on MgO substrates, using stripline resonators, at frequencies f = 2.3 – 11.2 GHz and temperatures T = 1.7 K- T_c. The power dissipation decreased by up to one order of magnitude as the microwave electric field was increased to 100 V/m for T < 20 K. The reactance showed only a weak increase. The minimum of the losses correlated with a plateau in the intermodulation signal. The same features were observed for a Nb film on MgO but not for $YBa_2Cu_3O_{7-\delta}$ and Nb on $LaAlO_3$ or sapphire. The anomalous response results from dielectric losses in MgO, most probably due to defect dipole relaxation.

viii. J. F. Trabert, R. Perrone, R. Münnich, R. Stephan, M. A. Hein, and H. Thust, "20 GHz LTCC applications for satellite communications - challenges for design and technology*",* International Student Seminar, St. Petersburg, 7.-9. Juni 2004.

Abstract: We develop a 4x4 single-pole multi-throw switch matrix in LTCC technology for satellite applications at 17-22 GHz. The matrix incorporates passive circuits and switches, including biasing and decoupling networks, which enable digitally controlled reconfiguration. In a first attempt, we have designed a test chip to characterise different types of switches and to identify the limits of the technology. The scattering parameters measured for a 11-layer structure with 4 layers containing RF signal lines and minimum line widths of 40 µm prove the principle-of-operation. The results illustrate the potential of our approach and indicate routes to optimise the RF design.

K. Brückner, R. Stephan, M. Hein, Ch. Förster, V. Cimalla, and O. Ambacher, "Micro-electromechanical RF resonators fabricated from SiC/Si heterostructures", MEMSWAVE 2004, Uppsala, Sweden, 30. Juni - 2. Juli 2004.

Abstract: Due to the combination of mechanical structures with electrically active elements for actuation and sensing, the technology of micro-electromechanical systems (MEMS) bears a huge potential for applications in many different fields. Recent activities have aimed at scaling MEMS into the submicron range, leading to the new category of nano-electromechanical systems (MEMS). The research on NEMS is focussed mainly on nano-scale resonators, to extend the corresponding resonant frequencies into the GHz range. This opens additional potential, e.g., for low-power high-frequency devices for mobile communications, or bio-sensors for the detection of single molecules by sensitised NEMS surfaces. Resonators in the submicron range have been fabricated, using Si and SIC. The focus on SiC reflects its chemical stability, but more importantly its significantly higher ratio of the Young´s modulus, E, to mass density, ρ, yielding higher resonant frequencies.

ix. D. Klugmann and R. Stephan, "Calibration of portable FM-CW Doppler RADAR profilers with an artificial target", International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage Alaska; September 20-24, 2004.

Abstract: Two portable mono-static FM-CW Doppler radar profilers at 24 GHz and 94 GHz, respectively, have been calibrated using a continuously rotating corner reflector. The front-ends of both radars apply semiconductors for the generation of the transmitted power Pt exclusively. The portable 24 GHz profiler´s aim is to record and investigate precipitation close to the ground. The 94 GHz profiler was developed for cloud investigation from the ground and from a research aircraft. The signal processing systems of both radar profilers are set up using the MATLAB *development environment. The calibration procedure yields the radar constant K_{Rad}. This constant connects the Power P_r received by the radar to the radar reflectivity Z of the investigated hydrometeors according to the formula $P_r = K_{Rad} \cdot \Delta R/R^2 \cdot Z$. The radar constant combines geometric and technical parameters of the radar system, e.g. transmitted power P_t, radar wavelength λ or antenna gain G. Only the range resolution ΔR and the distance R between radar and investigated scattering target are given explicitly, since these are non constants. The calibrations showed that the 24 GHz rain profiler is sensitive enough to fulfill its purpose: It is able to record Doppler backscatter spectra from precipitation near ground (R < 100 m) with a fine range resolution ($5\ m \leq \Delta R \leq 15\ m$). That finding is supported by Doppler backscatter spectra recorded in rain. The 94 GHz profiler, however, lacks the required sensitivity due to severe system noise problems. The system sensitivity is only sufficient to detect hail near ground (r < 100 m) with range resolutions set to values typically chosen for cloud investigation ($25\ m \leq \Delta R \leq 50\ m$). This diagnose is confirmed by the results from operating the 94 GHz radar profiler to date. Both radar systems will undergo major design revisions to gain higher system sensitivities. The 24 GHz rain profiler will become even more compact by this re-design.*

x. S. Y. Lee, J. H. Lee, J. Lim, J. C. Booth, H.N. Lee, S. H. Moon, B. Oh, and M.A. Hein, "Microwave properties of MgB_2 films before and after Ion milling", IEEE Trans. Appl. Supercond. 13, 3585-3589 (2003).

Abstract: The new superconductor MgB_2 may prove useful for microwave applications at intermediate temperatures. MgB_2 films with the thickness of 300 – 400 nm have surface resistance R_s less than 10 μΩ at a frequency ($\omega/2\pi$) of 8.5 GHz and 7 K, and ~ 1.5 mΩ at 87 GHz and 4.2 K. The critical temperature (T_c) of these films is ~ 39 K when they are prepared under optimum conditions. The R_s appears to scale as ω^2 up to 30 K. After surface ion-milling, a reduction of the T_c and an enhanced resistivity $\rho(T_c)$ are observed consistently at 8.5 GHz and 87 GHz along with a reduced R_s at low temperatures. The observed $\rho(T_c)$ - T_c relation and the uncorrelated behaviour between $\rho(T_c)$ and R_s values measured at low temperatures are well explained in terms of the two-gap model, with the observed $\rho(T_c)$ - T_c relation attributed to the properties of the large gap, and the R_s at lower temperatures reflecting the properties of the small gap, with an enhanced gap energy due to increased interband scattering. This study suggests that the interband scattering should be enhanced to improve the low temperature microwave properties of MgB_2 films and that the ion-milling process must be performed with great care to preserve the high quality of MgB_2 films.

xi. G. Harutyunyan, K. Blau, M. Hein, and G. Fuchs, "Wireless signal transmission through non-metallic pipes with transmission gain", 33^{rd} European Microwave Conference, Munich, 7-9. October 2003.

Abstract: We study the propagation of electromagnetic waves through non-metallic pipes with diameters D of the order of the wavelength λ. Comparative measurements in clean straight pipes reveal transmission gains relative to free-space propagation, for values $D/\lambda \approx 5$-10, which amount up to 25 dB. The wave-guiding effect depends on the boundary conditions, and is partially suppressed under conditions typical of sewerage pipes, which are soiled, wet, and rough. We present a phenomenological model that accounts for the multiple reflections along the propagation path, and find satisfactory agreement with experimental data. Based on our empirical studies, which extend knowledge available in literature, we aim at maximizing the achievable range of wireless signal transmission for pipecleaning devices with real-time inspection capability by prober choise of carrier frequency and antenna design.

xii. M. A. Hein, M. Perpeet and G. Müller, "Nonlinear microwave response of Nb_3Sn films: a case study of granular superconductors", IEEE Trans. Appl. Supercond. 11, 3434-3437 (2001).

Abstract: We have investigated the microwave magnetic field dependent surface resistance $R_s(B_s)$, of Nb_3Sn films of different film thickness and on different substrates at 19 GHz. The film thickness controls the grain size of the polycrystalline films. It provides a tool to study the role of grain boundaries on the nonlinear microwave response of granular superconductors. We find a *non-monotonic dependence of the onset field, B_{on}, of nonlinear surface resistance on film thickness, with a maximum of 25 mT at 1.2 μm. This behaviour reveals that magnetic losses at grain boundaries dominate in thin films, and microwave heating in thick films. The universal scaling behaviour of B_{on} with temperature, its dependence on the thermal conductivity of the substrate, and the good agreement between the quadratic field dependence of R_s and a weakly-coupled grain model indicate heating at grain boundaries as a possible mechanism. The correlation between the nonlinear microwave response and microstructure of the granular films indicates possible improvements and intrinsic limitations.*

xiii. M. A. Hein, R. J. Ormeno, and C. E. Gough, "The high-frequency electrodynamic response of strongly anisotropic clean normal and superconducting metals", Phys. Rev. B. 64, 024529-1/6 (2001).

Abstract: We consider the influence of quasiparticle relaxation and nonlocality on the complex conductivity and microwave surface impedance of isotropic and quasi-two-dimensional metals in the normal and superconducting states for arbitrary electronic parameters intermediate between the classical skin effect and extreme anomalous limits. We describe the superconducting state by a two-fluid model with a nonlocal retarded quasiparticle response and derive an expression for the surface impedance at low temperatures in the extreme anomalous limit. We show how microwave measurements can be used to probe the k dependence of the superconducting order parameter in layered materials.

xiv. R. Stephan and H. Loele, "Theoretical and experimental characterization of a broadband random noise RADAR", Proc. IEEE International Microwave Symposium, 11.-16. Juni 2000, Boston, Focus Session: Sensor Technology and Product Applications, IEEE MTT-S Digest, 1555-1558 (2000).

Abstract: The bandwidth of the transmitted signal determines the possible range resolution of a radar system. Compared with short pulses as test signal there are advantages for fine structured patterns with long duration [1,2]. Chirps, Barker codes and pseudorandom pulse sequences [3] are common examples for the application of this effect. Despite of all progress in digital signal pro- cessing the generation and analysis of high-speed pulse sequences is still a technological demanding and thereby expensive problem. The application of stochastic noise offers an interesting and inexpensive approach for the generation of a broadband test signal. It can be generated by a microwave noise source and its nonperiodic nature supplies a unique pattern in each observed interval. The key problem is to find a suited way to keep a copy of the original signal in order to compare it with the received signal. If the delay time of the reference channel is equal to that of the transmitted channel, the crosscorrelation function (CCF) between both signals becomes maximum. For large differences this correlation vanishes. An approximation of the CCF is formed by the combination of an analog mixer and integrator. To check a range bin whether it contains a reflecting obstacle, it is necessary to match the delay time of the reference channel to the corresponding distance. The authors present practical results for an X-band noise radar with a bandwidth of 1.3 GHz. The radar system and its components are described in detail and the measured data for fixed and moving targets will be presented. Major advantages of this system concept are the low RF output power density (-26 dBm) and the insensitivity to interfered signals. The most critical components is the variable delay line that chooses the different range bins. The analog signal pro-cessing without high data rate digitizing the technological effort.

4.2.7 UoP

i. L. Fanucci, E. Greco, N. Nardini, B. Neri, G. Scandurra and D. Zito, "5.25 GHz Fully Integrated Heterodyne Down-converter with Hi-Image Rejection", International Conference on Signals and Electronic Systems (ICSES 2004), 11-13 Sep 2004;

Abstract: A fully integrated heterodyne RF down-converter for 5.15-5.35 GHz wireless applications is presented. The circuit realizes a high image rejection by a selective low noise amplifier with an integrated notch filter and an image-reject mixer. The main characteristics are *an image-rejection greater than 65.8 dB, a conversion power gain of 29.6 dB, an input linearity range up to -21 dBm, a power consumption of 175.5 mW @ 3V power supply, and it does not require any external components.*

ii. L. Benedettini, B. Neri and D. Zito, "5.25 GHz SiGe-CMOS 0.35 μm Fully Integrated Power Amplifier", International Conference on Signals and Electronic Systems (ICSES 2004), 11-13 Sep 2004;

Abstract: A fully integrated power amplifier for wireless transceiver front-end is presented. The circuit has been designed for 5.15-5.35 GHz applications. The main characteristics of this design are a maximum power transducer gain of 24.9 dB, an input linearity range up to -10.8 dBm, a saturation power level of +15.4 dBm, a power consumption of 144 mW @ 3V power supply, and finally, it does not require any external components since the inductors are realized by means of the bonding-wire.

iii. D.Zito, F. De Bernardinis and B. Neri, "Modelling and design of a tunable high Q LNA for WLAN", International Conference on Signals and Electronic Systems (ICSES 2004), 11-13 Sep 2004;

Abstract: In this paper we describe the design, the modelling and simulation results of a fully integrated, high Q, tunable LNA for 5.2 GHz WLAN. A completely integrated solution is achieved with an approach based on active circuits to implement high Q tunable inductors with excellent controllability. A digital control loop is proposed in order to achieve reliable performances with process variations and operating conditions and provide a very selective operation over the whole 5-6 GHz frequency band. The proposed LNA is able to achieve a noise figure around or better than 2.5 dB while exploiting high selectivity (Q>25) and control of center frequency, bandwidth and gain.

iv. S. Di Pascoli, L. Fanucci, B. Neri and D. Zito, "Base coupled differential amplifier: a new topology for RF integrated LNA", International Journal of Circuit Theory and Applications, Wiley, Volume 31, Issue 4, July/August 2003, pp.351-360

Abstract: A new topology of bipolar Low Noise Amplifier (LNA) for RF applications, named Base Coupled Differential (BCD), is presented. The proposed approach is compared by simulation against most classical topologies. The BCD configuration has the key advantage to join an integrated matching on a single-ended input with a differential output. This is done by using down-bond wiring, so that no integrated inductors are needed. The main advantages of this new topology are a drastic area reduction and an increased linearity range (or a reduced biasing current with the same linearity) together with a Noise Figure (NF) and voltage supply reduction. Particularly, the BCD LNA presented in this paper has been designed for 2.44 GHz frequency operation. It is characterized by a NF of 1.93 dB, a voltage gain (Av) of 19.5 dB, an input impedance of 50 Ω, a 3rd Input-referred Intercept Point (IIP3) of -7.25 dBm and a dissipated power (PD) equal to 19 mW.

v. S. Di Pascoli, L. Fanucci, F. Giusti, B. Neri, D. Zito, "Fully integrated heterodyne RF receiver for ISM band applications", IEEE International Symposium on Signals, Circuits and Systems, 2003 (SCS 2003), Volume 1, 10-11 July 2003, pp. 125 –128;

Abstract: A fully integrated RF single-conversion heterodyne receiver front-end for ISM band (2.44 GHz) wireless applications is presented. The circuit realizes a high image rejection by exploiting a band pass low noise amplifier and an image-reject mixer according to the Hartley architecture. The front-end has been designed on a 50 GHz cut-off frequency bipolar process. The main characteristics of this design are an overall image-rejection greater than 57 dB at 110 MHz of intermediate frequency, a transducer power gain of 32 dB, a bandwidth of 80 MHz, an input linearity range up to –20 dBm, a power consumption of 96 mW, and finally, it does not require external components.

vi. [3] S. Di Pascoli, L. Fanucci, B. Neri, G. Scandurra, D. Zito, "Single chip 1.8 Ghz band pass LNA with temperature self-compensation", IEEE International Symposium on Signals, Circuits and Systems, 2003 (SCS 2003), Volume 1, 10-11 July 2003, pp. 121 –124;

Abstract: This paper presents the design and post-layout simulation results for a single chip 1.8 GHz band-pass LNA using the Boot-strapped Inductor approach. It is characterized by a bandwidth of 54 MHz, a minimum noise figure of 1.8 dB, a transducer power gain of 27.5 dB, an input linearity range up to –20 dBm and a power consumption of 20.7 mW. The circuit features a proper self-adaptive compensation to achieve robustness against temperature variations.

vii. L. Fanucci, A. Hopper, B. Neri, D. Zito, “A Novel Fully Integrated Antenna Switch for Wireless Systems”, IEEE European Solid State Device and Technologies Conference, 2003 (ESSDERC 2003), 16-18 September 2003.

Abstract: A novel RF switch for single antenna time division multiplexing systems, based on the boot-strapped inductor approach is presented. It allows to wire on-chip the output of the power amplifier and the input of the low noise amplifier directly to the antenna. The approach does not require any external component, it gives better performance and lower cost with respect to the front-end RF switches which commonly use PIN diodes as switching element and it allows to step forward to fully integrated transceiver solutions. The operating principle is demonstrated, the most representative performances are summarized and a preliminary estimation of the yield has been obtained by means of Monte Carlo simulations.

viii. S. Di Pascoli, L. Fanucci, B. Neri, D. Zito “A New Differential LNA Topology for Wireless Applications”. Proc. IEEE Int. Conf. on Electronics, Circuits and Systems (ICECS 2002), pp. 105-108, Dubrovnik, Croatia, 15-18 September, 2002.

Abstract: In this paper a new topology of differential Low Noise Amplifier for wireless applications is presented. This solution allows a drastic area reduction, with respect to traditional emitter coupled topology, in that it makes possible to achieve the integrated matching at the input by using only down-bond wiring. In this way no integrated inductors are needed. As shown by simulations, an increased linearity range can be also obtained, without impairing the noise figure. As an example of this new solution, a LNA has been designed for 2.44 GHz frequency operation. The main characteristic of this amplifier are: a noise figure of 1.56 dB, a voltage gain of 30 dB, an input impedance of 50 Ω, an input-referred 3rd intercept point of -7.25 dBm and a dissipated power equal to 19 mW.

ix. S. Di Pascoli, L. Fanucci, F. Giusti, B. Neri, D. Zito “A Single-Chip 1.8 GHz Image Reject RF Receiver Front-end with Boot-Strapped Inductors”. Proc. IEEE Int. Conf. on Electronics, Circuits and Systems (ICECS 2002), pp. 77-80, Dubrovnik, Croatia, 15-18 September, 2002.

Abstract: A fully integrated RF front-end for 1.8 GHz wireless receiver is presented. The circuit is based on a single-conversion heterodyne architecture with a band-pass low noise amplifier and an image-reject mixer. Boot-strapped inductors are used to realize the high quality factor inductors of the tunable LC active filters in the variable gain low noise amplifier.
The front-end, which has been designed for a 50 GHz bipolar process, presents an overall image-rejection greater than 62 dB at 100 MHz of intermediate frequency. The main characteristics of this design are a gain of 17.3 dB, a bandwidth of 45 MHz, a linearity range up to –20 dBm, a power consumption of 120 mW, a low area on die and a low cost, since no external components in the RF and IF signal paths are needed

x. L. Fanucci, G. D’Angelo, A. Monterastelli, M. Paparo, B. Neri, “Fully Integrated Low-Noise-Amplifier with High Quality Factor L-C Filter for 1.8 Ghz Wireless Applications”, Proc. IEEE International Symposium on Circuits and Systems (ISCAS 2001), Vol. 4, pp. 462-465, Sydney, Austrialia, 6-9 May, 2001.

Abstract: Actual challenge for RF ICs designers lays in the realization of high-quality integrated inductors. This paper introduces the concept of boot-strapped inductor and presents its application in a fully-integrated LNA with resonant LC preselect filter. The LNA achieves a power gain of 36 dB, a band-pass of 140 MHz and a noise figure of 2.0 dB at a working frequency of 1.8 GHz with a 3 V power supply.

xi. F. Albertoni, L. Fanucci, B. Neri, E. Sentieri, “Tuned LNA for RFICs using boot-strapped inductor”, Proc. 2001 IEEE Radio Frequency Integrated Circuits (RFIC 2001) Symposium, pp. 83-86, Phoenix, Arizona, USA , 20-22 May, 2001.

Abstract: In this paper, the principle of operation of a new type of active inductor and its application to a tuned LNA are described. The design is optimized at 1.8 GHz. An integrated transformer in connection with a current amplifier realizes a “boot-strapped” inductor with a L x Q factor never obtained before at this frequency. This way a selective LNA with a 60 MHz bandwidth, corresponding to a Q of 30, was designed. The circuit exhibits a matched noise figure of 1.8 dB with 25.5 dB transducer power gain while dissipating 20.7 mW from a 3 V power supply.

xii. G. D’Angelo, L. Fanucci, A. Monorchio, A. Monterastelli and B. Neri, “High Quality Active Inductors”, IEE Electronics Letter, N. 20, pp. 1727-1728, 30th September 1999.

Abstract: A high quality active integrated inductor is presented. The circuit reaches 20nH and a quality factor of 47 at 1.8 GHz. It is designed on a standard silicon bipolar technology and consumes 2.6mW at a supply voltage of 3V

4.2.8 UU

xiii. D.G. Kurup, A. Rydberg and M. Himdi, "Transmission line model for field distribution in microstrip line fed H-slots", Electronics Lett., vol. 37, pp. 873-874, 2001

Abstract: A method for finding the electric field distribution of microstrip line fed H-slots is described. A transverse resonance technique is first applied to find a second-order approximation of the slot propagation constant, which is then used in the transmission line model for the H-slot. The proposed model for the field distribution can be applied to the transmission line and cavity model analysis of H-slot coupled microstrip antennas

xiv. D.G.Kurup, A. Rydberg and M. Himdi, "Compact Microstrip-T coupled Microstrip Patch Antenna for dual polarisation and Active Antenna Applications", Electronics Lett., vol. 38, pp. 1240-1241, 2002.

Abstract: A novel way of feeding single layer microstrip patch antennas using electromagnetically coupled microstrip-T junctions is proposed. The measured isolation and 10dB bandwidth of an X-band dual polarised antenna are ~32dB and 2.1% respectively on an Er 3.0 substrate. Since both ports of the antenna are electromagnetically coupled, the proposed antenna eliminates the need of capacitors in the RF path for active antenna applications.

xv. D.G. Kurup, A. Rydberg and M. Himdi, "Design of an unequally spaced reflectarray", Antennas and Wireless Propagation Letters , vol. 2, pp. 33 –35, 2003.

Abstract: We present the design and experimental results of an X-band unequally spaced reflectarray of microstrip patch elements. For a given number of elements, it is shown that reduced sidelobe levels can be attained for unequally spaced reflectarrays compared to that of equally spaced reflectarrays with no significant change in directivity and array size . The synthesis tool used for deriving the element positions is a variant of the Genetic Algorithm namely the Differential Evolution Algorithm.

xvi. D.G. Kurup, M. Himdi, and A. Rydberg, "Synthesis of uniform amplitude, unequally spaced antenna arrays using the differential evolution algorithm", IEEE Trans. on Antennas and Propagation, vol. 51, pp. 2210-2217, 2003.

Abstract: A computationally efficient global optimisation method namely the Differential Evolution Algorithm (DEA) is proposed for the synthesis of uniform amplitude arrays of two classes, i.e unequally spaced arrays with equal phases and unequal phases. Phase only synthesis and the synthesis of uniformly exited unequally spaced arrays (position only

synthesis) are compared and it is seen that, by using unequal spacing, the number of array elements can be significantly reduced for attaining reduced sidelobe levels. From the DEA based synthesis of unequally spaced arrays with uniform amplitudes and unequal phases, it is found that a tradeoff exists between the size of the unequally spaced arrays and the range of phases for the same radiation characteristics. The proposed synthesis technique using uniform amplitudes, unequal spacing and unequal phases (position-phase synthesis) not only decreases the size of the array for the same sidelobe level compared to both the phase only synthesis and position only synthesis but also retains their advantages.

xvii. M. Wennström, T. Öberg and A. Rydberg, "Effects of nonlinear distortion on switched multibeam FDMA systems" IEEE Trans. Antennas and Propagation, vol. 51 , pp. 575 – 584, 2003.

Abstract: The effects of using an multicarrier amplifier (MCPA) in the transmit chain of a cellular FDMA system utilizing switched multibeam base-station antennas is investigated. By combining several carriers prior to amplification, the signal envelope will be time varying and the MCPA will introduce non-linear distortion of the amplified waveforms. It is shown how the main beam direction and frequency of any intermodulation product of any order can be calculated and a frequency allocation scheme is presented that reduces the intermodulation distortion at the mobile users. By Monte Carlo simulations, the probability distribution function of the received intermodulation distortion power is estimated, assuming a GSM system, as a function of the number of antenna elements and the number of active users. Comparisons with a one-element reference antenna is made, and it is shown that the received intermodulation distortion power for the users in the system is substantially reduced when the number of beams are increased or the user activity is reduced.

xviii. D.G. Kurup and A. Rydberg, "Amplifying active reflect-antenna using a microstrip-T coupled patch design and measurement", IEEE Trans. Microwave Theory Tech., vol. 51, pp. 1960 – 1965, 2003.

Abstract: A compact design of an amplifying active reflect-antenna using a novel microstrip-T coupled patch antenna is proposed. The dual polarized ports of the microstrip-T coupled patch antenna provide excellent RF isolation as well as DC isolation. The DC isolation helps in avoiding additional coupling capacitors in the RF path, thereby achieving reduced layout size and cross-polarization levels for the active reflect-antenna. The gain and the monostatic RCS (Radar Cross Section) measurement of the active reflect-antenna has been carried out using a time domain technique based on a single dual polarized antenna and a vector network-analyzer. The measured monostatic RCS and gains are then compared with the calculated ones using two different modelling approaches.

xix. D. G. Kurup, A. Rydberg and E. Öjefors, "Design of millimeterwave micro-machined patch antennas for WLAN applications using a computationally efficient method", European Microwave Conference 2001, pp. 453 - 456, London, England, Sept. 25 – 27, 2001.

Abstract: This paper presents a computationally efficient method for the design of millimeter wave H-slot coupled silicon micromachined patch antennas using a transmission line model. The analysis incorporates CAD models of the suspended substrate microstripline for the calculation of the effective dielectric constant of the radiating patch. The theoretical and experimental results for a fabricated 60 GHz micromachined patch antenna are compared, showing good agreement

xx. E. Öjefors and A. Rydberg, "Design and cross--talk simulations of on-chip antennas for integration in a SiGe process", 4th Workshop on MEMS for Millimeterwave Communications (MEMSWAVE), 2 - 4 July 2003, Toulouse, France.

Abstract: This paper addresses the monolithic integration of a 24 GHz slot loop antenna with a transceiver circuit manufactured in a commercial SiGe process. Measurements on an antenna manufactured on a low resistivity silicon wafer using a BCB interface layer are presented and improvements by the use of bulk micromachining are suggested. The crosstalk between the

antenna and signal traces in the transceiver circuit is analysed with finite element simulations and a novel antenna-grounding scheme is suggested.

xxi. E. Öjefors, F. Bouchriha, K. Grenier, A. Rydberg, "24 GHz ISM-band antennas on surface micromachined substrates for integration with a commercial SiGe process," European Conference on Wireless Technology 2003, Munich, Germany, 6-10 October, 2003.

Abstract: This paper addresses the integration of 24 GHz slot loop antennas on low resistivity silicon wafers using BCB and micromachining post-processing techniques, compatible with commercial SiGe processes. To reduce the coupling to the substrate a novel front-side surface micromachining process is used, where part of the lossy silicon under the slots is removed. Crosstalk between the antenna and on-chip traces is analyzed with 3D EM simulations and a new antenna grounding scheme is proposed which facilitates compact integration of the antenna with active circuits.

xxii. E. Öjefors and A. Rydberg "LTCC and glob and glob top packaging for 24 GHz MMIC with integrated antennas," GigaHertz2003, Linköping, Sweden, 4-5 November, 2003.

Abstract: A packaging method for low cost 24 GHz MMIC:s with on chip antenna using LTCC carrier substrates and glob-top encapsulation is evaluated. Microstrip ring resonators are used for characterization of single and double layers of Ferro A6-S LTCC material at 24 GHz. Quality factors close to 100 are obtained, and good agreement with the manufacturers data is demonstrated. Five different commercial glob-top, side-fill and cavity fill materials are used to cover the LTCC ring resonators. Measurements show only minor degradation in resonator quality factor when glob-tops are applied, thus indicating low dielectric losses in the encapsulation material.

xxiii. E. Öjefors and A. Rydberg, "Micromachined 24 GHz Antennas on Low Resistivity Silicon, 5th Workshop on MEMS for Millimeterwave Communications (MEMSWAVE), 30 June - 2 July 2004, Uppsala, Sweden.

Abstract: Micromachined 24 GHz on-chip loop and dipole antennas for integration in low cost SiGe tech-nology are presented. Bulk micromachining of low resistivity silicon wafers is used to improve the efficiency of the on-chip antennas, yielding antenna gains between 0 and 2 dBi.

xxiv. P. Lindberg, E. Öjefors, E. Sönmez and A. Rydberg, "A SiGe HBT 24 GHz Sub-Harmonic", to be presented at 2004 IEEE Topical Meeting on Si Monolithic ICs in RF Systems, Atlanta, Georgia, USA, 2004.

Abstract: This paper presents an IQ-demodulator for use in a 24 GHz direct conversion receiver. The circuit has been monolithically implemented in a commercial SiGe HBT process production line using standard (20 Ωcm) substrate. Measured results show a conversion gain of 11 dB, a LO/RF isolation of 35 dB and a 1-dB compression point of –10 dBm while consuming 101 mA at 3V Vcc.

xxv. E. Öjefors, F. Bouchriha , K. Grenier, A. Rydberg and R. Plana, "Compact Micromachined Dipole Antenna for 24 GHz Differential SiGe Integrated Circuits", to be presented at the European Microwave Conference 2004, Amsterdam, Holland, 11-15 October, 2004

Abstract: A compact micromachined meander dipole antenna, suitable for on-chip integration with 24 GHz differential SiGe circuits, is presented. By implementing the antenna on a 2.5 mm2 large, low loss BCB membrane close to free space radiation properties are obtained, despite the presence of a low resistivity silicon substrate.

xxvi. Erik Öjefors, Anders Rydberg, Mikael Lindeberg and Klas Hjort, "Millimeterwave antennas for integration into a commercial SiGe process", published in the “Micro and Nanotechnologies” series. Edited in the cooperation with Publishing House of the Romanian Academy, 2003.

Abstract: This work presents the on-going integration of 24 GHz ring-slot antennas on a thick polymer layer on top of a low resistivity silicon wafer. Antennas using 50 um thick polyimide sheet as well as 10 and 20 um thick BCB layers have been fabricated and measured, and the effect of dielectric thickness on antenna parameters has been studied. –26 dB return loss at 24 Ghz is obtained for an antenna with a 20 um thick BCB layer. Methods of reducing crosstalk between the slot loop antenna has been analyzed. Better than –50 dB isolation beween the antenna and typical circuit elements is shown in simulations.

xxvii. Anders Rydberg and Eric Öjefors, "Monolithic Antenna", to be published as Chapter in "Encyclopedia of RF and Microwave Engineering", edited by Kai Chang, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2004.

Abstract: Design of monolithic antennas for manufacturing using primarily silicon-based technologies is presented. Emphasis is put on space efficient, low gain antennas, suitable for integration in active device processes. Different micromachining methods for improving the performance of the integrated antennas are considered.

4.3 Completed or ongoing projects on related areas

4.3.1 Bilkent

Completed research projects:

i. Formation of a MMIC and Optoelectronics Design Center, supported by NATO as an SfS Project, (1993-1998). The purpose of this project is to setup a center capable of designing MMIC and optoelectronic chips for the local industry. During the project we developed a parameterized library for GEC-Marconi foundry for use with Cadence. We designed the first Turkish MMIC chips such as voltage controlled oscillators, LNAs, mixers, switches, distributed amplifiers, optical receivers in the frequency range up to 18 GHz. The chips are manufactured by the GEC-Marconi GaAs foundry.

ii. Hardware and software design of TASMUS Microwave Radiolink, financed by ASELSAN, 1997-2003. This project involves design of a radio to be used by Turkish army as a backbone in a tactical area communication system. We designed the architecture, hardware and software of this highly secure and reliable radio which has the following basic characteristics: E1 interface with 2.048 Mbits/sec, 1.35-2.69 GHz frequency range, maximum 50 km line-of-sight communication distance, frequency hopping and DSSS, automatic power level adjustment, maximum RF power 5 W, bit-error-rate better than 10^{-8}.

Ongoing research projects:

i. Hardware design of a secure wireless local area network, financed by ASELSAN. This project involves the hardware design of wireless LAN system to be used by Turkish army.

4.3.2 Chalmers

Ongoing research projects:

i. HFE – High frequency electronics. System models of hardware components in a 60 GHz communication system are developed. Nonlinearity in the power amplifier and oscillator phase noise has been concluded to lead to the worst performance reductions.

ii. TFR project on system design for a 60 GHz wireless communication system – The Swedish research council sponsored this project, where joint optimization of modulation methods and hardware components is studied.

4.3.3 CTTC

Ongoing research projects:

i. SURFCOM (Superconducting RF front-end receiver with Radio over Fiber technology for mobile communication). This project comprises R&D activities related to the design of advanced receiver front-ends, including the development of filters made with High Temperature Superconductors (HTS), and the use of radio over fiber (RoF) techniques to efficiently distribute the signal. The combination of both technologies may allow a significant reduction of the infrastructure necessary in third generation mobile communication systems and, at the same time, it may improve the system performance. The project partially funded by Spanish National Funds (CICYT) under contract TEC2004-06194-C02-01. The duration of this project is 36 months.

ii. MARQUIS (Multi-Antenna tRansceivers for QoS, Ubiquitous and Improved wireless Services**),** supported by the European Program EUREKA - MEDEA+ (label A111) and partially funded by the Spanish Government (contract FIT-070000-2003-257), has started on July 1 2003. The duration of this project is divided in two periods of 30 months each. The aim of this project is to obtain a set of integrated circuits, algorithms and architectures for transmission/reception that allow for radio communications using multiple antenna techniques, as well as to develop tools and instrumentation suited for measuring antenna systems.

4.3.4 POLITO

Partnerships:

i. TARGET NoE *Top Amplifier Research Groups in a European Team*
ii. CERCOM *Center for Multimedia Radio Communications* (Italian Excellence Center established through the Italian Research Ministry)

Completed Research Projects:

i. 1999-2000 Microelettronica - Progetto MURST di Ricerca Applicata. WP 3.2.3 - *Amplificatore di trasmissione di potenza (Power trasmission amplifier)*: Italian national research program co-financed by Italian Research Ministry
ii. COFIN 2000 - Programma di ricerca MURST, Linea di ricerca *Tecnologie e tecniche di progetto per trasmettitori a stato solido per telecomunicazioni mobili della terza generazione (Solid-state trasmitter design and technology for third generation mobile communications)*: Italian national research program co-financed by Italian Research Ministry
iii. 2001-2003 SIAE MICROELETTRONICA - *Moduli a microonde e a onde millimetriche con circuiti monolitici multi funzione ad alta integrazione (Microwave and millimeter waves modules with high integration monolitic multifunction circuits)*: Research contract with SIAE Microelettronica.

Ongoing research projects:

i. FIRB PRIMO - *Reconfigurable platforms for wideband wireless communications*: Italian national research program co-financed by the Italian Research Ministry
ii. COFIN 2003 - *Design of high linearity and high efficiency K/Ka transmitters for telecommunication systems adopting complex modulation schemes* Italian national research program co-financed by Italian Research Ministry
iii. COFIN 2003 - *GaN heterostructure FETs for wideband telecom systems* Italian national research program co-financed by Italian Research Ministry
iv. COFIN 2003 - *Non-linear noise models and design of low-phase noise oscillators for high performance communication systems Italian national research program co-financed by Italian Research Ministry*
v. COFIN 2003 – *Fotorivelatori organici sensibili nel vicino infrarosso per sistemi ottici di telecomunicazione (Near-Infrared Organic Photodetectors for optical telcommunication systems) Italian national research program co-financed by Italian Research Ministry*
vi. 2004 PATRAS - Amplificatori di Potenza ad Alta Efficienza per Moduli Trasmetti Ricevi in Banda X (X-Band T/R Modules) per Payload SAR di Seconda Generazione *(High efficiency power amplifiers for X-Band T/R Modules for second generation Payload SAR)*: Contract among ASI – Italian Space Agency and various Italian academic partners.

4.3.5 TUI

Completed research projects

i. National research project "Integrated coplanar microwave filters on GaAs", funded by BMFT (01BT308). Partner: Fraunhofer Institute for Applied Solid State Physics IAF (Freiburg, Germany). Duration: April 1993 until March 1996.

ii. National research project "Broadband noise RADAR", funded by the German Science Foundation (LO 577/2-1). Duration: January 2000 until December 2001.

iii. AFOSR International Research Initiative: "Nonlinear microwave response of HTS microwave devices“, funded by the European Office of Aerospace Research and Development (EOARD), London (F61775-01-WE033). Partners: MIT Lincoln Laboratory (U.S.A.) and QinetiQ Malvern (UK). Duration: August 2001 until September 2003.

iv. National research project "Wireless digital transmission of video sequences through non-metallic pipes", funded by AiF/BMWi (KF 0285501 KLF). Partner: KEG Burgstädt. Duration: July 2001 until December 2003.

Ongoing research projects:

i. Interdisciplinary research project "KERAMIS – Ceramic Microwave Circuits for Satellite Communications", funded and supported by DLR/BMBF, Germany (50YB0313). Partners: Technische Universität Braunschweig, IMST GmbH, RHe GmbH, MSE GmbH, TESAT Spaceom. Duration: October 2003 until September 2006.

ii. Priority programme "Integrierte elektrokeramische Funktionsstrukturen" of the German Science Foundation: "π-NEMS – Piezoelectrically coupled integrated nano-electromechanical sensor circuits" (AM 105/2-1). Duration: January 2004 until December 2005, extension until December 2009.

iii. Installation of an anechoic chamber for a main frequency range of 0.8 to 100 GHz, equipped with precision antenna positioner and set of reference antennas, funded by the Regional Government of Thuringia (2004).

iv. Interdisciplinary research project "WIGWAM“ - Wireless Gigabit with Advanced Multimedia Support, within priority programme "Mobile Internet“ of the BMBF. Part: "Channel measurements and modelling for GBit WLAN“, Duration: April 2004 until April 2007.

v. EU-project PULSERS: "Pervasive ultra-wideband low spectral energy radio system“, three phases with a total duration of 6 years, beginning in August 2004.

vi. Installation of a "Centre of Competence for Innovation" within the Centre for Micro- and Nano-Technologies at the Technische Universität Ilmenau, funded by FZJ/BMBF. Duration: five years. The area of research focuses on "functional micro- and nanoperipheriy", to account for the need to access the new types and strengths of signals occuring in micro- and nanoscopic devices, and to enhance the functional density available with such devices. Aspects like three-dimensional packaging, modern materials (glasses, conductive polymers, piezo-electric semiconductors), and applications like sensing, RF, and micro-electronics are addressed.

4.3.6 UoP

Completed research projects

i. National research project: “Design and simulation of functional blocks of an integrated RF front-end using silicon technology for telecommunication mobile systems“, Funded by Italian National Research Council, Industrial partner: STMicroelectronics, Technology: Bipolar HSB2 and HSB3 by STMicroelectronics. Duration: 1998-2001.

ii. National research project, “RF Integrated Front-End for Bluetooth @ 2.4 GHz”, Funded by STMicroelectronics, Technology: Bipolar HSB3 by STMicroelectronics, Duration: 1999-2000

Ongoing research projects:

i. National research project "Multi-standard RF integrated front-end for Wireless LAN 5-6 GHz", Funded by Italian Ministry of Research and Education, Technology: SiGe BiCMOS 0,35 μm by Austriamicrosystems, Duration: 2002-2004

4.3.7 UU

Completed research projects

i. Advanced RF-IC Technology using Micromachined Si/SiGe Structures (EC IST-program ARTEMIS).
ii. Hybrid photonic-antennas for 5 and 17 GHz
iii. Antenna integrated circuit implementation techniques for future software radio.
iv. Beam monitors for the CERN Compact Linear Collider (CLIC) Test Facility 3.

4.4 Available measuring equipment and design/analysis software packages

4.4.1 Bilkent

Measuring equipment:

i. Scalar Network Analyzer (26 GHz)
ii. Vector Network Analyzers (6 GHz and 26 GHz)
iii. Spectrum Analyzers (up to 26 GHz)
iv. Signal Generators (up to 26 GHz)
v. Noise measurement setup (up to 26 GHz)

Design/analysis software:

i. Cadence (IC Design package)
ii. XILINX (FPGA)
iii. Serenade (Ansoft)
iv. Sonnet (2.5D EM simulator)
v. Allegro (PCB Design)
vi. MATLAB/Simulink
vii. SystemView (Elanix)

4.4.2 Chalmers

Design/analysis software:

i. MATLAB 6.5
ii. IT++, a signal processing library in C++, focused on communication. IT++ is the choice as a common platform of NEWCOM, see WPI3. For more details, see https://sourceforge.net/projects/itpp

4.4.3 CTTC

Measuring equipment:

i. Digital Oscilloscope: Model TDS 7254 Tektronix. Bandwidth 2.5 GHz. 4 input channels. Sampling Freq: 20/10/5 GS/s (1/2/3-4 channels). Active probe 4GHz.
ii. 2. Logic Analyzer. Model TLA715- Tektronix. Sampling frequency 8GS/s.
iii. Source. Model E3648A – Agilent (0-8V/5A)(0-20V/2.5 A)
iv. BGA rework machine. Model Expert 09-Martin. Positioning: 0.025 mm
v. Spectrum analyzer. Model E4445A- Agilent 3Hz-13.2GHz. Resolution Bandwidth 1Hz
vi. Spectrum Analyzer. Model E4448A – Agilent Technologies. Freq. Range 3 Hz- 50GHz

vii. Vector Signal Generator. Model E4438C-Agilent Technologies. Frequency range 250 KHz-6GHz. RF modulation Bandwidth: 160MHz / PSK, FSK, MSK, QAM, AM, FM, Bluethooth, WLAN, WDMA.
viii. Vector Signal Analyzer. Model 89611- Agilent Technologies. Frequencies up to 6 GHz. Bandwidth 36 MHz. FSK, GFSK, MSK, GMSK, QAM, VSB, Bluethooth, WLAN, CDMA2000.
ix. Vector Network Analyzer. Model ZVC Rohde&Schwarz. Freq. Range: 300 KHz – 8GHz. 4 port matrix up to 6 GHz.
x. Microwave Vector Network Analyzer. Model E8361 – Agilent 10MHz – 67 GHz.
xi. CW Signal Generator. Model E82476 – Agilent 250 KHz – 40 GHz.

Design/analysis software:
i. Matlab 6.4 R14
ii. Mentor Graphics.
iii. Physical Dsn, Analysis and Board Dsn (1) – PCB
iv. High Speed Board / System Dsn (1) – FPGA
v. ISE Fundation 6.2i
vi. Opnet
vii. Modeler
viii. Radio/Wireless Module (5)
ix. UMTS
x. VPIsystems: VPItransmissionMaker (WDM, Cable Access)
xi. In house made software for analysing the nonlinear effects on HTS devices.

4.4.4 ISIK

Measuring equipment:
i. Lab-Volt Microwave Training Set (10.5 GHz)
ii. HP-Agilent Spectrum Analyzer (9 KHz-1.8 GHz)
iii. Gunn Oscillator (10.5 GHz)
iv. RF Cable Assemblies and Connectors (10 MHz to 10 GHz)
v. Waveguide Hardware (2 GHz to 10 GHz)
vi. RF Components : (800 MHz to 10 GHz) Amplifiers, Mixers, Detectors, Couplers, Power Dividers,Terminations, Attenuators)
vii. Various Antennas
viii. Analog/Digital base band modulation and communication training set

Design/analysis software:
i. MATLAB, C, C++ and all related mathematical toolboxes.
ii. Spice (Electronic circuit analysis and simulation)
iii. WMCD- Wide Band Microwave Circuit Designer (Real Frequency, Microwave Circuit Design and Optimization)
iv. RF Modelling Toolbox (Construction of Circuit Models for RF Data)
v. FILPRO (Filter Design)
vi. Microwave Office, (Microwave Circuit analysis)
vii. Sonnet (EM layout simulation for microwave planar circuits)

4.4.5 POLITO

Measuring equipment:
i. Active load and source pull set-up for non linear characterization of coaxial and on-wafer systems and devices;
ii. Vector Network Analyzers covering the range up to 40 GHz;
iii. Spectrum Analyzer up to 40 GHz;
iv. RF synthesized generator up to 20 GHz;
v. RF complex modulation envelope generator;
vi. Power meter up to 40 GHz;
vii. Manual and fully automated probe stations for on-wafer characterization;
viii. DC and multi bias scattering parameter characterization system;
ix. GAASCODE pulsed DC characterization system;

x. Electro-optical Agilent test bench for optical modulator characterization up to 20 GHz;
xi. Electro-optical home set-up for optical modulator characterization up to 40 GHz;
xii. In house developed software for the RF instrumentation and GPIB interface management;

Design/analysis software:
i. Agilent ADS full program suite with maintenance support;
ii. AWR Mwoffice and VSS with maintenance support;
iii. WINCAL calibration tools for NVA;
iv. Physics-based simulations
v. ISE TCAD
vi. Silvaco ATLAS
vii. Padre from Bell Laboratories
viii. In house software for noise analysis based on 2D drift-diffusion solver in linear and nonlinear conditions (MATLAB based)

4.4.6 TUI

Measuring equipment:
i. Broadband modulated signal sources and detectors (Rohde & Schwarz AMIQ und SMIQ06, SMP04)
ii. Multichannel simulator ProbSim C8
iii. Vector network analyser (Rohde & Schwarz ZVK)
iv. Spectrum analyser (Rohde & Schwarz FSU8)
v. Multiport matrix (Rohde & Schwarz ZVR-B13).
vi. Coplanar microwave prober (Cascade Summit 9000)
vii. Coaxial vector network analysis up to 50 GHz (HP8510C)
viii. Waveguide measurements from 75 to 110 GHz (Anritsu Wiltron 360)
ix. Spectrum analysis up to 32 GHz (Anritsu MS 2802)
x. Time domain reflectometry (Tektronix CSA 8000)
xi. Analog and digital signal sources.
xii. RUSK vector channel sounder (see WPR2)
xiii. Multifunctional coaxial network and spectrum analysis up to ~ 70/50 GHz (from 2005)
xiv. Anechoic chamber (frequencies from 0.8 up to 100 GHz; from 2005)

Design/analysis software:
i. MicroSim (PSpice)
ii. Serenade
iii. Agilent ADS
iv. Ensemble (MoM)
v. IE3D (MoM)
vi. Ansoft HFSS (FEM)
vii. CST Microwave Studio (FDTD)

4.4.7 UoP

Measuring equipment:
i. Probe station for microelectronic probing: DC - low frequency;
ii. Signal sources up to 3GHz;
iii. Spectrum Analyzer up to 21 GHz;
iv. Vector Network Analyzers covering the range up to 40 GHz (Anritsu).

Design/analysis software:
i. Cadence Design Framework (CDF)
ii. Agilent ADS full program suite with maintenance support;
iii. Agilent RFDE full program suite with maintenance support;
iv. AWR MwOffice with maintenance support;
v. Electrical (Spice, RFSpectre, Mentor Graphics Eldo)
vi. Functionals (MatLab, Simulink, Verilog-A, VHDL-AMS)

4.4.8 UU

Measuring equipment:

i. Wiltron 360B NA: 40 MHz - 40 GHz and 50 – 80 GHz
ii. Probe station for microelectronic probing: DC - 65 GHz.
iii. Signal sources up to 40GHz, Signal analyzers
iv. Anechoic chamb.: >1 GHz, (6x2.5x2.5m3)
v. Process Laboratory: Photolithography with sub-micron pattern generation capability, ion implantation, equipment's for diffusion and oxidation, low pressure CVD and plasma etching facilities.

Design/analysis software:

i. Agilent ADS (12 site licences, for PC and/or workstation)
ii. Agilent High Frequency Structure Simulator HFSS (2 site licences for PCs)
iii. Agilent Momentum (2 site licences for PCs)
iv. IE3D Method of Moment Simulator (Zeland Software) (1 site licence for PC)
v. Matlab
vi. Student labs: with microwave and telecommunication set-ups.

4.5 Graduate level courses given on related areas

4.5.1 Bilkent

All courses are given in English.

i. **Microwave Electronics** (4 credits: 42 lecture hours+labs, senior or graduate level)
(Textbook: "RF Circuit Design, Theory and Applications" Ludwig, Reinhold and Bretchko, Pavel Prentice Hall. Software Tools: Serenade or Analog Designer by Ansoft.) Subjects covered: S-parameters, Smith Chart, Gain definitions, matching network design using Smith chart, constant gain circles, Amplifier design, Gain compansation techniques, stability, wide band amplifier design, power amplifier design, nonlinearity characterization, harmonic balance method, oscillator design.

ii. **Telecommunication Electronics** (4 credits: 42 lecture hours+labs, senior or graduate level) http://www.ee.bilkent.edu.tr/~ee411/
(Textbook: T.H. Lee, The Design of CMOS Radio-Frequency integrated circuits, Cambridge Univ. Press. Recommended Textbooks: "The RF and Microwawe Design Cookbook" Maas, A. Stephen Artech House 1999 "Design of RF and Microwave Amplifiers and Oscillators" Abrie, Pieter L. D. Artech House 1999.) Subjects covered: Component models, RLC networks and distributed systems, bandwidth estimation techniques, high frequency amplifier design, noise, LNA design, mixers, RF power amplifiers, feedback systems, oscillators, regeneretive amplifiers, phase-locked loops, frequency synthesizers and phase noise, dynamic range, receiver architectures, transmitter architectures.

iii. **Microwave Engineering** (4 credits: 42 lecture hours+labs, senior or graduate level)

(Textbook: D.M.Pozar, Microwave Engineering, John Wiley & Sons, 3rd Edition.)
Review of basic electromagnetic theory, introduction to guided waves, introduction to guided waves, introduction to guided waves, transmission lines, transmission lines, Smith Chart, transients in transmission lines, TE, TM and TEM waves in printed lines and waveguides, microwave network analysis, impedance matching and tuning, passive microwave circuit elements.

iv. **Wireless Communications** (3 credits: 42 lecture hours, senior or graduate level)

(Textbook: "Wireless Communications, Priciples and Practice" T.S. Rappaport, Prentice- Hall.) Wireless communications, wireless communications systems, trends, cellular concept, teletraffic engineering, mobile radio propagation, large scale path-loss, fading and multipath, wireless modems, channel coding, multiple access techniques, wireless networking, network planning, broadcast systems.

v. **Communication Network Analysis** (3 credits, 42 lecture hours, graduate level)

(Textbook: "Data Networks" D. Bertsekan and R. Gallager, Prentice Hall, 1992. Recommended Textbooks: "Telecommunication Networks" M. Schwartz, Addison-Wesley, 1987; "Queueing systems: Volumes I and II" L. Kleinrock, Computer Applications, 1975.) Circuit/packet switching, layered network architecture, retransmission algorithms, introduction to queueing systems, Markov chains, M/M/m queues, M/G/1 System, networks of queues, multiaccess communication, slotted aloha, CSMA/CD, Ethernet, other multiaccess communications, fast packet switching, routing, shortest path routing, optimal routing, flow control, flow control, technology primer, TCP/IP, ATM, MPLS.

4.5.2 Chalmers

For undergraduate studies, Chalmers has an international masters program in "digital communication systems and technology", see http://www.s2.chalmers.se/imp. An abstract: "Digital Communication Systems and Technology is designed to prepare students for advanced engineering careers or Ph.D. studies in the field of communications. This rapidly advancing field of science and technology will continue to have an immense impact on human, social, and industrial life in the foreseeable future. The emphasis of the program is placed on fundamental principles for digital communications: coding, modulation, signal processing, transmission, and protocols. The design of modern communication systems and applications is also covered, including cellular systems and the Internet."

We also have some graduate courses that may be interesting to WPR3 partners, see http://www.s2.chalmers.se/graduate/index.html.en.

i. **OFDM** (Textbook: van Nee, Prasad, "OFDM for Wireless Multimedia …") The course introduces Orthogonal Frequency Division Multiplex (OFDM).

ii. **Digital communications** (Textbook: Proakis "Digital Communications") Transmission of digital information on an AWGN channel with fading and intersymbol interference is the topic of this course. Such a channel model is realistic for most communication systems used today. This course covers design and analysis of major parts of a modern communication system. It also discusses some fundamental limits for transmission of digital information over noisy channels. The aim is that part 1 shall give a thorough understanding of principles for digital communications, while part 2 goes into more details of specific principles and algorithms used in digital communication systems. Part 1 is suitable for students who want to obtain a general understanding about digital communication systems, while part 2 is for students who want to specialize in the field. The course comprises source coding, signals and systems, optimal detectors in AWGN, carrier and symbol synchronization algorithms, channel capacity and coding, block and convolutional coding, signals for band limited channels, transmission of signals on band limited channels with ISI, adaptiv equalization, multichannel and multicarrier systems, spread spectrum systems, fading channels and multiuser communications.

iii. **Error control systems** (Textbook: Bossert "Channel coding for telecommunications") Error control systems for digital communications and storage is the main topic of this course. Digital communication systems have many advantages compared to their analog counterparts and almost all future communication systems will be based on digital techniques. One of the advantages is that error control techniques can easily be employed. The basic principle is that the transmitted information is coded before transmission over a channel. The code is selected such that it may be used for error correction or error detection (with or without retransmission) at the receiver. In this way significant improvements in error performance may be obtained. One disadvantage is that the added data requires some extra bandwidth making traditional coding schemes most appropriate for power limited channels, one example being the uplink in a mobile radio communication system. More recently error control coding has been design jointly with modulation scheme, resulting in trellis coded modulations (TCM). These schemes are designed such that no increase in channel bandwidth is necessary, but instead they are not as power efficient as traditional coding schemes. TCM is now in use in most telephone line modems. The course comprises introduction to error control coding for digital communication systems, theory of Galois fields, polynomials over Galois fields, linear block codes, cyclic codes, Golay codes, Reed-Muller codes, BCH and Reed-Solomon codes, block code performance analysis, trellis representations of block codes, hard and soft decoding of block codes, convolutional codes, the Viterbi decoding algorithm, the sequential decoding algorithms, trellis coded modulation, concatenated coding, turbo codes, iterative decoding of turbo codes, error control for channels with feedback, applications.

iv. **Information Theory** (Textbook: Cover, Thomas, "Elements of information theory") The course introduces key elements of information theory, and the use of information theory in communication theory and statistics. After studying basic concepts, such as entropy and mutual information, *typical sequences* are defined, and the *asymptotic equipartition property* (AEP), roughly paraphrased as "Almost everything is almost equally probable", is introduced as one of the key ideas. The AEP leads to important concepts such as rate-distortion theory, data compression, and channel capacity, and these subjects are thoroughly studied. The material in the course is fundamental for understanding the international scientific literature in the area.

4.5.3 CTTC

The Telecommunication Technological Centre of Catatalonia (CTTC) and its activities offer a pre and post doc training environment in R+D. This environment should be defined as experimental in R+D activities in telecommunications and as highly reputed both in science and technology, and should contribute to reduce the existing gap between graduate training and industry. CTTC has also opened a way of training towards a productive environment where R+D is the main activity. The objective at long term is to contribute decisively to presence of researchers in the private sector. Moreover part of CTTC staff are sharing their research activities with teaching activities, both for undergraduate and postgraduate studies.

- CTTC offers undergraduate trainees at CTTC in the development framework of its R&D projects.
- CTTC has hosted a number of undergraduate students, some of which are currently pursing their Diploma Thesis. Topics cover CTTC's research areas of Radio Communications, Access Technologies, Optical Networking, Microwave Communication Subsystems and IP Technologies, as well as the more practical views of CTTC's Engineering Unit.
- CTTC organizes open weekly seminars on Information and Communications Technologies, in which the speakers are researchers working at or visiting CTTC, as well as invited researchers from outstanding universities and research institutions.
- CTTC has their own PhD Felloswhip Program, which grants up to 4-year doctoral studies. PhD Fellowship Program is NOW OPEN for applications.

4.5.4 ISIK

i. **Microwave Communications (3 hrs/week + Lab. 2 hrs/week, 14 weeks undergraduate) :**
Transmission line theory, transmission lines and waveguides, impedance transformation and matching techniques, microwave network analysis and matrix representations, generalized scattering parameters, signal flow graphs, modal analysis, power dividers, introduction to microwave communication systems and microwave propagation.
Textbook: David M. Pozar, Microwave Engineering, John Wiley & Sons,

ii. **Wireless Communications (3 hrs/week , 14 weeks undergraduate):**
Design and analysis of wireless communication systems, with an emphasis on understanding the unique characteristics of these systems. Topics include: cellular planning, mobile radio propagation and path loss characterization of multi-path fading channels, modulation and equalization techniques for mobile radio systems, multiple access techniques.

Textbook: Theodor Rappaport, Wireless Communications, Prentice Hall

iii. **Microwave Circuit Design for Wireless Communications (3 hrs/week, 14 weeks, graduate)**
Radio Transceiver Technology Requirements, RF Component Requirements for Transceivers; Filter, Amplifier, Mixer, Frequency Synthesizer and Dublexer Requirements. RF/Microwave Circuit Implementation Options;Semiconductor Devices and Passive Devices. Design of microwave filters and impedance matching networks; analytic and semi-analytic approaches; Low-Power Radio Frequency ICs for Broadcast Radio Receivers and Wireless Cellular Telephone Transceivers
Textbooks: Lawrence E. Larson, RF and Microwave Circuit Design for Wireless Communications, Artech House; Reinhold Ludwig & Pavel Bretchko, RF Circuit Design: Theory and Applications, Pearson Education

iv. **Advanced Microwave Circuit Design (3 hrs/week, 14 weeks, graduate)**
Characterization of linear circuits at microwave frequencies: Brune functions, Piloty functions, realizability conditions for lossless networks, scattering description of lossless two-ports. Design of microwave filters, distributed Richards frequency transformation and theorem, Kroda's identities, microwave filter design, broadband matching: Analytic and semi-analytic approaches, mixed lumped-distributed network design.
Textbooks: H.J. Carlin & P.P.Civalleri, Wideband Circuit Design, CRC Press
V.Belevitch, Classical Network theory, Holden Day
Lecture Notes; A. Aksen, Design of lossless two-ports with mixed lumped and distributed elements for broadband matching

v. **Microwave Amplifier Design (3 hrs/week, 14 weeks, graduate)**
Active circuits at microwave frequencies: Noise parameters, SNR, noise figure, noise temperature, microwave transistor amplifier design with gain and NF constraints, low noise amplifiers, broadband amplifiers, power amplifiers, numerical methods for multistage amplifier design.
Textbooks: Guillermo Gonzalez, Microwave Transistor Amplifiers: Analysis and Design, Prentice Hall; Steve C. Cripps, Advanced Techniques in RF Power Amplifier Design, Artech House

4.5.5 POLITO

Politecnico offers since the academic year 2001-2002 a postgraduate one-year program (according to the Italian university system this is called a 2nd level Master program) on **Wireless Systems and Related Technologies,** in English, whose subject fits the main interests of NEWCOM, see more information in http://didattica.polito.it/master/III/wireless.html ; the courses listed in the following list are those directly organized by our research group.

i. **Modulatori e rivelatori ottici - *Optical modulators and detectors*** (March-May 2005, English, Master in Optical Communications and Photonic Technologies)

ii. **Elettronica RF per sistemi di comunicazione mobili – *RF Electronics for mobile communication systems*** (Jan-March 2005, English, Master in Wireless Systems and Related Technologies)

iii. **Dispositivi e tecnologie per sistemi di comunicazione mobili - *Technologies and devices for mobile communication systems*** (Oct.-Dec. 2004, English, Master in Wireless Systems and Related Technologies)

iv. **Radiofrequency devices** (Jan.-Msarch 2005, English, Laurea Specialistica in Ingegneria dell'Informazione)

v. **Electron Devices** (Nov. – Jan. 2004, English, Laurea Specialistica in Nanotechnologies)

vi. **Elettronica delle Microonde - *Microwave Electronics*** (Feb.-Apr. 2005, italian, Laurea Specialistica in Elettronica)

vii. **Progetto di circuiti integrati a radiofrequenza – *RF Integrated Circuit Design*** (May-June 2005, italian, Laurea Specialistica in Elettronica)

viii. **Dispositivi Elettronici per la Microelettronica - *Electron Device for Microelectronics*** (May-June 2005, italian, Laurea Specialistica in Elettronica)

4.5.6 TUI

TUI, as a German University, offers the academic degree "Diplom-Ingenieur", while the introduction of Bachelor and Master degrees according to the Bologna-process is rapidly progressing. During and after the conversion into international academic degrees, the well-accepted high quality of education will be sustained.

In our advanced studies (honours degree), a range of compulsory and optional courses on RF and microwaves, mobile communications, and related areas are offered. At present, most of them are taught in German. More information and actual updates can be found at www.tu-ilmenau.de/englisch/bildung/studframe.html or on request.

In the following, selected courses, offered by the HMT group, with close relation to WPR3 are listed.

i. **Analog circuits**
Aims: In-depth consideration of knowledge acquired in electronic circuits during the basic degree, application to analog signal processing in systems for information and communication techniques, emphasis on RF properties. Basic types, building blocks, and applications of the key components used in analog RF circuits.
1. Introduction and overview: contents, background, analysis and synthesis of electronic circuits.
2. Small-signal broadband amplifiers: basic circuits, RC-coupling, Bode diagram, frequency limits, gain- bandwidth-product, cascaded amplifiers.
3. Selective amplifiers: principle, amplification and selectivity, feedback, stability, matching, amplifier cascades, RF-bandpass amplifiers.
4. Gain, mixing, modulation: electronic gain control, DGFET, PIN-diodes, controllable difference amplifiers, analog multiplication (two and four quadrants).
5. High-power output amplifiers: large-signal mode, characteristic parameters, classes of amplifiers, single-ended and push-pull amplifiers, examples.
6. Oscillators: feedback, stability, two-pole and four-pole oscillators, examples.
7. Design and simulation lab: complementary information, practical circuits, introduction to computer-based circuit design.

ii. **High-frequency techniques**
Aims: Introduction to functions and architectures of RF components and subsystems, relevance of such systems for applications (communications, multimedia, biomedical, sensing, metrology).
1. Introduction: Background, frequency ranges, architectures and functions of RF subsystems.
2. Receivers: Noise (origin, description, equivalent circuits), noise figure and noise temperature.
3. Frequency synthesis: direct analog, indirect, direct digital (DDS).
4. Transmitters: Nonlinearities, class-C amplifiers, linearization techniques.
5. Analog modulation and demodulation: amplitude, phase and frequency, bandwidth and robustness.
6. Digigal modulation and demodulation: Overview, amplitude, phase and frequency shift keying, trends in modern communication systems.

iii. **Radio systems**
Aims: Description of fundamental phenomena and systems of wireless RF and microwave systems. Basic knowledge for the layout of application-specific systems. Part I: wave propagation. Part II: Wireless systems. Contents complementary to the course "antennas" (see below).
I.1. Fundamentals: Maxwell's equations, plane waves in lossless media, losses (conductivity, permittivity, loss tangent).
I.2. Free-space propagation: lossless media, homogeneous lossy media, propagation along the interface of two different homogeneous media (ground-air).
I.3. Atmosphere: Ionosphere (layered structure), propagation effects, ionograms.

I.4. Propagation in the UHF range: reflection, tropospheric refraction, scattering, absorption.
I.5. Diffraction and interference: Kirchhoff's theory of diffraction, obstacles, multi-path propagation.
II.1. Basic receiver concepts: homodyne, heterodyne, zero-IF, receiver parameters.
II.2. Mixers: single-ended, push-pull, ring-mixers.
II.3. Technical antennas: wire antennas, baluns, matching networks.
II.4. Fundamentals of satellite radios: geostationary orbits, low earth orbits.
II.5. Point-to-point systems: systems concepts, examples.
II.6. Fundamentals of radioastronomy: radiative sources, detection principles.

iv. **Circuits and Devices of RF and microwave techniques**
Aims: Introduction to the physical effects of basic passive and active RF semiconductor devices and their applications. Lab course, introducing numerical simulations using Agilent ADS.
1. Introduction: Overview of device elements, modern trends of technology.
2. Circuits: two-ports, S-parameters.
3. Transistors: Bipolar transistors, field-effect transistors, transistor circuits.
4. Varactors: PN and MIS diodes, tuning elements, parametric amplification, frequency multiplication and conversion.
5. Varistors: Schottky diodes, PIN diodes, switches, modulators, phase shifters, attenuators, mixers.
6. Active two-poles: tunnel diodes, IMPATT diodes, Gunn elements, one-port amplifiers, two-pole oscillators.
7. Micro-electromechanical systems: Principles, properties, areas of applications.
8. Vacuum-electronic devices (tubes): density-controlled electron tubes, klystrons, travelling wave tubes, magnetron, carcinotron.
9. Circuit simulation using ADS: linear models in frequency domain, circuit optimisation, nonlinear analysis (harmonic balance), transient analysis, method of moments.

v. **Antennas**
Aims: Fundamentals of antenna operation and design, applications and trends. Single radiating elements, antennas and signal-processing. Practical excercises.
1. Introduction: contents, motivation, historical developments, applications and trends, electromagnetic fundamentals.
2. Antennas in transmission: Radiated fields, far field condition, elementary antennas (Hertz dipole, radiating plane), characteristic parameters of antennas.
3. Antennas in reception: theorem of reciprocity, effective aperture, power transmission (Friis equation and RADAR equation), effects of noise.
4. Types of simple antennas: plane radiators, wire antennas, planar antennas, modelling and parameters.
5. Antenna arrays: phased arrays, linear arrays, radiation pattern of arrays (radiative coupling), beam forming.
6. Antennas and signals: Fundamentals of polarimetry, spatial frequencies, antennas as filters, aperture synthesis, superdirective antennas, adaptive antennas.
7. Antenna measurements: gain, radiation pattern (near and far fields), noise temperature.

4.5.7 UoP

i. **Integrated microwave circuits**
(12 CFU) for LS Electronics Engineering degree
ii. **Design of Microelectronics Systems**
(12 CFU) for LS Electronics Engineering degree
iii. **Electronics for mobile telecommunication systems**
(12 CFU) for LS Electronics Engineering degree
iv. **Electromagnetic Compatibility**
(6 CFU) for LS Telecommunication Engineering degree
v. **Electromagnetic Field Propagation**
(12 CFU) for LS Telecommunication Engineering degree
vi. **Microwave**
(6 CFU), for LS Telecommunication Engineering degree

4.5.8 UU

i. **Microwave Engineering I**
(Prerequisites Electromagnetic field theory)
Aims of the course: The aim of this course is to give knowledge about basic concepts, methods and components in microwave technology.
Course Content: Transmission line theory. The Smith chart. Waveguide theory. Stripline and Microstrip. Losses and damping in waveguides and transmission lines. Microwave network analysis. Equivalent voltages and currents. Impedance matrix. Scattering matrix. Methods for impedance matching. Microwave resonators. Various passive microwave components.
Laboratory work: Rectangular waveguide, Impedance matching, Network analyser.
Literature: D. M. Pozar: Microwave engineering, 2nd ed, John Wiley & Sons, 1998.

ii. **Microwave Engineering II:**
(Prerequisites: Microwave Engineering I)
Aims of the course: To give knowledge and understanding active microwave components. In a compulsory assignment an active microwave system component is designed and evaluated.
Course Content: Two port power gains. Transducer gain and stability. Design of amplifiers for maximum and constant gain. Noise in microwave systems. Design of low noise amplifiers. Bias networks. Oscillators. Detectors and mixers. Intermodulation. Integrated microwave circuits.
Project work: Amplifiers for low power or low noise as well as oscillators are designed and fabricated.
Literature: Pozar, D.M., Microwave Engineering, 2ed, John Wiley & Sons, 1998.

iii. **Antenna Engineering**
(Prerequisites: Electromagnetic field theory)
Aims of the course: The aim of this course is to introduce, in a unified manner, the fundamental principles of antenna engineering and to apply them to the analysis, design, and measurements of antennas. Applications are made to some of the most basic and practical configurations, such as linear dipoles, loops, arrays, microstrip and aperture antennas.
Course Content: Definition of an antenna. The radiation mechanism. Fundamental parameters of antennas. Friis transmission equation and the radar range equation. Radiation integrals and auxiliary potential functions. Duality theorem. Reciprocity and reaction theorems. Linear wire antennas. Infinitesimal dipole, small dipole and half-wavelength dipole. Linear elements near or on infinite plane conductors. Circular loop antennas. Arrays: linear, planar and circular. Self- and mutual impedance's of linear elements. Antenna synthesis and integral equations. Travelling wave and broadband antennas. Field equivalence principle. Rectangular and circular aperture antennas. Microstrip antennas. Antenna measurements. Laboratory work: Numerical calculation of antenna characteristics. Design of microstrip antenna and measurement of its radiation pattern.
Literature: C. A. Balanis "Antenna Theory. Analysis and Design, 2nd Ed.", John Wiley & Sons Inc., 1997.
Study visit: Study visit to an industry working with microwave engineering.

iv. **Microwave Systems**
(Prerequisites: Courses in Signals and linear systems EI1 and Telecommunication EI1.)
Contents: Transmission line theory and matching, Microstriplines, Noise in microwave systems, Detectors and Mixers, Antennas, Microwave communication systems, Satellite communication systems, Radiometry, Microwave propagation, Microwave heating and energy transfer, Biological effects of microwave radiation.
Laboratory work: Components for a microwave radiolink at 5 GHz are analysed.
Literature: Pozar, D.M., Microwave Engineering, 2ed, John Wiley & Sons, 1998.
Study visit: Study visit to an industry working with microwave engineering.

ABBREVIATIONS

BER – Bit error rate
CAD – Computer aided design
CDMA – Code division multiple access
CMOS – Complementary metal oxide semiconductor
CPE – Common phase error
CTTC – Telecommunication Technological Centre of Catalonia
EW – Electronic warfare
FPGA – Field-programmable gate array
GaAs – Gallium arsenide
GLONASS – Global navigation satellite system
GPS – Global positioning system
HBT – Heterojunction bipolar transistor
HTS – High-temperature superconductors
HW – Hardware
ICI – Intercarrier interference
IP – Intermodulation product
ISI – Intersymbol interference
ISM – Industrial, scientific and medical (frequency band)
LAN – Local area network
LNA – Low Noise Amplifier
LTCC – Low-temperature cofired ceramic
LUT – Lookup table
MEMS – Micro-electromechanical system
MIMO – Multiple input, multiple output
MMIC – Microwave monolithic integrated circuit
OFDM – Orthogonal frequency division multiplexing
PA – Power amplifier
PAPR – Peak to average power ratio
PHEMT – Pseudomorphic high electron mobility transistor
PIC – Parallel interference cancellation
POLITO – Polytechnic of Torino
QAM – Quadrature amplitude modulation
RF – Radio frequency
RFI – Radio frequency interference
RFIC – Radio frequency integrated circuit
SIC – Serial interference cancellation
SiGe – Silicon germanium
SW – Software
TUI – Technische Universität Ilmenau
UoP – University of Pisa
URA – Uniform rectangular antenna array
UU – University of Uppsala
UWB – Ultra-wideband
WLAN – Wireless Local Area Network