INSTITUT FÜR NACHRICHTENTECHNIK UND HOCHFREQUENZTECHNIK

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Institut für Nachrichtentechnik und Hochfrequenztechnik
Technische Universität Wien
Gußhausstraße 25/389
A-1040 Wien, Austria
Tel.: (+43 1) 588 01-ext.
Fax: (+43 1) 588 01-38999
Email: sekretariat@nt.tuwien.ac.at
http://www.nt.tuwien.ac.at/

KONTAKTPERSONEN / CONTACTS

	Nebenstelle/ Extension
Sekretariat / Secretariat (Fr. Frech, Fr. Schwab)	38901
❏ Automatische Codeerzeugung / Automatic Code Generation Prof. Mecklenbräuker / Dr. Wess	38929, 38919
❏ Codierung und Datenübertragungsverfahren / Coding and Data Transmission Prof. Weinrichter	38928
❏ Digitale Filter und Signalprozessoren / Digital Filters and Signal Processors Dr. Doblinger	38927
❏ Digitale Signalverarbeitung / Digital Signal Processing Prof. Mecklenbräuker	38929
❏ Hochfrequenztechnik / Radio Frequency Technology Prof. Bonek, Prof. Scholtz	38936, 38945
❏ Mobilkommunikation / Mobile Communications Prof. Bonek	38936
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❏ Rapid Prototyping in der Mobilfunkkommunikation/ Rapid Prototyping in Mobile Communications Prof. Rupp	38967
❏ Zeit-Frequenz-Signalverarbeitung / Time-Frequency Signal Processing Prof. Hlawatsch	38915

MITARBEITER DES INSTITUTS / STAFF MEMBERS

Stand 30.09.2002

Professoren:
O.Univ.Prof. Dr. Ernst Bonek
O.Univ.Prof. Dr. Wolfgang Mecklenbräuker
Univ.Prof. Dr.-Ing. Markus Rupp
Univ.Prof. Dr. Walter Leeb
Univ.Prof. Dr. Johann Weinrichter

Dozenten:
Ao.Univ.Prof. Dr. Franz Hlawatsch
Ao.Univ.Prof. Dr. Arpad L. Scholtz

Beamte des wissenschaftlichen Dienstes:
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Dr. Christian Seyringer
Dr. Martin Steinbauer
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Dr. Martin Toeltsch
cand.-Ing. Zrin Ziborski

Gastmitarbeiter:
Dr. Wang Yu, SwissCom, Schweiz, 06/2002 -
Luis Weruaga, Universidad Politécnica de Cartagena, Cartagena, Spanien, 01/2002 - 10/2002
Dr. Jon Wallace, Brigham Young University, Provo, Utah, USA, 05/2002 – 05/2003
Dr. Xiangxiang Wang, Beijing University of Post & Telecommunications, Beijing, China, 10/2001 – 10/2002
Dr. Zhen Jie, Information Engineering College, Dalian Maritime University, Dalian, China, 10/2001 – 10/2002

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COST 273 „Toward Mobile Broadband Multimedia Networks“
COST 277 „Nonlinear Speech Processing“
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AKTUELLE FORSCHUNGSGEBIETE: ÜBERSICHT / CURRENT RESEARCH AREAS: SYNOPSIS

Im Bereich der *digitalen Signalverarbeitung* bearbeiten wir derzeit die folgenden Schwerpunkte: *Zeit-Frequenz-Signalverarbeitung*, *Nichtlineare Signal- und Sprachverarbeitung*, *Digitale Filter und adaptive Systeme zur Sprachentstörung* sowie die *Automatische Generierung optimierter Programme für Signalprozessoren*.

Die Arbeitsgruppe *Zeit-Frequenz-Signalverarbeitung* entwickelt Methoden zur Analyse, Verarbeitung, Modellierung und Simulation von hochgradig instationären Signalen und schnell zeitvarianten Systemen bzw. Kanälen. Unsere derzeitigen Arbeiten konzentrieren sich auf den Einsatz neuartiger Zeit-Frequenz-Methoden in der Mobilkommunikation. Wir entwickeln Algorithmen zur Kanalschätzung und -prädiktion, Zeit-Frequenz-Synchronisierung und Impulsoptimierung für OFDM-Systeme. Ein neuartiges Raum-Zeit-Modulationsverfahren und ein effizienter iterativer Decodieralgorithmus ermöglichen schnelle Datenübertragung über Mehrfachantennen-Funkverbindungen auch ohne Kenntnis der Kanaleigenschaften. Als Teilnehmer eines EU/IST-Projekts setzen wir fortschrittliche Signalverarbeitungsalgorithmen zur Analyse von Gleichkanal-Interferenz in UMTS-Netzen und zellularen DVB-T-Netzen ein.

Wir entwickeln weiters Zeit-Frequenz-Methoden zur Modellierung und Simulation von zeitvarianten Systemen und Mobilfunkkanälen. Zeit-Frequenz-Filter erlauben eine einfache Spezifikation zeitvarianter Filtercharakteristiken. Zeit-Frequenz-Leistungsdichtespektren ergeben eine hochauflösende Spektralanalyse instationärer Zufallssignale. Neuartige Zeit-Frequenz-Methoden zum Entwurf und zur Implementierung instationärer Signalschätzer und -detektoren zeichnen sich durch hohe statistische Robustheit und numerische Effizienz aus.

Im Bereich *nichtlineare Signal- und Sprachverarbeitung* werden Algorithmen zur Modellierung von nichtlinearen dynamischen Systemen und aus der Informationstheorie sowie neuronale Netze angewendet. Wir beschäftigen uns im besonderen mit Sprachsignalanalyse und -synthese. Projekte werden mit Unterstützung des FWF, und im Rahmen der europäischen COST Aktion 277 durchgeführt.

Die Leistungsfähigkeit moderner Signalprozessoren kann nur durch effiziente Programme wirklich ausgenutzt werden. Dazu entwickeln wir *Algorithmen für die automatische Umsetzung von Datenflußgraphen* in optimierte Programme für Signalprozessoren. Auf diesem Gebiet bestehen enge Kooperationen mit Industriefirmen.

Ein weiteres Forschungsgebiet umfasst die Entstörung verrauschter Audiosignale mit Hilfe *adaptiver Filter und Filterbänken*. Neben dem Entwurf von Multiratenfilterbänken werden auch adaptive Algorithmen zur Modifikation der einzelnen Teilbandsignale entwickelt. In Kooperation mit einem Industriepartner werden derzeit Anwendungen im Bereich adaptiver, ein- und zweidimensionaler Mikrofon- und Lautsprecherarrays untersucht.

In the area of *digital signal processing* we focus on the following topics*: Time-frequency signal processing*, *nonlinear signal and speech processing*, *digital filters and adaptive systems for speech enhancement*, and *automatic program generation for signal processors*.

The *time-frequency signal processing* group is developing techniques for the analysis, processing, modeling, and simulation of highly nonstationary signals and fast time-varying systems/channels. Our current work focuses on the application of time-frequency techniques to mobile radio communications. We develop algorithms for channel estimation/prediction, time-frequency synchronization, and pulse optimization within OFDM systems. In the framework of an EU/IST project, we use advanced signal processing to analyze co-channel interference within UMTS networks and cellular DVB-T networks. Recently, we devised a novel space-time modulation technique and an efficient iterative decoding algorithm that allow to boost bit rates over multi-antenna wireless links with unknown channel characteristics.

We are also developing and studying time-frequency techniques for the modeling and simulation of time-varying systems and mobile radio channels. Time-frequency filters allow an easy specification of time-varying filter characteristics. Novel time-frequency power spectra perform a high-resolution spectral analysis of nonstationary random signals. Our time-frequency designs and implementations of nonstationary signal detectors and estimators are statistically robust and numerically efficient.

In the field of *nonlinear signal and speech processing* algorithms for nonlinear dynamic system modelling and from information theory as well as neural networks are applied. Our specific interest lies in speech signal analysis and synthesis. Current projects are supported by FWF, and we actively contribute to the European COST action 277.

The exploitation of the full performance of modern signal processors requires efficient programs. To meet this challenge, we develop *algorithms for the automatic conversion of data flow graphs* into highly optimized programs for signal processors. In this area there exist close cooperations with industrial companies.

Another research area comprises the enhancement of noise-corrupted audio signals using *adaptive filters and filterbanks*. Besides the design of multirate filterbanks, a number of adaptive algorithms is developed for the modification of the subband signals. In cooperation with an industrial partner, we currently investigate design and application of two-dimensional adaptive microphone arrays.

Die Abteilung *Codierung und Datenübertragungsverfahren* beschäftigt sich mit der Optimierung von Übertragungssystemen. Von aktuellem Interesse sind zeitvariante Mobilfunkkanäle (stochastisch auftretender Schwund). Das Gedächtnis des Kanals wird dabei als innerer Code interpretiert und Modulation und äußere Codierung darauf abgestimmt.
In letzter Zeit wurden verschiedene Codierverfahren (Turbo-Codes, Low density parity check codes, Mehrdimensionale Produkt-Codes) bekannt, mit denen man praktisch die Shannon´sche Kanal-Kapazität erreicht. Ein brandaktuelles neues Forschungsgebiet ist die Raum-Zeit-Codierung, bei der Sender und Empfänger in Form von Antennengruppen realisiert sind. Die Theorie zu diesem Verfahren verspricht hohe Diversität und hohen Codegewinn sowie eine Steigerung der Kanalkapazität um eine Größenordnung. Dafür effiziente Raum-Zeit-Codes zu finden, ist eine faszinierende Aufgabe.
Wir untersuchen sowohl Raum – Zeit Block Codes als auch Raum – Zeit Trellis Codes und ihre Gewinne in Bezug auf eine größere Diversität bzw. ihre Gewinne in Bezug auf eine Reduktion der benötigten Sendeleistung (Code Gewinne). Von großem Interesse sind die Gewinneinbußen bei zunehmender Korrelation der Teilübertragungsfunktion zwischen den einzelnen Antennen – Elementen. Mit zunehmender Korrelation gewinnen die adaptiven Antennen (smart antennas) mit einstellbarer Richtcharakteristik an Bedeutung. Diese Thematik wird in der Mobilfunkgruppe an unserem Institut seit längerer Zeit sehr erfolgreich bearbeitet.

In der *Mobilkommunikation* arbeiten wir mit der Mobilkom Austria AG zusammen auf den Gebieten Optimierung von Mobilfunknetzen, UMTS (Universal Mobile Telecommunications System), Scheduling für paketvermittelte Dienste, künftige neue Systeme sowie Funkzugang zum Internet. In Zusammenarbeit mit Partnern am ftw., in Helsinki, Paris und Ilmenau verfeinern wir Modelle des Funkkanals, die seine letzte noch ungenützte Komponente, nämlich die räumliche, in bisher nicht erreichtem Detailreichtum beschreiben. Diese Charakterisierung wird erforderlich, wenn man die ungeheure Übertragungskapazität der neuen MIMO Systeme nutzen will. MIMO steht für multiple-input multiple-output und beschreibt Funkstrecken/system, die bei Sender und Empfänger Antennengruppen einsetzen. Für intelligente Antennen entwickeln wir Algorithmen für die Auf- und Abwärtsstrecke, die auf Signalprozessoren in Echtzeit implementiert sind. Mit „blinden“ Algorithmen nutzen wir strukturelle Eigenschaften der Mobilfunksignale, um gewünschte Teilnehmer von unerwünschten zu trennen, selbst wenn sie räumlich nicht trennbar sind. Die Ergebnisse der COST Aktion 259 „Wireless Flexible Personalized Communications“ wurden als Buch veröffentlicht, in dem unsere Mitarbeit an führender Stelle (Arbeitsgruppenleiter Antennen und Wellenausbreitung, Autoren mehrerer Kapitel) dokumentiert ist. In COST 273 führen wir dieselbe Arbeitsgruppe weiter, die Unterarbeitsgruppe über MIMO-Kanäle wird von einem Absolventen betreut.
Die Spezialausbildung in der Mobilkommunikation, zu der verschiedene Bereiche des Instituts beitragen,

In the area of *coding and data transmission* we try to optimize data transmission over difficult channels by combining modulation, equalization and channel coding.
Today we focus on time variant mobile radio channels with deep fades. Methods to cope with the resulting intersymbol interference like Turbo-equalization are investigated. In some cases the channel memory can be considered as inner code. Then the outer code can be matched to the inner code and recursive detection methods can be applied.
Examples of most effective codes like Turbo-codes, low density parity check codes, and product codes, which have been become popular in the very last time are under investigation. A newly attacked field of investigation are space-time codes applied to antenna arrays. With this approach diversity and channel capacity can be increased by an order of magnitude.
Several Space-Time Codes for various multiple antenna element systems are under investigation.

In the field of *mobile communications*, we cooperate with Mobilkom Austria AG on mobile network optimization, UMTS (Universal Mobile Telecommunications System), scheduling for packet-switched services, future systems, and radio access to the internet. In cooperation with groups at ftw and in Helsinki, Paris and Ilmenau we refine models of the mobile radio channel that exploit the last frontier of this channel, the spatial component. We can establish directions of arrival and of departure (DOAs, DODs) with unprecedented precision in several domains at the same time. Such characterization of the mobile radio channel becomes crucial to put to use the enormous transmission capacity, offered theoretically by MIMO systems. MIMO stands for multiple-input multiple-output and describes radio links with antenna arrays at the receiver and at the transmitter.
We develop smart antenna algorithms for up- and downlink, which are implemented on a DSP in real time. With so-called „blind“ algorithms we utilize structural signal properties to separate and detect desired/interfering user signal, which are not separated in the spatial domain. Our leading involvement in COST 259 „Wireless Flexible Personalized Communications“ is documented in the book about this action (chapter authors, chairman of the working group on antennas and propagation.)
We continue this leadership in COST 273 „Towards Mobile Broadband Multimedia Networks“. The newly founded sub-working group on MIMO is led by an alumni of our group.
The dedicated course plan in mobile communications

zieht Studenten aus ganz Europa an. Mit der ETH Zürich und der TU München bieten wir ein gemeinsames Mobilfunkseminar an.

Der Schwerpunkt der Forschung auf dem Gebiet der *Digitalen Signalverarbeitung in der Mobilkommunikation* liegt in den Methoden des Rapid Prototyping. Dabei werden Ideen und Algorithmen der digitalen Signalverarbeitung sehr schnell in Echtzeitexperimente umgesetzt. Aussagen über die technische Realisierbarkeit sind daher schon sehr früh möglich. Konkret befassen wir uns mit Verfahren zur Kanalschätzung für sehr schnell veränderliche Kanäle, wo lange Beobachtungszeiten für die Schätzung von Kanalparametern nicht möglich sind. Wir versuchen, eine adaptive, nichtlineare Vorverzerrung für UMTS-Endverstärker zu entwickeln, um nichtlineare Verzerrungen des Sendesignals und störendes Übersprechen in Nachbarbänder zu verringern. Wir entwickeln Empfänger für Mehrfachantennensysteme (MIMO-Systems). Weiters befassen wir uns mit Entzerrerstrukturen für UMTS- und Mehrfachantennensysteme. In Zukunft werden auch Funksysteme der 4. Generation verschiedene Forschungsschwerpunkte bilden. Die größten Verbesserungen gegenüber Systemen der 3. Generation (UMTS) werden momentan in der Verbindung von Kanal- und Quellkodierung gesehen; auch neuartige Kodierungsmethoden und Methoden zur Fehlerverdeckung zeigen Verbesserungen auf. Ein Systemdesign mit Hinblick auf solche Methoden ist eine sehr lohnende Herausforderung für die Zukunft.

draws students from all over Europe. Together with ETH Zurich and TU Munich we offer an International Seminar on Mobile Communications.

Signal Processing in Mobile Communications focusses on methods for rapid prototyping. Here, system concepts and algorithms are mapped rapidly into real-time experiments, hence, allowing to conclude technical feasibility at an early stage of the development process. Hereby, we are investigating rapid channel movements in which channel estimation based on long periods for observation are not available. We develop adaptive, nonlinear predistortion techniques for UMTS power amplifiers, in order to reduce nonlinear distortion in neighboring bands. Furthermore, we develop receiver for multiple transmit and receive antenna systems (MIMO) and investigate possible structures for equalizers in UMTS and MIMO receiver systems. In future, also wireless systems of the fourth generation will be a focus. The most important improvements when compared with 3rd generation wireless systems (UMTS) are expected in the combination of channel and source coding. Also new methods for error concealment are of interest. A complete system design based on such new techniques is a very interesting challenge for the future.

Auf dem Gebiet der *Hochfrequenztechnik* beschäftigen wir uns mit integrierten Schaltungen in Si und SiGe Technologien. Das Ziel dieser in Zusammenarbeit mit Infineon Technologies AG durchgeführten Untersuchungen ist es, die physikalischen Grenzen der Herstellungsverfahren auszuloten.
Weitere Arbeiten befassen sich mit Sonderformen von Funkantennen und der Erfassung der Leistungsfähigkeit von Bluetooth-Verbindungen in industrieller Umgebung.
Gemeinsam mit dem Institut für Astronomie der Universität Wien sind wir dabei, eine Erdefunkstelle in städtischer Umgebung für die Kommunikation mit LEO-Satelliten aufzubauen.

In the domain of *radio frequency technology* we deal with the design of integrated circuits in Si and SiGe technologies. The goal is to find out the physical limits of chip performance for existing fabrication methods. Our industrial partner here is Infineon Technologies AG.
Further, we are involved in the custom design of antennas and in testing of Bluetooth-links in industrial scenarios.
Together with the University Vienna we are just setting up a ground station in the urban area for communication with low earth orbiting satellites.

Auf dem Gebiet der *Optischen Nachrichtentechnik* untersuchten wir für die Europäische Weltraumbehörde ESA Laser-Freiraum-Übertragungssysteme, die bei einer Wellenlänge von 1550 nm und mit Datenraten von 10 Gbit/s arbeiten. Dabei werden mit Hilfe von Erbiumdotierten Faserverstärkern Sendeleistungen von 1 Watt erzielt. In Hinblick auf einen möglichst empfindliche Detektion optischer Signale erforschten wir die Vorteile von RZ-Codierung gegenüber herkömmlicher NRZ-Codierung und erreichten im Experiment einen Wert von nur 1,4 dB über dem Quantenlimit. Im Zusammenhang mit dem Einsatz von besonders leichten, durch Elektroformung hergestellten Teleskopen haben wir Pegelpläne für die Laser-Datenübertragung zu und zwischen Satelliten erstellt. Diese Studie berücksichtigte die schon heute bei $\lambda = 1550$ nm verfügbaren Baugruppen, eine Datenrate von 2,5 Gbit/s, und

In the area of *optical communications* we investigated for the European Space Agency ESA free space data links operating at a wavelength of 1550 nm and a data rate of 10 Gbit/s. In the system tested, an Erbium-doped fiber amplifier provided a transmit power of 1 Watt. With the aim to detect low-level optical signals we researched possible advantages of RZ coding compared to NRZ coding and experimentally obtained a sensitivity of just 1.4 dB above the quantum limit. Further, with an eye towards an implementation of light-weight electroformed telescopes in optical terminals, we determined link budgets for various intersatellite and ground-to-satellite link scenarios. Our analysis took into account present-day technology at $\lambda = 1\,550$ nm, a data rate up to 2.5 Gbit/s and telescopes with either multi-mode fiber coupling or diffraction-limited operation.

Teleskope, die entweder an Multimode-Fasern oder an Singlemode-Fasern gekoppelt sind.
Auf dem Konzept eines Interferometers beruht das von uns in Hinblick auf das ESA-Projekt DARWIN untersuchte Vielfach-Raumteleskop zur Vermessung extrasolarer Planeten. Für dieses Instrument beteiligen wir uns auch an der Entwicklung von Infrarot-Fasern, die im Wellenlängenbereich zwischen 4 μm und 20 μm als räumliche Modenfilter eingesetzt werden. Dieses Bauelement ist entscheidend für die Erzielung eines tiefen Minimums im Strahlungsdiagramm der optischen Antenne.
Gemeinsam mit der Abteilung Quantenexperimente von Prof. Zeilinger (Universität Wien) untersuchen wir Konzepte zur optischen Datenübertragung, die auf der Quantenmechanik beruhen. Eine typische Anwendung wäre der Schlüsselaustausch für krytographische Zwecke (Teleportation) zwischen einer Bodenstation und einem Satelliten.

The concept of an interferometer is the underlying principle of a multiple-arm space-borne telescope, which ESA plans to use as an optical antenna in one of its future space missions called DARWIN. We participate in research towards this goal, among others by developing single-mode fibers acting as spatial mode filters in the 4 μm-to-20 μm band. Such devices are essential to achieve the required deep null in the antenna pattern.
We teamed up with Prof. Zeilingers group at Vienna University to investigate concepts for optical space communications based on the principle of quantum mechanics. A typical application would be quantum key distribution (teleportation) along a link between a ground station and a low-Earth-orbiting satellite.

CHRISTIAN-DOPPLER PILOTLABOR

für Entwurfsmethodik von Signalverarbeitungsalgorithmen

CHRISTIAN DOPPLER PILOT-LABORATORY

for Design Methodology for Signal Processing Algorithms

Das Christian-Doppler Pilotlabor für Entwurfsmethodik von Signalverarbeitungsalgorithmen befasst sich mit der Entwurfsmethodik für Systeme mit komplexen Signalverarbeitungsproblemen vornehmlich im Mobilfunkbereich. Hierbei wird die Problematik des Systementwurfs von Anwendungen im Bereich der Signalverarbeitung als eine Einheit betrachtet, die sich von der Forschung bis zur Implementierung spannt und alle unterschiedlichen Beschreibungsformen einschließt, die während des Systementwurfs auftreten.
Im Mobilfunkbereich für die sogenannte dritte Generation Wireless (UMTS) zeichnet sich das Problem der effizienten Produkterstellung besonders ab. Durch immer leistungsfähigere Hardwareelemente wie Embedded Systems alleine, wird es nicht möglich sein UMTS mit all seinen signalverarbeitungsintensiven Diensten und Funktionen als Produkt anzubieten. Erst durch eine wesentlich effizientere Vorgehensweise in der Produktentwicklung kann man gewährleisten, dass dieser Herausforderung an verfügbare Hardwareelemente entgegnet werden kann. Im Christian-Doppler Pilotlabor für Entwurfsmethodik von Signalverarbeitungsalgorithmen wird diese Entwurfsmethodik optimiert werden, sodass mit Hilfe von automatischen Werkzeugen ein konsistenter Entwurfsfluss entsteht, der wiederum eine deutliche Produktivitätssteigerung erzielt.
Durch die partnerschaftliche Vorgehensweise mit der Firma Infineon Technologies wird garantiert, dass die Methoden und ihre Randbedingungen auf heutige Systementwürfe anwendbar sind, während schon ein Weg zu den Entwurfsmethoden von morgen geschaffen wird.

The Christian Doppler Pilot-Laboratory for Design Methodology for Signal Processing Algorithms contributes to the design methodology of signal processing algorithms, basically in the areas of mobile communications. Hereby, the system design in signal processing is considered a single process ranging from research to actual implementation including all possible descriptions required for the system design.
Mobile communications of the third generation (UMTS) has a problem in efficient product development. Purely based on higher performing hardware elements like embedded systems it will not be possible to offer a product for UMTS with all its high complex services and functionalities. Only by a very efficient design methodology it will be possible to meet such challenge on the hardware. In the Christian Doppler Pilot-Laboratory for Design Methodology for Signal Processing Algorithms such methodology will be optimized resulting in a consistent design flow allowing for much higher efficiency.
Partnering with Infineon Technologies will guarantee that the developed methods and their constraints will be applicable to today‘s system design, already preparing the path for tomorrows.

ERNENNUNGEN VON UND PREISE AN MITARBEITER / NOMINATION AND AWARDS

30.9.2001 - 1.10.2002

Martin Strasser, IEEE Student Paper Award 2001 / Austria (IEEE Sektion Österreich), November 2001

H. Bölcskei, F. Hlawatsch, and H. G. Feichtinger, IEEE Signal Processing Society 2001 Young Author Award for the paper “Frame-theoretic analysis of oversampled filter banks” (IEEE Trans. Signal Processing, vol. 46, Dec. 1998, pp. 3256-3268)

LEHRVERANSTALTUNGEN / COURSE PROGRAM

im Studienjahr 2001/2002

1. Pflichtlehrveranstaltungen / Mandatory Courses

			WS	SS
Weinrichter:	Einführung in die Nachrichtentechnik	VO	—	3,0
Dortschy:	Einführung in die Nachrichtentechnik	UE	—	1,5
Weinrichter:	Grundlagen nachrichtentechn. Signale	VO	—	2,0
Zeitlhofer:	Grundlagen nachrichtentechn. Signale	UE	—	1,0
Magerl:	Hochfrequenztechnik 1	VO	—	2,0
Trojer:	Hochfrequenztechnik 1	UE	—	1,0
Ehrlich-Schupita:	Hochfrequenztechnik 2	VO	2,0	—
Ehrlich-Schupita:	Hochfrequenztechnik 2	UE	1,0	—
Mecklenbräuker, Bonek, Leeb, Weinrichter, Rupp:	Nachrichtentechnik Labor A	LU	—	5,0
Bonek, Mecklenbräuker, Leeb, Weinrichter:	Nachrichtentechnik Labor B	LU	9,0	—
Bonek:	Nachrichtentechnik Labor für TPH	LU	—	4,0
Leeb:	Optische Nachrichtentechnik	VO	2,0	—
Pfennigbauer:	Optische Nachrichtentechnik	UE	1,0	—
Mecklenbräuker:	Signal- und Systemtheorie 1	VO	1,5	—
Rank:	Signal- und Systemtheorie 1	UE	1,0	—
Mecklenbräuker:	Signal- und Systemtheorie 2	VO	—	1,5
Doblinger:	Signal- und Systemtheorie 2	UE	—	1,0
Hlawatsch:	Übertragungsverfahren 1	VO	2,0	—
Seyringer:	Übertragungsverfahren 1	UE	1,0	—
Hlawatsch:	Übertragungsverfahren 2	VO	—	2,0
Matz:	Übertragungsverfahren 2	UE	—	1,0
Bonek:	Wellenausbreitung 1	VO	2,0	—
Pospischil:	Wellenausbreitung 1	UE	1,0	—
Bonek:	Wellenausbreitung 2	VO	—	2,0
Özcelik:	Wellenausbreitung 2	UE	—	1,0

2. Wahllehrveranstaltungen / Optional Courses

			WS	SS
Scholtz:	Antennentechnik	LU	—	2,0
Mecklenbräuker, Doblinger, Zeitlhofer:	Digitale Signalverarbeitung A	SE	3,0	—
Mecklenbräuker, Doblinger, Zeitlhofer:	Digitale Signalverarbeitung B	SE	—	3,0
Wess:	Dimensionierung und Simulation analoger Filter	SE	1,5	—
Professoren und Assistenten:	EDV-orientierte Projektarbeit für ET	AG	4,0	4,0
Weinrichter:	Einführung in die Codierung	VO	2,0	—
Kommenda:	Ein- und Ausgabe von Sprache	VO	2,0	—
Garn:	Elektromagnetische Verträglichkeit elektronischer Geräte	VO	—	1,5
Lamedschwandner, Garn:	Elektromagnetische Verträglichkeit elektronischer Geräte	UE	—	1,5
Weinrichter:	Filter	VO	1,5	—
Scholtz:	Funkweitverkehrstechnik	VO	1,5	—
Braunbeck:	Geschichte der Nachrichtentechnik	VO	1,5	—
Leeb:	Glasfaser-Nachrichtensysteme	VO	—	1,5
Scholtz:	Hochfrequenz-Schaltungstechnik	KO	—	1,5
Hlawatsch:	Information Theory for Communications Engineers	VO	2,0	—
Magerl:	Integrierte Mikrowellenschaltungen	VO	—	1,5
Bonek, Leuthold, Nossek:	Internationales Seminar Mobile Kommunikation	SE	—	3,0
Leeb:	Kohärente optische Empfänger	VO	—	1,5
Ehrlich-Schupita:	Messgeräte der Hochfrequenztechnik A	KO	—	1,5
Wess:	Methoden der automatischen Codegenerierung	VO	—	1,5
Magerl:	Mikrowellenmesstechnik	VO	1,5	—
Bonek, Weinrichter, Rupp:	Mobilfunk	KO	3,0	—
Bonek, Rupp:	Mobilkommunikation	SV	—	2,0
Bonek, Rupp:	Mobilkommunikation	UE	—	1,0
Bonek, Weinrichter, Rupp:	Mobile Radio Communications	KO	3,0	—
Fröhling, Renner:	Numerische Methoden in der HF- und Mikrowellentechnik	VO	1,5	—
Proksch:	Phasenregelschleifen in der Nachrichtentechnik	VO	—	1,5
Doblinger:	Programmieren von Signalverarbeitungsalgorithmen in C	SE	—	1,5
Riegl, Ullrich:	Radartechnik	VO	—	1,5
Hlawatsch, Doblinger:	Research Projects in Advanced Signal Processing	SE	3,0	3,0
Weinrichter:	Schnelle Datenübertragung über Kabel (xDSL)	VO	3,0	—
Doblinger:	Signalprozessoren	VO	1,5	—
Mecklenbräuker, Doblinger, Matz:	Signalverarbeitung mit MATLAB	LU	3,0	—

			WS	SS
Hlawatsch:	Statistical Signal Processing	VO	—	2,0
Mecklenbräuker, van As, Magerl:	Telekommunikationsforum	KO	2,0	2,0
Leeb, Bonek:	How to publish a scientific paper	KO	2,0	—
C. Mecklenbräuker	Mobilfunknetze der dritten Generation	VO	2,0	—
Müller	Multi-User Communications	VO	2,0	—
Matz	Signal Detection	VO	2,0	—
Mayr	Telekommunikation und Telekomm. Politik in Österreich	VO	1,5	—
Leeb	Simulation breitbandiger optischer Übertragungssysteme	SE	2,0	—
Rupp, Aschbacher	Adaptive Filter	VU	—	3,0

3. Gastvorlesungen / Guest Lectures

		WS	SS
Prof. Dr. Ing. Zoran Salcic, Auckland University	Rapid Prototyping of Algorithms in Telecommunications	—	4,0

4. Gastvorträge / Guest Talks

Prof. Dr. Rüdiger Urbanke, EPFL Lausanne	Advanced Coding Theory

5. Gastvorlesungen von Institutsmitgliedern / Guest Lectures by Members of the Institute

Bonek, E.	Site-specific propagation-based MIMO channel modelling Tohoku University, Sendai, Japan, 14.2.2002.
Bonek, E.	Site-specific propagation-based MIMO channel modelling Osaka University, Osaka, Japan, 25.2.2002.
Bonek, E.	Mobile communications for Beginners University of Tokyo, Tokyo, Japan, 1.3.2002.
Bonek, E.	The essence of wireless communications: ropagation and antennas Aalborg University, 1.5.2002.
Hlawatsch, F.	The Importance of Being Underspread: A Time-Frequency Paradigm for Nonstationary Statistical Signal Processing and Communications. EPFL Lausanne, Switzerland, 19.-21.6.2002.

Digitale Signalverarbeitung / Digital Signal Processing

The Naturalness of Synthetic Speech
Contact: E. Rank *Partner:* COST 258 Duration: 12.1996 - 12.2001

Segmental Duration in German Speech
Contact: E. Rank *Partner:* ÖFAI (Öster. Forschungsinstitut für Artificial Intelligence), FWF (Project P13224-INF) Duration: 12.1996 - 12.2001

Nonlinear Speech Processing
Contact: E. Rank *Partner:* COST 277 Duration: 06.2002 - 05.2005

Advanced Multicarrier Systems for Wireless Communications
Contact: Franz Hlawatsch *Partner:* FWF (Project P15156) Duration: 01.2002 -

Christian Doppler Pilot-Lab for Design Methodology of Signal Processing Algorithms
Contact: M. Rupp *Partner:* Christan Doppler Society and Infineon Technologies Duration: 06.2002 - 06.2004

Konzeptstudie zur Optimierung eines Multiraten ASMD-Programms
Contact: B. Wess, T. Zeitlhofer *Partner:* Infineon, München Duration: 08.2002 - 09.2002

Mobilkommunikation / Mobile Communications

Smart Antennas in Cellular Networks
Contact: W. Weichselberger *Partner:* Nokia Research Center, Helsinki Duration: 08.1999 - 12.2003

Mobilkommunikation
Contact: E. Bonek *Partner*: mobilkom Austria Duration: 01.2001 -

UMTS
Contact: T. Baumgartner *Partner:* mobilkom Austria Duration: 01.2001 -

Advanced Network Radio Identification Equipment for Universal Mobile Communications (ANTIUM)
Contact: F. Hlawatsch *Partner*: EU (Project IST-2000-26222) Duration: 01.2001 - 06.2003

Toward Mobile Broadband Multimedia Networks
Contact: E. Bonek *Partner:* COST 273 Duration: 04.2001 - 04.2005

Semi-blind Signal Detection with Adaptive Antennas for CDMA
Contact: C. Pommer *Partner*: FWF (Project P14935) Duration: 06.2001 - 05.2003

Algorithmenentwicklung zur Optimierung von Mobilfunksystemen
Contact: W. Weichselberger *Partner:* Symena Duration: 03.2002 - 01.2003

Optische Nachrichtentechnik / Optical Communications

Impulscodierung für optische Satellitenkommunikation
Contact: W.Leeb *Partner:* FWF (Project P13998-TEC) Duration: 03.2000 - 03.2002

Multi-Aperture Imaging Interferometer (NBB)
Contact: O. Wallner *Partner:* Astrium GmbH/D, TNO-TPD/NL, ESA-ESTEC Duration: 02.2001 - 02.2003

Quantum Communications in Space
Contact: W. Leeb *Partner:* Inst. f. Experimentalphysik,Univ. Wien, ESA-ESTEC Duration: 08.2002 - 02.2003

Feasibility study of lightweight communication terminals for intersatellite links
Contact: W. Leeb *Partner:* Media Lario S.r.l./I, ESA-ESTEC Duration: 01.2002 - 11.2002

Single-Mode Fibres for DARWIN
Contact: O. Wallner *Partner:* Astrium GmbH/D, ART Photonics/D, ESA-ESTEC Duration: 08.2001 -

Zeit-Frequenz-Signalverarbeitung / Time-Frequency Signal Processing

Oversampled Filter Banks and Redundant Signal Expansions
Contact: F. Hlawatsch *Partner*: FWF (Project P11228-TEC) Duration: 09.1997 - 10.2001

BALDEMAIR Robert **Time-domain equalization and digital notching in multicarrier systems**

This thesis deals with Discrete Multitone (DMT) modulation in the Digital Subscriber Line (DSL) technology. DMT modulation is part of the Asymmetric Digital Subscriber Line (ADSL) and Very-High-Bit-Rate Digital Subscriber Line (VDSL) standards. DMT modulation divides the available bandwidth into narrowband subchannels and considers each subchannel independently. The first part of this thesis provides an overview of DMT modulation and typical environments for DSL systems.

The frequency band allocated by the VDSL technology includes some narrow frequency bands occupied by amateur radio services (HAM bands). Within these bands, the Power Spectral Density of the transmitted VDSL signal must be reduced substantially. Even if all tones overlapping with HAM bands are not used, sidelobes of adjacent subchannels contribute a considerable power to these bands. The second part of this thesis presents a method where tones in and adjacent to the HAM bands are used to generate compensation signals, which reduce the power within these bands. The provided algorithms minimize the power transmitted within the HAM bands by sending appropriate dummy data on the compensation tones.

DMT modulation allows for a simple receiver structure if the impulse response of the communication channel is shorter than the cyclic prefix. In ADSL, Time-Domain Equalizers (TEQ) are used to fulfil this requirement. Without a TEQ, unwanted Intercarrier Interference (ICI) and Intersymbol Interference (ISI) occur. In the last part of this thesis, matrix formulations are developed to calculate the contributions of ICI and ISI to the desired signal. Based on these expressions, a family of new TEQs is derived which minimizes the effects of ICI, ISI, and additive noise. Simulations in the context of ADSL compare the abilities of these new algorithms with the state of the art.

HACKL Sabine **Monolithische Integration von Frequenz≠umsetzern bis 45GHz in Silizium und SiGe**

In this work the suitability of frequency converters in silicon based technologies for broadband communication systems from 20GHz to more than 40GHz is discussed. Silicon is well suited for circuit realizations at high frequencies, high integrations and low cost.

High gain, low power consumption, high linearity, and low noise represent the main challenges of frequency converters like mixers, modulators and multipliers. They should all be optimized at the same time.

Because of the low current gain in the transistors at high frequencies circuit innovations are necessary in addition to exploiting the full potential of the used technology. This determines the way this work was done.

The first part describes optimization strategies for maximum bandwidth of basic mixer circuits. The transistors are driven at the upper limits of the technologies. The sensitivity of the gilbert mixers gain is discussed and related to transistor parameters to allow careful transistor parameter optimizations. To improve the mixers bandwidth new circuit methods are developed and investigated with simulations. A modification of the gilbert mixer with resonant circuits improves the mixers bandwidth and doubles the frequency for maximum gain.

Experimental results are presented. An active broadband mixer up to about 30GHz, 3dB bandwidth of 20GHz, and maximum gain of 15dB is described. A quadrature demodulator for LMDS frequencies at 28GHz is realized with an integrated quadrature oscillator and mixers which provide gain for frequencies up to more than 40GHz (maximum gain of 30dB at 20GHz). A frequency quadrupler with gain between 23GHz and 45GHz uses two frequency doublers and a differential amplifier.

All circuits set a new state of the art for maximum bandwidth in silicon based technologies and show suitability for future broadband applications. An integration of the frequency converters presented above in transmitter or receiver systems is possible.

It is shown that a combination of careful circuit optimizations and improvements in the circuit design allows the realization of frequency converters up to 45GHz in silicon based technologies.

With further improvements in the silicon technology and/or modifications in the circuit design higher bandwidth, lower power consumption, etc. can be expected.

HUGL Klaus **Spatial channel characteristics for adaptive antenna downlink transmission**

In this thesis, I investigate the effects of physical wave propagation on adaptive antenna operation in cellular mobile communications systems. I especially focus on the downlink of systems applying frequency division duplex (FDD).

I present evaluation results of array channel measurements performed simultaneously on an uplink and downlink carrier in the UMTS frequency band 1. The utilization of a vehicular mobile station transmitter allowed measurements of time-varying channels on continuous routes. The investigations indicate that the propagation environment together with the base station antenna height has a strong influence on propagation parameters such as path-loss, time dispersion, and the congruence of dominant direction of arrival and geometrical mobile station position. Even the occurrence of several angular propagation clusters is affected. In 40% of the cases there exist more than a single azimuthal propagation cluster.

My evaluations demonstrate that the mobile radio channel as seen from a base station antenna array is extremely directional. The performance degradation of uplink signal processing in reduced dimensions compared to optimal space-time processing is negligible. Therefore, independent spatial and temporal adaptive antenna uplink processing is reasonable.

The temporal correlation of the instantaneous channel realization is quickly decreasing with increasing time shift. This effect is diminished by applying small-scale averaged channel information. Therefore, smart antenna downlink transmission in FDD systems using mobile station feedback information has to be based on small-scale averaged information. Even in outdoor TDD systems serving vehicular users, the utilization of small-scale averaged uplink information improves the downlink transmission robustness. Furthermore, I prove that the array channel impulse responses at uplink and downlink frequency are decorrelated because of uncorrelated fading and the frequency dependent antenna array response. Therefore, the uplink antenna weights should not be directly used for downlink beamforming purpose. Nevertheless, the dominant direction of arrival and the entire azimuth power spectrum show a strong congruence in uplink and downlink. As a consequence, their utilization in the downlink beamforming process is reasonable.

Finally, I derive the ASCOFT algorithm and compare it with three other proposed frequency transformation methods of the spatial covariance matrix. The capability of these algorithms to compensate for the changing antenna array response is investigated using measurement data and a simple synthetic spatial channel model. I conclude that the ASCOFT algorithm is the best method for transforming the spatial information contained in the spatial covariance matrix from uplink to downlink frequency. Therefore, ASCOFT is an important means in downlink smart antenna processing for cellular mobile communications systems using frequency division duplex.

NEUBAUER Thomas **Smart antenna radio network planning in third generation mobile communication systems**

In this work I investigate radio network planning aspects of Smart Antennas in third generation mobile communication systems. I focus on the FDD mode in UMTS, the Universal Mobile Telecommunications System. For this I develop a static Monte Carlo simulation platform. This simulation approach is capable of both conventional and Smart Antenna UMTS networks that makes it possible to compare the performance of both system configurations.

Since UMTS will be an interference limited system, I start with basic interference considerations. I measure the background noise power in the UMTS FDD uplink band in urban, suburban and rural environments. Based on this I study the impact of the variation of the background noise power level on the system coverage and -capacity.

I investigate the impact of various system-specific parameters on the overall network performance. This includes investigations of the Channel Model, the Signal & System Model, the UMTS Receiver Structures and the Weight Adaptation Algorithms. I characterize the system performance by means of statistical evaluations. The most interesting parameters for this evaluation are the uplink interference (uplink noise rise), the uplink transmit power of all mobiles, the downlink interference at all mobiles and the resulting downlink base station transmit power. Since the system capacity will be measured by the number of served users in the system and the overall system data throughput, I evaluate these parameters as well.

My results show that Smart Antennas will boost the system capacity of UMTS FDD networks by a factor 2.5 or higher! The results show that with Smart Antennas the downlink TX power limits can be fully exploited. The limit of the network then will become a shortage of OVSF codes in the downlink. In order to overcome this problem I suggest the use of a secondary scrambling code for base station identification in the downlink.

It turns out that a single Monte Carlo realization is sufficient to estimate the overall system capacity and to analyze the system performance. Radio resource management (RRM) algorithms will play a crucial role in the deployment and the roll-out of Smart Antennas in third generation mobile communication networks.

From the results I conclude that there is a huge potential for system optimization. The more equally the traffic demand can be shared among all cells in the system, the better the overall system performance will be. Since the traffic demand of 3G networks will steadily migrate to mobile data traffic networks rather than speech traffic networks, I conclude that the radio system will have to be permanently optimized in order to satisfy the traffic demand. A powerful measure for this system optimization will be the pilot power of each sector.

I conclude that the success of Smart Antenna deployment in 3G mobile communication systems will depend on comprehensive planning and optimization tools that will automatically parameterize the radio network in order to enable optimum system performance.

PAIER Mario **Frequenzmanagement in der Mobilkommunikation in Österreich**

Frequency spectrum is a limited resource of high economic value. The utilization of parts of the spectrum that can be used for radio transmission has to be optimized considering political, economic and technical aspects. This is the task of frequency management. The aims of frequency management encompass the accommodation of different radio services in the spectrum, achievement of a high efficiency of frequency utilization and the avoidance of interference between radio systems. National and international procedures are necessary to achieve these aims. These procedures are discussed in this work.

„Beauty contests“ (comparative hearings) and auctions are used to allocate frequency utilization rights to mobile operators. The advantages and disadvantages of these procedures are analyzed. The essential advantage of „beauty contests“ for operators is that often, very low licence fees are charged. On the other hand, the low transparency of the procedure can result in legal uncertainties. Both procedures should not be used to maximize the income for the state but to select the licence winners efficiently. A clear trend towards auctions can be observed worldwide. In Austria, this procedure has been used to allocate licences for mobile communication. The allocation of the UMTS licences end of the year 2000 was performed by a simultaneous, ascending multiple-round auction. Depending on the behavior of the bidders, four to six licences were possible. The reasons for the regulator to choose this procedure and the results of the auction are analyzed.

The definition of the precise frequency channels in the spectrum for each operator was done after the auction. The consequences of the utilization of neighboring frequency bands, the optimization of the carrier frequencies and the coordination to the frequency usage in neighboring countries are discussed. It is shown, that in some cases the carrier separations have to be lower then the nominal figure of 5 MHz and that the carrier frequencies will often be different in neighboring countries. The coordination of the frequency usage for UMTS in border areas to neighboring countries constitutes a high challenge because of the low number of frequency channels per operator. Within the scope of this work the coverage situation in border areas is analyzed by means of simulations. According to ERC regulations, a threshold of the field strengths caused by base stations is defined at the border line and the coordination of the primary scrambling codes is assumed. It is shown, that because of potential interference from neighboring countries, high data rates in border areas can only be achieved with an increased number of base stations.

RITZBERGER Günther **Hochintegrierte Frequenzsynthesizer für Anwendungen im Millimeterwellen-Bereich**

The overall goal of this work is to investigate if and to which extent the different RF functions of a frequency synthesizer for the millimeter wave frequency range around 40GHz can be integrated in single chips using standard silicon technology. The silicon technology is a SiGe bipolar technology with 0.4 μm lithography and 85GHz transit frequency.

In the 40GHz frequency range new wireless broadband applications will be provided in the future, like LMDS (Local Multipoint Distribution System) and MVDS (Microwave Video Distribution System). In all these wireless systems frequency synthesizers are needed.

Up to data frequency synthesizers for millimeter waves consist of several single building blocks manufactured in III-V-semiconductor materials like GaAs and InP.

Different frequency synthesizer concepts are investigated in terms of maximum operating speed and suitability for monolithic integration. These investigations lead to the phase-locked loop concept, which is capable to proved output frequencies beyond 40GHz. The basic phase-locked loop (PLL) consists of voltage-controlled oscillator, frequency divider, phase detector, loop filter, and reference oscillator. For mobile applications up to 6GHz, the building blocks phase detector and frequency divider are monolithically integrated and are available as PLL-IC products.

In this work the monolithic integration of the oscillator and the frequency divider (as prescaler) is discussed. In order to extend the operating frequency range of the circuit an additional frequency multiplier is used. Different circuit concepts for the three building blocks are presented and best suited concepts are selected. The blocks are optimized by circuit simulations. The limits for the high integration degree for operating frequencies beyond 40GHz are identified. Methods to minimize the influences between the different building blocks caused by cross coupling via parasitics are discussed.

The experimental verification is done with a highly integrated 40GHz PLL synthesizer containing all key function, e.g. VCO, frequency divider, and frequency multiplier. For complete characterization a demonstration board has been developed allowing for all necessary DC and RF measurements.

The experimental results of the synthesizer show output frequencies between 36GHz and 45.5GHz at an output power in the range of –15dBm consuming only 650 mW from the single 5V supply. The effects due to the cross coupling between the different building blocks can be measured. In the spectrum of the output signal at 40GHz also lines at the fundamental frequencies of the VCO and the frequency divider appear. To minimize these influences further investigations are necessary.

The output frequency of this circuit exceeds the frequency of synthesizers realized in GaAs-technology by more than 30% and those realized in Si-based technologies by more than 500%. A new state of the art for frequency synthesizers is set.

This work provides the evidence that functional integration of different RF building blocks on a single chip for operating frequencies beyond 40 GHz is feasible.

STEINBAUER Martin **The Radio Propagation Channel – A Non-Directional, Directional and Double-Directional Point-of-View**

This thesis describes in three parts the evolution from non-directional via directional to double-directional mobile radio. Emphasis was laid on the question how to achieve maximum system independence. The result is a comprehensive frame-work spanning the whole range from measurement over evaluation, characterization and classification to modeling, usage of the model in simulations and interpretation thereof. In line with this logical work ow is the structure of the thesis.

First, a clear definition of the channel system functions and their averaged versions, e.g. the delay power profile, is given. Next, the various types of channel sounders, their principles and their shortcomings are discussed in line with aspects on their practical application to the specialties of mobile radio. The traditional way of data extraction via windowing and Fourier transform is reviewed shortly. Non-directional channel characterization summarizes channel parameters to cover all effects of the radio wave propagation process except for polarization which is discussed later on. The commonly used pathloss measure is generalized to apply to different signal combining schemes. Indoor measurement results predict a 3-6dB frequency diversity gain in 90% of all cases when increasing bandwidth from 800kHz to 50MHz. Non-stationary behavior is characterized through the new concept of local stationarity regions that result from the large-scale fading of a wideband channel impulse response. From measurements in urban and sub-urban environments, the span of these regions is evaluated to range up to 20 meters for a correlation threshold of 0.5. Related is the identification of a cluster, for which a physical definition is given. Channel parameters for the small-scale effects complete the non-directional description. Channel classification is a must for parametric channel modeling. Two principally different approaches are dealt with herein: One is based on a mathematically rigorous multivariate analysis of channel parameters, the other empirically on an inspection of the morphology of base-station sites.

The second part of this thesis describes directional channel modeling. It is mostly based on the European directional channel model proposal that was developed jointly in two cooperative bodies, the EU-project METAMORP and the action COST259. While for the actual model parameters (external, global and local parameters) the reader is referred to the corresponding published literature, the aim here is on a concise summary of the philosophy behind (cell types, radio environments, propagation scenarios). A detailed ow chart is set up to explain how the model structure lends itself to multi-layered link-level simulations.

The emphasis of the thesis lies on the third part. After giving a brief mathematical derivation of the double-directional radio propagation channel based on the theory of linear time-varying systems, a block diagram of the double-directional channel model shows how the antennas both at the transmitting and at the receiving link-end are removed from the channel. Correspondingly, a compatible model of the antenna subsystem(s) is needed which is covered as well. The matrix notation of the double-directional transmission leads to double-directional channel measurement techniques and their evaluation. In the developed array cross-multiplexing technique, a multiple-input multiple-output (MIMO) measurement system is used to capture the joint double-directional nature of the channel. From the several existing multipath evaluation methods (Unitary) ESPRIT is applied, and beamforming is used to obtain the multipath weights. From the measured microcellular back-yards, 17 up to 54 paths are identified and in part traced across up to three reflections. Besides the application of algorithms for one-dimensional data in multiple fashion, the described joint multidimensional parameter estimation and combination utilizes also the relations between different physical domains to improve the estimate, and it circumvents the otherwise occurring pairing problem. It is shown by simulation that the parametric double-directional wideband channel estimate is generic for simulating any MIMO system in the same radio environment, i.e. independent of most system parameters and the used antenna configuration. Double-directional channels and MIMO capacity turn out to be inseparable related; the used antennas bridge the remaining gap from the system-independent double-directional propagation channel to the system-related MIMO radio channel. Further, the notion of capacity is reviewed. Thereupon, random phase factors are used to compute outage capacities of 17-26 bits/s/Hz 20dB SNR for an 8 x 8 antenna arrangement from singular MIMO channel snapshots in a microcell.

STRASSER Martin **Optical free-space transmitters and their effects on preamplified direct detection.**

Sensitive detection of data signals is of major interest for optical high speed communication systems. In fiber-optic networks, sensitive receivers reduce transmitter or mid-span amplifier requirements, extend link distances, and provide additional margins. For the emerging class of free-space optical (FSO) communication systems, sensitive receivers are keys to closing the link over long distances in inter-satellite transmission scenarios or to overcoming large atmospheric attenuation in terrestrial FSO systems.

This thesis deals with the design and optimization of transmitters and receivers for FSO applications with the aim to achieve maximum receiver sensitivity. Coherent detection of PSK (phase shift keying) coded signals theoretically yields the highest receiver sensitivity. However, in practical and economically attractive systems operating at data rates in the Gbit/s regime, direct detection (DD) receivers using RZ-OKK (return-to-zero on/off keying) coding outperform all other systems. Hence, I focus on RZ transmitters and optically preamplified direct detection receivers.

For optimum RZ data modulation, I review various optical pulse generation methods such as mode-locking, gain-switching, and pulse carving by means of sinusoidally modulated Mach-Zehnder modulators or electroab-

sorption modulators. I theoretically and experimentally characterize the properties of the pulses generated by these methods, and discuss the different methods with respect to their application in FSO communication systems. Taking into account transmitter robustness and complexity, the optimum FSO transmitter is shown to be a DFB laser monolithically integrated with a dual-stage electroabsorption modulator.

For receiver modelling, advanced Gaussian noise statistics are used to simulate detection noise in a more accurate way than with conventional noise models. The simulations presented in this work verify that RZ coding can outperform NRZ (non return-to-zero) by up to 4 dB in receiver sensitivity. For RZ coding, the optimum optical and electrical detection bandwidths yielding maximum receiver sensitivity represent a trade-off between filter-induced signal rejection and noise suppression. This is in strong contrast to NRZ coding, where intersymbol interference plays a major role. I show that the optimum bandwidths are strongly influenced by the characteristics of the RZ data signal such as duty cycle, extinction ratio, and frequency chirp. Hence, a joint optimization of transmitter and receiver is necessary. This optimization (i) identifies a duty cycle of about 33 percent as being optimum for practically relevant receiver bandwidths, (ii) chooses modulation concepts that minimize the penalty in sensitivity due to a finite transmitter extinction ratio, and (iii) results in system architectures that keep low the influence of degradation effects such as jitter and chirp. Especially for chirp, a comprehensive investigation of its influence on the sensitivity of direct detection receivers is presented.

For a detailed assessment of the chirp characteristics of the transmitter I develop an extended chirp model predicting the phase distortions more realistically than the so-called effective chirp model. The extended model enables an accurate chirp characterization of any intensity modulated optical source. Simulations using the extended model show that chirped RZ signals always deteriorate the receiver sensitivity by up to several dB. In the case of NRZ coding, chirp is even capable of improving the bit error probability (BEP).

Transmission experiments performed at a data rate of 10 Gbit/s verify the simulation results. An optimized experimental RZ transmitter and receiver setup yielded a record receiver sensitivity of 52 photons per bit at a BEP of $10e^{-9}$, which is just 1.4 dB above the quantum limit.

TOELTSCH Martin Spatial characterization of urban radio channels

One of the most promising technologies for a significant capacity improvement and enhanced spectral efficiency of current - but also future - mobile communication systems is the utilization of adaptive antenna arrays. GSM field trials with adaptive antenna testbeds provided a capacity increase of 2-3 in urban environment. The feature of adaptive antennas compared to a conventional technique is their ability to exploit the spatial nature of the radio channel. Thus, a detailed knowledge of the radio channel, particularly of its temporal and spatial behavior, is crucial for an optimal operation of both the antenna arrays itself and the whole mobile radio network. Accurate channel models have to be developed in order to enable system simulations with smart antennas at the base stations and/or the mobile stations.

In this thesis, I report and discuss the evaluation of important parameters of urban radio channels. The evaluation is based on uplink channel measurements. During the measurement campaign, the transmitters were placed in streets and squares in downtown Helsinki, Finland. The receiving base station 2-D antenna array, consisting of 62 x 16 single antenna elements, was placed at typical micro- and macro-cell base station locations at heights of about 15-25 m over ground. I investigate temporal and directional properties as well as statistical parameters of the radio channel for macrocellular and microcellular environments, separately for the cross- and co-polarized component. The European research cooperation COST 259 recently developed a directional channel model (DCM). I also evaluate fundamental parameters of this COST 259 DCM.

One of the most important results is that the radio waves tend to concentrate in narrow angular and temporal regions seen from the base station. I call such a region a cluster. By means of detailed plots of the received power over the azimuth-elevation-delay planes, the clustered nature of the propagation becomes evident. A detailed discussion of the definition of the clusters' borders and the most relevant cluster parameters - like e.g. inter- and intra-cluster spreads - follows.

A significant parameter is the distribution of the total received power over the clusters. It turns out that 75% of the received co-polarized energy is concentrated in the two strongest clusters. The attenuation of the cluster-power with increasing delay is in the order of 10dB/s, and the most probable number of clusters seen by the base station is three. The power-weighted average size of a cluster (intra-cluster spread) is 4° - 5° and some 1.5° in horizontal and vertical direction, respectively.

The results of my investigations can be used in various ways. The extracted parameters provide a basis for link-level as well as system-level simulations. Simple channel models, based on the statistical results reported in this thesis, and also very accurate models based on the temporal and spatial parameters, can be developed. Smart antenna algorithms can now be compared in an adequate and straightforward way by considering the directional and temporal radio channel properties that I investigated in this work.

ZÖSCHG Dietmar **Monolithische Integration von rauscharmen Verstärkern für den Hochfrequenzbereich von 2GHz bis 28GHz**

This work shows by theoretical analysis and experimental verifications how to achieve minimum noise figure for monolithically integrated low-noise RF amplifiers.

Necessary precondition for the complete monolithic integration of receivers in RF networks is the possibility to realize all functional building blocks as monolithic integrated circuits with sufficient performance at low power consumption. In particular the low-noise amplifier limiting the sensitivity of the receiver by its noise properties was and is a very critical building block.

Traditionally, the best results for low-noise amplifiers are obtained with HEMTs on III-V-materials. In this work modern silicon and SiGe technologies are used, which are state of art in its field. Additional to the suitability for high working frequencies of digital and analogue circuits all well-known advantages of silicon, high integratability at lowest cost, are found with these technologies. For the classification of the results comparisons with earlier results in the same and other semiconductor technologies inclusive CMOS are given at the end of the work.

The investigations are based on a well-proven circuit concept also suited for technology evaluation and comparison. The noise behavior of the complete amplifier is dominated in this circuit concept by the input stage. Therefore, it can be treated analytically with reasonable effort if some simplifications are accepted. This analytical treatment yields surprising results: only a few transistor parameters determine the noise behavior of the optimized amplifier. The minimum noise is described by the current gain and two time constants which are determined by the device technology used. With this knowledge, it is clear how the circuit, active and passive elements, hat to be designed. Especially the selection of transistor configurations and calculating the size of the critical transistors is clarified.

The experimental verification is done using three frequency bands of technical importance: mobile communications at about 2GHz, WLAN at about 5-6GHz, and satellite communications at 10-12GHz. Special care is devoted to the layouts of the circuits because all additional couplings can deteriorate the noise minimum. The same holds for the mounting and measurement techniques. The precise measurement of very small noise figures, as could be expected from the simulations, demands for special care and large effort in all steps of adjustment, calibration, and measurement.

The experimental results prove the success of the methodology: For all silicon as well as for SiGe amplifiers the state of art is remarkably improved. With 0.8dB at 1.8GHz, 1.3dB at 6GHz, and 2dB at 10GHz the noise figures can compete with those of monolithic integrated III-V-amplifiers.

The difference between Si and SiGe is small for 2GHz in noise figures as well as in gain. With raising frequency the advantages of SiGe are increasing. The gain of all amplifiers is in the range of 20-30dB, the power consumptions are only about 30mW. Therefore it is proven that these Si and SiGe technologies are well suited for low-noise amplifiers for frequencies of 2GHz to 10GHz. Simulations show that this frequency range can be extended up to 28GHz with SiGe amplifiers.

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