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Introduction to Digital Communications

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Preface

Digital communication has found an increasing interest in the past 70 years starting with the telephone network on copper wires, the development of the optical transmission, and the emerging Internet based on wire-line and wireless transmission technologies. Today, the trend to serve an increasing number of mobile users and also machines with information through digital networks is unbroken.

The new book *Introduction to Digital Communications* is aiming at graduate students, scientists, and engineers, who are interested in getting an introduction to modern digital communications. The main focus is on the fundamentals of the physical layer from the perspective of the theory of linear time-invariant as well as time-variant systems. The book draws a bow from single input single output to multiple input multiple output systems with an emphasis on wireless transmission over time-variant channels. The main concern lies in an accurate mathematical description, wherein the findings and lemmas are proven in detail. Various chapters are enriched by numerical examples and also illustrated with results from computer simulations provided by the open platform "webdemo" of the Institute of Telecommunications at the University of Stuttgart, http://www.inue.uni-stuttgart.de.

Organization of the Book

The book covers three main parts and the fourth part with two Appendices.

Part I

It deals with the principles of digital transmission, which are important for wire-line as well as wireless communications. It describes the main building blocks for single input single output (SISO) systems. The concept of quadrature amplitude modulation is introduced. An important part is the design of the overall system for

minimal intersymbol interference with Nyquist's first criterion. The introduction of the equivalent baseband system allows the concise definition of the link between the transmitter input and the receiver output as a "black box" without details of the modulation, the spectral signal shaping, and the channel. For the receive signal, several detection methods are described in detail, such as threshold decision, maximum likelihood, and maximum a posterior detection. Also, the difference between symbol-by-symbol and sequence detection is addressed, and the maximum likelihood sequence estimator is described as an example. With an adequate model of the noise at the receiver, the symbol error probability is calculated.

The following chapters in Part I are devoted to the wireless transmission. The main difference is the wireless channel, which changes its characteristic with time. Therefore, the theory of linear time-variant systems is introduced to describe the building blocks of the system with time-variant impulse responses and delay spread functions. As not all students and engineers are frequently involved with this topic, the book contains an own Part II devoted to the theory of linear time-variant systems. Selected points are briefly reported for Part I; hence, the reader is not required to study Part II beforehand. However, for a deeper understanding, the reader should get involved in Part II. The introduction of the equivalent baseband system, which is then time-variant, follows. With this model, the increase of the output signal bandwidth at the receiver compared to the transmit signal is shown as an example. The multipath channel model is described in detail. As the wireless transmission link is multifaceted, a statistical characterization of the channel is helpful. To this end, various channel models are reviewed, such as the Rayleigh and Nakagami-*m* fading as well as the model according to Clarke and Jakes.

Part II

It is devoted to the theory of linear time-variant systems. In many cases, this topic is just touched upon during the education of graduate students in Electrical Engineering and Computer Science. Therefore, this dedicated Part II is provided. The input–output relation given by the time-variant convolution is addressed in detail and the mathematical properties are derived. We outline the relation with the well-known (time-invariant) convolution used by engineers in most applications. The time-variant impulse response and the delay spread function turn out to be the proper system descriptions in the time domain. Also, the system functions in the frequency domain are presented, such as the time-variant transfer function and the Doppler spread function. For the statistical description of randomly changing time-variant systems, autocorrelation functions as well as power spectral densities of the system functions are studied.

Part III

It deals with multiple input multiple output (MIMO) systems. First, the input–output relation is derived using matrix notation. We discuss the principle MIMO channel models, such as the time-variant finite impulse response and the i.i.d. Gaussian model. Furthermore, spatial correlations at the transmitter and the receiver are incorporated leading to the Kronecker model. Linear and nonlinear MIMO receivers are investigated in detail, such as the zero-forcing, the minimum mean squared error, and the maximum likelihood receiver. An important question is how many bits per channel use can be transmitted over an MMO channel. This issue is studied together with the maximization of the channel capacity. Next, the principles of spatial prefiltering and space-time encoding are investigated to improve transmission quality and to increase the data rate. In the last chapter, we leave the single-user transmission and consider the MIMO principle for a multitude of users in a network. Various multi-user MIMO schemes for the uplink and downlink are discussed, which can reduce the interference when the users transmit their signals in the same time slots and frequency bands.

Part IV

In **Appendix A**, a summary of the characterization of random variables and stochastic processes is given.

Appendix B provides an overview on the most important lemmas of linear algebra required for the understanding of some topics of this book.

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Stuttgart, Germany Prof. Dr.-Ing. Joachim Speidel

Actual notes can be found at:
http://www.inue.uni-stuttgart.de/institut/mitarbeiter/joachim_speidel_01.en.html

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About the Author

Joachim Speidel earned his Dipl.-Ing. (M.Sc.) in Electrical Engineering with a major in telecommunications theory from the University of Stuttgart in 1974 followed by a Dr.-Ing. degree (Ph.D.) in 1980 in the field of signal processing and system theory. From 1980 to 1992, he worked in various R&D positions for Philips in the broad field of video and data transmission. Among others, he and his team contributed significantly to algorithms and standards for video data compression and transmission. In 1992, he became a Professor at the Faculty of Computer Science, Electrical Engineering and Information Technology at the University of Stuttgart and was appointed Director of the Institute of Telecommunications. His research area includes telecommunications in wireless, fixed, electrical, and optical networks with a focus on encoding, modulation, detection, and MIMO systems. Since 2017, he is a Professor Emeritus. Through his numerous publications and patents, Prof. Speidel has made extensive contributions in the advancement of the field of telecommunications, the success of its products, and international standards. He is a member of various national and international organizations and advisory and review boards.