CODED MODULATION SYSTEMS

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John B. Anderson and Arne Svensson

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CODED MODULATION SYSTEMS

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To Janet, Kate and Alix

—jba

To my parents Nannie and Bertil; to Gun-Britt and Arvid

—as

Preface

Twenty-five years have passed since the first flowering of coded modulation, and sixteen since the book *Digital Phase Modulation* appeared. That book, the first of its kind and the antecedent of this one, focused mainly on phase coded modulation, although it did contain a few sections on what became known as TCM coding, and a whole chapter on Shannon theory topics. No one 25 years ago imagined how the field would grow. The driving force from the beginning can be said to be more efficient codes. At first, this meant codes that worked more directly with what the physical channel has to offer – phases, amplitudes, and the like. Rather quickly, it meant as well bandwidth-efficient coding, that is, codes that worked with little bandwidth or at least did not expand bandwidth.

Today we have much more complete ideas about how to code with physical channels. An array of techniques are available that are attuned to different physical realities and to varying availabilities of bandwidth and energy. The largest subfield is no longer phase coded modulation, but is codes for channels whose outputs can be directly seen as vectors in a Euclidean space. The ordinary example is the in-phase and quadrature carrier modulation channel; the Killer Application that arose is the telephone line modem. In addition, new ideas are entering coded modulation. A major one is that filtering and intersymbol interference are forms of channel coding, intentional in the first case and perhaps not so in the second. Other ideas, such as Euclidean-space lattice coding, predate coded modulation, but have now become successfully integrated. One such old idea is that of coding with real-number components in Euclidean space in the first place. Traditional parity-check coding was launched by Shannon's 1948 paper "A Mathematical Theory of Communication". Just as with parity-check coding, Shannon definitively launched the Euclidean concept, this time with his 1949 Gaussian channel paper "Communication in the Presence of Noise". As in 1948, Shannon's interest was in a probabilistic theory, and he specified no concrete codes. These arrived with the subject we call coded modulation.

This book surveys the main ideas of coded modulation as they have arisen in three large subfields, continuous-phase modulation (CPM) coding, set-partition and lattice coding (here unified under the title TCM), and filtering/intersymbol interference problems (under partial response signaling, or PRS). The core of this book comprises Chapters 4–6. Chapters 2 and 3 review modulation and traditional coding theory, respectively. They appear in order that the book be self-contained.

They are a complete review, but at the same time they focus on topics, such as quadrature amplitude modulation, discrete-time modeling of signals, trellis decoders, and Gaussian channel capacity, that lie at the heart of coded modulation. Many readers may thus choose to read them. The last two chapters of the book are devoted to properties, designs and performance on fading channels, areas that recently have become more important with the explosion of mobile radio communication.

The book is not a compendium of recent research results. It is intended to explain the basics, with exercises and a measured pace. It is our feeling that coded modulation is now a mature subject and no longer a collection of recent results, and it is time to think about how it can best be explained. By emphasizing pedagogy and underlying concepts, we have had to leave out much that is new and exciting. We feel some embarrassment at giving short shrift to such important topics as iterative decoding, concatenations with traditional coding, block coded modulation, multilevel coding, coding for optical channels, and new Shannon theory. One can name many more. Our long range plan is to prepare a second volume devoted to special topics, in which all these can play a role, and where the issues related to fading channels can be expanded and covered in more detail. Some recent advances in the PRS, CDMA, and ARQ fields were needed to give a complete picture of these fields and these do find inclusion.

In writing this book we have attempted to give an idea of the historical development of the subject. Many early contributors are now passing from the scene and there is a need to register this history. However, we have certainly not done a complete job as historians and we apologize to the many contributors who we have not referenced by name. The priority in the references cited in the text is first to establish the history and second to give the reader a good source of further information. Recent developments take third priority.

The book is designed for textbook use in a beginning graduate course of about 30 lecture hours, with somewhat more than this if significant time is spent on modulation and traditional coding. At Lund University, a quarter of the time is spent on each of introduction/review, TCM, CPM, and PRS coding. Full homework exercises are provided for the core Chapters 2–6. The prerequisites for such a course are simply good undergraduate courses in probability theory and communication engineering. Students without digital communication, coding and information theory will need to spend more time in Chapters 2 and 3 and perhaps study some of the reference books listed there. The book can be used as a text for a full course in coding by augmenting the coding coverage in Chapter 3.

It is a pleasure to acknowledge some special organizations and individuals. A critical role was played by L. M. Ericsson Company through its sponsorship of the Ericsson Chair in Digital Communication at Lund University. Without the time made available by this Chair to one of us (JBA), the book could not have been finished on time. Carl-Erik Sundberg, one of the pioneers of coded modulation, was to have been a co-author of the book, but had to withdraw because of other commitments. We acknowledge years – in fact decades – of discussions with him. Rolf Johannesson and Kamil Zigangirov of Lund University were a daily source of advice on coding and Shannon theory, Göran Lindell of Lund University on digital modulation, and Erik Ström and Tony Ottosson of Chalmers University of Technology on channel coding, modulation, fading channels, spread spectrum, and CDMA. Colleagues of past and current years whose work plays an important role in these pages are Nambirajan Seshadri, Amir Said, Andrew Macdonald, Kumar and Krishna Balachandran, Ann-Louise Johansson, Pål Frenger, Pål Orten, and Sorour Falahati. We are indebted to many other former and current coworkers and students. The dedicated assistance of our respective departments, Information Technology in Lund and Signals and Systems at Chalmers, stretched over 7 years. We especially acknowledge the administrative assistance of Laila Lembke and Lena Månsson at home and our editors Ana Bozicevic, Tom Cohn, and Lucien Marchand at Plenum. The graduate students of Information Technology and the undergraduate students in Wireless Communications at Chalmers were the *försökskaniner* who first used the book in the classroom. All who read these pages benefit from their suggestions, corrections, and homework solutions.

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