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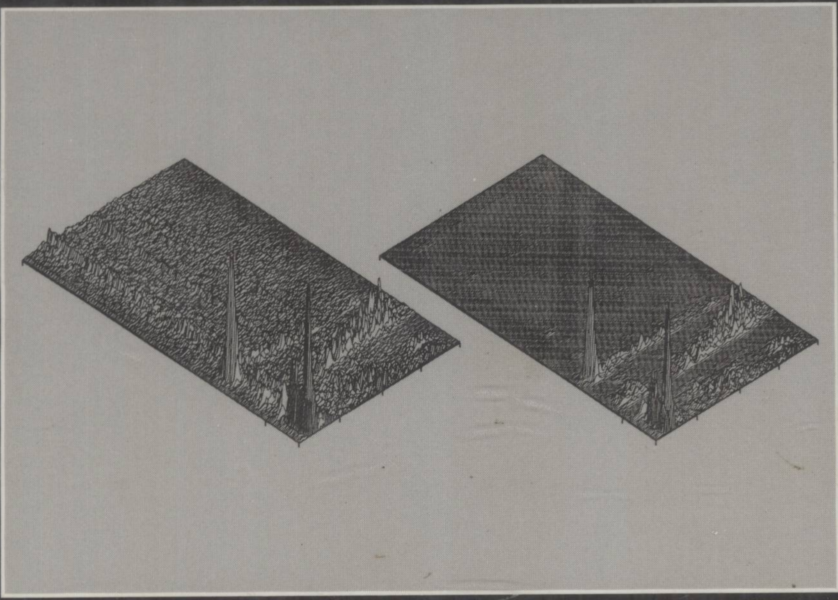

Digital Signal Processing in Telecommunications

Edited by

F.A. Westall and S.F.A. Ip

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DIGITAL SIGNAL PROCESSING IN TELECOMMUNICATIONS

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DIGITAL SIGNAL PROCESSING IN TELECOMMUNICATIONS

BT Telecommunications Series

The BT Telecommunications Series covers the broad spectrum of telecommunications technology. Volumes are the result of research and development carried out, or funded by, BT, and represent the latest advances in the field.

The series includes volumes on underlying technologies as well as telecommunications. These books will be essential reading for those in research and development in telecommunications, in electronics and in computer science.

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   Edited by F A Westall and S F A Ip
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Preface

This book is dedicated to the subject of digital signal processing (DSP) in telecommunications. As the term 'DSP' means different things to different people, the chapters have been carefully selected to give the reader a broad perspective of the subject. The book is intended to provide an insight into the DSP technologies and techniques that are regularly deployed at BT Laboratories to solve practical telecommunications problems.

At the start of the information age, information was transmitted from place to place on telecommunications networks and received directly by another human being. As the age progressed it became possible to store information and effectively reduce the requirement for the sender and recipient to be simultaneously available. At the current time it is becoming increasingly possible to process the information before or after storage to detect, sense, extract, transform or convert information into a form more suitable for humans to comprehend or even to reduce the need for human interaction in some cases. It is at this human/machine interface where the real world phenomena of information as a stream of continuous analogue signals meets the discrete, discontinuous world of digital technology. It is here that the role of digital signal processing and the related specialised DSP devices provides the vital link between the two worlds.

DSP is a rich subject, and to do it justice would require much more space than is available here, though most chapters provide tutorial material to help those unfamiliar with the subject. In attempting to keep the mathematics to a manageable level, some of the elegance and rigour has been lost. For this the editors apologise in advance, though the ample references associated with each chapter should satisfy all but the most insatiable of academic appetites.

BT Laboratories have made notable contributions in the development and application of digital signal processing — from early work on PCM systems and C J Hughes' work on the conception of microprocessor structures in the 1960s through to work in the 1970s leading to a variety of practical fixed and adaptive filtering devices and to commercial systems for deployment in data transmission and switching applications. However, it was the advent of low-cost programmable DSP devices during the 1980s that allowed a wide range of practical and cost-effective systems to emerge from laboratories such as ours. After a decade of practical experience using DSP devices, the time is ripe for a retrospective review and a glimpse into the exciting future of this key technology.

This book brings together the work of many of the DSP practitioners based at BT Laboratories and concentrates on applications developed over the last three to four years. The introductory chapter provides a broad overview to set the scene and to put the subject into context. The second chapter addresses the important topic of fixed digital filtering and presents some new ideas as illustrations. Two tutorial chapters then cover adaptive filtering — a major component in the ubiquitous application of DSP technology within speech-band (3 kHz) systems. There then follow several chapters describing representative telecommunications applications in some detail — high-speed digital subscriber-loop systems, data transmission including PSTN modems and channel coding, speech coding, network emulation and noise suppression applications. In order to place the speech applications even more clearly in context, a further chapter provides a background to the speech production and perception processes that underpin the key speech applications. To round off the broad coverage of DSP applications, further developments of considerable potential are covered in two chapters on video coding and adaptive neural processing.

As DSP devices grow in complexity, so does the need for design methods and associated tools, to allow the dramatic potential of this technology to be economically unleashed. Recent advances in computer-aided development tools and environments to support DSP system design are described in one chapter, while several authors describe different aspects of the development process relevant to their particular applications, a good example being that of the DSP development method and tool employed for the Skyphone speech codec. Further advances in this area are anticipated, which will slow the growth of software costs and open up important new possibilities for DSP technology.

The last chapter illustrates the impact of DSP in the varied fields of network modelling and channel monitoring. These embryonic subjects will be among the main beneficiaries of progress in leading-edge DSP technology, illustrating the extent to which traditional boundaries between telecommunications and computing are blurring.

It can now truly be claimed that DSP has come of age. The authors hope that this snap-shot of the broad range of telecommunications applications for DSP has effectively communicated the excitement of working in this dynamic and rapidly expanding field.

Last, but not least, a considerable amount of effort goes into the production of a book like this, and the editors would like especially to thank all the authors and reviewers, too numerous to mention by name, for their dedication, skill and hard work. Additionally, one of us (FAW) has had the

good fortune to have been associated with many of the DSP practitioners at the laboratories at some stage over the formative last two decades. To all of you, mentors and managers alike, thank you for your support.

F A Westall
S F A Ip

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DIGITAL SIGNAL PROCESSING IN TELECOMMUNICATIONS

F A Westall and S F A Ip

1.1 INTRODUCTION

Over the last decade digital signal processing (DSP) has emerged as a key enabling technology in telecommunications. In this short period it has moved from being a research curiosity into use in a broad spectrum of practical applications within both public and private networks. It has heralded a resurgence of interest in signal processing, and could provide a key to the long-awaited convergence of telecommunications and computing [1]. It is therefore timely to review progress on DSP and it is to this end that this book is directed.

The term DSP means different things to different people. To many it is synonymous with a class of exceptionally fast microcomputers targeted at real time signal processing; whilst to others it relates to the algorithms or mathematical processes that accomplish the desired signal transformation.

There are other viewpoints too. A development engineer may be less concerned with the best attainable theoretical performance, than with achieving the specified goals within cost, timescale and marketing constraints. The concern will be with issues of documentation, testability, manufacturability and product support, whilst at the same time trying to build in future-proof safeguards against advances in technology, loss of key staff, or customers' changing requirements.

Signal processing, as with other engineering disciplines, requires an accurate assessment and balancing of these often conflicting viewpoints to ultimately achieve success in the market-place. In order to appreciate the impact of DSP, it is necessary to be aware of the environment in which it operates (Fig. 1.1) and to consider the subject from the different viewpoints indicated above. It is this breadth of treatment that makes this book timely.

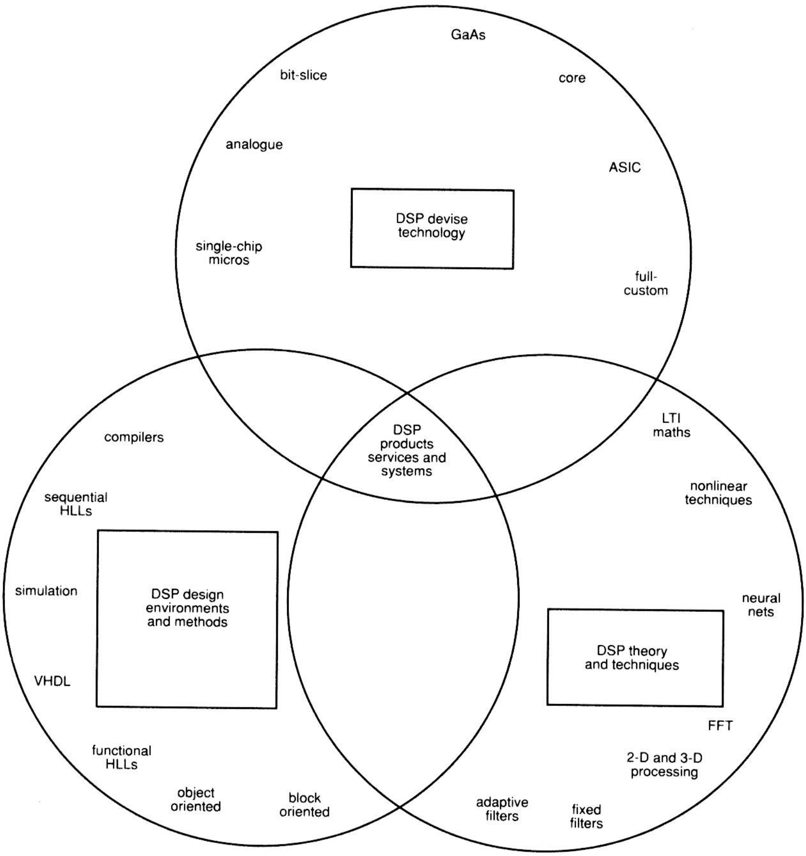

Fig. 1.1 Digital signal processing environment.

Although digital techniques have been pre-eminent in recent years, signal processing itself is not a new subject. Telegraphic transmission, now over 150 years old, was the forerunner of modern high-speed adaptive modems; early voice coders (such as Dudley's voice operation demonstrator — VODER) date back to the late 1930s and Von Kempelen made a voice synthesizer as early as 1791 [2]. The mathematics on which many current

DSP systems are based were established over 20 years ago, such as with the work of Widrow on adaptive filtering in the early 1960s [3].

However, it was the advent of the single-chip digital signal processing microcomputer in the late 1970s that helped to convert research into practical, cost-effective systems and has resulted in the upsurge of interest in new telecommunications applications.

Although impressive progress has been made over the last decade in silicon technology, engineers are still presented with some special problems when implementing DSP systems. Real time constraints and other hardware limitations all conspire to limit the performance that can be achieved in practice. The designer often has to work with fuzzy specifications, as with a speech codec, where the aim might be to achieve the best 'subjective' performance. Although some computer-based support tools are available to help, these generally still lack the necessary integration to ensure that designs are consistent and supportable, whilst at the same time achieving the real time requirements.

Despite these reservations DSP is now firmly established as a key technology, with many current applications giving a taste of the potential power of this technology for the future.

This chapter provides a broad overview of the subject. A review is given of the key technologies that underpin the field, followed by a snap-shot of current DSP-related activities at BT Laboratories. To conclude, some predictions are made on future trends and applications.

1.2 WHAT IS DSP?

1.2.1 A DSP system

A typical DSP system is shown in Fig. 1.2. The input signal can take a variety of forms. For example, it could represent a speech signal from a microphone, or be a modulated data signal from a telephone line. It could be a video signal from a camera to be encoded for transmission over a digital link, or to be stored on a computer.

The input signal is band-limited and sampled prior to conversion into an encoded bit stream using the analogue-to-digital converter. If information is not to be lost, then the sampling rate (f_s) should be at least twice the highest frequency of the input band-limited signal.

The digital signal processing device acts on the digitized input, sample-by-sample, and modifies the data in some way, such as via a sequence of multiplier-accumulator (MAC) operations. This processing of data is the key to DSP and is quite different from, for example, switching systems, where

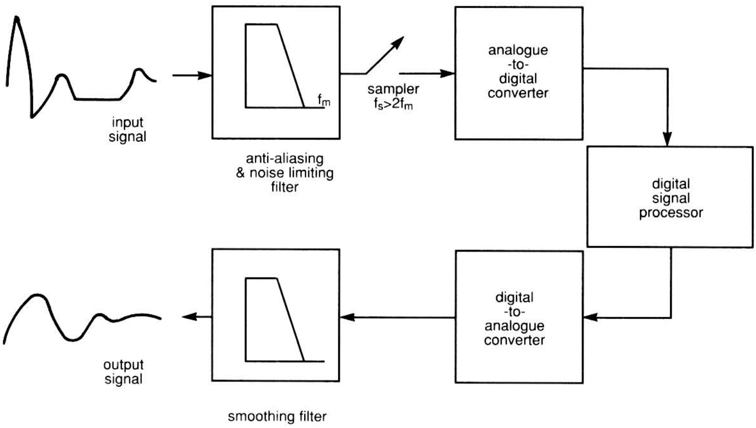

Fig. 1.2 Digital signal processing system.

the processor provides routeing only and does not substantially modify the data *en route*. The run-time constraints are therefore quite different, although both are often referred to as 'real time systems'.

Finally, after processing, the digitized samples are converted back to analogue values, and a subsequent filter provides interpolation, or smoothing, back to a continuous waveform.

It should be noted that this model, whilst being typical of many cases, is by no means universal. Speech recognizers, for example, do not produce continuous waveforms at the output, rather they produce decisions on which of a group of possible utterances the input speech most resembles. Sometimes the input signals are already in discrete form, as from a compact disc, thereby obviating the need for an analogue-to-digital converter.

1.2.2 DSP versus analogue — pros and cons

DSP has been one of the major beneficiaries of the dramatic reductions in cost, size and power consumption of silicon technologies in recent years. DSP systems are also compatible with other modern digital technologies such as transmission and switching networks, and computers. Interfacing to such systems is therefore much simpler than with analogue technology of equivalent functionality. Other advantages are:

- programmability — this gives the designer the flexibility to modify or upgrade the program late in the development, perhaps even in the cold light of field-trial experience;

- stability with time — digital signal processing does not drift or age with time;
- good accuracy, with excellent definability and repeatability — this extends the range of signal processing tasks that can be implemented reliably, and reduces manufacturing and testing costs.

On the other hand, for simple signal processing tasks, such as telephones interfacing to analogue exchange lines, the extra cost of DSP may be unacceptable. Furthermore, the high clock speeds associated with DSP devices can present problems with crosstalk and electromagnetic radiation. Such systems also tend to be more power-hungry than equivalent analogue systems. Other factors that may be grouped into the 'con' category include:

- rapid rate of technological change — there is often a steep learning curve associated with the introduction of each new family or generation of technology leading to 'family inertia' — a tendency to stick with one device manufacturer to minimize re-learning costs;
- more mathematical knowledge needed — DSP is a rich subject with solid mathematical foundations and, as there are often a variety of alternatives for progressing towards a performance target, some mathematical knowledge is required to reduce the bewildering choice of algorithms on which to concentrate for more detailed consideration;
- poor development and debug tools — although improving, current design tools lack the sophistication, integration and usability to allow the designer to exploit the full potential of the device technology.

Now that a basic DSP system has been defined, the means available for implementing the processing function in Fig. 1.2 are reviewed, starting with the most popular programmable technologies.

1.3 PROGRAMMABLE DSP DEVICES

1.3.1 Historical background

A major milestone for DSP came in 1979 with the announcement of the first commercial programmable device from Intel, the 2920. This device contained on-board analogue converters, but was limited in not containing a single-cycle multiplier. The credit for the first 'true' single-chip DSP microprocessor