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the M68000 family

Volume 1

Architecture, Addressing Modes, and Instruction Set

MOTOROLA

Series in Solid-State Electronics

The M68000 Family
Volume 1

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Architecture, Addressing Modes and Instruction Set

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Preface to the English Edition

The original German edition of this book that first appeared in 1984 has been a major success on the German market, primarily

- as an official training manual in many courses on microcomputers by many professional and public schools,
- as a reference work for designers and developers of both hardware and software for the M68000 family, and
- as an introduction to microprocessors in general and the M68000 family in particular for many enthusiasts.

In particular, it consolidates a large amount of relevant information from a variety of both English and German sources into one book that is convenient for the reader to use. This success led to the decision to publish an English edition of the book.

Several additions and changes have been incorporated into this new English edition. Due to the later release, all information has been updated to include new support devices and microprocessors (such as the 68030 microprocessor). The literature on the M68000 family comes from a variety of sources and points-of-view, with the result that there are many apparent logical inconsistencies in the information. We have therefore made a major effort to resolve these apparent inconsistencies in one single consistent treatment of the subject. Examples include such simple problems as how to count the number of instructions and addressing modes for each microprocessor in the family.

Realizing that many readers of this new edition will be beginners in the field of computers, we have included a more complete history of computers that tries to show why the M68000 family was designed the way it was–in its historical context. The emphasis of Chapter 2 was changed, from a presentation on the architecture of the 68000 microprocessor to a presentation on the architecture of all M68000 microprocessors with emphasis upon the 68000 microprocessor as an example. Therefore, specific differences between the 68000, 68008, 68010, 68012, 68020, and 68030 microprocessors are at least mentioned as the general architecture is described in Chapter 2. These differences are explained in more detail in Chapter 8 where the later processors are presented separately. The description of the additional addressing modes for the 68020 and 68030 microprocessors has been expanded and brought forward from Chapter 8 to the last section of Chapter 3 on addressing modes in general. Likewise, the additional instructions and changed instructions for the 68010 and 68012 microprocessors have been brought forward from Chapter 8 and integrated in alphabetical order in Chapter 4. However, the additional instructions for the 68020 and 68030 microprocessors have only been presented separately in summary form as the last section of Chapter 4. They are presented in more detail in Chapter 8.

Our special thanks to Jack L. Davies for his excellent translation and supportive ideas in issuing this book.

Munich, West Germany

W. Hilf, A. Nausch

Preface to the Second German Edition

This book is intended for use both as an introduction to the M68000 family and as a reference work. The authors have attempted to present complex information explicitly in detail. This is one of the main reasons why this book had to be divided into two volumes shortly before it was first published in 1984. Fortunately, a separation was possible that is convenient for the reader.

In Volume I, the fundamentals are presented and the architecture for both hardware and software is presented more or less theoretically. You will find a brief historical background and second sources in Chapter 1. Fundamentals for a microcoded CPU and the pin layouts for the 68000 microprocessore are given in detail in Chapter 2. Important concepts and definitions that you will encounter in both volumes are also presented in Chapter 2. The addressing modes are presented in detail in Chapter 3 and the individual instructions are presented in detail with numerous small examples in Chapter 4. The last chapter in this volume presents the different versions of the 68000 microprocessor at the mask level.

Volume II is particularly suitable for those readers who have already acquired some experience with the M68000 family. It has the subtitle of "Applications and the M68000 Devices". You will find supplementary information and practical hints for working with the 68000 microprocessor in it. The software aspects are covered in Chapter 6, with many examples of short programs in assembler with M68000 instructions. Chapter 7 covers the most important support devices in both the 8-bit M6800 and 16-bit M68000 families. Chapter 8 covers the new and future microprocessors in the M68000 family. A complete single-board computer system, including software monitor, is described in Chapter 9 and a more complete illustrative example. Since the VME bus should not be overlooked in any discussion of the M68000 family, it is described in Chapter 10.

Both volumes present additional information concerning the 68000 microprocessor, e.g. laying the foundations for new programming techniques, new operating systems, and support devices for the next generation within the M68000 family.

The authors are in the fortunate position to have been intimately involved with the M68000 family, as employees of the prime source, from the day when this family was first introduced to the market. In creating and presenting numerous training courses internationally, the authors were able to develop their own understanding of this information, as well as to experiment with techniques for explaining this information to typical users. This experience played an important role in developing the format for this book.

The reader should realize that the information in this book assumes some prior knowledge about microprocessors. As an example, the basic functions of a microprocessor are not explained in detail in this book. However, the reader will find a variety of other good books available for this type of introduction.

The authors wish to thank Motorola Inc. for the information and illustrations that they have made available to us for this purpose. We also wish to thank the companies Hitachi Europe, Rockwell International GmbH, and Valvo (Hamburg) for the information that they gave to us, particularly for Chapter 7 in Volume II.

In the second edition, a number of typographical errors were corrected and some of the formulations were improved. In particular, an extra subchapter, 2.4.4, was added to Chapter 2 in order to explain the differences between user and supervisor modes in more detail. The treatment of interrupts was expanded to include summaries. The "MC68000 16-bit Microprocessor Programming Reference Card" from Motorola, that is included separately with this book should be a welcome supplement for most readers. We thank Motorola Inc. for having provided the master copy for printing this card. The addition of an index in this edition emphasizes the role of this book as a training and reference work.

Munich, West Germany W. Hilf, A. Nausch

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General Background Information

1.1 Introduction

1.1.1 Definition of the "M68000 Family"

When Motorola introduced its 8-bit "M6800 family" in 1974, the 6800 was approximately the 20th 8-bit microprocessor released to the market–but it was the first microprocessor that was released as a family, together with various support devices. Since then, other manufacturers have adopted the same procedure of developing and releasing families rather than individual processors. In this context, it is not surprising that in 1979 Motorola also introduced its first 16-bit microprocessor, the 68000 microprocessor, as a member of a new family, called "the M68000 family".

The "M68000 family" has two dimensions or subfamilies:

- a subfamily of different microprocessors and
- a subfamily of different support devices.

In addition, the microprocessors of the M68000 family can also use the support devices from the related 8-bit M6800 family.

The subfamily of microprocessors is illustrated in Figure 1-1 below:

The subfamily of support devices contains the following categories of devices:

- peripheral-interface devices, including
- serial-interface devices
- parallel-interface devices
- data-communications devices
- floppy-disk controllers
- graphics controllers
- multi-function devices
- DMA devices
- memory-management units
- clocks and timers

As you can see from this listing, the availability of single devices for these complex functions can greatly simplify the task of an engineer in designing a new computer system around a new microprocessor. Otherwise, the engineer would have to design all of these circuits in detail himself, rather than to connect standard building blocks with predefined interfaces to the new microprocessor.

Since different terminolgy is used to describe the microprocessors and support devices of the M68000 family by

- Motorola (all device names begin with the prefix "MC", but the family is called the "M68000 family"),
- the second sources (all device names have the same number but different prefixes and suffixes), and
- the neutral literature (uses no prefixes),

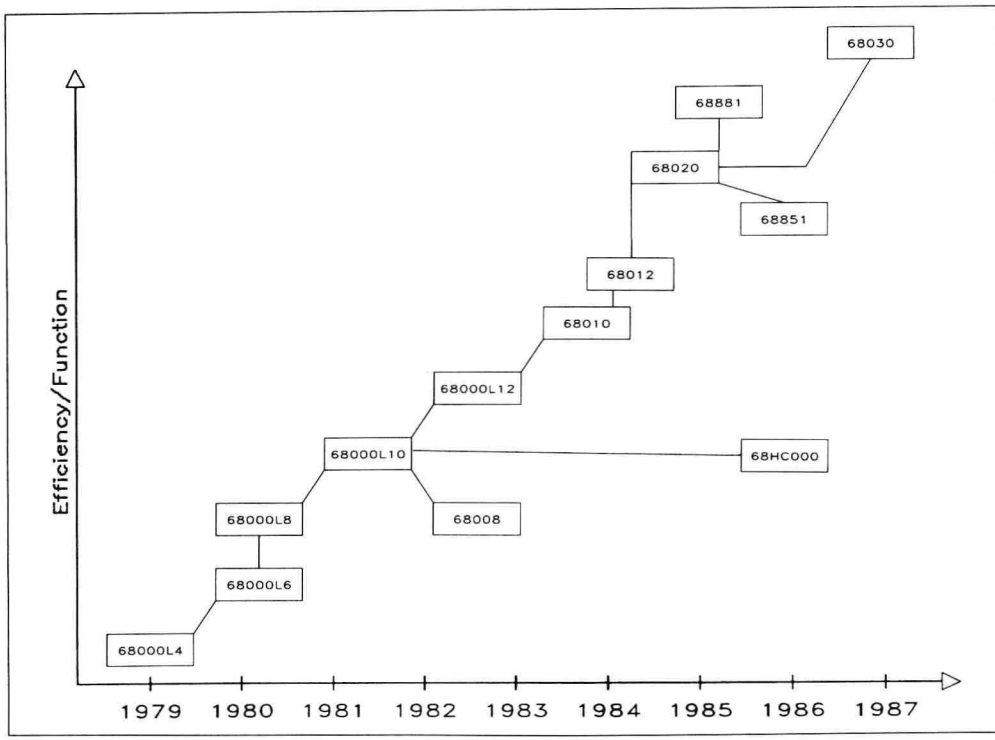

Figure 1-1: Microprocessors in the M68000 Family

we have established the following conventions for this book:
- "the M68000 family" refers to all microprocessors and support devices in the family,
- "an M68000 microprocessor" refers to any one of the several microprocessors in the M68000 family,
- "a 68000 microprocessor" refers to the single microprocessor with the Motorola designation of "MC68000",
- the names of individual support devices also have no prefix, and
- a "C" is sometimes used in a number or as a suffix for a device that is implemented in CMOS technology.

In addition, references to the literature that is listed in the bibliography are enclosed in square brackets, [ ]'s.

1.1.2 Who the Book is Designed for

This book is designed for both
- hardware engineers, who want to design the hardware for a simple or complex computer system that is based upon the M68000 family of microprocessors and support devices, and
- software engineers, who want to develop system software or specialized application software for use on computer systems that are based upon the M68000 family (at the level of an assembler language),

as well as
- owners or users of computer systems that are based upon the M68000 family, who have an interest in understanding more clearly how their computer systems and software work, and

- computer enthusiasts who are curious and want to know more about how microprocessors work and how the microprocessors in the M68000 family work as specific examples.

Therefore, the potential reader can be

- a beginner, with some basic knowledge of the binary number system and access to a computer system that is based upon the M68000 family (with an assembler for some simple experimentation) or
- an experienced professional who wants to study the details of how the M68000 family works or to use the book as a reference work (from one single consistent source).

This book, or subsets thereof, can be used as a part of a neutral course on microcomputers in general, hardware design with microprocessors, or software design with microprocessors. In this case, this book presents the M68000 family as one example and other books can be used to present other families in order to maintain neutrality.

The reader does not have to read this book from A to Z, but rather can select most any order for reading the individual chapters. Cross references are included in each chapter to sections of the same or other chapters that may be relevant for understanding a particular point. This enables a casual reader to read the book in most any order, to browse through the main points, and then to study particular points of interest in more detail. An expert with prior experience with the M68000 family can use the book as a reference work for more detailed information on most aspects from one single source.

Volume I presents a more general background, including:

- a general history of microprocessors, that shows the relationships between the M68000 microprocessors within this historical framework,
- an explanation of the architecture of the M68000 microprocessors, with particular emphasis upon the 68000 microprocessor as the first in this family,
- an explanation of the basic concepts that are necessary to understand how M68000 microprocessors work, such as registers, data formats, exceptions, interrupts, buses and timing for the 68000 microprocessor,
- an explanation of the addressing modes that are available within the M68000 family (extended for the 68020 and 68030 microprocessors), and
- a complete description of each instruction in the instruction sets for the 68000, 68008, 68010, and 68012 microprocessors (some additions for the 68010 and 68012) and a summary description of the instructions added for the 68020 and 68030 microprocessors.

Volume II presents more specific information, including:

- how to program M68000 microprocessors, with practical examples (based upon the instruction set of the 68000 and 68008 microprocessors – that is a subset of the instruction sets of the other microprocessors),
- a detailed description of all major support devices in the M68000 family,
- a detailed description of the differences of the 68008, 68010, 68010, 68020, and 68030 microprocessors to the first 68000 microprocessor (the emphasis is on the differences in this volume, whereas it was on the similarities in the first volume), and
- a detailed description of a single-board computer system, as a practical example, including a monitor program as system software.

1.2 History of the M68000 Family

Where does the history of the M68000 family begin? To be complete, we would have to start with the discovery of the number systems and ancient tools to aid in computations with numbers. Then, we would have to trace the development of mathematics and computers, as well as related technologies. However,

we must limit the presentation here to the more recent developments that have a more direct bearing upon explaining why the M68000 family has become what it is today.

1.2.1 General History of Computers

One way of classifying computers into different groups is by the criterion of the technology that they use for performing computational tasks. With this approach, there are four generations, as follows:

Generation 0: Mechanical and Electromechanical

Examples of mechanical computers include:
- the abacus
- the slide rule
- the Jacquard loom
- the analytical engine of Charles Babbage

Examples of electromechanical computers include:
- the Bush differential analyzer
- the Mark I computer (with relays)

Generation 1: Electronic Tubes

The ENIAC was the first of the "first-generation computers". It was developed by the US Army in order to meet the computational requirements for calculating ballistic trajectories during the second world war. It was followed by the EDVAC and EDSAC computers, with improved architectures. The first commercial computers were based upon the EDVAC and EDSAC computers.

Generation 2: Transistors

Seymour Cray pioneered in designing the first computer that used only transistors without any electronic tubes in 1960 at the Control Data Corporation (he later formed his own company). However, the basic architecture and design remained essentially the same. (It was difficult to combine transistors and electronic tubes in the same computers, since both the signal levels and the required power voltages are quite different.)

Generation 3: Integrated Circuits

Since integrated circuits are essentially several transistors on one crystal "chip", the transition from using transistors to integrated circuits was more gradual, whereby many computers were made using both transistors and integrated circuits during this transition.
It is semantically incorrect to speak of 4th and 5th generation computers in this sequence, since the so-called 4th and 5th generation computers are really only third-generation computers that differ from one another in other ways than their basic technology. Therefore, we are still in the middle of the third generation in this sequence defined by basic technology as the criterion. The true 4th and 5th generations, in this sequence, will use other technologies, such as optics, 3-dimensional integrated circuits or biological molecules.
IBM came close to developing the first 4th-generation computer in this sequence, based upon Josephson junctions as the basic technology. However, both IBM and its competitors encountered technical dif-