Amstrad CPC 464: Architecture of a Home Microcomputer

Iain Emslie University of Victoria
CSC 350 Computer Architecture
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iemslie@uvic.ca

Abstract

This paper will detail the architecture and system design of popular home computer the Amstrad CPC 464. Topics covered include the components of the system and an analysis of the underlying CPU architecture. Finally a comparison between the CPC and similar computers of the time.

1. Introduction

The CPC 464 was an 8-bit microcomputer that was popular in Europe during the 1980s. It was produced by Amstrad, a British company founded by entrepreneur Alan Michael Sugar. The company made its name selling low priced consumer stereos and televisions before moving into the home computer market with the introduction of the CPC 464, the first in a line of Amstrad computers. The primary competitors to the 464 were the Sinclair ZX Spectrum, Acorn BBC Micro and the Commodore 64. The philosophy behind the 464 was to produce a computer that would appeal to the average person at a price that was low enough to encourage impulse purchases.

The computer came bundled with everything needed, including a CRT monitor. The first version of the 464 was self-contained with a built-in keyboard, speaker and 3.5 mm headphone jack. One notable feature of the computer was a built-in tape drive which provided storage for games and other programs. There were connections on the back for a 9-pin Atari style joystick and an expansion port to which external peripherals such as disk drives could be attached.

The computer supported three basic screen modes and 27 different colours. The three screen modes were normal, multicolour and high resolution. Normal mode used 320x200 pixels and 4 addressable colours. The multicolour mode offered 16 colours but only a 160x200 resolution while the high resolution mode offered 640x200 pixels but only 2 colours.

The computer used a custom operating system named AMSDOS and a dialect of BASIC named Locomotive BASIC with an interpreter through which the user could provide commands to the machine.

2. Architecture Overview

The CPC 464 used a Zilog Z80A as its CPU which had an upgraded clock rate of 4Mhz from the standard Z80 at 2.5Mhz. It was equipped with 64K of RAM. Sound was implemented using a General Instruments AY-3-8912 chip which interfaced with the tape drive to allow for reading and writing of cassette tapes. The joystick port was implemented using a port on the sound chip. The CRT monitor was interfaced with the computer through the use of an Hitachi HD6854R CRT controller chip and the 20RA043 gate array.

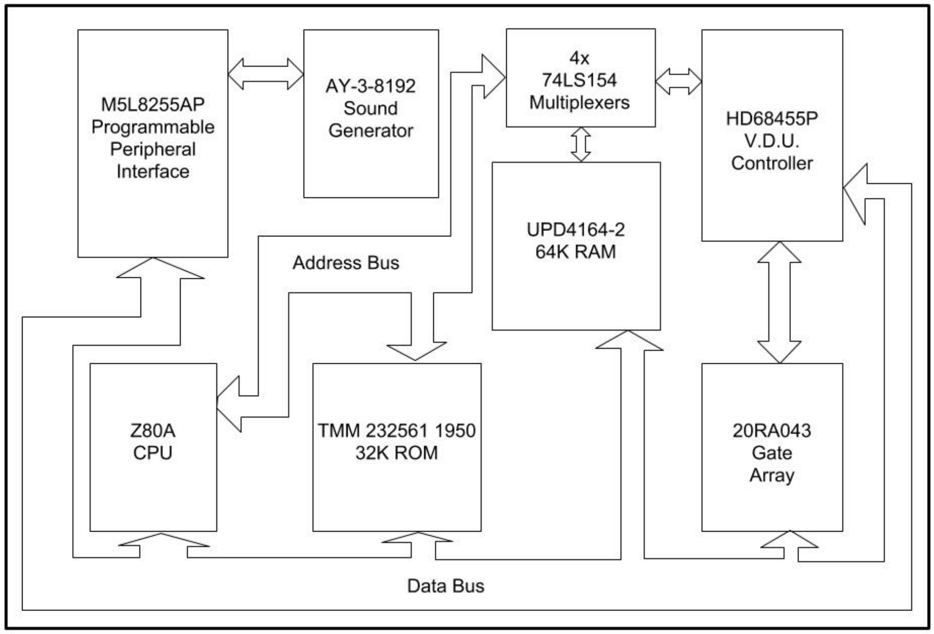
Table 1.1 below shows the most crucial components of the 464. The following sections will outline the basic architecture and design of the system and detail the chips noted in the table and Figure 2.1.

Table 2.1 - The Main Components of the Computer

CPU	4 Mhz 8-bit Zilog Z80
RAM	8192 Word x 8-bit NEC UPD4164-2 NMOS XRAM
ROM	256K Bit 32K Word x 8-bit Toshiba MOS TMM23261
Audio	General Instruments AY-3-8912 Programmable Sound Generator
Video	Hitachi HD68455P VDU Controller 20RA043 Gate Array
Input/Output	Mitsubishi M5L8255AP

The Z80 interacts with these components through the use of the busses. The address bus is used for 16-bit addressing. While the data bus is used to send and receive data.

Figure 2.1 - A simplified diagram of the layout of the main components



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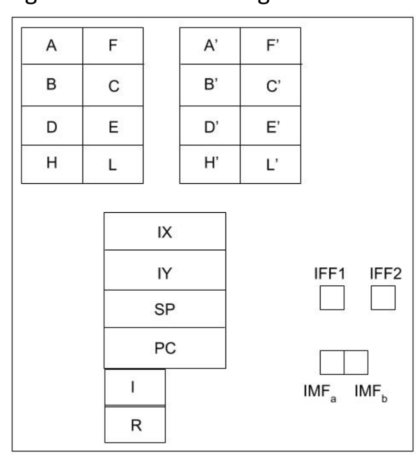
2.1 The Z80 Processor

The Z80 is an 8-bit processor introduced in 1976 by Zilog. The chip was part of the second generation of microcomputers and was designed to be compatible with software written for other processors; principally the Intel 8080. This was achieved by making the instruction set of the 8080 a subset of the instruction set of the Z80. As a result of this decision, the registers of the Z80 were designed to be compatible with the 8080 instruction set.

The registers of the Z80 include an accumulator and flag register noted in Figure 2.2 as A, and F. The accumulator stores the result of all 8-bit arithmetic and logical operations. The 8-bit flag register stores bits based on the result of values in the accumulator including overflow, zero, and carry bit and whether or not interrupts are enabled. Registers B, C, D, E, H and L serve as general purpose registers. They can be used as individual 8-bit registers or used as 16-bit pairs. The Z80 includes a second set of alternate A' through L' registers with identical functions to the primary registers. These can be swapped out for fast service of interrupt routines or used as an additional group of general purpose registers. The IX and IY are 16-bit registers used to address memory and provide for simplified use of tables and other data structures. The SP is used as the stack pointer. The PC is the program counter. The I register served as the lower 8-bits of an interrupt vector address when the CPU is in its second interrupt mode. The IMF registers are 1-bit registers used to determine these interrupt modes. Finally, the IFF registers are 1-bit registers to enable or disable interrupts.

Figure 2.2 - Z80 CPU Registers



[2]

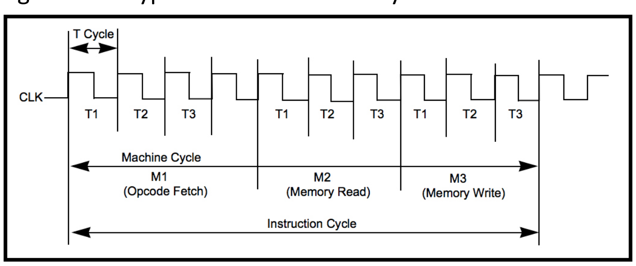
The ISA of the Z80 features 158 instructions with 78 of these being an identical subset to that of the 8080. The instructions have a range from 1-bytes to 4-bytes and have variable length in terms of clock cycle execution. They fall into the following 8 categories.

1. Load and Exchange
2. Arithmetic and Logical

3. Block Transfer and Search
4. Rotate and Shift
5. Bit Manipulation
6. Jump, Call and Return
7. Input and Output
8. CPU Control [3]

The Z80 executes instructions by stepping through a set of basic operations. These are outlined in Fig. 2.3 as; opcode fetch, memory read and memory write. Individual instructions will have a different series of these instructions depending on their purpose The machine cycles vary in length according to the instruction being executed from two up to six clock periods. These machine instructions can be lengthened using wait states to synchronize the CPU to external devices and memory access. All instruction cycles consist of a first opcode fetch machine cycle. The subsequent machine cycles depend on the operation being performed. Falling and rising clock cycle edges are used to synchronize control operations within instructions. Today, the Z80 is considered to have a CISC instruction set architecture. Since it was released in 1976 It does not follow many of the ideas later outlined by Patterson et. al to reduce complexity. [4] For example, it was designed to have a larger and more complex instruction set than the existing 8080 chip. The variable length machine cycles would make full pipelining next to impossible.

Figure 2.3 - Typical Z80 Instruction Cycle



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2.2 The Sound Generator

The AY-3-8912 includes a general purpose 8-bit input/output port which is used as a joystick interface. The three analog pins A,B and C are used to generate three-channel sound which is output to the computer's built-in speaker and stereo jack. These 3 outputs are also used for writing audio signals to the cassette tape drive for the storage of program. The chip is controlled by the CPU through writing to 16 8-bit memory-mapped I/O registers. These are accessed by an 8-bit data port connected to the peripheral interface chip. The chip is comprised of basic blocks to generate and modify sounds these are; tone generators, a noise generator, mixers, amplitude, an envelope generator and digital-to-analog converters.[6]

2.3 The Programmable Peripheral Interface

The M5L8255AP-5 is used as an interface between the CPU, sound generator, external keyboard connector, audio output and the cassette tape port. In addition, it is connected to the vertical sync of the CRT monitor. It features 3 input/output ports and a bidirectional connection to the data bus. It has two address pins, A_1 and A_2 which are used to select which ports are used. [7]

2.4 The Gate Array

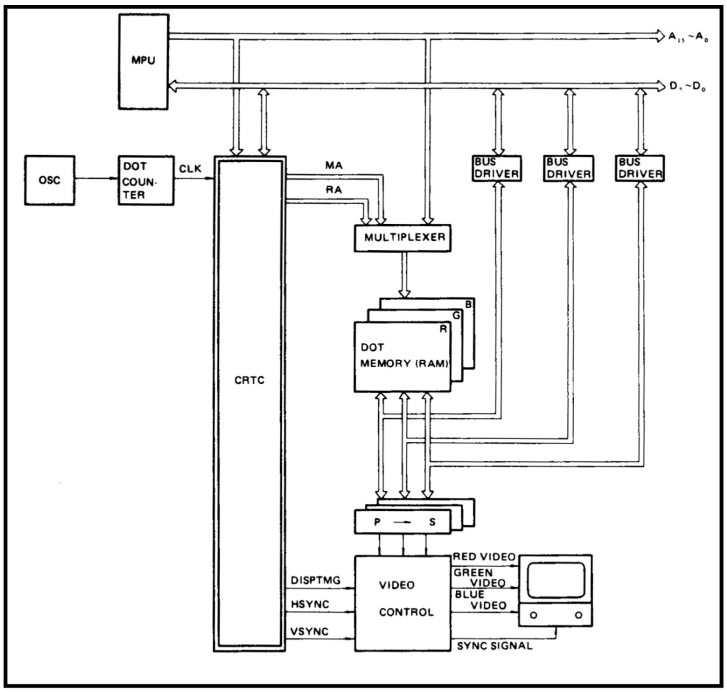
The gate array is a custom chip designed by Amstrad. There is little official documentation on it. It connects with the V.D.U. controller to control output to the CRT monitor. The chip connects directly to the 6-pin DIN video output connector. Three of these pins are the red, green and blue colour signals. The functions of the gate array are the following;

1. To generate all of the frequencies for the different components of the main board according to the signal provided by the clock.
2. To generate interrupts for the CPU
3. Switching between the different ROMS and RAMS
4. Generation of red, green, and blue video signals based on the information provided by the V.D.U controller
5. Switching of screen modes, colour palettes and resolution. [8]

2.5 The V.D.U Controller

The HD6845SP is responsible for interfacing between the computer and the CRT monitor. Its role is to generate timing signals for the scanline display and to send data to the gate array to be output to the screen. The horizontal and vertical sync signals are output to the gate array. The chip contains 16 8-bit registers which determine the control and operation of the monitor. Some of these registers include horizontal and vertical screen positioning and dimensions, and the position of the cursor. The chip is connected to the CPU by the data bus through which display data is sent. Figure 2.3 outlines a typical configuration for a full color CRT display using the HD6845SP. The 464 uses a setup almost identical to this with the gate array performing the role of "video control" in the image and the V.D.U controller being the "CRTC". The role of the multiplexed RAM is to periodically refresh the display on the screen. This is connected to 14-pins on the V.D.U chip which allows for 16K word addressing of screen data.

Figure 2.3 - Interface between the V.D.U controller, CRT and Gate Array [9]



3. Strengths and Weaknesses

The CPC 464 was designed as a low-cost home computer. The best way to analyze its success is to compare it to similar computers of the time. The closest competitor to the Amstrad was the Commodore 64 . Both were designed to be mass-market home computers that would appeal to video game players as well. It's notable that the Amstrad, which came out two years later than the Commodore, was sold at the same release price. A crucial difference is that the Amstrad was sold with a built in tape drive as well as a monitor which the Commodore buyer would have had to purchase in addition to the computer itself. The BBC Micro was intended to be sold as an educational computer for use in schools while the ZX Spectrum was the cheapest of the group and was marketed primarily to the computer game market. The following table outlines the release cost of some of the 464's primary competitors. Since the computer was built by a British company and sold primarily in Europe the prices listed are in pounds sterling

3.1 Price, Sales and Hardware Comparisons

Table 3.1 - Comparison between early 1980s home computers

Computer	Price at Release	Release Date	Units sold
Amstrad CPC 464	Green monitor: £199 Colour monitor: £299	April 12 1984	3 million (CPC range)
Commodore 64	£299	August 1982	12.5-17 million
Acorn BBC Micro	Model A: £235 Model B: £335	December 1 1981	1.5 million
Sinclair ZX Spectrum	16KB Ram: £129 48KB Ram: £175	April 23 1982	5 million

The most successful sales were by far by the Commodore 64. It was sold in the large American market as well as throughout the world. While the other three were all British made computers and sold primarily in Europe.

The following table outlines a basic comparison of the hardware between the 4 microcomputers. While it may seem that the Z80 had a much higher clock rate than the MOS CPUs, in reality the performance was not necessarily reflected by this. This is due the the difference in the instruction cycles between the two processor architectures.

Table 3.2 - Hardware comparison of 464 competitors

	Amstrad CPC 464	Commodore 64	BBC Micro	ZX Spectrum
CPU	Z80A 4Mhz	MOS 6510 0.985 MHz	MOS 6502 2 Mhz	Z80 3.5 MHz
RAM	64KB	64KB	Model A: 16 KB Model B: 32KB	16KB or 48 KB
ROM	32KB	20KB	32KB	16KB

3.2 Benchmark Comparisons

In 1985 N.J. Higham [10] translated two linear equation solving routines from the LINPACK library of Fortran benchmarks into interpreted Basic. These adapted routines, SGEFA and SGESL were then run on the Commodore 64, Amstrad CPC 464, BBC Micro, and the BBC Micro with a Z80 processor. Some of the benchmark results are provided here as a comparison of the computational power of these computers.

SGEFA performs LU decomposition of a matrix using a column oriented version of Gaussian elimination. SGESL then uses the factorization to solve linear equations of the form Ax = b. To make his programs more efficient, Higham translated Fortran Basic Linear Algebra Subprograms (BLAS) into assembly language on the Commodore and BBC Micro. Since this was not done for the CPC 464 these results will not be considered here. Column N indicates the number of linear systems solved. The blank entries in the table indicate values of N that were too large for the available memory.

Table 3.3 - SGEFA timings in seconds

N	CBM 64	CBM 64 Comal	BBC	BBC Z80	CPC 464
5	1.33	1.23	0.39	0.54	0.83
10	8.9	7.92	2.47	3.25	4.39
20	62.6	53.6	18.0	23.7	29.5
30	202	170	58.9	76.1	94.9
40	466	392	137	177	219
50	896	-	266	341	422
60	1535	-	458	584	722
70	2416	-	-	922	1140
80	-	-	-	1371	1694
90	-	-	-	1946	-

Table 3.4 - SGESL timings in seconds

N	CBM 64	CBM 64 Comal	BBC	BBC Z80	CPC 464
5	0.57	0.53	0.17	0.22	0.34
10	1.97	1.75	0.56	0.76	1.03
20	7.18	6.30	2.11	2.86	3.59
30	15.6	13.7	4.66	6.22	7.76
40	27.2	23.8	8.16	10.9	13.5
50	42.1	-	12.6	16.9	20.9
60	60.1	-	18.1	24.2	29.7
70	81.2	-	-	32.7	40.4
80	-	-	-	42.6	52.4
90	-	-	-	53.8	-

The Commodore 64 was tested using both its default BASIC as well as Comal, a separate programming language. In both the SGEFA and SGESL computations, the BBC Micro using the 6502 processor performs the fastest overall while the CPC 464 comes in third, behind the Z80 BBC Micro and ahead of the Commodore 64.

The following table outlines the relative performance compared to the 464. The CPU time is the sum of SGEFA and SGESL for N = 40, the final value of N for which each system can perform the calculations.

Table 3.5 - Performance Relative to CPC 464 for N=40

	CBM 64	CBM 64 Comal	BBC	BBC Z80	CPC 464
CPU Time	493.2	415.8	145.16	187.9	232.5
Relative Performance	0.4714	0.5592	1.6017	1.2374	1

The result indicates that the BBC Micro outperformed the 464 by around 60% with the standard 6502 chip and by almost 24% using the Z80. The 464 outperforms the Commodore 64 using Commodore Basic by approximately 53% and using Comal by about 44%. It's interesting to note that the BBC Micro outperforms the CPC 464 while using a similar 6502 processor to the Commodore's 6510. Although of course, the Micro is running at 2 Mhz compared to 0.985 Mhz. It's also important to note that the BBC using the Z80 was able to perform the highest number of N calculations at 90, followed by the CPC 464 at 80 and thirdly by the Commodore using standard BASIC.

4. Overall Analysis

The differences in the performance between the BBC Micro running using 2 MHz MOS 6502 and the CPC 464 running at 4 MHz using the Zilog Z80 are attributable in part to the difference in instructions sets and the hardware cycles between the two machines. The 6502 instruction set is made up of only 56 instructions compared to the 158 instructions of the Z80. The 6502 reads from and writes to memory in only one clock cycle and uses pipelining to allow for new instructions to be fetched while memory is being read in previous instructions. [11] The 464 however does perform adequately for its intended use as a general-purpose home computer and gaming machine. The 64 KB or memory was adequate for these purposes and the tape drive was an effective low cost means of data storage. The gate array and V.D.U. created full colour graphics. The sound generator doesn't enjoy the same nostalgia as the popular Commodore 64 SID chip today but provided adequate multi-channel sound for its time. The Locomotive BASIC interpreter allowed users to interact with the machine to create their own software. The use of the expansion port allowed for the addition of disk drives, modems, serial interfaces and teletext adapters. The Z80 processor allowed the use of the CP/M operating system in addition to AMSDOS.

5. Conclusion

The Amstrad CPC 464 was a fairly typical example of an early 80s home computer. It used the popular Z80 microprocessor as its CPU and was designed to be made cheaply using a collection of generic chips to perform its main operations. In terms of value for the consumer the 464 was very competitive with the Commodore. Both were sold at the same price but the Commodore buyer would have to purchase an additional monitor and storage drive while the Amstrad contained everything needed in one box. The BBC Micro was the most expensive machine when using 32 KB of ram. The ZX Spectrum was cheaper than but its awkward keyboard meant it was used more as a games machine than anything else. The BBC, Commodore and Amstrad machines were all usable for a wide variety of applications from text processing to music creation. In Higham's BASIC benchmarks the BBC Micro outperforms both the Commodore and the Amiga computers. The 464 does better than the Commodore on these benchmarks however. In terms of graphical capabilities the modes of the 464 are quite similar to those of the Commodore and BBC Micro and superior to the Spectrum. In summary the Amstrad CPC 464 was successful in Europe because it offered competitive performance and value for money in comparison to its main competitors the Commodore 64, BBC Micro and Sinclair ZX Spectrum.

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