

EVALUATION OF
OFF-THE-SHELF EQUIPMENT
MEETING THE
REQUIREMENTS SPECIFICATION
FOR THE
MODULE LEVEL CONTROLLER

FSI PROJECT NO. 3509
PHASE II

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Executive Summary
Phase II Project 3509
Module Level Controller

Phase II consisted of an attempt to match the requirements specification of Phase I with off-the-shelf equipment. A single board computer/controller system is not available to handle all of the requirements of a more than minimal system. Therefore, the phase II research concentrated on the evaluation of bus systems, processor families, interface boards, and software development facilities.

1 - The VMEbus is recommended as an internationally recognized standard bus which has many vendors supplying processor boards, interface boards, and memory boards which will meet most of the requirements specified. By choosing such a bus standard, the system designer can concentrate his efforts on designing the custom made interface boards which are not available. These include the pneumatic control boards and the self-test features that are desired.

2 - The Motorola 680X0 family is the recommended processor family to match both the high and low end requirements of the specification. The Intel 80X86 family is the alternative choice. Both families are well supported, internationally recognized, and good choices for the embedded controller. The major advantage of the Motorola 680X0 family is that the nine address registers and eight data registers allow smooth transitions between tasks in a multitasking system which is not available throughout the Intel family. The choice of the VMEbus also gravitates the choice to Motorola as the VMEbus is oriented toward the bus structure of the 680X0 family. Operating system kernels are available which run on the lowest as well as highest end processors.

3 - Interface cards are available from multiple vendors to handle the interface specifications if the VMEbus is chosen. A spreadsheet listing the vendors who have boards that would meet the requirements is included in the full report. The operating systems that are available are listed but without recommendations. Once the processor and bus specification is decided upon, the operating systems needs to be evaluated through system tests.

Introduction

Phase II of the single board computer project consisted of evaluating possible control systems which are available in the form of off-the-shelf components and subsystems to meet the requirements specified in phase I. A single board computer/controller system is not available to handle the requirements of more than a minimum system. Therefore, the Phase II research concentrated on the evaluation of processor families, I/O boards, and bus systems.

I. SYSTEM BUS STANDARDS

System buses provide a standardized set of signals such as address, data, and control signals as well as power, system control and bus arbitration. Using an internationally sanctioned system bus specification allows the selection of processor, memory, and interface boards from multiple vendors with a reasonable expectation that they will operate correctly together. The specification of a backplane and standard card sizes means that any of the boards can be plugged into any slot with the possible exception of a bus arbitration or interrupt controller card. With the standard system bus chosen, the system designer can utilize standard off-the-shelf processor, memory, and I/O boards with a standard backplane and card cage. The system designer can thus concentrate on the development of the overall system hardware and software plus the design of any custom cards when necessary.

A number of buses were evaluated for their applicability. Among the buses which were considered were VME, VXI, Qbus, NuBus, Versabus, Multibus, Multibus II, STD, and G-64. Matrices were constructed showing the relationship of the interface requirements with the bus systems and availability of off-the-shelf subsystems. Only four of the bus systems which were considered were actually capable of fulfilling the specified requirements. These results are shown in the attached spreadsheets. When selecting a bus structure, it is necessary to look at such factors as standardization, availability, expansibility, growth path and relative cost. Thus, the following is a listing of the advantages and disadvantages of each of the four bus standards considered:

1. VMEbus

Advantages:

- supports 8,16,or 32 bit processors including Motorola and Intel families
- provides 8, 16, 24, and 32 bit data transfers
- provides seven priority interrupts; multiple boards may share the same interrupt priority
- specification of VME allows for low end systems to be built with single height boards
- systems may be composed with single height boards (100mm by 160mm), double height boards (233mm by 160mm), or a mixture of both
- systems may be built with or without a power monitor
- up to 21 cards may be inserted into the backplane
- the backplane pin-in-socket connector is more reliable than card edge connectors
- large number of vendors
- up to 32 Mbyte/sec data transfer rate
- IEEE standard 1014

Disadvantages:

- more expensive than some other bus standards
- Motorola is promoting Futurebus for high end systems

2. G-64 bus

Advantages:

- supports 8, 16, and 32 bit processors including Motorola and Intel families
- provides 8, 16, and 32 bit transfers
- provides six priority interrupts; multiple boards may share the same interrupt priority
- small size (100mm by 160mm)
- power monitor built into backplane
- up to 20 cards may be inserted into the backplane
- pin-in-socket connector
- significantly lower cost than VME - eleven year history
- multivendor support
- up to 40 Mbyte/second transfer rate

Disadvantages:

- G-64 is not a high-profile (i.e., well-known) bus outside the embedded control industry
- not an IEEE standard

3. Multibus II

Advantages:

- supports 8, 16, and 32 bit processors including Motorola and Intel families
- provides 8, 16, and 32 bit transfers - provides 9 priority interrupts
- up to 16 cards may be inserted into the backplane
- lower cost than VME
- approximately 40 Mbyte/second transfer rate

Disadvantages:

- large size (171mm by 304mm)
- power monitor not available on backplane
- few vendors other than Intel

4. STD bus

Advantages:

- up to 8 cards per rack; racks may be coupled together in the same card cage thus a large number of cards may be placed in one card cage
- small size (114mm by 165mm)
- multivendor support
- low cost

Disadvantages:

- only 1 priority interrupt
- only supports 8 or 16 bit transfers through backplane bus
- while STD-32 bus supports 32 bit transfers, the transfer rate is limited
- only 1.3 Mbyte/sec data transfer rate for standard STD
- uses card edge connectors on backplane

CONCLUSIONS ON SELECTION OF A SYSTEM BUS STANDARD

The VMEbus (IEEE std 1014) appears to be the most appropriate choice at the present time. The bus is supported by multiple vendors, with a choice of processors, both in versions, and in manufacturers. The bus has multiple size cards available depending on the necessity for 16 or 32 bit data buses. There is expansion capability in the extended or VXIbus which is being promoted by instrumentation companies such as Hewlett-Packard who wish to put an instrumentation device on an individual card. The pin and socket type of connection is also more reliable than card edge connectors used in PCs.

II. Processors

There are many processors available for use in equipment controllers that could meet the basic requirements of FSI as listed in the Phase I report. However, it is important to ensure that the selected processor would not constrain any possible or foreseeable future applications for the next 5 years and beyond. It was relatively easy to look at what is available in the marketplace for the standard or most popular bus cages.

The eight bit processors were surveyed. While there are some interesting possibilities which would be very well suited for the low end applications, such as the Motorola 68HC11 and the Intel 8096, the major constraint is that the available memory space with the 16 address lines is limited to 64K bytes. While this would easily be more than adequate for many of the low end applications, it is obviously not sufficient for the high end system which needs to handle many tasks in real time.

The Intel 80X86 family, the Intel 80960 family, and the Motorola 680X0 family are possible processor candidates. These families have sophisticated software development systems and upward compatible instruction sets, which minimize cross training. They have wide popularity and familiarity with customers. Newer and faster versions are being developed each year.

The Intel 80960 is the most recently developed processor. It has the capability of handling the real time multitasking systems best. For use in high end systems, it would definitely be the obvious choice. However, for the low end systems the 80960 would provide much more computing power than necessary and be too expensive.

The investigation was, therefore, narrowed to two possibilities. The Intel 80X86 family and the Motorola 680X0 family. As indicated in the overviews, each family has been available for over ten years. Each family has versions which span the needed capabilities from low end 8 bit data bus system to a full 32 bit data bus for graphical and high end requirements. Some versions have floating point processors on-chip. CPU boards are available for most of the major bus systems. The following is an overview and listing of the advantages and disadvantages for each of the two families.

Motorola 680X0 family

Overview

The 680X0 family was introduced in 1979 as the first 32 bit microprocessor architecture.

All processors in the 680X0 family have two modes of operation, user mode and supervisor mode.

Application programs execute in user mode.

All 680X0 processors share the same user programming model . The user programming model consists of:

The MPU:

- 8 - 32 bit general purpose data registers
- 8 - 32 bit address (index) registers one of which is used as the user stack pointer
- 1 - 32 bit program counter
- 1 - 8 bit condition code register

The FPU :

- (may be emulated by system software if hardware FPU is not present)
- 8 - 80 bit general purpose floating point registers
- 1 - 32 bit PPU control register
- 1 - 32 bit FPU status register
- 1 - 32 bit instruction address register

The operating system software operates in supervisor mode. Supervisor mode provides additional instructions and registers which vary from processor to processor.

All members of the 680X0 family have a 32 bit internal data path.

The 680X0 family consists of:

- 68008 - introduced in 1980
 - 8 bit data bus
 - available with 22 or 20 bit address bus
 - multiprocessing support
- 68000 - introduced in 1979
 - 16 bit data bus
 - 24 bit address bus
 - multiprocessing support
- 68010 - introduced in 1981
 - 16 bit data bus
 - 24 bit address bus
 - multiprocessing support
 - built-in virtual memory support

- 68020 – introduced in 1984
 - 32 bit data bus
 - 32 bit address bus
 - expanded instruction set
 - coprocessor interface for P}NU and FPU
 - 256 byte instruction cache
 - parallel pipelined architecture
 - 2 new data types:
 - quad word integers (64 bits)
 - bit fields (useful for graphics and Boolean flags)
 - multiprocessing support
- 68030 – introduced in 1987
 - 32 bit data bus
 - 32 bit address bus
 - all features of 68020
 - 256 byte data cache
 - on chip PMMU
 - increased parallelism
 - multiprocessing support
- 68040 – introduced in 1990
 - 32 bit data bus
 - 32 bit address bus
 - all features of 68030
 - on chip FPU
 - increased speed
 - multiprocessing support

Advantages of choosing the 680X0 family

- numerous processor boards available for VME, G-64 , and Multibus II
- there are many operating systems available such as VxWorks, OS9, Unix, VRTX, pSOS, PDOS, and VMEPROM
- C compilers are available
- compilers and assemblers are relatively easy to write for the 680X0 family
- a very large amount of software has been written for the 680X0 family
- Ethernet is readily available for the 680X0 on the CPU board
- there are several sources for processors and boards (especially VME)
- extremely rich assembly language similar to DEC VAX
- orthogonal instruction set makes 680X0 language assembly easy to learn
- consistent user programming model for each member of the family
- object code need not be modified to run on different systems
- address registers allow for multitasking without swapping complete register sets

Disadvantages of choosing the 680X0 family

- not suitable for STD bus because of the limited data and address bus provided by STD

Module User I/F - Ext. I/F	Outputs
	LED display 165 ??? ??? 7?? 7??
	LCD display 165 110 ??? 70 70
	CRT display 165 110 ??? 70 70
	Graphics display 165 110 ??? 70 70
	Inputs
	keypad 165 110 ??? 7?? 7??
	touch screen 165 110 ??? 7?? 7??
	keyboard 165 110 ??? 70 70
	track ball 165 ??? 7?? 7?? 7??
Ext. Equipment I/F	SCSI 165, 170 110 ??? 7?? 7??
	IEEE 488 115, 165 110 ??? 70 70
	serial port(s) 170 110 10 70 70
	parallel port(s) 165 110 ??? 70 70
Terminal Ext. I/F	RS 232C 165, 170 110 10 70 70
	RS 422 115 110 10 70 70
	RS 485 115 110 10 70 70

*** Performance Characteristics**

Failure Detection	Watchdog Timer 165 110 ??? 70, 65
	Bus error detection 165 110 ??? 7?? 7??
Initialization Mode	System-wide reset signal all yes yes
Recovery Mode	Non-volatile RAM 165 110 ??? 70, 65
Test & Maintenance	Single-step processor 165 110 yes yes
Work Cell / Cluster Mode	Multiple LAN connections 165 110 ??? 7?? 7??

Intel 80X86 family

Overview

The 80X86 family was introduced in 1978. The 80X86 family is based upon the 8 bit architecture of the 8085.

Most of the members of the 80X86 family have the following programming model :

The MPU:

- 4 - 16 bit semi-general purpose data registers
- 4 - 16 bit index registers one of which is used as the stack pointer
- 4 - 16 bit segment registers
- 1 - 16 bit instruction pointer
- 1 - 16 bit status register

The FPU:

(may be emulated by system software if hardware FPU is not present)

- 8 - 80 bit floating point registers (configured as a stack)
- 1 - 16 bit FPU control register 1
- 16 bit FPU status register
- 1 - 32 bit instruction pointer
- 1 - 32 bit data pointer

Some of the high end processors have 4 - 32 bit semi-general purpose data registers instead of 16 bit data registers

All 80X86 family processors are capable of operating in real mode. Advanced versions of the processor also provide a protected mode which provides additional instructions for virtual memory support.

The 80X86 family consists of:

- 8088 - introduced in 1978
 - 16 bit internal data path
 - 8 bit data bus
 - 20 bit address bus
 - real mode only
- 8086 - introduced in 1978
 - 16 bit internal data path
 - 16 bit data bus
 - 20 bit address bus
 - real mode only

- 80186 – introduced in 1980
 - 16 bit internal data path
 - 16 bit data bus
 - 20 bit address bus
 - on chip system clock generator
 - on chip system controller
 - on chip interrupt controller
 - on chip DMA controller
 - on chip timer/ counters
 - real mode only
- 80286 – introduced in 1982
 - 16 bit internal data path
 - 16 bit data bus
 - 24 bit address bus
 - protected mode (some virtual memory support)
 - coprocessor available
 - multiprocessing support
 - expanded instruction set
- 80386sx – introduced in 1989
 - 32 bit internal data path
 - 16 bit data bus
 - 24 bit address bus
 - on chip breakpoint register
 - on chip MMU
 - protected mode
 - full multiprocessing support
 - registers expanded to 32 bits
 - instruction set expanded to include 32 bit operands
 - 2 segment registers added
 - pipelined address decoding
- 80386 – introduced in 1985
 - 32 bit internal data path
 - 32 bit data bus
 - 32 bit address bus
 - protected mode
 - all features of 80386sx
 - pipelined instruction execution
- 80486 – introduced in 1989
 - 32 bit internal data path
 - 32 bit data bus
 - 32 bit address bus
 - protected mode
 - all features of 80386
 - on chip FPU
 - increased speed

Advantages of choosing the 80X86 family:

- numerous processor boards available for Multibus II, STD bus, and VME
- there are many operating systems available such as VxWorks,
- Unix, pSOS, iAMX, iAMX386, and VRTX32
- C compilers are available
- a large amount of software has been written for the 80X86 family
- Ethernet is readily available for the 80X86 on the CPU board
- there are several sources for processors and boards (especially STD)

Disadvantages of choosing the 80X86 family:

- non-orthogonal instruction set is difficult to learn and use
- inconsistent user programming model makes programming more difficult
- lack of true general purpose registers
- object code will not run efficiently on high end machines if it is compiled to run on low end machines
- not totally object code compatible throughout family
- 80X86 object code is generally 20% to 30% larger than 680X0 code
- 80X86 has a limited register set
- many instructions make implicit use of particular registers

CONCLUSIONS ON SELECTION OF A PROCESSOR FAMILY

Only the 680X0 and 80X86 families provide sufficient breadth to cover all foreseeable applications. Both families provide approximately the same performance. Both processor families have the same, or similar, high level software development systems. In terms of high level software development, there is very little reason to give preference to either processor. However, the large number of address registers make the 680X0 family more efficient at task switching than the 80X86 family. The 680X0 is, therefore, better suited to the multitasking operating systems which will be needed for the high end systems. The consistent, modern architecture of the 680X0 family may provide long-term advantages over the 80X86 family, especially in low level software development.

III. Operating Systems

There are a number of operating systems and real time kernels available for both of the two processor candidates. It would not be wise to choose an operating system without first having the opportunity to work with it. The following is a list of operating systems which should be considered for future evaluation:

VxWorks:

- real time multiuser multitasking operating system designed specifically for process control applications
- supports full UNIX 4.3 BSD
- kernel runs faster than UNIX
- arithmetic coprocessor support
- uses UNIX as software development platform
- widely accepted by the industry
- very strong support for networking including a complete UNIX 4.3 BSD networking package
- symbolic and source level debugging
- supports C and Ada programming languages
- available for both Intel and Motorola processors

Unix:

- multiuser multitasking general purpose operating system
- arithmetic coprocessor support
- self hosted software development platform
- very strong support for networking including a complete UNIX 4.3 BSD networking package
- symbolic and source level debugging
- supports many programming languages
- available for both Intel and Motorola processors

OS/9:

- real time multitasking operating system designed for process control applications
- kernel runs faster than UNIX
- similar to UNIX
- most C code written for UNIX can be ported without modification
- I/O and Arithmetic coprocessor support
- self-hosted software development platform
- widely accepted by the industry
- optional networking support
- symbolic and source-level debugging
- supports C, Pascal, Fortran, and BASIC - available for Motorola processors

pSOS:

- real time multitasking kernel designed for embedded systems
- easy configuration due to modular architecture
- extremely fast execution and very small code size
- optional file system support
- arithmetic coprocessor support
- many host development systems to choose from
- widely accepted by the industry
- debugging
- supports Assembly, C, Pascal, Fortran77, and Forth
- available for Motorola and Intel processors

PDOS:

- real time multitasking multiuser operating system designed for scientific education, industrial, and business applications
- modular configuration
- extremely fast execution and small code size
- optional file system support
- arithmetic coprocessor support
- self-hosted development
- optional networking support
- debugging
- supports Assembly, C, Pascal, and Fortran 77
- available for Motorola processors
- ROM version available

AMX 386:

- real time multitasking executive
- priority-based preemptive multitasking; can be time-sliced
- kernel can be placed in ROM or launched from DOS
- runs in protected mode; memory size limited to physical memory
- supports C and Assembly
- requires DOS extender
- superset of currently utilized AMX 86 multitasking executive
- requires less than 6K bytes for program store (ROM) and 1K byte of data storage (RAM) in its minimal form
- can be customized to suit needs; comes with Assembly source code
- no vendors known that provide suitable graphics packages written in protected mode
- utilized at Texas Tech University
- available for Intel 80386, 80386sx, and 80486 processors

VRTX32:

- real time multitasking operating system designed for use in communications, instrumentation, military aerospace, and factory automation
- fast execution
- optional file system support
- arithmetic coprocessor support
- many host development systems
- optional networking support
- debugging available
- supports Assembly and C
- available for Motorola 680X0 and Intel 80X86 processors

The operating systems that are available are listed above without recommendations. Once the processor and bus specification is decided upon, the operating systems need to be evaluated through system testing.

Glossary of Terms

MMU – memory management unit

PMMU – paged memory management unit

FPU – floating point unit (numeric coprocessor)

MPU – microprocessor unit

I/O – input/output

DMA – direct memory access

List of Sources

VMEbus products:

- 35 - Logical Design Group
- 100 - Datel
- 105 - Force
- 115 - Green Spring
- 120 - Heurikon
- 130 - Ironics
- 140 - Omnibyte
- 145 - Performance Technologies
- 150 - Tadpole Technology
- 155 - Telesis High Vacuum
- 165 - Themis
- 170 - Matrix
- 175 - Motorola
- 180 - Nissho

G-64 bus products:

- 110 - Gespac

Multibus II products:

- 10 - Concurrent Technologies
- 50 - Nissho
- 55 - Single Board Solutions
- 70 - Ziatech

STD bus products: (Note attached Memo of Dec 20, 1990 on page 20)

- 30 - Lelko
- 65 - WinSystems
- 70 - Ziatech

CONTROLLER SPECIFICATIONS

CATEGORY	REQUIREMENT	VME Bus	GS4 Bus	MultiBus II	STD Bus
* External Interface Requirements					
Work Cell Ext. I/F	Ethernet	165	110	10	65
Analog - Ext. I/F	12 bit A-D/-10 to +10 volt range	115, 170	110	10	65
	12 bit A-D/4-20 ma current loops	100	110	???	30
Analog Signal Conditioning	1 KHz sampling rate	yes	yes	yes	yes
	Differential input amplifier	170	110	10	65
	Active filtering	170, 100	110	???	???
	Sample and hold circuitry	170, 100, 115	110	10	65
	Gains of .1, .5, 1, 10, 100, 1000	170, 115	110	1-20 -- 10	1-1000 -- 65
	Programmable gain amplifiers	115, 170	110	10	65
	Programmable level translation	170, 165	???	???	65
	# signal lines available	48 -- 170, 100	32 -- 110	48 -- 10	144 -- 70
	Min data transfer rate	1 Mb/sec -- 170	???	???	???
	0 to 24 vdc input	170, 100, 165	110	???	???
TTL input	115, 165	110	48 -- 10	70, 65	
Digital Signal Conditioning					
Digital - Ext. I/F	Input signal conditioning				
	Translation	165, 100	???	???	???
	Scaling	165, 100	???	???	???
	Noise isolation	165, 100	110	???	70
	250 ma output	115	110	???	30
	GND to 24 volt output	115, 165	110	???	30
	Optical isolators	165	110	???	70
	Differential inputs	165	110	???	???
	16 channels	7 -- 165	32 -- 110	???	8 -- 70
	Response time -- 1 to 50 μ sec	yes	yes	yes	yes
Counter/Timer I/O Ext. I/F	Up to 8 16-bit counter/timers	2 24b - 115, Mult of 5 - 110	2 -- 110	2 -- 10	3 -- 70
	Cascadable	3 16b, 1 24b - 165	???	???	???
	0 to 24 vdc	0 to 5 vdc -- 165	???	???	???

• Additional Design Issues

Materials				???	???	???
Electromagnetic Radiation Safety	FCC class	EMI/RFI ---	165	yes	???	???
	Power failure detection		yes	yes	110	???
	EPO		yes	yes	???	no
Human Engineering	Grid matrix		yes	yes	???	???
	LED module status indicators		165	???	???	???
Documentation	Supports design		yes	yes	yes	yes
	Theory of operation		yes	yes	yes	yes
	Block diagrams		yes	yes	yes	yes
	Schematics		yes	yes	yes	yes
	Trouble-shooting information		yes	yes	yes	yes
	Testing procedures		yes	yes	yes	yes

• Characteristics of Auxiliary Elements

Software Support	C		175	110	yes	yes
	Assembly		175	110	yes	yes
	Multitasking kernel		yes	yes	yes	yes
	Performance analysis tools		175	???	???	70
Hardware Support	Emulators		175	???	???	???
	Logic analyzers		175, 180	???	???	???
	Controller serialization via ROM		Optional	Optional	Optional	Optional
Testing & Verification	POST		???	???	10	???
	Test cards		175, 180	???	???	???
	Closed loop checks		N/A	N/A	N/A	N/A
Technology Export License	Exportable		Unknown	Unknown	Unknown	Unknown

MEMO

DATE: DECEMBER 20, 1990
BRUCE ESTES AND DALE COURTNEY
FROM : DONALD GUSTAFSON
SUBJECT: PHASE II EVALUATION OF OFF-THE-SHELF EQUIPMENT
MEETING REQUIREMENTS FOR MODULE LEVEL CONTROLLER

For each bus standard, we compiled a list of companies to contact. In order to keep our information to a manageable level while still obtaining a fair sample of the available products, we limited the list to the most promising 20 vendors for each bus. For most of the bus standards, we could not find that many vendors. The only two bus standards for which we found more than 20 vendors were STD and VME. The following is a list of companies which we attempted to contact about STD products:

Advanced Micro Devices	Allen Systems
Analog Devices, Inc.	Burr-Brown Corp.
Computer Dynamics	Data Translation, Inc.
Dy-4 Systems	Hybricon Corp.
Lelko	Matrix Corp.
Micro-Link	Mizar
National Instruments	Pro-Log Corp.
Spurrier Peripherals Corp.	STD
Sytek	Teknor Microsystems, Inc
WinSystems	Ziatech

Some of the companies listed above have gone out of business or no longer supply STD products. We received literature form the following companies:

Analog Devices, Inc.	Burr-Brown Corp.
Computer Dynamics	Hybericon Corp.
Lelko	Matrix Corp.
Micro-Link	Mizar
Pro-Log Corp.	Winsxstems
Ziatech	

Three of the companies sent literature indicating that they actively support the STD bus and that they have many component boards which meet the requirements specified in Phase I. These three companies are:

Lelko	Winsxstems
Ziatech	

The STD bus is a possible alternative but the limitation of an eight bit data bus for the high end module level controller needs to be recognized.