NB-MIO-16
User Manual

Multifunction I/O Board for Macintosh NuBus Computers

September 1994 Edition

Part Number 320295B-01

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About This Manual

This manual describes the mechanical and electrical aspects of the NB-MIO-16 and contains information concerning its operation and programming. The NB-MIO-16 is a high-performance multifunction analog, digital, and timing input/output (I/O) board for the Macintosh NuBus family of computers.

Organization of This Manual

The *NB-MIO-16 User Manual* is organized as follows:

- Chapter 1, *Introduction*, describes the NB-MIO-16; lists the contents of your NB-MIO-16 kit, the optional software, and optional equipment; and explains how to unpack the NB-MIO-16.
- Chapter 2, *Configuration and Installation*, describes the jumper configuration, installation of the NB-MIO-16 in the Macintosh, signal connections to the NB-MIO-16, and cabling considerations.
- Chapter 3, *Theory of Operation*, contains a functional overview of the NB-MIO-16 and explains the operation of each functional unit making up the NB-MIO-16.
- Chapter 4, *Programming*, describes in detail the address and function of each of the NB-MIO-16 registers. This chapter also includes important information about programming the NB-MIO-16.
- Chapter 5, *Calibration Procedures*, discusses the calibration procedures for the NB-MIO-16 analog input and analog output circuitry.
- Appendix A, *Specifications*, lists the specifications of the NB-MIO-16.
- Appendix B, *I/O Connector*, shows the pinout and signal names for the 50-pin I/O connector on the NB-MIO-16.
- Appendix C, *AMD Data Sheet*, contains a manufacturer data sheet for the Am9513A/Am9513 System Controller (Advanced Micro Devices, Inc.) integrated circuit. This circuit is used on the NB-MIO-16.
- Appendix D, *Customer Communication*, contains forms you can use to request help from National Instruments or to comment on our products.
- The *Glossary* contains an alphabetical list and description of terms used in this manual, including abbreviations, acronyms, metric prefixes, mnemonics, and symbols.
- The *Index* contains an alphabetical list of key terms and topics in this manual, including the page where you can find each one.

Conventions Used in This Manual

The following conventions are used in this manual:

bold italic	Bold italic text denotes a note, caution, or warning.
DIFF	DIFF refers to differential input configuration.
DMA board	DMA board refers to the NB-DMA-8-G board or the NB-DMA2800 board unless otherwise noted.
italic	Italic text denotes emphasis, a cross reference, or an introduction to a key concept.
Macintosh	Macintosh refers to all Macintosh computers with 13 in. NuBus slots unless otherwise noted.
NI-DAQ	NI-DAQ is used throughout this manual to refer to the NI-DAQ software for Macintosh unless otherwise noted.

Abbreviations, acronyms, metric prefixes, mnemonics, symbols, and terms are listed in the *Glossary*.

About the National Instruments Documentation Set

The *NB-MIO-16 User Manual* is one piece of the documentation set for your data acquisition system. You could have any of six types of manuals. Use these different manuals as follows:

- *Getting Started with SCXI*–If you are using SCXI, this is the first manual you should read. It gives an overview of the SCXI system and contains the most commonly needed information for the modules, chassis, and software.
- Your SCXI user manuals–These manuals contain detailed information about signal connections and module configuration. They also explain in greater detail how the module works and contain application hints.
- Your data acquisition board user manuals–These manuals have detailed information about the data acquisition board that plugs into your computer. Use these manuals for board installation and configuration instructions, specification information about your data acquisition board, and application hints.
- Software manuals–Examples of software manuals you may have are the LabVIEW and LabWindows manual sets and the NI-DAQ manuals. After you set up your hardware system, use either the application software (LabVIEW or LabWindows) manuals or the NI-DAQ manuals to help you write your application. If you have a large and complicated system, it is worthwhile to look through the software manuals before you configure your hardware.

- Accessory manuals–These are the terminal block and cable assembly installation guides. They explain how to physically connect the relevant pieces of the system. Consult these guides when you are making your connections.

- SCXI chassis manuals–These manuals contain maintenance information on the chassis, installation instructions, and information about making custom modules.

Related Documentation

The following documents contain information you may find useful as you read this manual if you are writing your own Macintosh programs:

- Your Macintosh *Owner's Manual*, *Getting Started* manual, or *Setting Up* manual

Consult the following National Instruments manuals if you plan to program DMA operations with this board:

- The *NB-DMA-8-G User Manual*

- The *NB-DMA2800 User Manual*

You may also want to consult the following manual if you plan to program the Am9513 Counter/Timer used on the NB-MIO-16:

- *The Am9513A/Am9513 System Timing Controller* technical manual

Customer Communication

National Instruments wants to receive your comments on our products and manuals. We are interested in the applications you develop with our products, and we want to help if you have problems with them. To make it easy for you to contact us, this manual contains comment and configuration forms for you to complete. These forms are in Appendix D, *Customer Communication*, at the end of this manual.

Chapter 1
Introduction

This chapter describes the NB-MIO-16; lists the contents of your NB-MIO-16 kit, the optional software, and the optional equipment; and explains how to unpack the NB-MIO-16.

The NB-MIO-16 is a high-performance multifunction analog, digital, and timing I/O board for Macintosh NuBus computers. The NB-MIO-16 contains a 12-bit ADC with 16 analog inputs, two 12-bit DACs with voltage outputs, 8 lines of TTL-compatible digital I/O, and three 16-bit counter/timer channels for timing I/O. If you need additional analog inputs, you can use the AMUX-64T analog multiplexer.

The NB-MIO-16 is designed for use in many different environments. It can be used for automating machine and process control, level monitoring and control, instrumentation, electronic test, and many other functions. The multichannel 12-bit resolution analog input can be used for such functions as signal and transient analysis, data logging, and chromatography. The two 12-bit analog output channels can be used for such functions as machine and process control, analog function generation, 12-bit resolution voltage source, and programmable signal attenuation. The eight TTL-compatible digital I/O lines can be used for machine and process control, intermachine communication and relay switching control. The three 16-bit counter/timers can be used for such functions as pulse and clock generation, timed control of laboratory equipment, and frequency, event, and pulse width measurement. With all these functions on one board, laboratory processes can be automatically monitored and controlled.

The NB-MIO-16 is interfaced to the National Instruments RTSI bus to provide DMA in conjunction with a DMA board for high-speed function generation. The NB-MIO-16 is a member of the National Instruments NB family of products for Macintosh NuBus computers.

The NB-MIO-16 contains an ADC with a 9 µs conversion time and is available in two versions–the NB-MIO-16L-9 and the NB-MIO-16H-9. The NB-MIO-16L-9 provides software programmable gain settings of 1, 10, 100, and 500 for low-level analog input signals. The NB-MIO-16H-9 provides software programmable gain settings of 1, 2, 4, and 8 for high-level analog input signals. The NB-MIO-16(L/H)-9 is capable of data acquisition rates of up to 100 kbytes/s.

Detailed specifications for the NB-MIO-16 are in Appendix A, *Specifications*, of this manual.

What You Need to Get Started

- A Macintosh computer with 13 in. NuBus slots
- Your NB-MIO-16 board
- *NB-MIO-16 User Manual*
- NI-DAQ software for Macintosh, with manuals
  - *NI-DAQ for Macintosh Software Reference Manual*

You can tell which version of the NB-MIO-16 board you have by looking at the *-xx* extension of the part number, which is located in the bottom left corner of the component side of your board, as follows:

Board Version	Part Number Extension
NB-MIO-16L-9	-01
NB-MIO-16H-9	-11

If your kit is missing any of the components or if you received the wrong version, contact National Instruments.

Software Programming Choices

There are four options to choose from when programming your National Instruments DAQ and SCXI hardware. You can use LabVIEW, LabWindows, NI-DAQ, or register-level programming software.

LabVIEW and LabWindows Application Software

LabVIEW and LabWindows are innovative program development software packages for data acquisition and control applications. LabVIEW uses graphical programming, whereas LabWindows enhances traditional programming languages. Both packages include extensive libraries for data acquisition, instrument control, data analysis, and graphical data presentation.

LabVIEW currently runs on three different platforms—AT/MC/EISA computers running Microsoft Windows, the Macintosh platform, and the Sun SPARCstation platform. LabVIEW features interactive graphics, a state-of-the-art user interface, and a powerful graphical programming language. The LabVIEW Data Acquisition VI Library, a series of VIs for using LabVIEW with National Instruments DAQ hardware, is included with LabVIEW. The LabVIEW Data Acquisition VI Libraries are functionally equivalent to the NI-DAQ software, except that the SCXI functions are not included in the LabVIEW software for Sun.

LabWindows has two versions—LabWindows for DOS is for use on PCs running DOS, and LabWindows/CVI is for use on PCs running Windows. LabWindows/CVI features interactive graphics, a state-of-the-art user interface, and uses the ANSI standard C programming language. The LabWindows Data Acquisition Library, a series of functions for using LabWindows with National Instruments DAQ hardware, is included with LabWindows for DOS and LabWindows/CVI. The LabWindows Data Acquisition libraries are functionally equivalent to the NI-DAQ software, except that the SCXI functions are not included in the LabVIEW software for Sun.

Using LabVIEW or LabWindows software will greatly reduce the development time for your data acquisition and control application.

NI-DAQ Driver Software

The NI-DAQ driver software is included at no charge with all National Instruments DAQ hardware. NI-DAQ is not packaged with SCXI or accessory products except for the SCXI-1200. NI-DAQ has an extensive library of functions that you can call from your application programming environment. These functions include routines for analog input (A/D conversion), buffered data acquisition (high-speed A/D conversion), analog output (D/A conversion), waveform generation, digital I/O, counter/timer operations, SCXI, RTSI, self calibration, messaging, and acquiring data to extended memory.

NI-DAQ also internally addresses many of the complex issues between the computer and the DAQ hardware such as programming the PC interrupt and DMA controllers. NI-DAQ maintains a consistent software interface among its different versions so that you can change platforms with minimal modifications to your code. Figure 1-1 illustrates the relationship between NI-DAQ and LabVIEW and LabWindows. You can see that the data acquisition parts of LabVIEW and LabWindows are functionally equivalent to the NI-DAQ software.

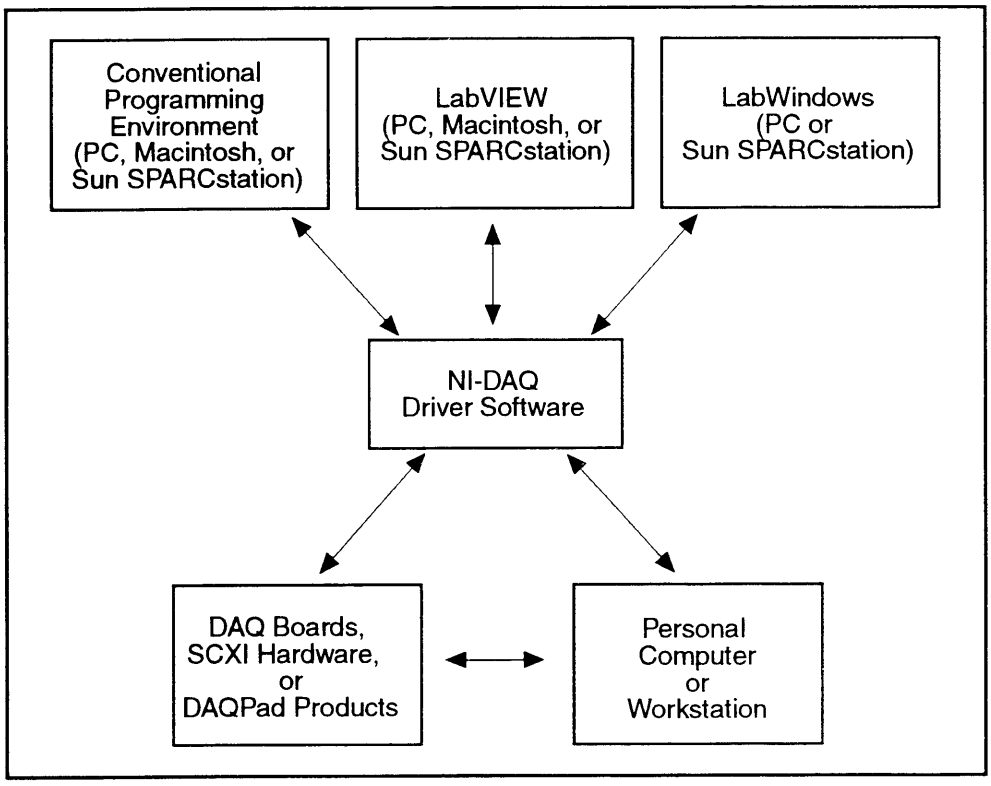


Figure 1-1. Relationship between the Programming Environment, NI-DAQ, and Your Hardware

The National Instruments PC, AT, MC, DAQCard, and DAQPad Series DAQ hardware is packaged with NI-DAQ software for PC compatibles. NI-DAQ software for PC compatibles comes with language interfaces for Professional BASIC, QuickBASIC, Visual Basic, Borland Turbo Pascal, Turbo C++, Borland C++, Microsoft Visual C++, and Microsoft C for DOS; and Visual Basic, Turbo Pascal, Microsoft C with SDK, Microsoft Visual C++, and Borland C++ for

Windows; and Microsoft Visual C++ for Windows NT. You can use your NB-MIO-16, together with other PC, AT, and MC Series DAQ boards and SCXI hardware, with NI-DAQ software for PC compatibles.

The National Instruments NB Series DAQ boards are packaged with NI-DAQ software for Macintosh. NI-DAQ software for Macintosh comes with language interfaces for MPW C, THINK C, Pascal, and Microsoft QuickBASIC. Any language that uses Device Manager Toolbox calls can access NI-DAQ software for Macintosh. You can use NB Series data acquisition boards and SCXI hardware with NI-DAQ software for Macintosh.

The National Instruments SB Series DAQ boards are packaged with NI-DAQ software for Sun, which comes with a language interface for ANSI C.

Register-Level Programming

The final option for programming any National Instruments DAQ hardware is to write register-level software. Writing register-level programming software can be very time-consuming and inefficient, and is not recommended for most users. The *only* users who should consider writing register-level software should meet at least one of the following criteria:

- National Instruments does not support your operating system or programming language.
- You are an experienced register-level programmer who is more comfortable writing your own register-level software.

Even if you are an experienced register-level programmer, always consider using NI-DAQ, LabVIEW, or LabWindows to program your National Instruments DAQ hardware. Using the NI-DAQ, LabVIEW, or LabWindows software is easier than, and as flexible as, register-level programming, and can save you weeks of development time.

The *NB-MIO-16 User Manual* and your software manuals contain complete instructions for programming your NB-MIO-16 with NI-DAQ, LabVIEW, or LabWindows. If you are using NI-DAQ, LabVIEW, or LabWindows to control your board, you should not need the register-level programming details, such as register maps, bit descriptions, and register programming hints.

Optional Equipment

You can use the following National Instruments products with your NB-MIO-16 board:

- NB-DMA2800 board
- NB-DMA-8-G board
- AMUX-64T analog multiplexer board with 0.2, 0.5, 1.0, or 2.0 m ribbon cable
- CB-50 I/O connector block with 0.5 or 1.0 m cable

- RTSI bus cable for 2, 3, 4, or 5 boards
- SC-2070 (general-purpose termination breadboard) with 0.5 or 1.0 m, 50-conductor cable

For more information about optional equipment available from National Instruments, refer to your National Instruments catalog or call the sales office nearest you.

Unpacking

Your NB-MIO-16 board is shipped in an antistatic package to prevent electrostatic damage to the board. Electrostatic discharge can damage several components on the board. To avoid such damage in handling the board, take the following precautions:

- Ground yourself via a grounding strap or by holding a grounded object, such as a computer chassis.
- Touch the antistatic package to a metal part of your computer chassis before removing the board from the package.
- Remove the board from the package and inspect the board for loose components or any other sign of damage. Notify National Instruments if the board appears damaged in any way. *Do not* install a damaged board into your computer.
- *Never* touch the exposed pins of connectors.

Chapter 2
Configuration and Installation

This chapter describes the jumper configuration, installation of the NB-MIO-16 in the Macintosh, signal connections to the NB-MIO-16, and cabling considerations.

Board Configuration

The NB-MIO-16 contains eight jumpers for changing the analog input and analog output configuration of the board. Jumpers W1, W2, W3, and W9 configure the analog input circuitry. Jumpers W4, W5, W6, and W7 configure the analog output circuitry. The jumpers are shown in the parts locator diagram in Figure 2-1.

Factory-Default Jumper Settings

The NB-MIO-16 is shipped from the factory with the following configuration:

- Differential analog input (8 channels)
- Bipolar analog input
- 20 V input range (±10 V)
- Bipolar analog output with internal reference selected (±10 V output range)

Table 2-1 lists all the available jumper configurations for the NB-MIO-16 with the factory defaults noted.

Table 2-1. Jumper Settings

	Configuration	Jumper Settings
Input Mode	Differential (DIFF) (factory setting)	**W1:** A-C, B-D, E-F **W9:** A-B
	Non-referenced single-ended (NRSE)	**W1:** A-B, C-E, G-H **W9:** B-C
	Referenced single-ended (RSE)	**W1:** A-B, C-D, G-H **W9:** B-C
Input Range	Unipolar 0 to 10 V	**W2:** B-C **W3:** B-C
	Bipolar ±5 V	**W2:** A-B **W3:** B-C
	Bipolar ±10 V (factory setting)	**W2:** A-B **W3:** A-B
Output CH0 Reference	Internal (factory setting)	**W5:** B-C
	External	**W5:** A-B
Output CH1 Reference	Internal (factory setting)	**W4:** B-C
	External	**W4:** A-B
Output CH0 Polarity	Unipolar	**W6:** B-C
	Bipolar (factory setting)	**W6:** A-B
Output CH1 Polarity	Unipolar	**W7:** B-C
	Bipolar (factory setting)	**W7:** A-B

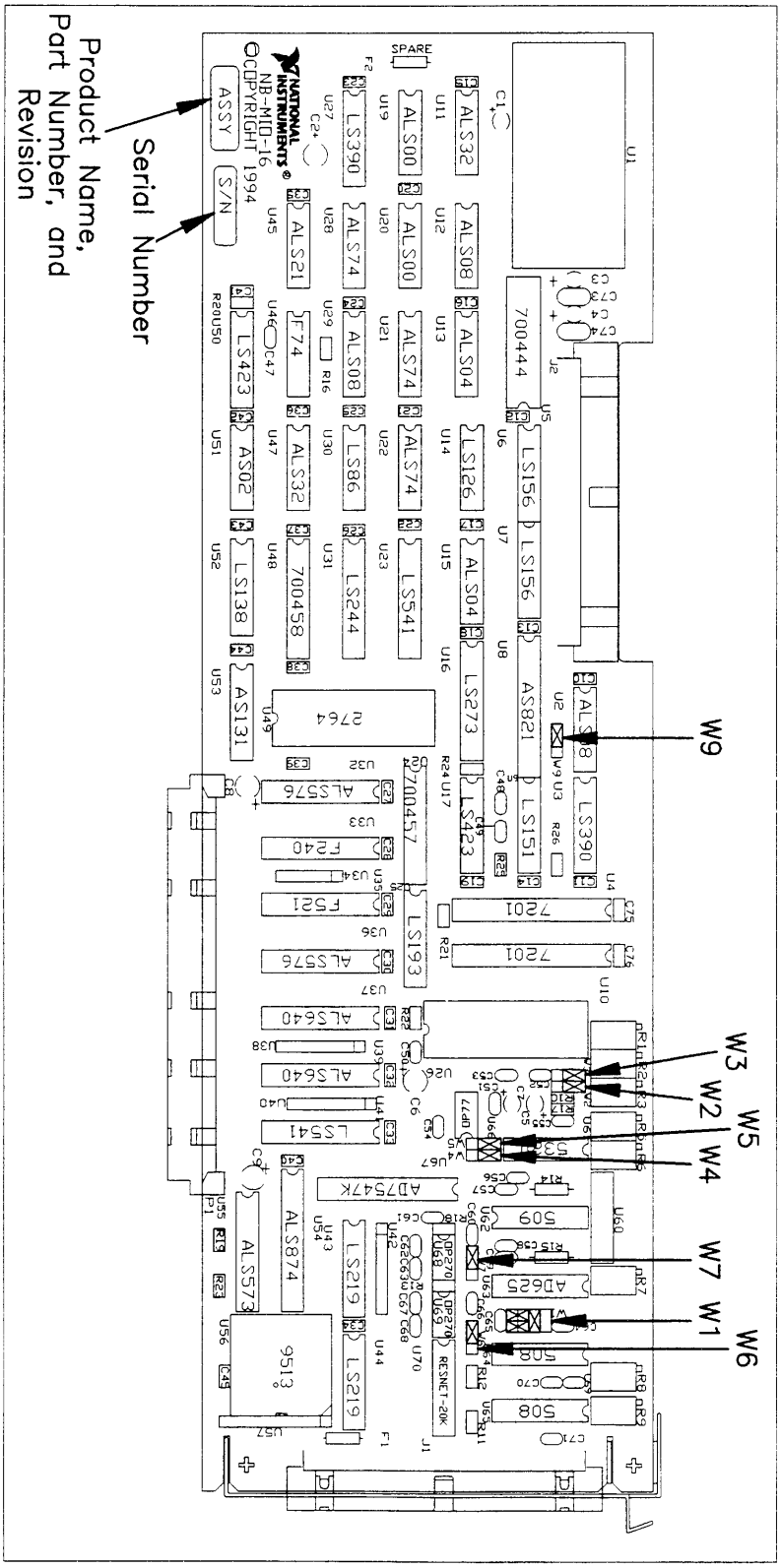


Figure 2-1. NB-MIO-16 Parts Locator Diagram

Analog Input Configuration

You can select different analog input configurations by using the jumper settings shown in Table 2-1. The following paragraphs describe each of the analog input categories in detail. In the configuration illustrations throughout this section, the black bars show where to place jumpers.

Input Mode

The NB-MIO-16 offers three different input modes: referenced single-ended (RSE) input, non-referenced single-ended (NRSE) input, and differential (DIFF) input. The single-ended input configurations use 16 channels. The DIFF input configuration uses eight channels. These configurations are described in Table 2-2.

Table 2-2. Input Configurations Available for the NB-MIO-16

Configuration	Description
DIFF	Differential configuration—Provides 8 differential inputs with the negative (-) input of the instrumentation amplifier tied to the multiplexer output of Channels 8 through 15.
RSE	Referenced Single-Ended configuration—Provides 16 single-ended inputs with the negative (-) input of the instrumentation amplifier referenced to analog ground.
NRSE	Non-Referenced Single-Ended configuration—Provides 16 single-ended inputs with the negative (-) input of the instrumentation amplifier tied to AISENSE and *not* connected to ground.

Refer to *Analog Input Signal Connections* later in this chapter for diagrams showing the resultant configurations of different jumper connections.

DIFF Input (8 Channels, Factory Setting)

DIFF input means that each input signal has its own reference. Each signal consists of a pair of wires that are tied to two input channels, and the difference between the two input channels is measured. With this input configuration, the NB-MIO-16 can be used to monitor eight different analog input signals. The DIFF input configuration is as follows:

W1 :	A - C	Jumper is placed in standby position. Jumper can be discarded.
	B - D	AISENSE is tied to the instrumentation amplifier output ground point
	E - F	Channels 0 through 7 are tied to the positive (+) input of the instrumentation amplifier. Channels 8 through 15 are tied to the negative (-) input of the instrumentation amplifier.
W9 :	A - B	Multiplexer control is configured to control eight input channels.

This configuration is shown in Figure 2-2.

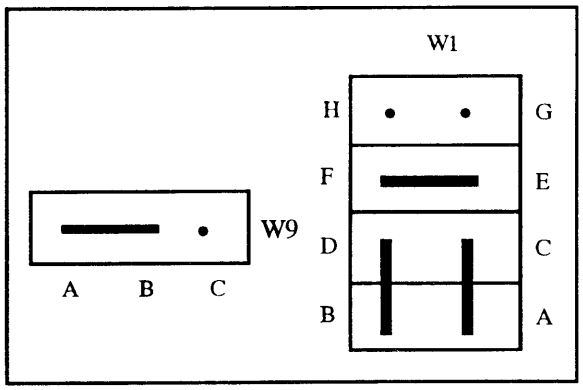


Figure 2-2. DIFF Input Configuration (Factory Setting)

Considerations in using the DIFF input configuration are discussed under *Signal Connections* later in this chapter. Figures 2-14 and 2-15 show schematic diagrams of this configuration.

RSE Input (16 Channels)

RSE input means that all input signals are referenced to a common ground point that is also tied to the analog input ground of the NB-MIO-16 board. The negative (-) input of the differential input amplifier is tied to analog ground. This configuration is useful when measuring floating signal sources. (See *Types of Signal Sources* later in this chapter for more information.) With this input configuration, the NB-MIO-16 is connected to 16 different analog input signals. The RSE input configuration is as follows:

W1 :	A - B	AISENSE is tied to the negative (-) input of the instrumentation amplifier.
	C - D	The negative (-) input of the instrumentation amplifier is tied to the instrumentation amplifier signal ground.
	G - H	Multiplexer outputs are tied together into the positive (+) input of the instrumentation amplifier.
W9 :	B - C	Multiplexer control is configured to control 16 input channels.

This configuration is shown in Figure 2-3.

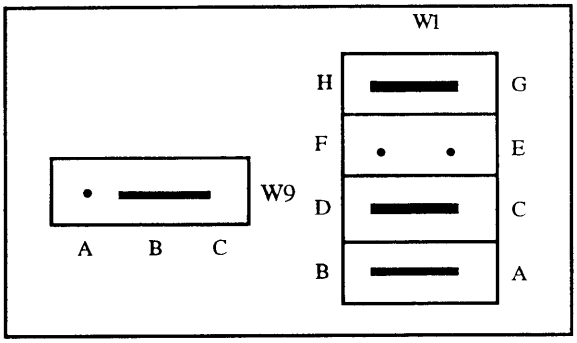


Figure 2-3. RSE Input Configuration

Considerations in using the RSE configuration are discussed under *Signal Connections* later in this chapter. Figure 2-16 shows a schematic diagram of this configuration.

NRSE Input (16 Channels)

NRSE input means that all input signals are referenced to the same common mode voltage but that this common mode voltage can float with respect to the analog ground of the NB-MIO-16 board. This common mode voltage is subsequently subtracted out by the input instrumentation amplifier. This configuration is useful when measuring ground-referenced signal sources. (See *Types of Signal Sources* later in this chapter for more information.) With this input configuration, the NB-MIO-16 can be used to monitor 16 different analog input signals. The NRSE input configuration is as follows:

W1 :	A - B	AISENSE is tied to the negative (-) input of the instrumentation amplifier.
	C - E	Jumper is placed in standby position. Jumper can be discarded.
	G - H	Multiplexer outputs are tied together into the positive (+) input of the instrumentation amplifier.
W9 :	B - C	Multiplexer control is configured to control 16 input channels.

This configuration is shown in Figure 2-4.

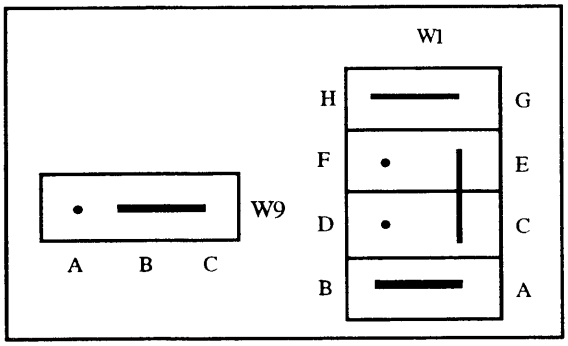


Figure 2-4. NRSE Input Configuration

Considerations in using the NRSE configuration are discussed under *Signal Connections* later in this chapter. Figure 2-17 shows a schematic diagram of this configuration.

Input Polarity and Input Range

The NB-MIO-16 has jumpers for choosing between unipolar and bipolar input. Unipolar input means that the input voltage range is between 0 and V_{ref} where V_{ref} is a positive reference voltage. Bipolar input means that the input voltage range is between $-V_{ref}$ and $+V_{ref}$. The NB-MIO-16 also has two different input ranges: a 10 V input range or a 20 V input range. By selecting the input polarity and range, you can choose between the following three input ranges:

Input Range	Input Polarity	Jumper Settings W2	W3
0 to +10 V (10 V range)	unipolar	B-C	B-C
-5 to +5 V (10 V range)	bipolar	A-B	B-C
-10 to +10 V (20 V range)	bipolar	A-B	A-B (factory setting)

Figures 2-5, 2-6, and 2-7 show the jumper positions for the 0 to 10 V, -5 to +5 V, and -10 to +10 V input range configurations, respectively.

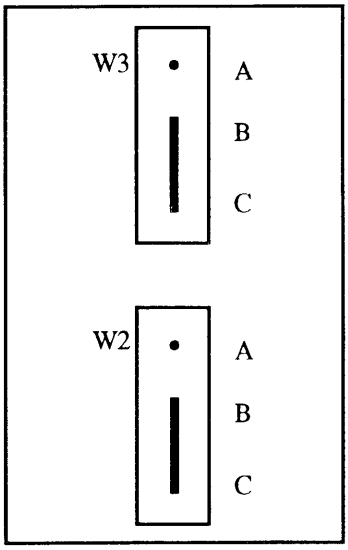


Figure 2-5. 0 to +10 V Input Range Configuration

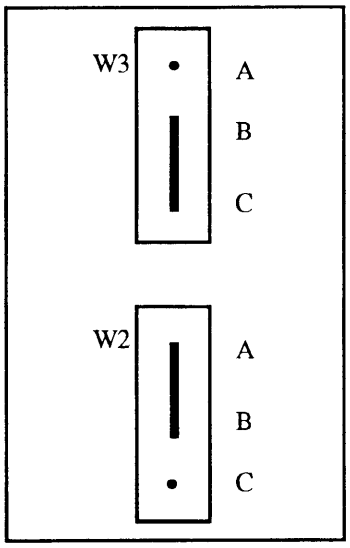


Figure 2-6. -5 to +5 V Input Range Configuration

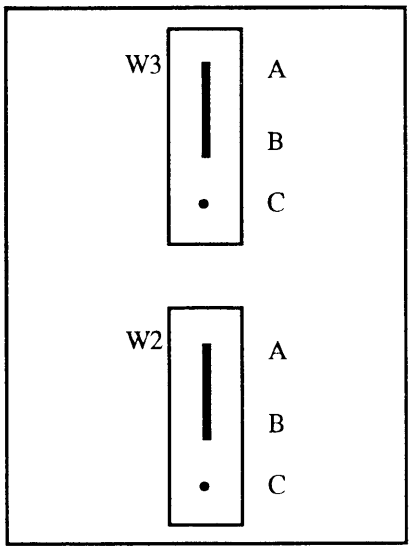


Figure 2-7. -10 to +10 V Input Range Configuration (Factory Setting)

Considerations for Selecting Input Ranges

Input range selection depends on the expected input range of the incoming signal. A large input range can accommodate a large signal variation but sacrifices voltage resolution. Choosing a smaller input range increases voltage resolution but may result in the input signal going out of range. For best results, the input range should be as closely matched as possible to the expected range of the input signal. For example, if the input signal will never go negative (below 0 V), a unipolar input range selection is best. However, if the signal does go negative, inaccurate readings occur.

Software-programmable gain on the NB-MIO-16 increases overall flexibility by matching input signal ranges to those accommodated by the NB-MIO-16 ADC. The NB-MIO-16H board provides gains of 1, 2, 4, and 8. These gains allow you to better match the already high-level input signal to the ADC range. The NB-MIO-16L board is designed to measure low-level signals and provides gains of 1, 10, 100, and 500. These high gains allow you to apply the 12-bit precision of the ADC to input signals with very small ranges.

Table 2-3 shows the overall input range and precision available, depending on the input range configuration and gain used.

Table 2-3. Actual Range and Measurement Precision Versus Input Range Selection and Gain

Range Configuration	Gain	Actual Input Range	Precision*
0 to +10 V	1	0 to +10 V	2.44 mV
	2	0 to +5 V	1.22 mV
	4	0 to +2.5 V	610 µV
	8	0 to +1.25 V	305 µV
	10	0 to +1 V	244 µV
	100	0 to +0.1 V	24.4 µV
	500	0 to +20 mV	4.88 µV
-5 to +5 V	1	-5 to +5 V	2.44 mV
	2	-2.5 to +2.5 V	1.22 mV
	4	-1.25 to +1.25 V	610 µV
	8	-0.625 to +0.625 V	305 µV
	10	-0.5 to +0.5 V	244 µV
	100	-50 to +50 mV	24.4 µV
	500	-10 to +10 mV	4.88 µV
-10 to +10 V	1	-10 to +10 V	4.88 mV
	2	-5 to +5 V	2.44 mV
	4	-2.5 to +2.5 V	1.22 mV
	8	-1.25 to +1.25 V	610 µV
	10	-1 to +1 V	488 µV
	100	-0.1 to +0.1 V	48.8 µV
	500	-20 to +20 mV	9.76 µV

* Corresponds to 1 LSB of the 12-bit ADC, that is, the voltage increment corresponding to a change of one in the ADC 12-bit count.

Analog Output Configuration

You can select different analog output configurations by using the jumper settings shown in Table 2-1. The following paragraphs describe each of the analog output categories in detail.

Internal and External Reference

Each analog output channel can be connected either to the NB-MIO-16 internal reference of 10 V or to the external reference signal connected to the EXTREF pin on the I/O connector. Both channels need not be configured the same way. However, at the factory both channels are configured to use internal reference.

External Reference Selection

You can select the external reference signal for either analog output channel (0 or 1) by setting the following jumpers:

Analog Output Channel 0:	W5	A - B	External reference signal connected to DAC 0 reference input.
Analog Output Channel 1:	W4	A - B	External reference signal connected to DAC 1 reference input.

This configuration is shown in Figure 2-8.

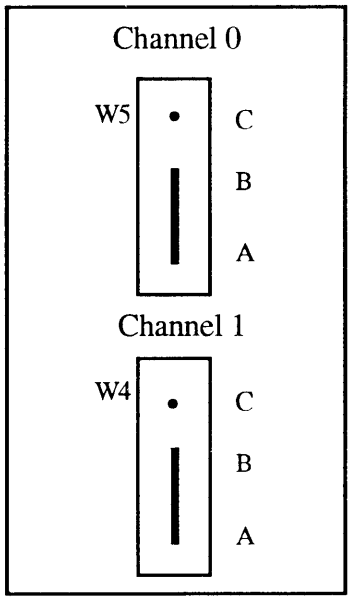


Figure 2-8. External Reference Selection Configuration

Internal Reference Selection (Factory Setting)

You can select the onboard 10 V reference for either analog output channel (0 or 1) by setting the following jumpers:

Analog Output Channel 0:	W5	B - C	10 V onboard reference connected to DAC 0 reference input.
Analog Output Channel 1:	W4	B - C	10 V onboard reference connected to DAC 1 reference input.

This configuration is shown in Figure 2-9.

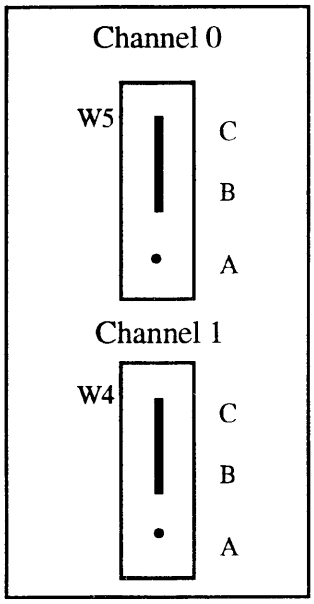


Figure 2-9. Internal Reference Selection Configuration (Factory Setting)

Analog Output Polarity Selection

You can configure each analog output channel for either unipolar or bipolar output. A unipolar configuration has a range of 0 to V_{ref} at the analog output. A bipolar configuration has a range of $-V_{ref}$ to V_{ref} at the analog output. V_{ref} is the voltage reference used by the DACs in the analog output circuitry and can either be the 10 V onboard reference or an externally supplied reference. Both channels need not be configured the same way; however, at the factory both channels are configured for bipolar output.

Bipolar Output Selection (Factory Setting)

You can select the bipolar output configuration for either analog output channel by setting the following jumpers:

Analog Output Channel 0:	W6	A - B
Analog Output Channel 1:	W7	A - B

This configuration is shown in Figure 2-10.

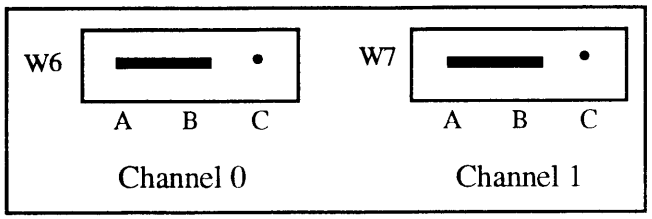


Figure 2-10. Bipolar Output Configuration (Factory Setting)

Unipolar Output Selection

You can select the unipolar output configuration for either analog output channel (0 or 1) by setting the following jumpers:

Analog Output Channel 0:	W6	B - C
Analog Output Channel 1:	W7	B - C

This configuration is shown in Figure 2-11.

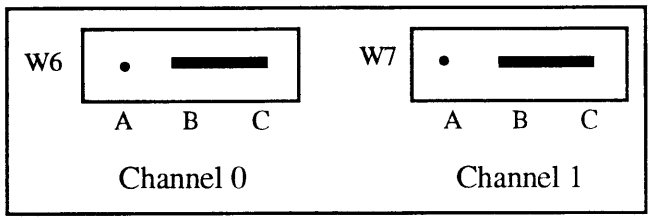


Figure 2-11. Unipolar Output Configuration

Note: ***If you are using a software package such as NI-DAQ or LabVIEW, you may need to reconfigure your software to reflect any changes in jumper or switch settings.***

Installation

Within the manual shipped with your Macintosh computer, read the instructions for installing the video card in the main unit. You can use these instructions as a universal board installation guide.

Read the entire installation procedure before installing the NB-MIO-16 into the Macintosh.

Signal Connections

This section describes input and output signal connections to the NB-MIO-16 board using the NB-MIO-16 I/O connector. This section contains specifications and connection instructions for the signals on the NB-MIO-16 I/O connector.

Warning: ***Connections that exceed any of the maximum ratings of input or output signals on NB-MIO-16 can damage the NB-MIO-16 board and the Macintosh computer. The description of each signal in this section includes information about maximum input ratings. National Instruments is NOT liable for any damages resulting from any such signal connections.***

The pinout for the NB-MIO-16 I/O connector is shown in Figure 2-12.

AIGND	1	2	AIGND
ACH0	3	4	ACH8
ACH1	5	6	ACH9
ACH2	7	8	ACH10
ACH3	9	10	ACH11
ACH4	11	12	ACH12
ACH5	13	14	ACH13
ACH6	15	16	ACH14
ACH7	17	18	ACH15
AISENSE	19	20	DAC0 OUT
DAC1 OUT	21	22	EXTREF
AOGND	23	24	DIGGND
ADIO0	25	26	BDIO0
ADIO1	27	28	BDIO1
ADIO2	29	30	BDIO2
ADIO3	31	32	BDIO3
DIGGND	33	34	+5 V
+5 V	35	36	SCANCLK
EXSTROBE*	37	38	EXTTRIG*
EXTGATE	39	40	EXTCONV*
SOURCE1	41	42	GATE1
OUT1	43	44	SOURCE2
GATE2	45	46	OUT2
SOURCE5	47	48	GATE5
OUT5	49	50	FOUT

Figure 2-12. NB-MIO-16 I/O Connector

The signals on the back of the I/O connector can be classified as analog input signals, analog output signals, digital I/O signals, digital power connections, or timing I/O signals. Signal connection guidelines for each of these groups are given below.

Analog Input Signal Connections

Pins 1 through 19 of the I/O connector are analog input signal pins. Pins 1 and 2 are AIGND signal pins. AIGND is an analog input common signal that is routed directly to the ground tie point on the NB-MIO-16. These pins can be used for a general analog power ground tie point to the NB-MIO-16 if necessary. Pin 19 is the AISENSE pin. In NRSE mode, this pin is connected internally to the negative (-) input of the NB-MIO-16 instrumentation amplifier. In DIFF mode, this signal is connected to the reference ground at the output of the instrumentation amplifier.

Pins 3 through 18 are ACH<15..0> signal pins. These are tied to the 16 analog input channels of the NB-MIO-16. In single-ended mode, signals connected to ACH<15..0> are routed to the positive (+) input of the NB-MIO-16 instrumentation amplifier. In DIFF mode, signals connected to ACH<7..0> are routed to the positive (+) input of the NB-MIO-16 instrumentation amplifier, and signals connected to ACH<15..8> are routed to the negative (-) input of the NB-MIO-16 instrumentation amplifier.

The following input ranges and maximum ratings apply to inputs ACH<15..0>:

Differential Input Range	±10 V
Common Mode Input Range	±7 V
Input Range	±12 V
Maximum Input Voltage Rating	±20 V for NB-MIO-16 board powered off ±35 DC or peak V for NB-MIO-16 board powered on

Warning: ***Exceeding the differential and common mode input ranges will result in distorted input signals. Exceeding the maximum input voltage rating can damage the NB-MIO-16 board and the Macintosh computer. National Instruments is NOT liable for any damages resulting from any such signal connections.***

The way in which you connect analog input signals to the NB-MIO-16 depends on the configuration of the NB-MIO-16 analog input circuitry and the type of input signal source. The different NB-MIO-16 configurations allow the NB-MIO-16 instrumentation amplifier to be used in different ways. Figure 2-13 shows a diagram of the NB-MIO-16 instrumentation amplifier.

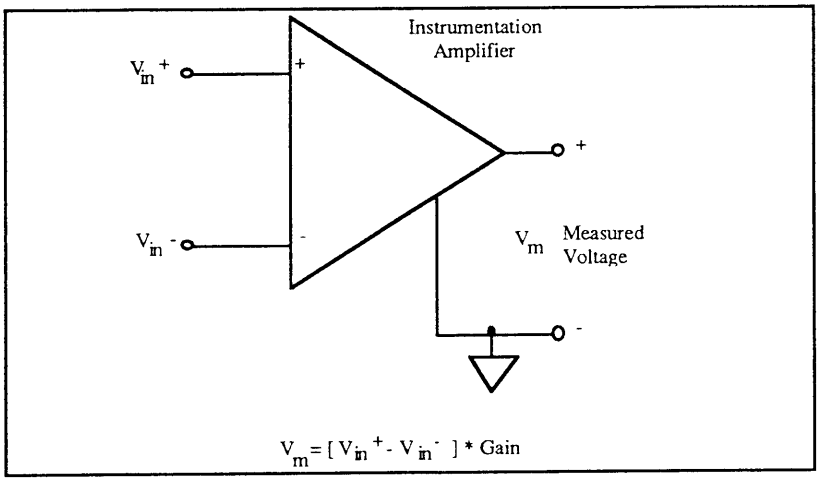


Figure 2-13. NB-MIO-16 Instrumentation Amplifier

The NB-MIO-16 instrumentation amplifier applies gain, common-mode voltage rejection, and high input impedance to the analog input signals connected to the NB-MIO-16 board. Signals are routed to the positive (+) and negative (-) inputs of the instrumentation amplifier through input multiplexers on the NB-MIO-16. The instrumentation amplifier converts two input signals to a signal that is the difference between the two input signals multiplied by the gain setting of the amplifier. The amplifier output voltage is referenced to the NB-MIO-16 ground. The NB-MIO-16 ADC measures this output voltage when it performs A/D conversions.

Types of Signal Sources

When configuring the input mode of the NB-MIO-16 and making signal connections, you must first determine whether the signal source is floating or ground-referenced. These two types of signals are described in the following sections.

Floating Signal Sources

A floating signal source is one not connected in any way to the building ground system but rather has an isolated ground reference point. If an instrument or device provides an isolated output, it falls into the floating signal source category. Some examples of floating signal sources are outputs for the following: transformers, thermocouples, battery-powered devices, optical isolators, and isolation amplifiers. In order to obtain reliable measurements, the ground reference of a floating signal must be tied to the NB-MIO-16 analog input ground. Consequently, the input signal source refers to the same ground as the NB-MIO-16.

Grounded Signal Sources

A grounded signal source is one that is connected in some way to the building system ground and is therefore already connected to a common ground point with respect to the NB-MIO-16 board (assuming that the Macintosh is plugged into the same power system). Non-isolated outputs of instruments and devices that plug into the building power system fall into this category. However, if an instrument or device provides an isolated output, it falls into the floating signal source category.

The difference in ground potential between two instruments connected to the same building power system is typically between 1 and 100 mV. If a grounded signal source is measured improperly, this difference may show up as an error in the measurement. The connection instructions for the grounded signal sources described below are designed to eliminate this ground potential difference from the measured signal.

Input Configurations

The NB-MIO-16 can be configured for one of three input modes–NRSE, RSE, or DIFF. The following sections discuss the use of single-ended and differential measurements, and considerations for measuring both floating and ground-referenced signal sources. Table 2-4 summarizes the recommended input configuration for both types of signal sources.

Table 2-4. Recommended Input Configurations for Ground-Referenced and Floating Signal Sources

Type of Signal	Recommended Input Configuration
Ground-Referenced (non-isolated outputs, plug-in instruments)	DIFF NRSE
Floating (batteries, thermocouples, isolated outputs)	DIFF with bias resistors RSE

Differential Connection Considerations (DIFF Configuration)

Differential connections are those in which each NB-MIO-16 analog input signal has its own reference signal or signal return path. These connections are available when the NB-MIO-16 is configured in the DIFF mode. Each input signal is tied to the positive (+) input of the instrumentation amplifier, and its reference signal, or return, is tied to the negative (-) input of the instrumentation amplifier.

When the NB-MIO-16 is configured for DIFF input each signal uses two multiplexer inputs–one for the signal and one for its reference signal. Therefore, only eight analog input channels are available when using the DIFF configuration. The DIFF input configuration should be used when any of the following conditions are present:

- Input signals are low-level (less than 1 V).
- Leads connecting the signals to the NB-MIO-16 are long (greater than 15 ft).
- Any of the input signals requires a separate ground reference point or return signal.
- The signal leads travel through noisy environments.

Differential signal connections provide reduction of acquired noise, common mode signal and noise rejection, and separate return paths for each input signal, and they allow input signals to float within the common mode limits of the input instrumentation amplifier.

Differential Connections for Grounded Signal Sources

Figure 2-14 shows how to connect a grounded signal source to an NB-MIO-16 board configured for DIFF input. Configuration instructions are provided under *Board Configuration* earlier in this chapter.

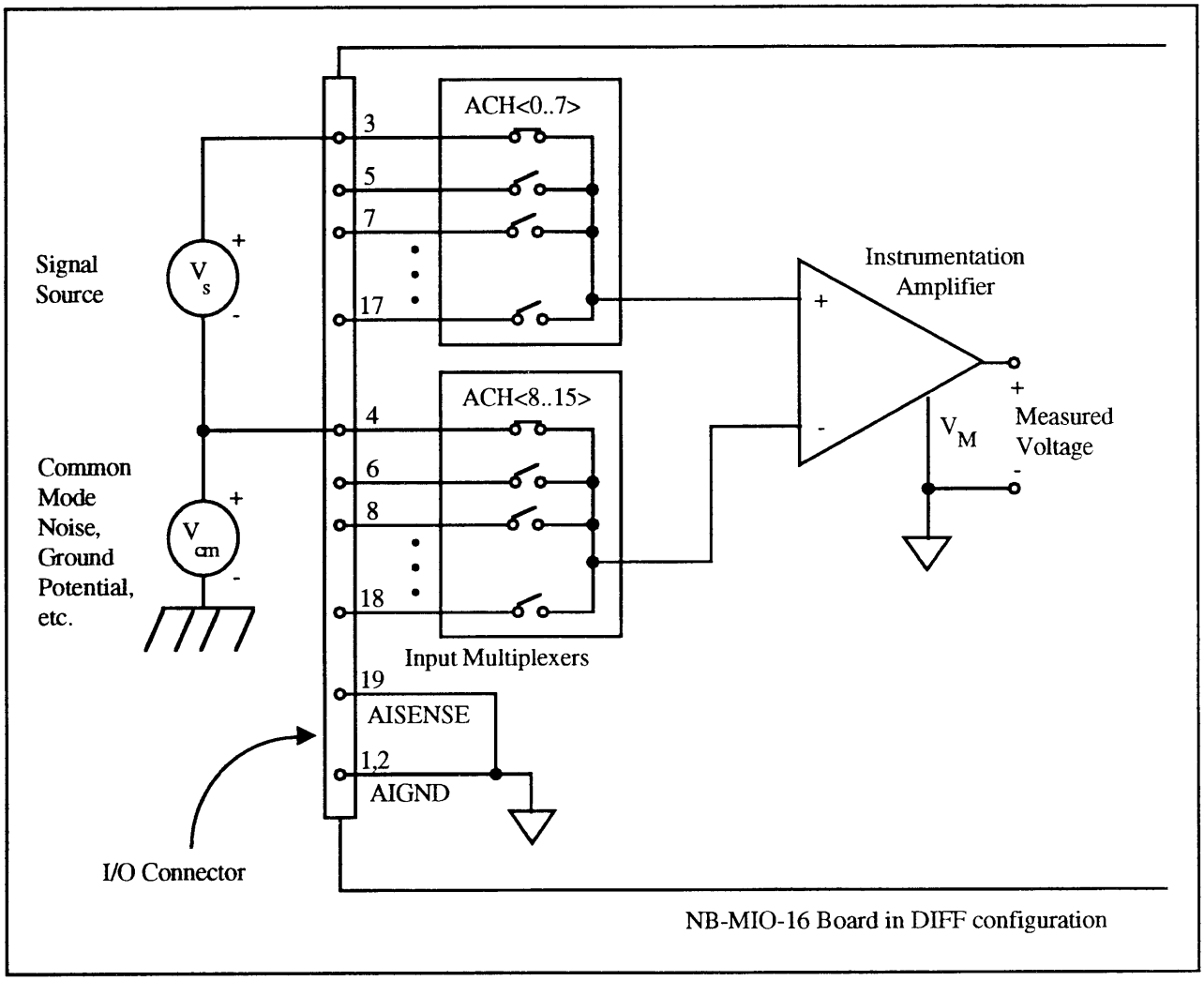


Figure 2-14. Differential Input Connections for Grounded Signal Sources

With this type of connection, the instrumentation amplifier rejects both the common mode noise in the signal and the ground potential difference between the signal source and the NB-MIO-16 ground (shown as V_{cm} in Figure 2-14).

Differential Connections for Floating Signal Sources

Figure 2-15 shows how to connect a floating signal source to an NB-MIO-16 board configured for DIFF input. Configuration instructions are described under *Board Configuration* earlier in this chapter.

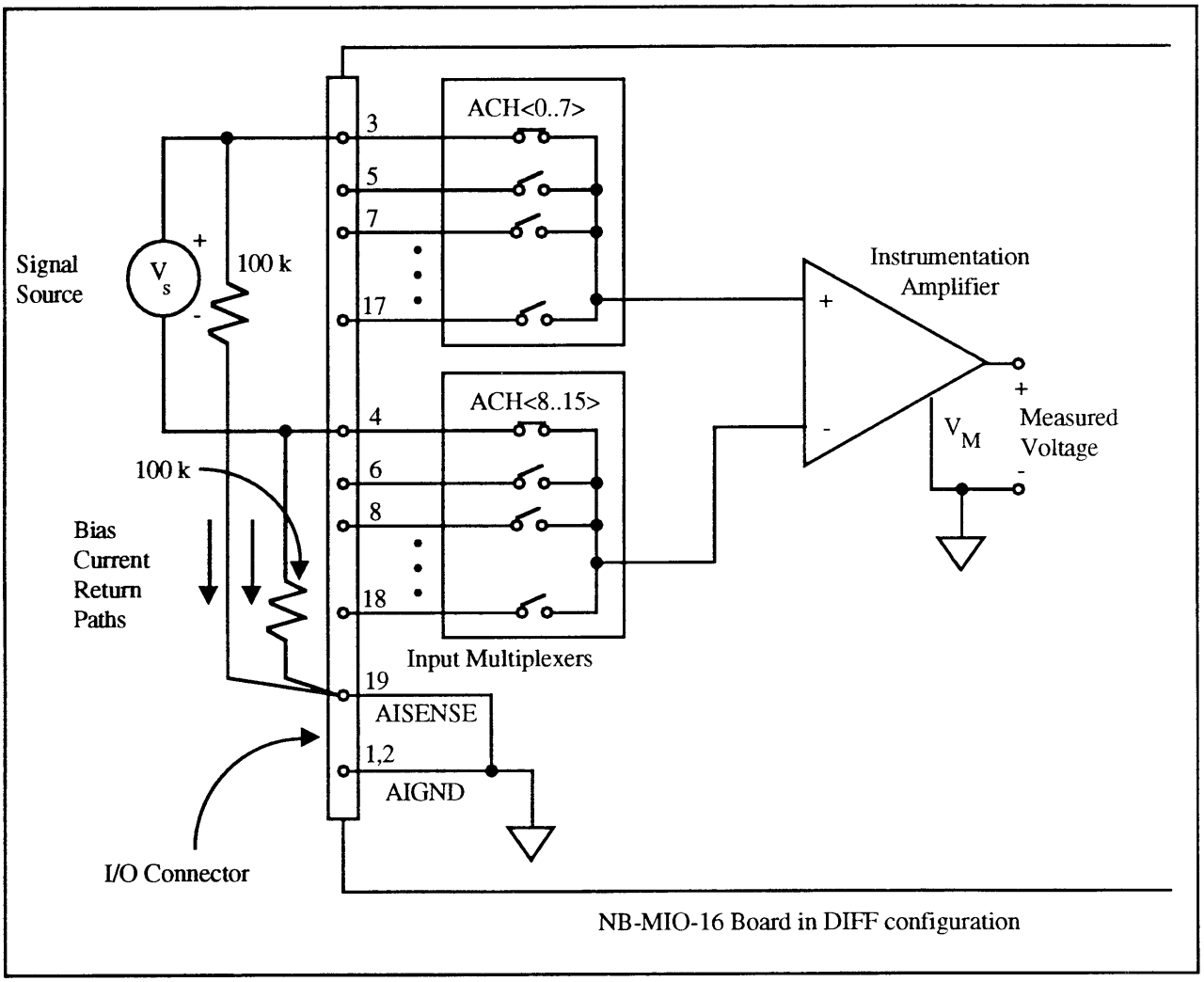


Figure 2-15. Differential Input Connections for Floating Sources

The 100 kΩ resistors shown in Figure 2-15 are necessary to provide a return path to ground for the bias currents of the instrumentation amplifier. If a return path is not provided, the instrumentation amplifier bias currents charge up stray capacitances, resulting in uncontrollable drift and possible saturation in the amplifier. Typically, values from 10 to 100 kΩ are used.

Tying a resistor from each input to ground, as shown in Figure 2-15, provides bias current return paths for an AC-coupled input signal. This solution, although necessary for AC-coupled signals, lowers the input impedance of the analog input channel. In addition, the input offset current of the instrumentation amplifier contributes a DC offset voltage at the input. The amplifier has a

maximum input offset current of ±15 nA and a typical offset current drift of ±20 pA/°C. Multiplied by the 100 k resistor, this current contributes a maximum offset voltage of 1.5 mV and a typical offset voltage drift of 2 µV/°C at the input. Keep this in mind when DC offsets are observed with AC-coupled inputs.

If the input signal is DC coupled, then only one resister connecting the negative (-) signal input to ground is required. This connection does not lower the input impedance of the analog input channel.

Single-Ended Connection Considerations

In single-ended connections, all NB-MIO-16 analog input signals are referenced to one common ground. The input signals are tied to the positive (+) input of the instrumentation amplifier, and their common ground point is tied to the negative (-) input of the instrumentation amplifier.

When the NB-MIO-16 is configured for single-ended input (NRSE or RSE), 16 analog input channels are available. Single-ended input connections can be used when the following criteria are met by all input signals:

- Input signals are high-level (greater than 1 V).
- Leads connecting the signals to the NB-MIO-16 are short (less than 15 ft).
- All input signals share a common reference signal (at the source).

If any of the above criteria is not met, you should use DIFF input configuration.

The NB-MIO-16 can be jumper configured for two different types of single-ended connections: RSE configuration and NRSE configuration. The RSE configuration is used for single-ended connections to floating signal sources. The NRSE configuration is used for single-ended connections to grounded signal sources.

Single-Ended Connections for Floating Signal Sources (RSE Configuration)

Figure 2-16 shows how to connect a floating signal source to an NB-MIO-16 board configured for single-ended input. The NB-MIO-16 analog input circuitry must be configured for RSE input in order to make these types of connections. Configuration instructions are provided under *Board Configuration* earlier in this chapter.

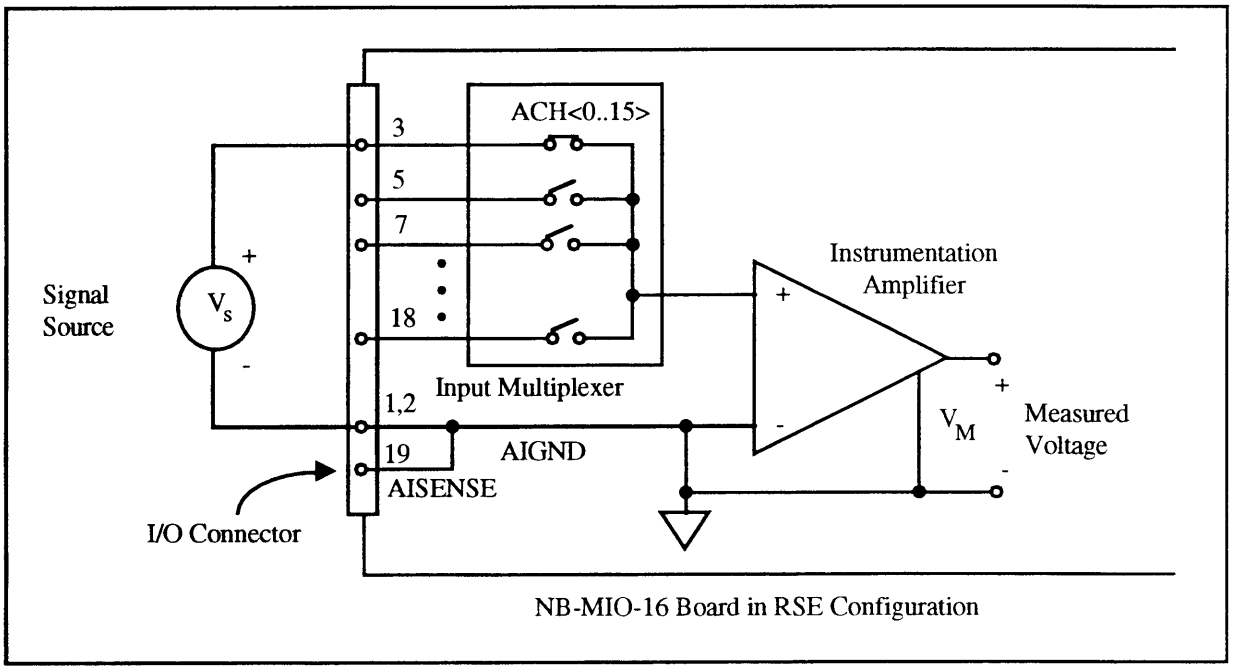


Figure 2-16. Single-Ended Input Connections for Floating Signal Sources

Single-Ended Connections for Grounded Signal Sources (NRSE Configuration)

If a grounded signal source is to be measured with a single-ended configuration, then the NB-MIO-16 must be configured in the NRSE input configuration. The signal is connected to the positive (+) input of the NB-MIO-16 instrumentation amplifier and the signal local ground reference is connected to the negative (-) input of the NB-MIO-16 instrumentation amplifier. The ground point of the signal should therefore be connected to the AISENSE pin. Any potential difference between the NB-MIO-16 ground and the signal ground appears as a common mode signal at both the positive (+) and negative (-) inputs of the instrumentation amplifier and this difference is rejected by the amplifier. On the other hand, if the input circuitry of the NB-MIO-16 is referenced to ground, such as in the RSE configuration, this difference in ground potentials appears as an error in the measured voltage.

Figure 2-17 shows how to connect a grounded signal source to an NB-MIO-16 board configured in the NRSE configuration. Configuration instructions are provided under *Board Configuration* earlier in this chapter.

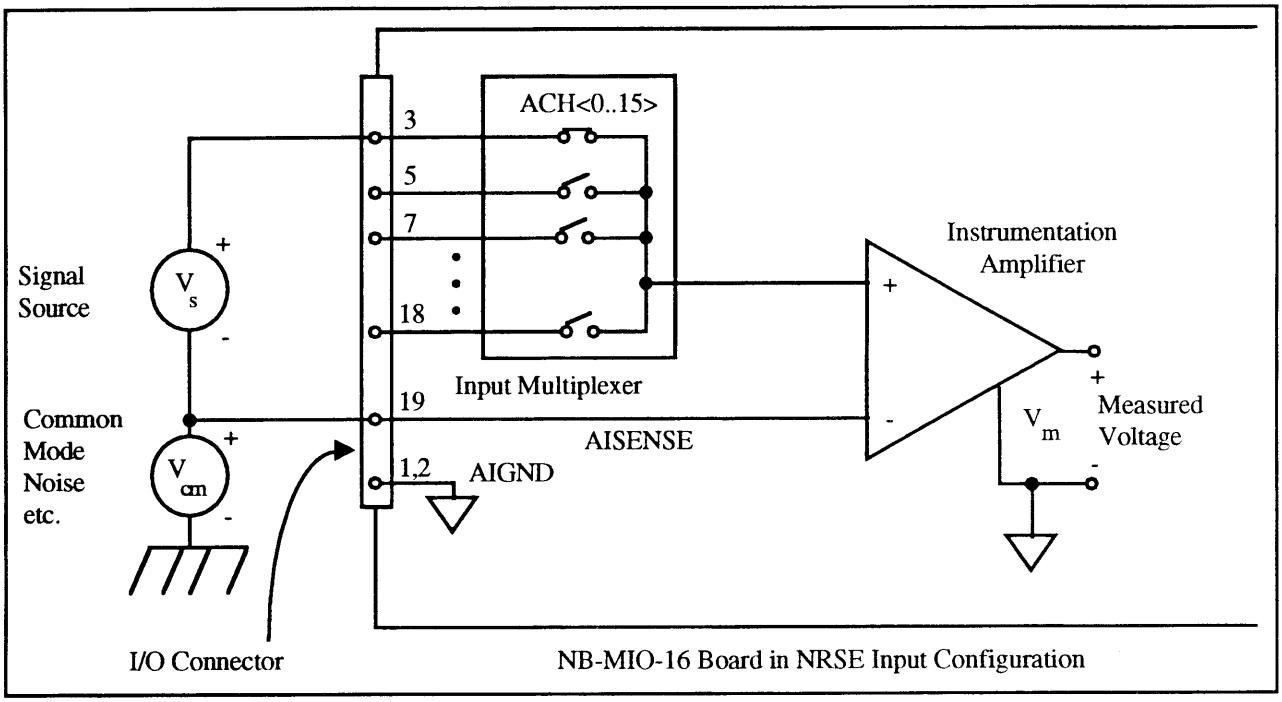


Figure 2-17. Single-Ended Input Connections for Grounded Signal Sources

Common Mode Signal Rejection Considerations

Figures 2-14 and 2-17 earlier in this chapter show connections for signal sources that are already referenced to some ground point with respect to the NB-MIO-16. In these cases, the instrumentation amplifier can reject any voltage due to ground potential differences between the signal source and the NB-MIO-16. In addition, with differential input connections, the instrumentation amplifier can reject common mode noise pickup in the leads connecting the signal sources to the NB-MIO-16.

The common mode input range of the NB-MIO-16 instrumentation amplifier determines the maximum size of a rejected common mode signal. This common mode voltage is measured with respect to the NB-MIO-16 ground and can be characterized by the following formula:

$$V_{cm} = \frac{(V^{+}_{in} + V^{-}_{in})}{2}$$

where V^{+}_{in} is the signal at the positive (+) input of the instrumentation amplifier and V^{-}_{in} is the signal at the negative (-) input of the instrumentation amplifier.

The common mode input range for the NB-MIO-16 instrumentation amplifier depends on the size of the differential input signal ($V_{diff} = V^{+}_{in} - V^{-}_{in}$) and the gain setting of the instrumentation amplifier. The exact formula for the allowed common mode input range is:

$$V_{cm\text{-}max} = \pm (12\ V - \frac{V_{diff} * gain}{2})$$

For example, for a differential voltage as large as 20 mV and a gain of 500, the largest common mode voltage that can be rejected is ±7 V. However, if the differential signal is 10 mV with a gain of 500, then ±9.5 V common mode voltage can be rejected.

If the input signal common mode range exceeds ±7 V with respect to the NB-MIO-16 ground, you need to limit the amount of floating that occurs between the signal ground and the NB-MIO-16 ground.

Analog Output Signal Connections

Pins 20 through 23 of the I/O connector are analog output signal pins.

Pins 20 and 21 are the DAC0 OUT and DAC1 OUT signals pins. DAC0 OUT is the voltage output signal for analog output channel 0. DAC1 OUT is the voltage output signal for analog output channel 1.

Pin 22, EXTREF, is the external reference input for both analog output channels. Each channel must be configured for external reference selection in order for the signal applied at the external input to be used by the analog output channel. Analog output configuration instructions are described under *Board Configuration* earlier in this chapter.

The following ranges and ratings apply to the EXTREF input:

Useful Input Voltage Range:	±10 V peak with respect to AOGND
Absolute Maximum Rating:	±25 V peak with respect to AOGND

Pin 23, AOGND, is the ground reference point for both analog output channels and for the external reference signal.

Figure 2-18 shows how to make analog output connections and the external reference input connection to the NB-MIO-16 board. If neither channel is configured to use an external reference signal, do not connect anything to the EXTREF pin.

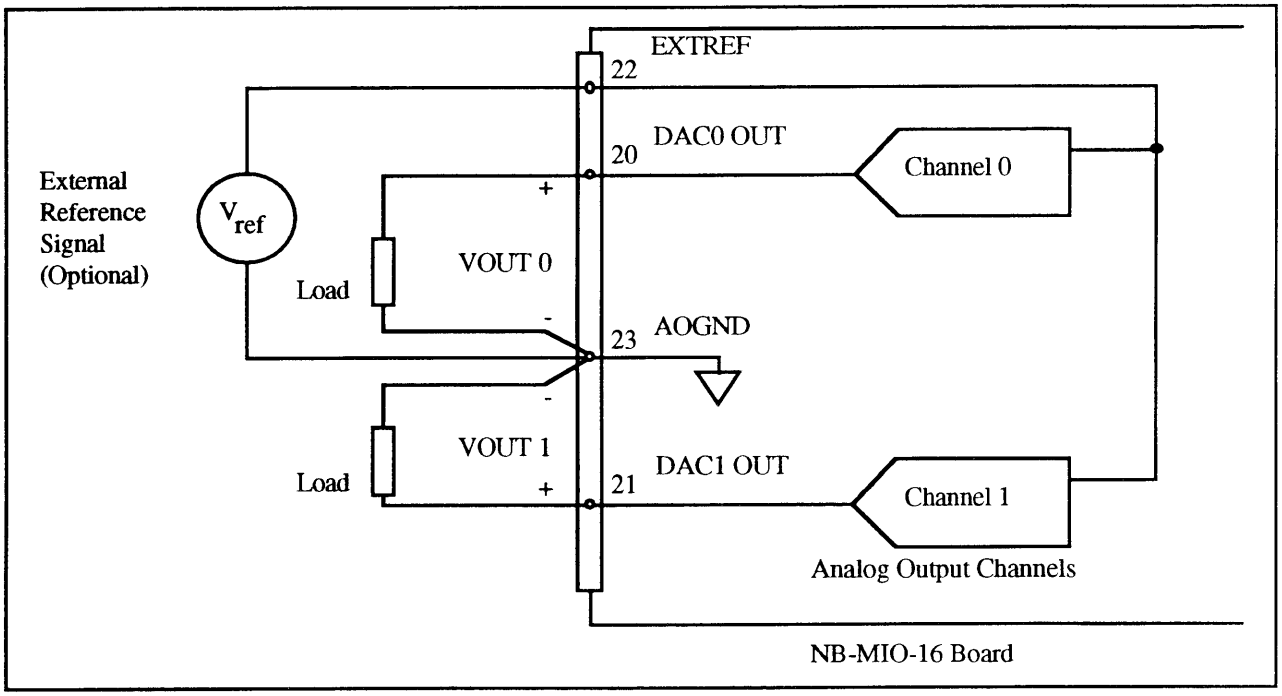


Figure 2-18. Analog Output Connections

The external reference signal can be either a DC or AC signal. The DACs in the analog output channels are rated for -82 dB total harmonic distortion with a 1 kHz, 6 Vrms sine wave reference signal and with the DACs set at their maximum (fullscale) digital value.

Digital I/O Signal Connections

Pins 24 through 32 of the I/O connector are digital I/O signal pins.

Pins 25, 27, 29, and 31 are connected to the digital lines ADIO<3..0> for digital I/O port A. Pins 26, 28, 30, and 32 are connected to the digital lines BDIO<3..0> for digital I/O port B. Pin 24, DIGGND, is the digital ground pin for both digital I/O ports.

The following specifications and ratings apply to the digital I/O lines.

Absolute Maximum Voltage
Input Rating: 5.5 V with respect to DIGGND

Digital Input Specifications (referenced to DIGGND):

V_{IH} input logic high voltage: 2 V minimum
V_{IL} input logic low voltage: 0.8 V maximum

I_{IH} input current load,
logic high input voltage: 40 µA maximum

I_{IL} input current load,
logic low input voltage: -120 µA maximum

Digital Output Specifications (referenced to DIGGND):

V_{OH} output logic high voltage: 2.4 V minimum
V_{OL} output logic low voltage: 0.5 V maximum

I_{OH} output source current, logic high: 2.6 mA maximum

I_{OH} output sink current, logic low: 24 mA maximum

With these specifications, each digital output line is capable of driving 11 standard TTL loads and over 50 LS TTL loads.

Figure 2-19 demonstrates signal connections for three typical digital I/O applications.

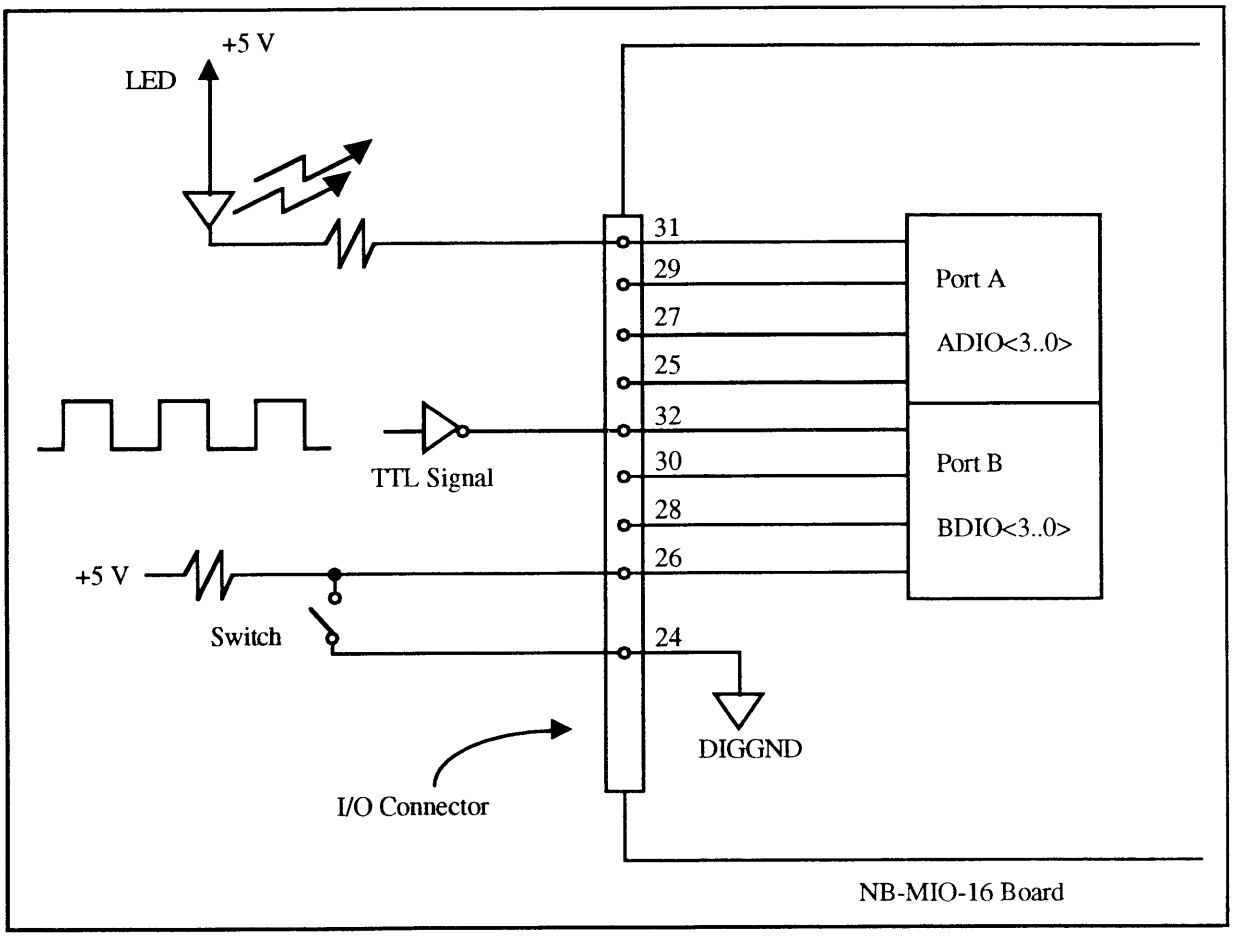


Figure 2-19. Digital I/O Connections

In Figure 2-19, port A is configured for digital output, and port B is configured for digital input. Digital input applications include receiving TTL signals and sensing external device states such as the state of the switch depicted in this figure. Digital output applications include sending TTL signals and driving external devices such as the LED shown in Figure 2-19.

Power Connections

Pins 34 and 35 of the I/O connector provide +5 V from the Macintosh power supply. These pins are referenced to DIGGND and can be used to power external digital circuitry.

Power Rating: 0.5 A at +5 V ± 10%

Warning: *Under no circumstances* ***should you connect these +5 V power pins directly to analog or digital ground or to any other voltage source on the NB-MIO-16 or on any other device. Doing so can damage the NB-MIO-16 and the Macintosh computer. National Instruments is NOT liable for damage resulting from such a connection.***

Timing Connections

Pins 36 through 50 of the I/O connector are connections for timing I/O signals. Pins 36 through 40 carry signals used for data acquisition timing. These signals are explained under *Data Acquisition Timing Connections* below. Pins 41 through 50 carry general-purpose timing signals provided by the onboard Am9513 counter/timer. These signals are explained under *General-Purpose Timing Connections* later in this chapter.

Data Acquisition Timing Connections

The data acquisition timing signals are SCANCLK, EXTSTROBE*, EXTTRIG, EXTGATE, and EXTCONV*.

SCANCLK is an output signal that generates a low-to-high edge whenever an A/D conversion begins. SCANCLK only pulses when scanning is enabled on the NB-MIO-16. SCANCLK is normally high and pulses low for approximately 1 µs before the A/D conversion begins. The low-to-high edge can be used to clock external analog input multiplexers to the NB-MIO-16 if desired. The SCANCLK signal is driven by one LS TTL gate.

A low pulse is generated on the EXTSTROBE* pin when the External Strobe Register is loaded (see *External Strobe Register* in Chapter 4, *Programming*). Figure 2-20 shows the timing for the EXTSTROBE* signal.

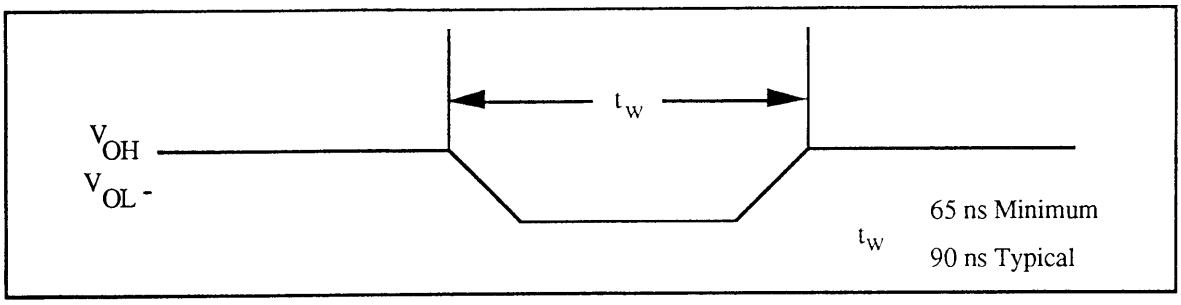


Figure 2-20. EXTSTROBE* Signal Timing

The pulse is typically 90 ns at a minimum 65 ns in width. The EXTSTROBE* signal can latch or trigger any external device. The EXTSTROBE* signal is an LS TTL signal.

The EXTCONV* pin externally triggers A/D conversions. Applying an active low pulse to the EXTCONV* initiates an A/D conversion. The A/D conversion is initiated by the high-to-low edge of the applied pulse. Figure 2-21 shows the timing requirements for the EXTCONV* signal.

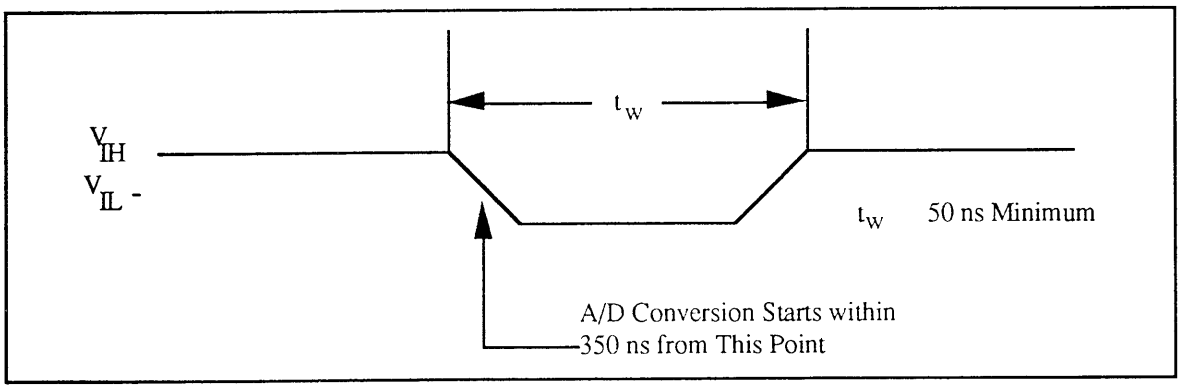


Figure 2-21. EXTCONV* Signal Timing

The minimum allowed pulse width is 50 ns. An A/D conversion starts within 350 ns of the high-to-low edge. There is no maximum pulse width limitation. EXTCONV* should be high for at least 50 ns before going low. The EXTCONV* signal is one LS TTL load and is pulled up to +5 V through a 4.7 kΩ resistor.

Note: ***EXTCONV* is also driven by the output of Counter 3 of the Am9513 Counter/Timer. This counter is also referred to as the sample-interval counter. The output of Counter 3 must be disabled to a high-impedance state if A/D conversions are to be controlled by pulses applied to the EXTCONV* pin. If Counter 3 is used to control A/D conversions, its output signal can be monitored at the EXTCONV* pin.***

A data acquisition operation controlled by the onboard sample-interval and sample counters can be initiated by an external trigger applied to the EXTTRIG* pin. If conversions are externally

timed or gated, EXTTRIG* does not apply. Once the two counters are initialized and armed, application of a falling edge to the EXTTRIG* pin starts the counters, thereby initiating a data acquisition operation.

The data acquisition operation is initiated by the high-to-low edge of the applied pulse. Figure 2-22 shows the timing requirements for the EXTTRIG* signal.

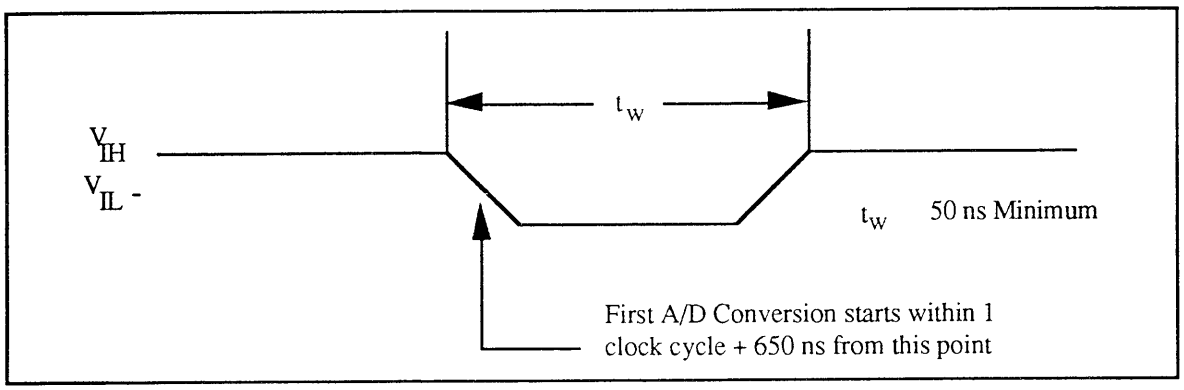


Figure 2-22. EXTTRIG* Signal Timing

The minimum allowed pulse width is 50 ns. The first A/D conversion starts within 1 clock period + 650 ns from the high-to-low edge. This clock period is the clock period of the timebase or source signal used by the sample-interval counter.

There is no maximum pulse width limitation; however, EXTTRIG* should be high for at least 50 ns before going low. The EXTTRIG* signal is one LS TTL load and is pulled up to +5 V through a 4.7 kΩ resistor.

When initiating a data acquisition operation with software, the EXTTRIG* pin at the I/O connector must be left unconnected, or driven high. If EXTTRIG* is held low, the software trigger is disabled.

Multiple A/D conversions can be externally enabled and disabled via the EXTGATE pin. The EXTGATE signal is applied to the GATE4 input of the Am9513 Counter/Timer and can be used to gate Counter 3, the sample-interval counter. Assuming that Counter 3 is programmed to generate conversion pulses and is armed, Counter 3 generates conversion pulses whenever EXTGATE is high and does not generate conversion pulses whenever EXTGATE is low. Figure 2-23 shows the timing requirements for the EXTGATE signal.

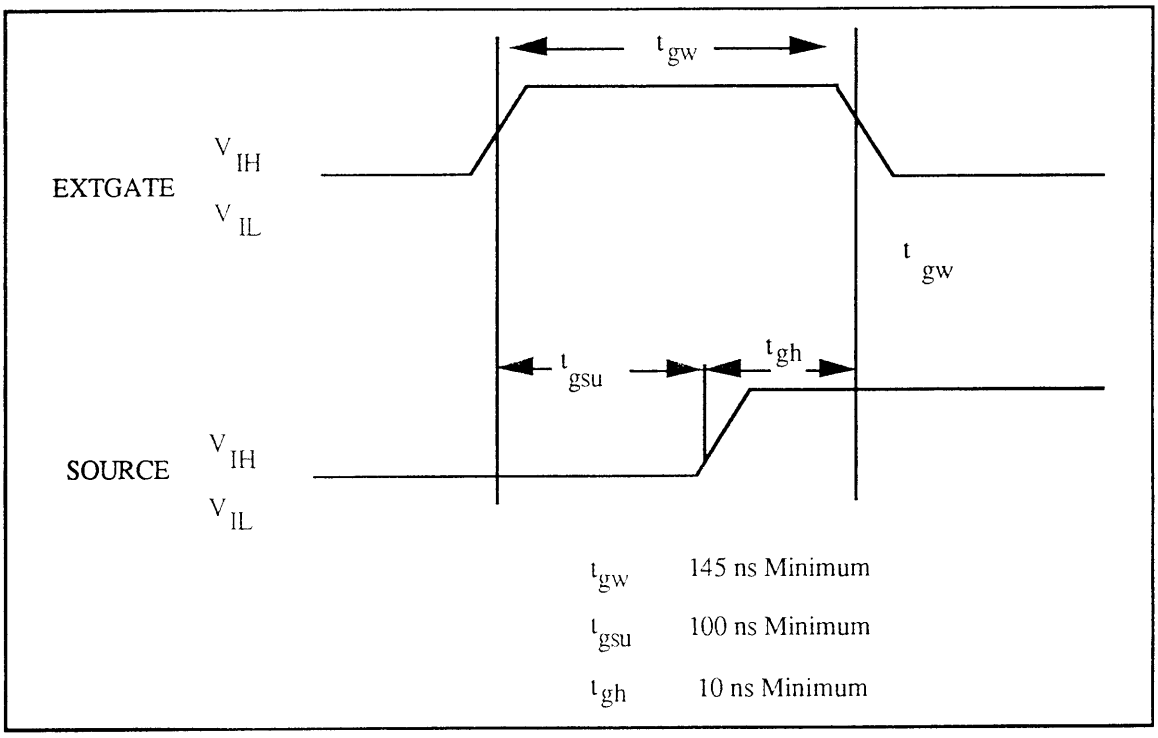


Figure 2-23. EXTGATE Signal Timing

The source signal shown in Figure 2-23 can be an externally supplied clock or one of the Am9513 internally generated timebases.

The EXTGATE signal is one LS TTL load and is pulled up to +5 V through a 4.7 kΩ resistor. The EXTGATE signal is tied directly to the GATE input of the Am9513 Counter/Timer and therefore must comply with the Am9513 signal requirements. The Am9513 specifications are given later in this chapter under *General-Purpose Timing Signal Connections*.

The sample-interval counter (Counter 3) can be gated by either the sample counter (Counter 4) or by the EXTGATE signal, but not both. If external gating is used, the sample counter no longer controls the sample-interval counter.

General-Purpose Timing Signal Connections

The general-purpose timing signals include the GATE, SOURCE, and OUT signals for the Am9513 Counters 1, 2, and 5, and the FOUT signal generated by the Am9513. Counters 1, 2, and 5 of the Am9513 Counter/Timer can be used for general-purpose applications such as pulse and square wave generation, event counting, and pulse-width, time-lapse, and frequency measurement. These applications can be executed by sending SOURCE and GATE signals to the counters and by programming the counters for various operations.

The Am9513 Counter/Timer is described briefly in Chapter 3, *Theory of Operation*. For detailed programming information, consult Appendix C, *AMD Data Sheet*. For detailed applications

information consult the technical manual titled *The Am9513A/Am9513 System Timing Controller* published by Advanced Micro Devices, Inc.

Pulses and square waves are generated by programming a counter to generate a timing signal at its OUT output pin. The counters can be programmed to generate pulses or to change state each time a counter reaches 0.

To perform event counting, a counter is programmed to count rising or falling edges applied to any of the Am9513 SOURCE inputs. The counter value can then be read to determine the number of edges that have occurred. Counter operation can be gated on and off during event counting. Figure 2-24 shows connections for a typical event-counting operation where a switch is used to gate the counter on and off.

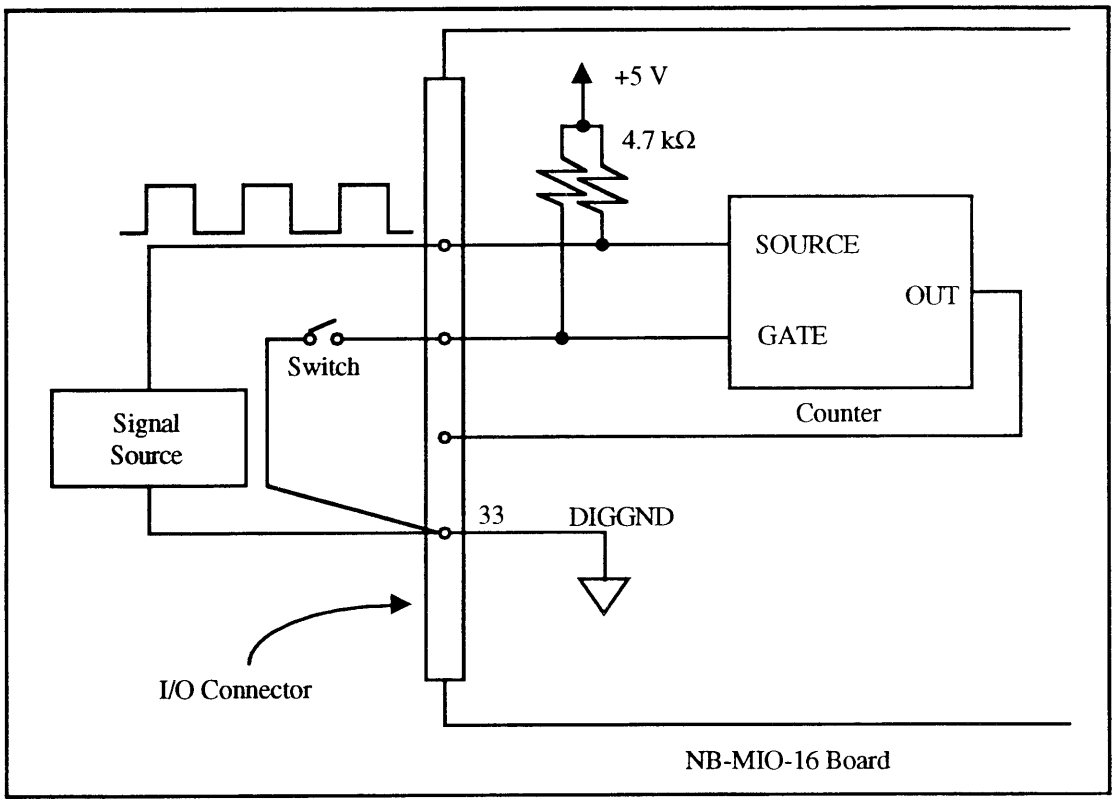


Figure 2-24. Event-Counting Application with External Switch Gating

To measure pulse width, a counter is programmed to be level gated. The pulse to be measured is applied to the counter GATE input. The counter is programmed to count while the signal at the GATE input is either high or low. If the counter is programmed to count an internal timebase, then the pulse width is equal to the counter value multiplied by the timebase period.

To measure time lapse, a counter is programmed to be edge gated. An edge is applied to the counter GATE input to start the counter. The counter can be programmed to start counting after receiving either a high-to-low edge or a low-to-high edge. If the counter is programmed to count

an internal timebase, then the time lapse since receiving the edge is the counter value multiplied by the timebase period.

To measure frequency, a counter is programmed to be level gated and to count the number of rising or falling edges in a signal applied to a SOURCE input. The gate signal applied to the counter GATE input is of some known duration. In this case, the counter is programmed to count either rising or falling edges at the SOURCE input while the gate is applied. The frequency of the input signal is then the count value divided by the known gate period. Figure 2-25 shows the connections for a frequency measurement application. A second counter could also be used to generate the gate signal in this application.

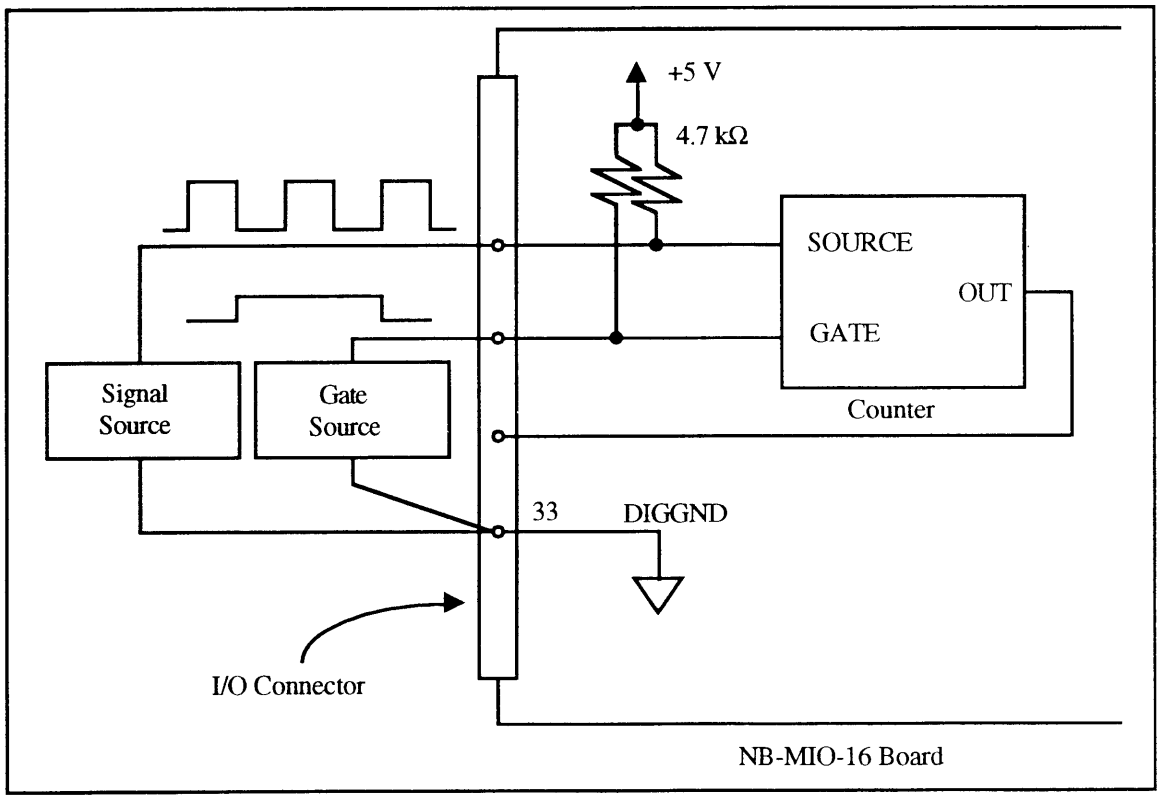


Figure 2-25. Frequency Measurement Application

Two or more counters can be concatenated by tying the OUT signal from one counter to the SOURCE signal of another counter. The counters can then be treated as one 32-bit or 48-bit counter for most counting applications.

The GATE, SOURCE, and OUT signals for Counters 1, 2, and 5, and the FOUT output signal are tied directly from the Am9513 input and output pins to the I/O connector. In addition, the GATE and SOURCE pins are pulled up to +5 V through a 4.7 kΩ resistor. The input and output ratings and the timing specifications for the Am9513 signals are given below.

The following specifications and ratings apply to the Am9513 I/O signals:

Absolute Maximum Voltage Input Rating: -0.5 to +7.0 V with respect to DIGGND

Am9513 Digital Input Specifications (referenced to DIGGND):

V_{IH} input logic high voltage:	2.2 V minimum
V_{IL} input logic low voltage:	0.8 V maximum
Input Load Current:	±10 µA maximum

Am9513 Digital Output Specifications (referenced to DIGGND):

V_{OH} output logic high voltage:	2.4 V minimum
V_{OL} output logic low voltage:	0.4 V maximum
I_{OH} output source current, @ V_{OH} :	200 µA maximum
I_{OH} output sink current, @ V_{OL}:	3.2 mA maximum
Output current, high-impedance state:	±25 µA maximum

Figure 2-26 shows the timing requirements for the GATE and SOURCE input signals and the timing specifications for the OUT output signals of the Am9513.

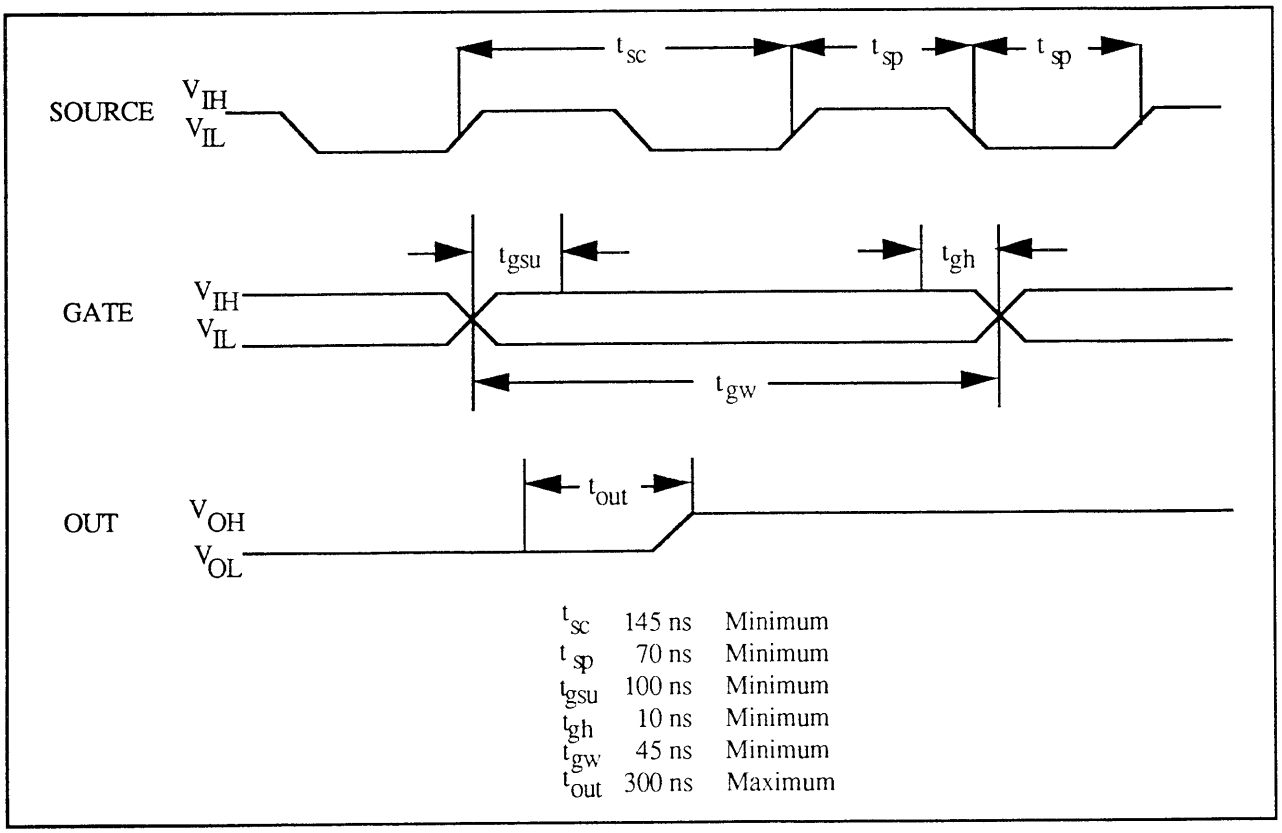


Figure 2-26. General-Purpose Timing Signals

The GATE and OUT signals in Figure 2-26 are referenced to the rising edge of the SOURCE signal. This timing applies to counters programmed to count rising edges. If the counter is programmed to count falling edges, the same timing, referenced to the falling edge of the source signal, applies.

The signal applied at a SOURCE input can be used by any of the Am9513 counter/timers and by the Am9513 frequency division output FOUT as a clock source. The signal applied to a SOURCE input must not exceed a frequency of 6 MHz for proper operation of the Am9513. The Am9513 counters can be individually programmed to count rising or falling edges of signals applied at any of the Am9513 SOURCE or GATE input pins. In addition to the signals applied to the SOURCE and GATE inputs, the Am9513 generates five internal timebase clocks from the 1 MHz signal supplied by the NB-MIO-16. These internal clocks can be used as counting sources. These clocks have a maximum skew of 75 ns between them. The SOURCE signal shown in Figure 2-26 represents any of the signals applied at the SOURCE inputs, GATE inputs, or internal timebase clocks. See Appendix C, *AMD Data Sheet*, for further details.

Specifications for signals at the GATE input are referenced to the signal at the SOURCE input or one of the Am9513 internally generated signals. Figure 2-24 shows the GATE signal referenced to the rising edge of a source signal. The gate must be valid (either high or low) at least 100 ns before the rising or falling edge of a source signal in order for the gate to take effect at that source edge. Similarly, the gate signal must be held for at least 10 ns after the rising or falling edge of a source signal in order for the gate to take effect at that source edge. The gate high or low period must be at least 145 ns in duration. If an internal timebase clock is used, synchronizing the gate signal with the clock is impossible. In this case, gates applied close to a source edge take effect either on that source edge or on the next one, providing an uncertainty of 1 source clock period with respect to unsynchronized gating sources.

Signals generated at the OUT output are referenced to the signal at the SOURCE input or to one of the Am9513 internally generated clock signals. Figure 2-26 shows the OUT signal referenced to the rising edge of a source signal. Any OUT signal state changes occur within 300 ns after the source signal rising or falling edge.

Field Wiring and Cabling

This section discusses cabling and field wiring guidelines for the NB-MIO-16.

Field Wiring

Accuracy of measurements made with the NB-MIO-16 can be seriously affected by environmental noise if proper considerations are not taken into account when running signal wires between signal sources and the NB-MIO-16. The following recommendations mainly apply to analog input signal routing to the NB-MIO-16.

Noise pickup can be minimized and measurement accuracy optimized if the following recommendations are followed for analog input signal connections:

- Use individually shielded, twisted pair wires to connect analog input signals to the NB-MIO-16. When you use this type of wire, the signals attached to the CH+ and CH- inputs are twisted together and then covered with a shield. This shield is then connected at only one point to the signal source ground. This connection is required for signals traveling through areas with large magnetic fields or high electromagnetic interference.
- Use differential analog input connections to reject common mode noise pickup.

The following recommendations apply for all signal connections to the NB-MIO-16:

- Physically separate NB-MIO-16 signal lines from high-current or high-voltage lines. These lines are capable of inducing currents in or voltages on the NB-MIO-16 signal lines if they run in parallel paths at a close distance. Reduce the magnetic coupling between lines by separating them by a reasonable distance if they run in parallel or by running the lines at right angles to each other.
- Do not run NB-MIO-16 signal lines through conduits that also contain power lines.
- Protect NB-MIO-16 signal lines from magnetic fields caused by electric motors, welding equipment, breakers, or transformers by running the NB-MIO-16 signal lines through special metal conduits.

Cabling Considerations

National Instruments currently offers a cable termination accessory for use with the NB-MIO-16 board, the CB-50. This kit includes a terminated 50-conductor flat ribbon cable and a connector block. Signal I/O leads can be attached to screw terminals on the connector block and thereby connected to the NB-MIO-16 I/O connector.

The CB-50 is useful for prototyping an application or in situations where NB-MIO-16 interconnections are frequently changed. Once a final field wiring scheme has been developed, however, you may want to develop your own cable. This section contains information and guidelines for designing such a cable.

The NB-MIO-16 I/O connector is a 50-pin male ribbon cable header. The manufacturer part numbers for the header used by National Instruments are as follows:

Electronic Products Division/3M	part number 3596-5002
T&B/Ansley Corporation	part number 609-5007

The mating connector for the NB-MIO-16 is a 50- position, ribbon socket connector, polarized, with strain relief. National Instruments uses a polarized (keyed) connector to prevent inadvertent upside down connection to the NB-MIO-16. Recommended manufacturers and the part numbers for this mating connector are as follows:

Electronic Products Division/3M	part number 3425-7650
T&B/Ansley Corporation	part number 609-5041CE

Standard ribbon cable (50-conductor, 28 AWG, stranded) that can be used with these connectors is as follows:

Electronic Products Division/3M	part number 3365/50
T&B/Ansley Corporation	part number 171-50

In providing your own cabling, you may want to include some shielding in your cables. The following guidelines may help:

- For the analog input signals, shielded twisted-pair wires for each analog input pair will yield the best results, assuming that differential inputs are used. Tie the shield for each signal pair to the ground reference at the source.
- The analog lines, pins 1 through 23 should be routed separately from the digital lines, pins 24 through 50.
- When using a cable shield, use separate shields for the analog and digital halves of the cable. Failure to do this will result in noise from switching digital signals coupling into the analog signals.

Chapter 3
Theory of Operation

This chapter contains a functional overview of the NB-MIO-16 and explains the operation of each functional unit making up the NB-MIO-16.

Functional Overview

The block diagram in Figure 3-1 contains a functional overview of the NB-MIO-16.

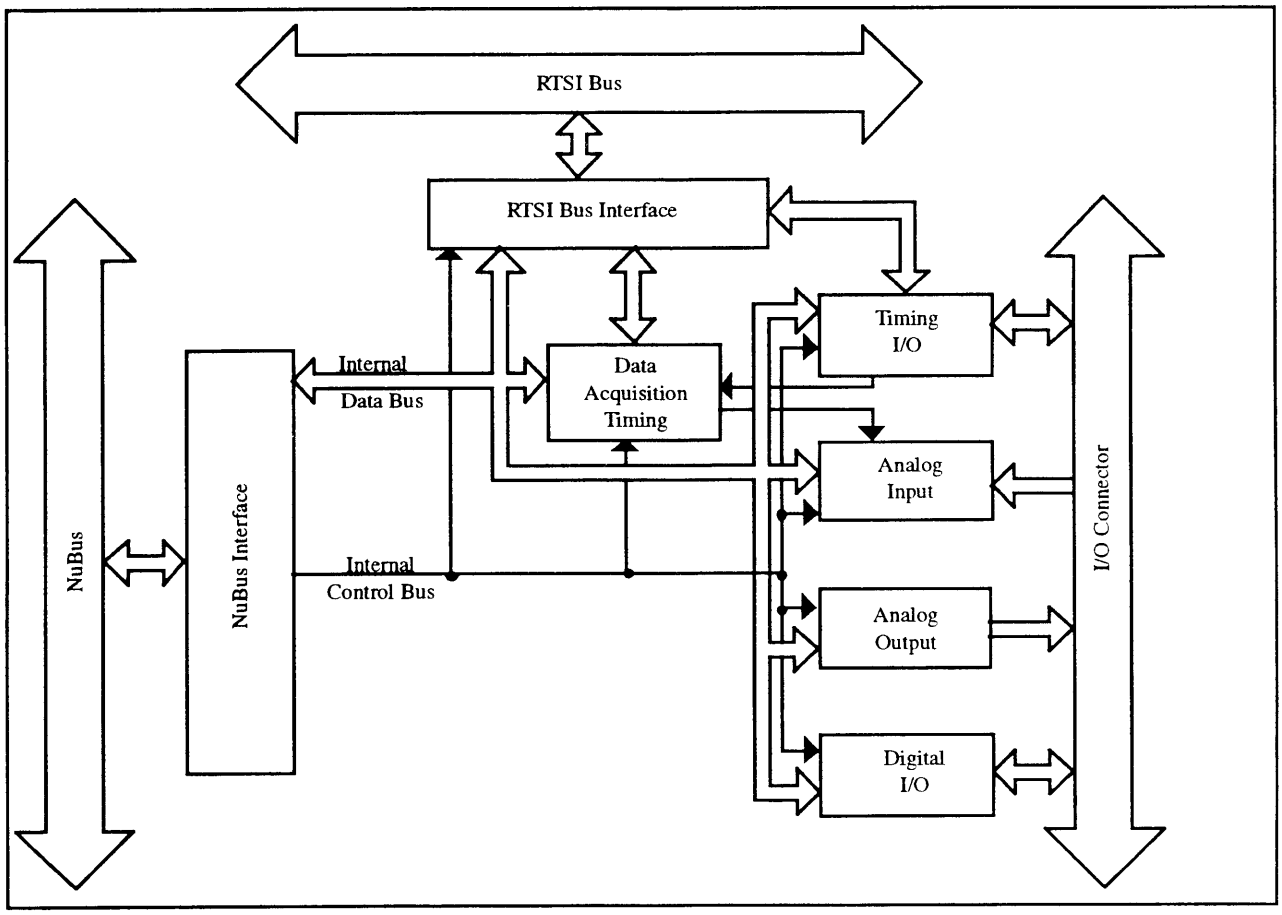


Figure 3-1. NB-MIO-16 Block Diagram

The major components making up the NB-MIO-16 board are the NuBus interface circuitry, the analog input and data acquisition circuitry, the analog output circuitry, the digital I/O circuitry, the timing I/O circuitry, and the RTSI bus interface circuitry. The internal data and control buses interconnect the components. The theory of operation of each of these components is explained in the remainder of this chapter.

NuBus Interface Circuitry

The NB-MIO-16 is a full-sized 16-bit NuBus slave board. The NuBus is a 32-bit address and data bus with a 10-MHz bus clock. In addition, the NuBus provides interface signals for read and write operations and an interrupt line that can be driven by boards in NuBus slots. The components making up the NB-MIO-16 NuBus interface circuitry are shown in Figure 3-2.

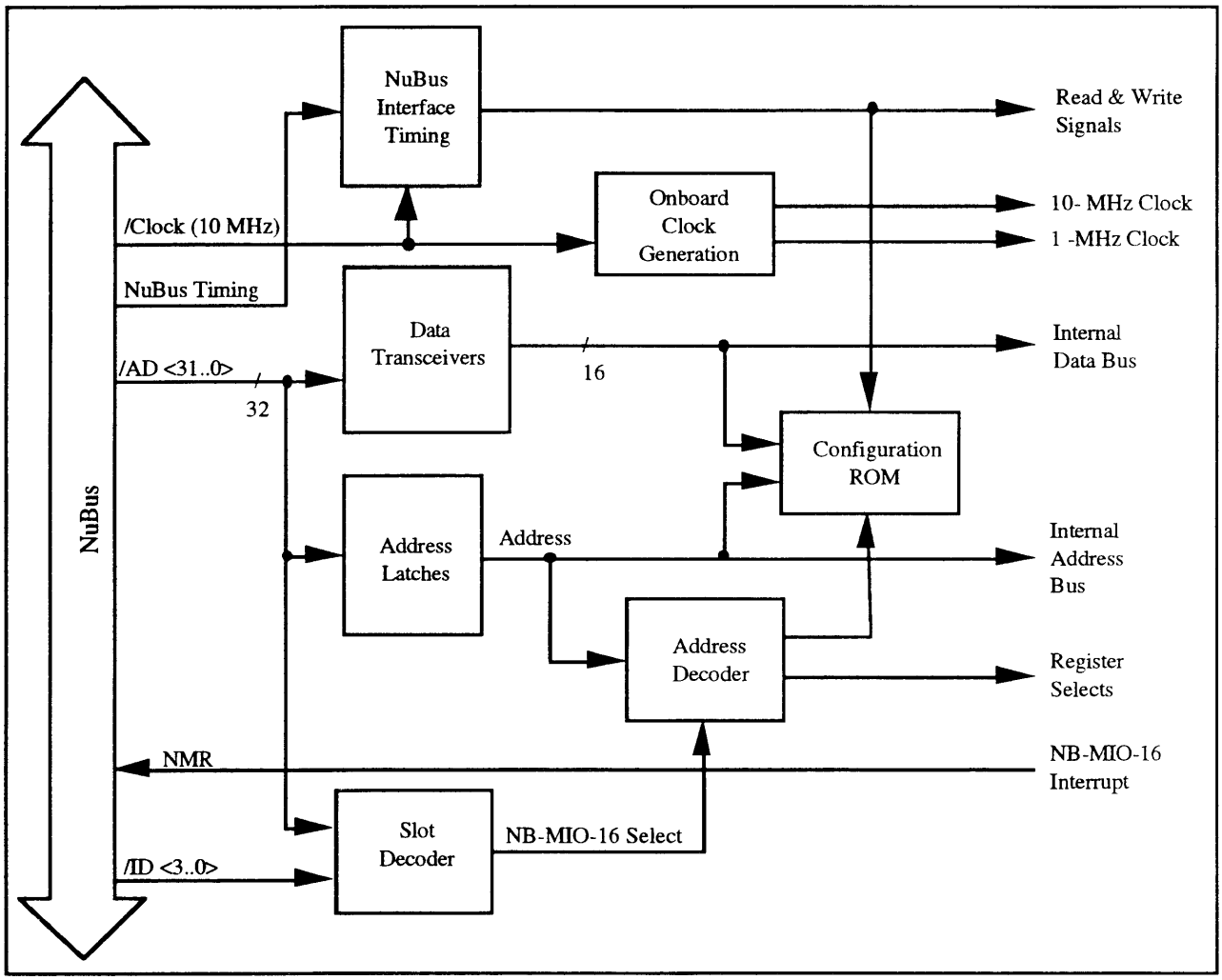


Figure 3-2. NuBus Interface Circuitry Block Diagram

The NuBus Interface Circuitry consists of slot-decoding circuitry, address latches, data transceivers, interface timing signals, address-decoder circuitry, EPROM, NMR interrupt circuitry, and generation of onboard 10-MHz and 1-MHz clocks. This interface circuitry generates the signals necessary to control and monitor the operation of the NB-MIO-16 multiple function circuitry.

The slot-decoding circuitry on the NB-MIO-16 matches NuBus address lines 27 through 24 to the slot ID lines provided by the slot that the board is plugged into. This configuration allows the board to determine when the slot that it occupies is being addressed. Each slot in the Macintosh has a unique slot address. The address latches on the NB-MIO-16 latch address lines 0 through 19 from the NuBus. These address lines are decoded by the NB-MIO-16 address-decoding circuitry to generate selects for the onboard configuration ROM and other registers on the board. Address lines 20 through 23 are left undecoded by the NB-MIO-16 board to make the NB-MIO-16 compatible with both the 24-bit and 32-bit bus modes used by the Macintosh.

The NB-MIO-16 is a 16-bit interface board and therefore only uses 16 of the 32 data lines on the NuBus. The NuBus interface timing signals are decoded by the NB-MIO-16 NuBus interface timing circuitry, which generates the proper read and write signals for the remaining NB-MIO-16 circuitry. The 10-MHz clock on the NuBus is used to clock the NuBus interface timing circuitry. This clock is also buffered onboard, generates a 1-MHz clock for the counter/timer, and generates a 10-MHz timebase for the data acquisition timing circuitry.

The configuration ROM is an 8K EPROM that contains information pertinent to the NB-MIO-16 board. This ROM is read by the Macintosh Slot Manager upon system startup. This configuration ROM is required by the NuBus and allows the Macintosh system and other software to identify the board.

The NB-MIO-16 can cause interrupts in the Macintosh by driving the NuBus NMR interrupt line.

Analog Input and Data Acquisition Circuitry

The NB-MIO-16 provides 16 channels of analog input with software-programmable gain and 12-bit A/D conversion. In addition, the NB-MIO-16 has data acquisition circuitry for automatic timing of multiple A/D conversions and includes advanced options such as external triggering, gating, and clocking. Figure 3-3 shows a block diagram of the analog input and data acquisition circuitry.

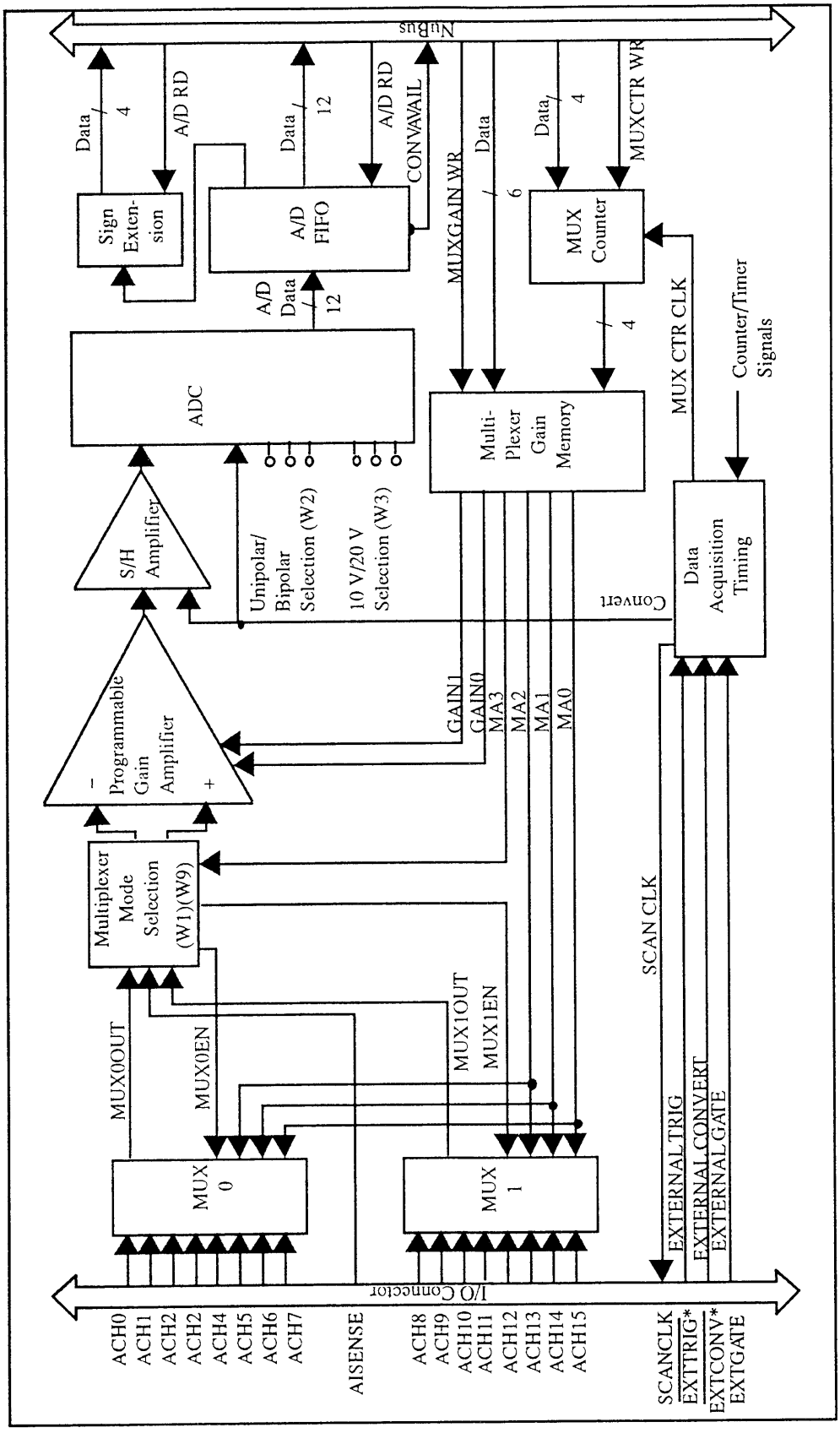


Figure 3-3. Analog Input and Data Acquisition Circuitry Block Diagram

Analog Input Circuitry

The analog input circuitry consists of an input multiplexer, multiplexer mode selection jumpers, a software-programmable gain instrumentation amplifier, a sample-and-hold amplifier, a 12-bit ADC, and a 12-bit FIFO with a 16-bit sign extension option.

The input multiplexer is made up of two CMOS analog input multiplexers and has 16 analog input channels. Multiplexer MUX0 is connected to analog input channels 0 through 7. Multiplexer MUX1 is connected to analog input channels 8 through 15. The input multiplexers provide input overvoltage protection of ±35 V powered on and ±20 V powered off.

The multiplexer mode selection jumpers can configure the analog input channels as 16 single-ended inputs or 8 differential inputs. When single-ended mode is selected, the outputs of the two multiplexers are tied together and routed to the positive (+) input of the instrumentation amplifier. The negative (-) input of the instrumentation amplifier is tied to the NB-MIO-16 and grounded for RSE input or is tied to the analog return of the input signals via the AISENSE input on the I/O connector for NRSE input. When DIFF mode is selected, the output of MUX0 is routed to the positive (+) input of the instrumentation amplifier, and the output of MUX1 is routed to the negative (-) input of the instrumentation amplifier.

The instrumentation amplifier fulfills two purposes on the NB-MIO-16 board. It converts a differential input signal into a single-ended signal with respect to the NB-MIO-16 ground for a minimum input common mode rejection ratio of 85 dB. This conversion and common mode rejection allow the input analog signal to be extracted from any common mode voltage or noise before being sampled and converted. The instrumentation amplifier also applies gain to the input signal, allowing an input analog signal to be amplified before being sampled and converted, thus increasing measurement resolution and accuracy. The gain of the instrumentation amplifier is selected under software control. The NB-MIO-16L (L stands for low-level signals) provides gains of 1, 10, 100, and 500. The NB-MIO-16H (H stands for high-level signals) provides gains of 1, 2, 4, and 8.

Selection of the analog input channel and the gain settings is controlled by the multiplexer-gain (mux-gain) memory. The mux-gain memory provides two gain control bits to the instrumentation amplifier and four multiplexer address bits to the input multiplexers and multiplexer mode selection circuitry that select the analog input channels. Operation of the mux-gain memory is explained in more detail under *Data Acquisition Timing Circuitry* later in this chapter.

The sample-and-hold amplifier aids the ADC in performing A/D conversions. At the beginning of an A/D conversion, the sample-and-hold amplifier is put in hold mode, which means that it holds its output voltage at a steady value (its value when the hold period started) regardless of voltage changes at its input. This arrangement provides the ADC with a steady voltage while it is performing an A/D conversion. Without the sample-and-hold amplifier, the analog input signal could change during a conversion, thereby causing errors during A/D conversion. By isolating the ADC from the analog input signals during conversion, it is possible to change the input multiplexer and allow the instrumentation amplifier to settle to a new value while the ADC is converting the old value. This isolation creates a two-stage pipeline and increases and optimizes the performance of the analog input circuitry during high-speed, multiple A/D conversions.

The ADC is a 12-bit, successive approximation ADC. The 12-bit resolution of the converter allows the converter to resolve its input range into 4096 different steps. This resolution also

provides a 12-bit digital word that represents the value of the input voltage level with respect to the converter input range. The ADC supports three input ranges that are jumper selectable on the NB-MIO-16 board: -10 to +10 V, -5 to +5 V, or 0 to +10 V. The ADC on the NB-MIO-16 has a 9 µs conversion time.

When an A/D conversion is complete, the ADC clocks the result into the A/D FIFO. The A/D FIFO is 12 bits wide and 512 words deep on the NB-MIO-16 revisions G and later (16 words deep on earlier revisions). This FIFO serves as a buffer to the ADC and provides two benefits. Any time an A/D conversion is complete, the value is saved in the A/D FIFO for later reading, and the ADC is free to start a new conversion. Secondly, the A/D FIFO can collect up to 512 A/D conversion values before any information is lost, thus allowing software or DMA some extra time (512 * sample interval) to catch up with the hardware. If more than 512 values are stored in the A/D FIFO without the A/D FIFO being read from, an error condition called A/D FIFO overflow occurs and A/D conversion information is lost.

The A/D FIFO generates a signal that indicates when it contains A/D conversion data. The state of this signal can be read from the NB-MIO-16 Status Register. This signal can be used to generate a DMA request signal over the RTSI bus or to generate a NuBus interrupt. Sign-extension circuitry at the A/D FIFO output adds four most significant bits (bits 15 through 12), to the 12-bit FIFO output (bits 11 through 0) to produce a 16-bit result.

The sign-extension circuitry is software programmable to generate either straight binary numbers or two's complement numbers. In straight binary mode, bits 15 through 12 are always 0 and provide a range of 0 to 4095. In two's complement mode, the most significant bit of the 12-bit ADC result, bit 11, is inverted and extended to bits 15 through 12, for a range of -2048 to +2047.

Data Acquisition Timing Circuitry

A data acquisition operation refers to the process of taking a sequence of A/D conversions with the sample interval (the time between successive A/D conversions) carefully timed. The data acquisition timing circuitry consists of various clocks and timing signals that support this process. Two types of data acquisition are available on the NB-MIO-16 board: single-channel data acquisition and multiple-channel (scanned) data acquisition. Scanned data acquisition uses the mux counter and the mux-gain memory to automatically switch between analog input channels during data acquisition.

Data acquisition timing consists of signals that initiate a data acquisition operation, initiate individual A/D conversions, gate the data acquisition operation, and generate scanning clocks. The sources for these signals can be supplied by timers on the NB-MIO-16 board or by signals connected to the NB-MIO-16 I/O connector.

Single A/D conversions can be initiated by applying an active low pulse to the EXTCONV* input on the I/O connector or by writing to a register location on the NB-MIO-16 board. During data acquisition, the onboard sample-interval counter (Counter 3 of the Am9513 Counter/Timer) can generate pulses that initiate A/D conversions. External control of the sample interval is possible by applying a stream of pulses at the EXTCONV* input. In this case, you have complete external control over the sample interval and the number of A/D conversions performed.

The sample-interval timer is a 16-bit down counter and can be used with the five internal timebases of the Am9513 to generate sample intervals from 2 µs to 6 s (see *Timing I/O Circuitry*). The sample-interval timer can also use any of the external clock inputs to the Am9513 as a timebase. During data acquisition, the sample interval counts down at the rate given by the internal timebase or external clock. Each time the sample-interval timer reaches 0, it generates a pulse and reloads with the programmed sample-interval count. This operation continues until data acquisition halts.

Data acquisition can be controlled by the onboard sample counter. This counter is loaded with the number of samples to be taken during a data acquisition operation. The sample counter can be 16-bit for counts up to 65,535 or 32-bit for counts up to $(2^{32} - 1)$. If 16 bits are needed, Counter 4 of the Am9513 Counter/Timer is used. If more than 16 bits are needed, Counter 4 is concatenated with Counter 5 of the Am9513 to form a 32-bit counter. The sample counter decrements its count each time the sample-interval counter generates an A/D conversion pulse and stops the data acquisition process when it counts down to 0.

The data acquisition process can be triggered by writing to an address location on the NB-MIO-16 board or by applying an active low pulse to the EXTTRIG* input on the NB-MIO-16 I/O connector. These triggers start the sample-interval and sample counters. The sample-interval counter then manages the data acquisition process until the sample counter reaches zero.

Data acquisition can also be controlled by an external gate. In this case, the sample counter does not control data acquisition. The sample counter can be gated on and off by applying an active high gate signal to the EXTGATE input of the I/O connector. If the sample-interval counter is enabled, it generates conversion pulses while the EXTGATE signal is high and suspends counting while the EXTGATE input is low.

Single-Channel Data Acquisition

During single-channel data acquisition, the mux-gain memory is set up to select the gain and analog input channel before data acquisition is initiated. These gain and multiplexer settings remain constant during the entire data acquisition process; therefore, all A/D conversion data is read from a single channel.

Multiple-Channel (Scanned) Data Acquisition

Multiple-channel data acquisition is performed by enabling scanning during data acquisition. Multiple-channel scanning is controlled by the mux counter and the mux-gain memory.

The mux-gain memory consists of 16 words of memory. Each word of memory contains a multiplexer address (4 bits) for input analog channel selection and a gain setting (2 bits). The mux-gain memory address is controlled by the mux counter. Whenever a mux-gain memory address location is selected, the multiplexer and gain control bits contained in that memory location are applied to the analog input circuitry. For scanning operations, the mux counter steps through successive locations in the mux-gain memory at a rate determined by the scan clock. The mux-gain memory, therefore, allows an arbitrary sequence of 16 channels, with a separate gain setting for each channel to be clocked through during a scanning operation.

Both the mux counter and the mux-gain memory can be directly written to through NB-MIO-16 registers. For writing purposes, the mux counter serves as a pointer to the mux-gain memory. The counter can be loaded with any 4-bit value to point to any mux-gain memory location. Thus, scanning can start at any location in the mux-gain memory.

The SCANCLK signal is generated from the sample-interval counter. This signal pulses once at the beginning of each A/D conversion. The SCANCLK signal is supplied at the I/O connector. During multiple-channel scanning, the mux counter is incremented repeatedly, thereby sequencing through the mux-gain memory and automatically selecting new channel and gain settings during data acquisition. The MUXCTRCLK signal is generated from the SCANCLK and provides the pulses that increment the mux counter. MUXCTRCLK can be identical to SCANCLK, incrementing the mux counter once after every A/D conversion. MUXCTRCLK can also be generated by dividing SCANCLK by Counter 1 of the Am9513 Counter/Timer. Consequently, the mux counter can be incremented once every *N* A/D conversions such that *N* conversions can be performed on a single channel and gain selection before switching to the next channel and gain selection.

Data Acquisition Rates

Data acquisition rates (number of samples per second) are determined by the conversion period of the ADC plus the sample-and-hold acquisition time. During multiple-channel scanning, the data acquisition rates are further limited by the settling time of the input multiplexers and instrumentation amplifier. After the input multiplexers are switched, the instrumentation amplifier must be allowed to settle to the new input signal value before an A/D conversion is performed or else high accuracy will not be achieved. The settling time is determined by the gain selected.

The NB-MIO-16 data acquisition timing circuitry detects when data acquisition rates are so high that A/D conversions are lost. If this is the case, this circuitry sets an OVERRUN error flag in the NB-MIO-16 Status Register. If the recommended data acquisition rates given below are exceeded, the analog input circuitry may not perform at 12-bit accuracy. If these rates are exceeded by more than a few microseconds, A/D conversions may be lost.

Table 3-1 shows the recommended multiplexer and gain settling times for different gain settings.

Table 3-1. Analog Input Settling Time Versus Gain

Gain Setting	Settling Time Recommended
1, 2, 4, 8	10 µs
10	20 µs
100	40 µs
500	80 µs

The maximum recommended data acquisition rates for single-channel data acquisition at any gain setting is 100 kS/s.

Table 3-2 shows the maximum recommended data acquisition rates for multiple-channel data acquisition.

Table 3-2. NB-MIO-16 Maximum Recommended Multiple-Channel Data Acquisition Rates

Gain	Data Acquisition Rate
1, 2, 4, 8	100 kS/s
10	50 kS/s
100	25 kS/s
500	12.5 kS/s

Table 3-3 shows the typical settling accuracies for the maximum scanning rates allowed.

Table 3-3. Typical Settling Accuracies Versus Maximum Scanning Rates

Gain	Maximum Acquisition Rate	Settling Accuracy	
		20 V Step	10 V Step
1	100 kbytes/s	±2.5 LSB (±0.06%)	±1.2 LSB (±0.03%)
2	100 kbytes/s	±1.5 LSB (±0.04%)	±0.7 LSB (±0.02%)
4	100 kbytes/s	±1.0 LSB (±0.02%)	±0.7 LSB (±0.02%)
8	100 kbytes/s	±1.0 LSB (±0.02%)	±1.0 LSB (±0.02%)
10	50 kbytes/s	±0.5 LSB (±0.01%)	±0.5 LSB (±0.01%)
100	25 kbytes/s	±0.5 LSB (±0.01%)	±0.5 LSB (±0.01%)
500	12.5 kbytes/s	±0.5 LSB (±0.01%)	±0.5 LSB (±0.01%)

Appendix A, *Specifications*, includes more information on data acquisition rates.

Analog Output Circuitry

The NB-MIO-16 contains two channels of 12-bit D/A output. Each analog output channel provides options such as unipolar or bipolar output, and internal or external reference voltage selection. Figure 3-4 shows a block diagram of the analog output circuitry.

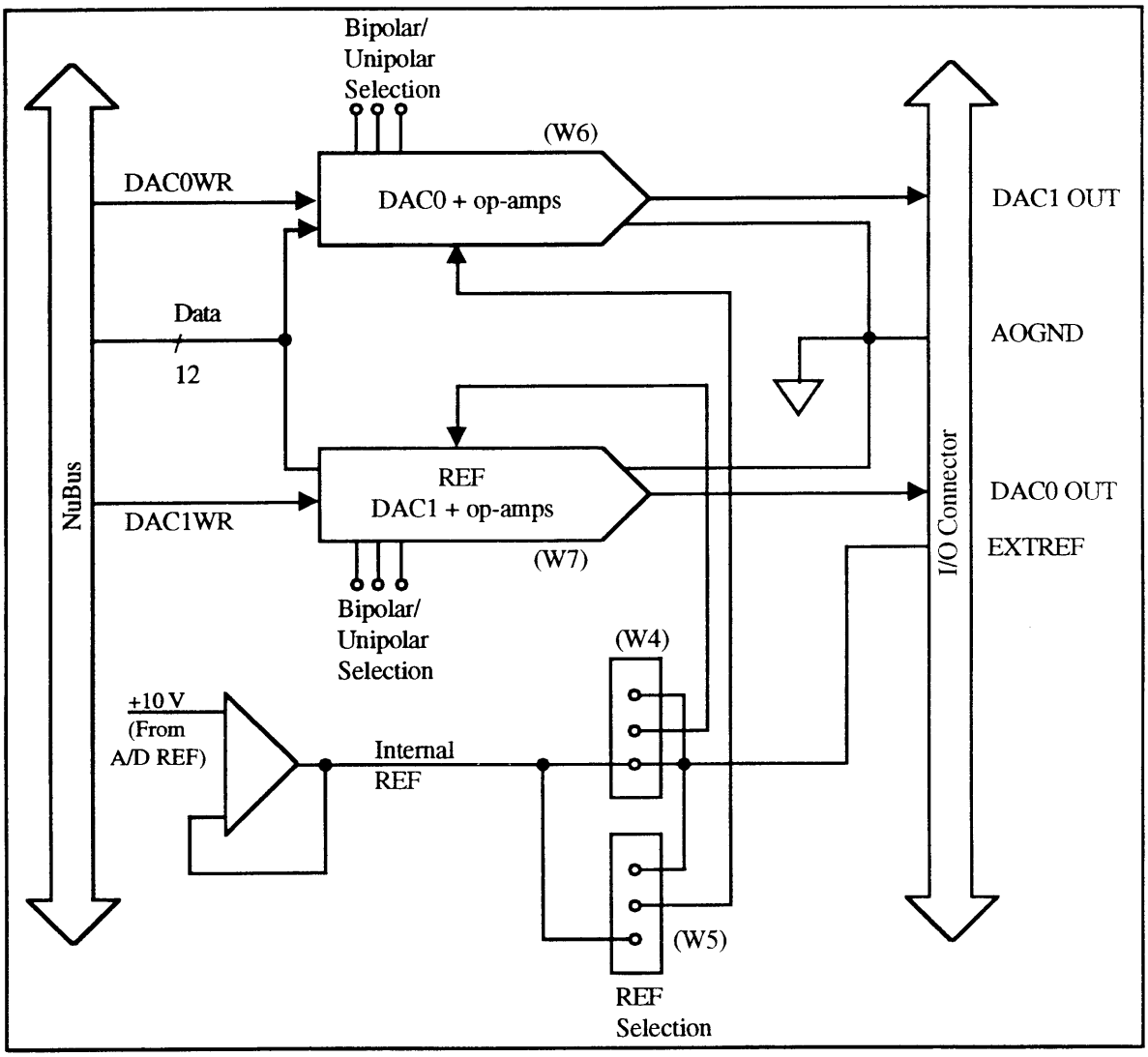


Figure 3-4. Analog Output Circuitry Block Diagram

Each analog output channel contains a 12-bit DAC, output operational amplifiers (op-amps), reference selection jumpers, and unipolar/bipolar output selection jumpers.

The DAC in each analog output channel generates a current proportional to the input voltage reference (V_{ref}) multiplied by the digital code loaded into the DAC. Each DAC can be loaded with a 12-bit digital code by writing to registers on the NB-MIO-16 board. The output op-amps convert the DAC current output to a voltage output provided at the NB-MIO-16 I/O connector DAC0 OUT and DAC1 OUT pins.

The DAC output op-amps can be jumper configured to provide either a unipolar voltage output or a bipolar voltage output range. A unipolar output provides an output voltage range of 0 to $+V_{ref}$ - 1LSB V. A bipolar output provides an output voltage range of $-V_{ref}$ to $+V_{ref}$ -1LSB V. For unipolar output, 0 V output corresponds to a digital code word of 0. For bipolar output, 0 V

output corresponds to a digital code word of 2,048. One LSB is the voltage increment corresponding to a least significant bit change in the digital code word.

For unipolar output, 1 LSB = $\frac{V_{ref}}{4,096}$

For bipolar output 1 LSB = $\frac{V_{ref}}{2,048}$

The voltage reference source for each DAC is jumper selectable and can either be supplied externally at the EXTREF input or internally. The external reference can be either a DC or an AC signal. If an AC reference is applied, the analog output channel acts as a signal attenuator, and the AC signal appears at the output attenuated by the following for unipolar output:

$$\frac{\text{digital code}}{4,096}$$

Bipolar output with an AC reference provides four quadrant multiplication, which means that the signal is inverted for digital codes 0 to 2,047 and not inverted for digital codes 2,049 to 4,095. A digital code word of 2,048 attenuates the input signal to 0 V. This attenuation is equivalent to multiplying the signal by the following:

$$\frac{\text{digital code word} - 2,048}{2,048}$$

The internal voltage reference is a buffered version of the 10 V reference supplied by the ADC. Using the internal reference supplies an output voltage range of 0 to 9.9976 V in steps of 2.44 mV for unipolar output and an output voltage range of -10 V to +9.9951 V in steps of 4.88 mV for bipolar output.

Digital I/O Circuitry

The NB-MIO-16 provides eight digital I/O lines. These lines are divided into two ports of four lines each and are located at pins ADIO<3..0> and BDIO<3..0> on the I/O connector. Figure 3-5 shows a block diagram of the digital I/O circuitry.

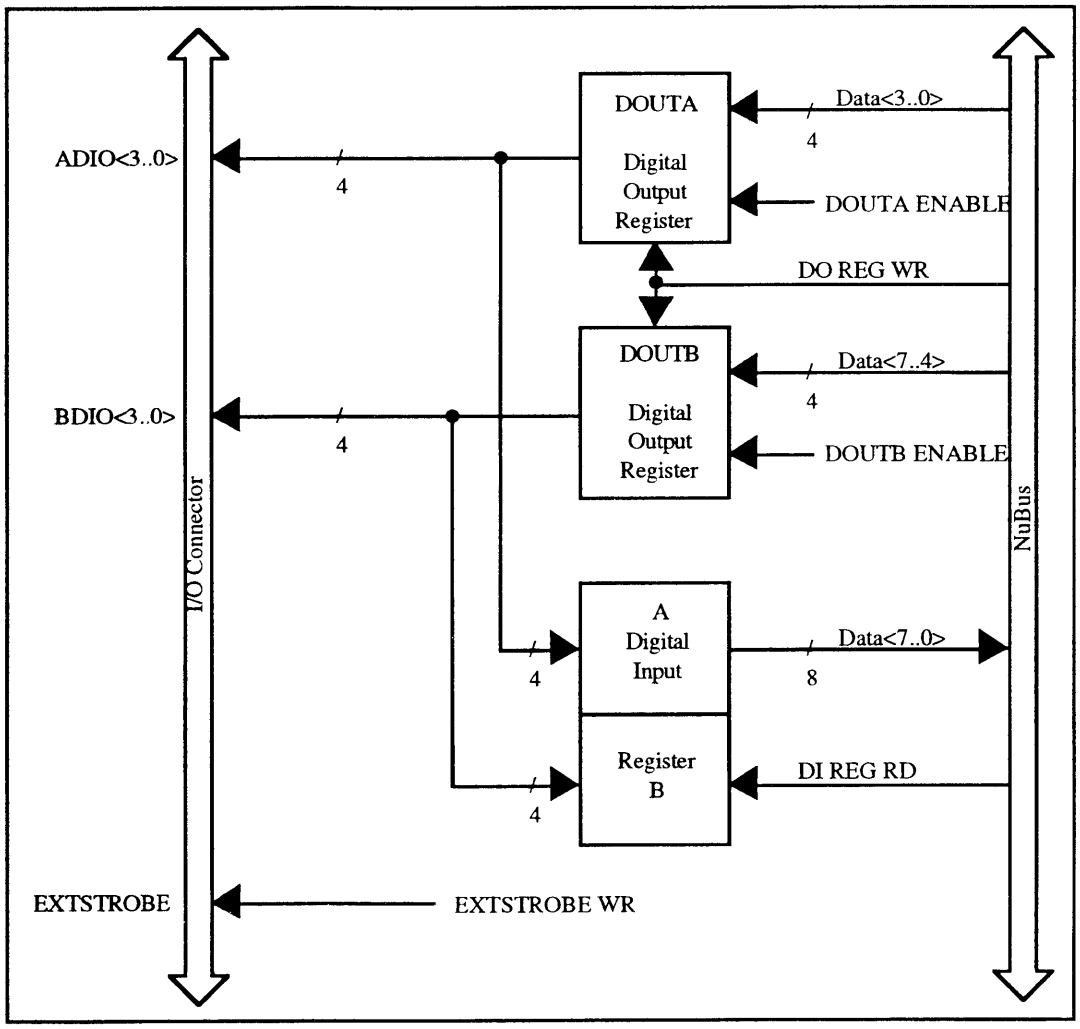


Figure 3-5. Digital I/O Circuitry Block Diagram

The digital I/O lines are controlled by the Digital Output Register and monitored by the Digital Input Register. The Digital Output Register is an 8-bit register that contains the digital output values for both ports A and B. When port A is enabled, bits <3..0> in the Digital Output Register are driven onto digital output lines ADIO<3..0>. When port B is enabled, bits <7..4> in the Digital Output Register are driven onto digital output lines BDIO<3..0>.

Reading the Digital Input Register returns the state of the digital I/O lines. Digital I/O lines ADIO<3..0> are connected to bits <3..0> of the Digital Input Register. Digital I/O lines BDIO<3..0> are connected to bits <7..4> of the Digital Input Register. When a port is enabled, the Digital Input Register serves as a read-back register, returning the digital output value of the port. When a port is not enabled, reading the Digital Input Register returns the state of the digital I/O lines as driven by an external device.

Both the digital input and output registers are TTL compatible. When enabled, the digital output ports can sink 24 mA of current and source 2.6 mA of current on each digital I/O line. When the ports are not enabled, the digital I/O lines act as high-impedance inputs.

The external strobe signal (EXTSTROBE*), shown in Figure 3-5, is a general-purpose strobe signal. Writing to an address location on the NB-MIO-16 board generates an active low 90 ns pulse on this output pin. EXTSTROBE* is not necessarily part of the digital I/O circuitry but is shown here because it can be used to latch digital output from the NB-MIO-16 into an external device, if desired.

Timing I/O Circuitry

The NB-MIO-16 uses an Am9513 Counter/Timer to support data acquisition timing and to provide general-purpose timing I/O functions. Figure 3-6 shows a block diagram of the timing I/O circuitry.

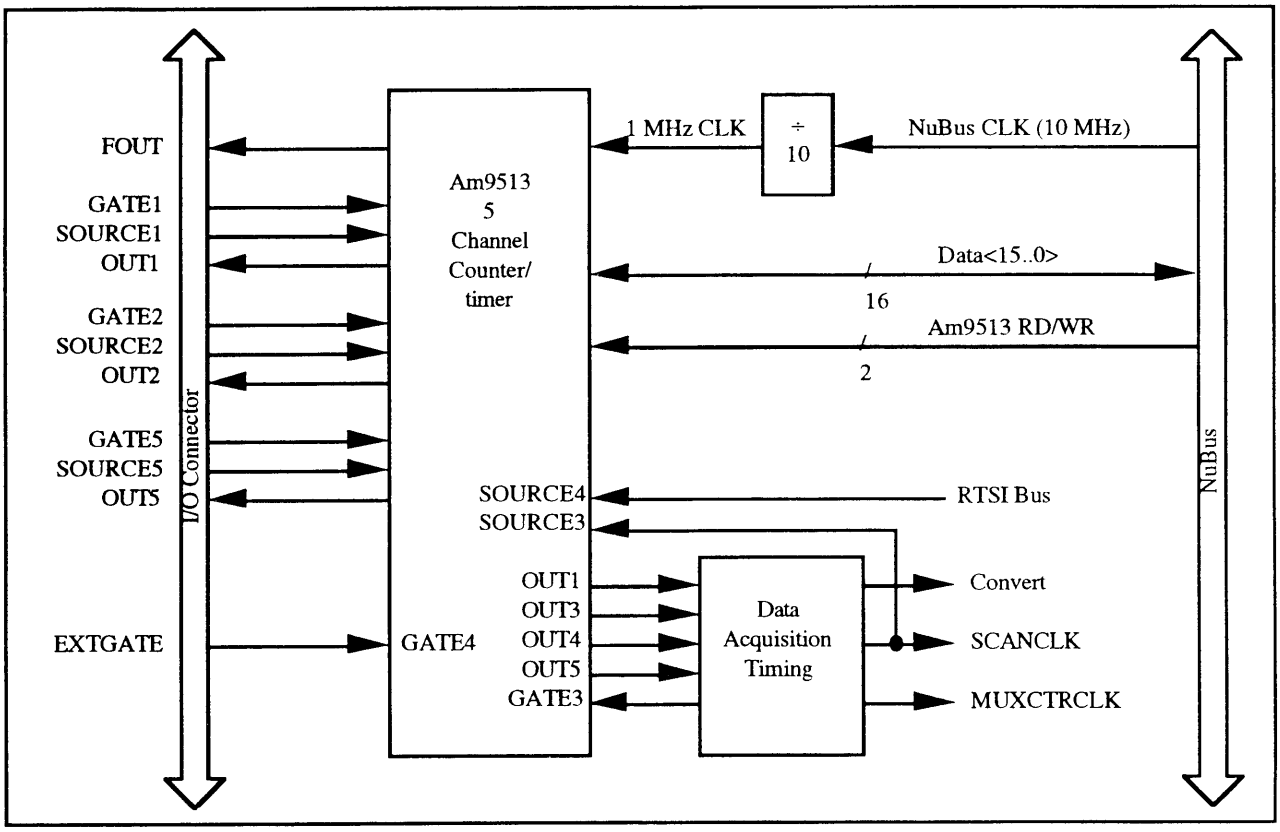


Figure 3-6. Timing I/O Circuitry Block Diagram

The Am9513 contains five independent 16-bit counter/timers, a 4-bit frequency output channel, and five internally generated timebases. The five counter/timers can be programmed to operate in several useful timing modes. The programming and operation of the Am9513 is presented in detail in Appendix C, *AMD Data Sheet*.

The Am9513 clock input is a 1-MHz clock generated from the NuBus 10-MHz clock. The Am9513 uses this clock input to generate five internal timebases. These timebases can be used as clocks by the counter/timers and the frequency output channel. The five internal timebases normally used for NB-MIO-16 timing functions are 1 MHz, 100 kHz, 10 kHz, 1 kHz, and 100 Hz.

The 16-bit counters in the Am9513 can be diagrammed as shown in Figure 3-7.

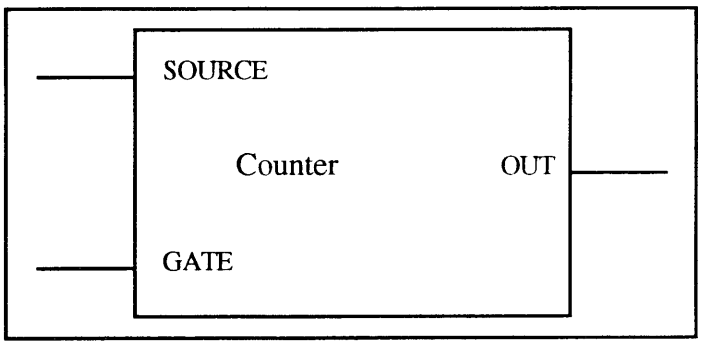


Figure 3-7. Counter Block Diagram

Each counter has a SOURCE input pin, a GATE input pin, and an output pin labeled OUT. The Am9513 counters are numbered 1 through 5 and their GATE, SOURCE, and OUT pins are labeled GATE *N*, SOURCE *N*, and OUT *N* where *N* is the counter number.

The counters can be programmed to use any of the five internal timebases, any of the five GATE and five SOURCE inputs to the Am9513, and the output of the previous counter (Counter 4 uses Counter 3 output, and so on) for counting operations. A counter can be configured to count either falling or rising edges of the selected input.

The counter GATE input allows counter operation to be gated. Once a counter is configured for an operation through software, a signal at the GATE input can be used to start and stop counter operation. There are five gating modes supported by the Am9513: no gating, level gating active high, level gating active low, low-to-high edge gating, and high-to-low edge gating. A counter can also be active high level gated by a signal at GATE *N*+1 and GATE *N*-1 where *N* is the counter number.

The counter generates timing signals at its OUT output pin. The OUT output pin can also be set to a high-impedance state or to a grounded output state. The counters generate two types of output signals during counter operation: terminal count pulse output and terminal count toggle output. Terminal count is often referred to as TC. A counter reaches TC when it counts up or down and rolls over. In many counter applications, the counter reloads from an internal register when it reaches TC. In TC pulse output mode, the counter generates a pulse during the cycle that it reaches TC and reloads. In TC toggle output mode, the counter output changes state after it reaches TC and reloads. In addition, the counters can be configured for positive logic output or negative (inverted) logic output to provide a total of four possible output signals generated for one timing mode.

The SOURCE, GATE, and OUT pins for Counters 1, 2, and 5 of the onboard Am9513 are available at the NB-MIO-16 I/O connector. The EXTGATE pin of the I/O connector is tied to the GATE4 input of the Am9513 and can be used as an additional gate or counting source input.

The Am9513 SOURCE4 pin is connected to the NB-MIO-16 RTSI switch, which means that a signal from the RTSI trigger bus can be provided as a counting source for the Am9513 counters.

Counters 3 and 4 of the Am9513 are dedicated to data acquisition timing and therefore are not made available for general-purpose timing applications. Signals generated at OUT3 and OUT4 are provided to the data acquisition timing circuitry. GATE3 is controlled by the data acquisition timing circuitry.

Counter 5 is sometimes used by the data acquisition timing circuitry and concatenated with Counter 4 to form a 32-bit sample counter. The SCANCLK signal is connected to the SOURCE3 input of the Am9513, and OUT1 is provided to the data acquisition timing circuitry. As a result, Counter 1 can be used to divide the SCANCLK signal for generating the MUX CTR CLK signal. See *Multiple-Channel (Scanned) Data Acquisition* earlier in this chapter.

The Am9513 4-bit programmable frequency output channel is provided at the I/O connector FOUT pin. Any of the five internal timebases and any of the counter SOURCE or GATE inputs can be selected as the frequency output source. The frequency output channel divides the selected source by its 4-bit programmed value and provides the divided down signal at the FOUT pin.

RTSI Bus Interface Circuitry

The NB-MIO-16 is interfaced to the National Instrument RTSI bus. The RTSI bus has seven trigger lines, seven DMA request lines, and eight interrupt lines. All National Instruments NB Series boards with RTSI bus connectors can be wired together inside the Macintosh and share these signals. A block diagram of the RTSI bus interface circuitry is shown in Figure 3-8.

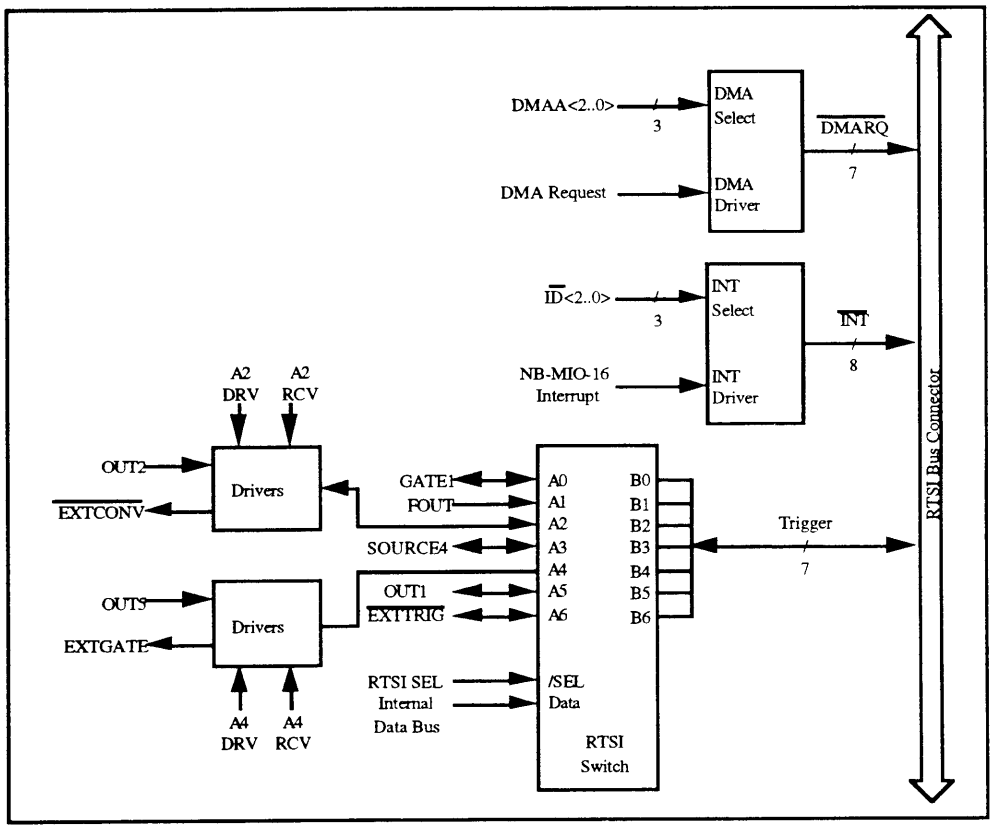


Figure 3-8. RTSI Bus Interface Circuitry Block Diagram

Figure 3-8 shows the DMA driver circuitry, the interrupt driver circuitry, and the RTSI switch. These drivers and the RTSI switch route NB-MIO-16 signals to and from the RTSI bus.

The seven RTSI DMA request lines are driven by the DMA driver circuitry. The DMA driver routes the NB-MIO-16 DMA request signal onto the DMA request line selected by the bits DMAA<2..0>. DMAA<2..0> are controlled by an NB-MIO-16 register.

The eight RTSI interrupt lines are driven by the interrupt driver circuitry. The interrupt driver routes the NB-MIO-16 interrupt signal onto the interrupt line selected by the bits ID*<2..0>. ID*<2..0> are provided at the NuBus connector and are unique to each NuBus slot; therefore, the RTSI interrupt line selected is determined by the slot that the NB-MIO-16 board is plugged into. For example, INT*1 will be used by a board plugged into slot 1.

The RTSI switch is a National Instruments custom integrated circuit that acts as a 7 by 7 crossbar switch. Pins B<6..0> are connected to the seven RTSI bus trigger lines. Pins A<6..0> are connected to seven signals on the board. The RTSI switch can drive any of the signals at pins A<6..0> onto any one or more of the seven RTSI bus trigger lines and drive any of the seven trigger line signals onto any one or more of the pins A<6..0>. This capability provides a completely flexible signal interconnection scheme for any NB Series board sharing the RTSI bus. The RTSI switch is programmed via its select and data inputs.

On the NB-MIO-16 board, nine signals are connected to pins A<6..0> of the RTSI switch with the aid of additional drivers. The signals GATE1, OUT1, OUT2, OUT5, FOUT, and EXTGATE, are shared with the NB-MIO-16 I/O connector and Am9513 Counter/Timer. The signal SOURCE4 is connected to the Am9513 SOURCE4 pin. The EXTCONV* and EXTTRIG* signals are shared with the I/O connector and the data acquisition timing circuitry. These onboard interconnections allow NB-MIO-16 general-purpose and data acquisition timing to be controlled over the RTSI bus as well as externally and allow the NB-MIO-16 and the I/O connector to provide timing signals to other NB boards connected to the RTSI bus.

Chapter 4
Programming

This chapter describes in detail the address and function of each of the NB-MIO-16 registers. This chapter also includes important information about programming the NB-MIO-16.

Note: ***If you plan to use a programming software package such as LabVIEW or NI-DAQ with your NB-MIO-16, you need not read this chapter.***

Register Access

The Macintosh uses memory mapping to access boards in the system. The following sections discuss how to access the various registers on the NB-MIO-16.

Slot Address Space

Each slot in the Macintosh is allocated a block of Macintosh memory addresses known as the *slot address space*. All I/O boards plugged into Macintosh NuBus slots are therefore memory mapped. When an I/O board is plugged into a given slot, the board's registers can be accessed within that slot address space. The block of memory addresses allocated to each slot depends on the slot number and whether the Macintosh memory manager is in 24-bit or 32-bit addressing mode. Consult your Macintosh manual to determine the slot numbers used in your computer. Table 4-1 shows the slot address space for each slot, both for 24-bit mode and for 32-bit mode.

Table 4-1. Macintosh Slot Addresses

Slot Number	Starting Address (Hex)	Ending Address (Hex)
24-Bit Mode		
9	0090 0000	009F FFFF
A	00A0 0000	00AF FFFF
B	00B0 0000	00BF FFFF
C	00C0 0000	00CF FFFF
D	00D0 0000	00DF FFFF
E	00E0 0000	00EF FFFF
32-Bit Mode		
0	F000 0000	F0FF FFFF
1	F100 0000	F1FF FFFF
2	F200 0000	F2FF FFFF
3	F300 0000	F3FF FFFF
4	F400 0000	F4FF FFFF
5	F500 0000	F5FF FFFF
6	F600 0000	F6FF FFFF
7	F700 0000	F7FF FFFF
8	F800 0000	F8FF FFFF
9	F900 0000	F9FF FFFF
A	FA00 0000	FAFF FFFF
B	FB00 0000	FBFF FFFF
C	FC00 0000	FCFF FFFF
D	FD00 0000	FDFF FFFF
E	FE00 0000	FEFF FFFF

Register Map

The register map for the NB-MIO-16 is given in Table 4-2. This table lists the register name, the register address offset from the slot starting address, the type of the register (read only, write only, or read and write), and the size of the register in bits.

Each register address in Table 4-2 is the offset address from the slot starting address. To calculate the absolute address of the register, add the register offset given in Table 4-2 to the slot starting address given in Table 4-1. For example, if the NB-MIO-16 is plugged into slot B and the memory manager is in 24-bit mode, the A/D FIFO Register is at address 0 002C + 00B0 0000, that is, address 00B0 002C. If the NB-MIO-16 is plugged into slot B and the memory manager is in 32-bit mode, the Am9513 Data Register is at address 0 0030 + FB00 0000, that is, address FB00 0030.

The address decoding circuitry on the NB-MIO-16 is such that using a slot starting address of Fss0 0000 (where the *s* is replaced by the slot number) properly accesses all registers in both memory modes.

Table 4-2. NB-MIO-16 Register Map

Register Name	Offset Address (Hex)	Type	Size
Configuration and Status Register Group:			
Command Register 1	0	Write-only	16-bit
Status Register	0	Read-only	16-bit
Command Register 1	4	Write-only	16-bit
Event Strobe Register Group:			
Start Convert Register	10	Write-only	16-bit
Start DAQ Register	14	Write-only	16-bit
A/D Clear Register	18	Write-only	16-bit
External Strobe Register	1C	Write-only	16-bit
Analog Output Register Group:			
DAC0 Register	20	Write-only	16-bit
DAC1 Register	24	Write-only	16-bit
DAC0 and DAC1 Register	28	Write-only	16-bit
Analog Input Register Group:			
Mux-Counter Register	8	Write-only	16-bit
Mux-Gain Register	C	Write-only	16-bit
A/D FIFO Register	2C	Read-only	16-bit
Counter/Timer (Am9513) Register Group:			
Am9513 Data Register	30	Read-and-write	16-bit
Am9513 Command Register	34	Write-only	16-bit
Am9513 Status Register	34	Write-only	16-bit
Digital I/O Register Group:			
Digital Input Register	38	Write-only	16-bit
Digital Output Register	38	Read-only	16-bit
RTSI Switch Register Group:			
RTSI Shift Register	C 0000	Write-only	8-bit
RTSI Strobe Register	C 0004	Write-only	8-bit
Configuration EPROM			
Starting offset	E 1000	Read-only	8-bit
Ending offset	F FFFC	Write-only	8-bit

Register Sizes

The Macintosh accepts three different memory word sizes for memory read and write operations: byte (8-bit), half-word (16-bit), and word (32-bit). Table 4-2 shows the word sizes of the NB-MIO-16 registers. For example, reading the A/D FIFO Register requires a 16-bit (half-word) read operation at the specified address, whereas writing to the RTSI Switch Strobe Register requires an 8-bit (byte) write operation at the specified address.

Register Description

Table 4-2 divides the NB-MIO-16 registers into eight different register groups. A bit description of each of the registers making up these groups is given later in this section.

The Configuration and Status Register Group controls the overall operation of the NB-MIO-16 hardware. The Event Strobe Register Group, when written to, generates some event on the NB-MIO-16 board. The Analog Output Register Group accesses the NB-MIO-16 DACs. The Analog Input Register Group reads ADC output.

The Counter/Timer Register Group is made up of the three registers of the onboard Am9513 Counter/Timer chip. The Digital I/O Register Group access the onboard digital input and output lines. The RTSI switch registers control the onboard RTSI switch.

Finally, the configuration EPROM is not a set of registers but rather onboard read-only memory that contains information required by the Macintosh operating system.

Register Description Format

The remainder of this register section describes each of the NB-MIO-16 registers in the order shown in Table 4-2. Each register group is introduced, followed by a detailed bit description of each register. Individual register descriptions give the address, type, word size, and bit map of the register, followed by a description of each bit.

Note: ***In these register descriptions and their accompanying illustrations, the names of negated bits may be denoted by either an overscore or a trailing asterisk (*).***

The register bit map shows a diagram of the register with the most significant bit (bit 15 for a 16-bit register, bit 7 for an 8-bit register) shown on the left, and the least significant bit (bit 0) shown on the right. Each bit is represented by a square and is labeled with a name inside or directly underneath this square. A bar above the bit name indicates that the condition is TRUE if this bit is not set; the condition is FALSE if the bit is set.

In many of the registers, several bits are labeled with an X, indicating *don't care* bits. When a register is read, these bits may appear set or cleared but should be ignored because they have no significance. When a register is written to, setting or clearing these bit locations has no effect on the NB-MIO-16 hardware.

The bit map field for some write-only registers may contain the message *not applicable, no bits used*. Writing to these registers generates a strobe in the NB-MIO-16. These strobes are used to cause some onboard event to occur. For example, they can be used to clear the analog input circuitry or to start a data acquisition operation. The data is ignored when writing to these registers; therefore, any bit pattern suffices.

Configuration and Status Register Group

The three registers making up the Configuration and Status Register Group allow general control and monitoring of the NB-MIO-16 hardware. Command Registers 1 and 2 contain bits that control operation of several different pieces of the NB-MIO-16 hardware. The Status Register allows the state of different pieces of the NB-MIO-16 hardware to be read.

Bit descriptions of the registers making up the Configuration and Status Register Group are as follows.

Command Register 1

Command Register 1 contains eight bits that control NB-MIO-16 interrupts, DMA, and some analog input modes.

Address: Slot starting address + 0 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
DAQINTEN	CONVINTEN	DMAEN	DAQEN	SCANEN	SCANDIV	16*/32CNT	2SCADC*

Bit	Name	Description
15-8	X	Don't care bits.
7	DAQINTEN	This bit enables or disables an interrupt at the end of a data acquisition operation. A data acquisition operation is a multiple A/D conversion sequence that is timed and controlled by the NB-MIO-16 onboard counter/timers. The onboard sample counter generates this interrupt when it counts down to zero. If external conversion timing is used, this interrupt does not occur. If this bit is set, an interrupt occurs whenever a data acquisition operation completes. If this bit is cleared, no interrupt occurs.
6	CONVINTEN	This bit enables or disables a conversion interrupt. If this bit is set, an interrupt is generated whenever an A/D conversion is available to be read from the A/D FIFO. If this bit is cleared, no interrupt is generated.

Bit	Name	Description (continued)
5	DMAEN	This bit enables or disables generation of DMA requests over the RTSI bus. If this bit is set, a DMA request is generated whenever A/D conversion is available to be read from the A/D FIFO. If this bit is cleared, no DMA request is generated.
4	DAQEN	This bit enables or disables a data acquisition operation that is controlled by the onboard sample-interval and sample counters. If this bit is set, a software or external trigger starts the counters (assuming that the counters are programmed and enabled), thereby starting a data acquisition operation. If this bit is cleared, software and external triggers are ignored.
3	SCANEN	This bit enables or disables multiple-channel scanning during data acquisition. If this bit is set, alternate analog input channels are sampled during data acquisition under control of the mux-gain memory. If this bit is cleared, a single analog input channel is sampled during the entire data acquisition operation.
2	SCANDIV	This bit enables or disables division of the mux-counter clock during data acquisition. The mux-counter clock controls sequencing of the mux-gain memory. If this bit is set, the mux-counter clock is controlled by Counter 1 of the Am9513 Counter/Timer. If this bit is cleared, the mux-counter clock generates one pulse per conversion.
1	16*/32CNT	This bit selects the count resolution for the number of A/D conversions to be performed in a data acquisition operation. If this bit is cleared, a 16-bit count mode is selected, and Counter 4 of the Am9513 Counter/Timer controls conversion counting. If this bit is set, a 32-bit count mode is selected, and Counter 4 is concatenated with Counter 5 to control conversion counting. A 16-bit count mode can be used if the number of A/D sample conversions to be performed is less than 65,537. A 32-bit count mode should be used if the number of A/D sample conversions to be performed is greater than or equal to 65,537.
0	2SCADC*	This bit selects the binary format for the 16-bit data word read from the A/D FIFO. If this bit is set, a straight binary format is used and the data read from the A/D FIFO ranges from 0 to 4095 decimal (0 to 0FFF hexadecimal). This mode is useful if a unipolar input range is used. If this bit is cleared, a 16-bit two's complement mode is used and the data read from the ADC ranges from -2048 to 2047 decimal (F800 to 07FF hexadecimal). This mode is useful if a bipolar input range is used.

Status Register

The Status Register contains 15 bits of NB-MIO-16 hardware status information, including interrupt and analog input status.

Address: Slot starting address + 0 (hex)

Type: Read-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
INT*	DAQCMPL	CONVAVAIL	X	DAQPROG	CONVPROG*	OVERFLOW	OVERRUN

7	6	5	4	3	2	1	0
GAIN1	GAIN0	GAIN SET	MUX1EN	MUX0EN	MA2	MA1	MA0

Bit	Name	Description
15	INT*	This bit shows the overall state of interrupts generated by the NB-MIO-16 board. If this bit is clear, the NB-MIO-16 is asserting an interrupt that has not yet been serviced. If this bit is set, no interrupt is pending. This bit is normally set.
14	DAQCMPL	This bit shows the state of the data acquisition operation interrupt. The NB-MIO-16 can be configured to generate an interrupt at the end of a data acquisition operation. If this bit is set, the current interrupt is due to a data acquisition interrupt. If this bit is clear, no data acquisition interrupt has occurred. This bit is cleared by writing to the A/D Clear Register.
13	CONVAVAIL	This bit shows the state of the A/D FIFO. If this bit is set, one or more A/D conversion results are available to be read from the A/D FIFO. If conversion interrupts are enabled, this bit setting indicates that a conversion interrupt is asserted. If DMA is enabled, this bit setting indicates that a DMA request is asserted. If this bit is clear, the A/D FIFO is empty and no conversion interrupt or DMA request is asserted.
12	X	Don't care bit.
11	DAQPROG	This bit indicates whether a data acquisition operation is in progress. If this bit is set, a data acquisition operation is in progress. If this bit is clear, a data acquisition operation is not in progress.
10	CONVPROG*	This bit indicates whether an A/D conversion is in progress. If this bit is clear, the ADC is performing an A/D conversion. If this bit is set, no A/D conversion is being performed. Notice that this bit is normally set.

Bit	Name	Description (continued)
9	OVERFLOW	This bit indicates whether the A/D FIFO has overflowed during a sample run. OVERFLOW is an error condition that occurs if the FIFO fills up with data and A/D conversions continue. If this bit is set, A/D conversion data has been lost because of FIFO overflow. If this bit is clear, no overflow has occurred. This bit can be reset by writing to the A/D Clear Register.
8	OVERRUN	If set, this bit indicates that an A/D conversion was initiated before the previous one was complete. OVERRUN is an error that may occur if the data acquisition sample interval is too small (sample rate is too high). If this bit is set, one or more conversions were skipped. If this bit is clear, no overrun condition has occurred. This bit can be reset by writing to the A/D Clear Register.
7-6	GAIN<1..0>	These two bits show the current gain setting for the programmable gain amplifier (see the description of the Mux-Gain Register).
5	GAIN SET	This bit indicates the state of the mux-gain circuitry. If this bit is set, the mux-gain circuitry is settling to a new state due to a change in multiplexer or gain setting. If this bit is clear, the mux-gain circuitry has settled to 12-bit accuracy.
4	MUX1EN	This bit indicates the state of multiplexer 1. Multiplexer 1 controls analog input channels 8 through 15. If this bit is set, multiplexer 1 is currently enabled. If this bit is clear, multiplexer 1 is currently disabled. In single-ended mode, multiplexer 1 is enabled only when one of the input channels 8 through 15 is selected. In this mode, the output of multiplexer 1 is connected to the positive (+) input of the instrumentation amplifier. In DIFF mode, multiplexer 1 is always enabled. In this mode, the output of multiplexer 1 is connected to the negative (-) input of the instrumentation amplifier.
3	MUX0EN	This bit indicates the state of multiplexer 0. Multiplexer 0 controls analog input channels 0 through 7. If this bit is set, multiplexer 0 is currently enabled. If this bit is clear, multiplexer 0 is currently disabled. In single-ended mode, multiplexer 0 is enabled only when one of the input channels 0 through 7 is selected. In DIFF mode, multiplexer 0 is always enabled. The output of multiplexer 0 is always connected to the positive (+) input of the instrumentation amplifier.
2-0	MA<2..0>	MA<2..0> give the low-order three bits of the analog input channel address. MA stands for multiplexer address. These three bits, in conjunction with the MUX1 EN and MUX0 EN bits, indicate which analog input channel is currently selected. In single-ended mode, the analog input channel selected is determined by the value of MA<2..0> if MUX0 EN is set and by the value of MA<2..0> + 8 if MUX1 EN is set. In DIFF mode, two analog input channels are selected simultaneously. The two channels are MA<2..0> and MA<2..0> + 8.

Command Register 2

Command Register 2 contains 10 bits that control NB-MIO-16 digital output drivers, NuBus interrupts, DMA channel selection, and RTSI bus DMA request routing.

Address: Slot starting address + 4 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	X	X	DOUTBEN	DOUTAEN

7	6	5	4	3	2	1	0
NINTDIS	DMAA2	DMAA1	DMAA0	A4RCV	A4DRV	A2RCV	A2DRV

Bit	Name	Description
15-10	X	Don't care bits.
9	DOUTBEN	This bit enables or disables driving of the 4-bit digital output port B by the Digital Output Register. If this bit is set, the Digital Output Register drives the digital lines. If this bit is cleared, the Digital Output Register drivers are set to a high-impedance state, thereby allowing an external device to drive the digital lines.
8	DOUTAEN	This bit enables or disables driving of the 4-bit digital output port A by the Digital Output Register. If this bit is set, the Digital Output Register drives the digital lines. If this bit is cleared, the Digital Output Register drivers are set to a high-impedance state, thereby allowing an external device to drive the digital lines.
7	NINTDIS	This bit disables or enables driving of the NuBus NMR interrupt line by the NB-MIO-16 interrupt line. If this bit is cleared, the NuBus NMR line is driven by the NB-MIO-16 interrupt line. If this bit is set, no interrupts are ever asserted onto the NuBus by the NB-MIO-16. Notice that this bit is normally cleared, which means that interrupts are normally gated onto the NuBus.
6-4	DMAA<2..0>	These three bits allow the RTSI bus DMA channel to be selected and route any DMA requests onto the RTSI DMA request line specified by DMAA<2..0>. For example, to select DMA Channel 2, set DMAA<2..0> to 010 (binary). DMA requests generated by the NB-MIO-16 are then gated onto DMA request line 2 of the RTSI bus.

Bit	Name	Description (continued)
3	A4RCV	This bit controls a driver that allows the EXTGATE signal to be driven from pin A4 of the RTSI switch. This action allows a signal to be received from one of the RTSI bus trigger lines and driven onto the EXTGATE line. If this bit is set, pin A4 of the RTSI switch drives the EXTGATE signal. If this bit is cleared, the EXTGATE signal is not driven by the RTSI switch.
2	A4DRV	This bit controls a driver that allows the OUT5 signal to drive pin A4 of the RTSI switch. This action allows the OUT5 signal to be driven onto one of the RTSI bus trigger lines. If this bit is set, pin A4 of the RTSI switch is driven by OUT5. If this bit is cleared, the pin A4 is not driven.
1	A2RCV	This bit controls a driver that allows the EXTCONV* signal to be driven from pin A2 of the RTSI switch. This action allows a signal to be received from one of the RTSI bus trigger lines and driven onto the EXTGATE line. If this bit is set, pin A2 of the RTSI switch drives the EXTCONV* signal. If this bit is cleared, the EXTCONV* signal is not driven by the RTSI switch.
0	A2DRV	This bit controls a driver that allows the OUT2 signal to drive pin A2 of the RTSI switch. This action allows the OUT2 signal to be driven onto one of the RTSI bus trigger lines. If this bit is set, pin A2 of the RTSI switch is driven by OUT2. If this bit is cleared, the pin A2 is not driven.

Event Strobe Register Group

The Event Strobe Register Group consists of four registers that, when written to, cause the occurrence of certain events on the NB-MIO-16 board, such as clearing flags and starting A/D conversions.

Descriptions of the registers that make up the Event Strobe Register Group are as follows.

Start Convert Register

Writing to the Start Convert Register location initiates an A/D conversion.

Address: Slot starting address + 10 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map: Not applicable, no bits used

Start DAQ Register

Writing to the Start DAQ Register location initiates a multiple A/D conversion data acquisition operation.

When initiating a data acquisition operation by writing to the Start DAQ Register, the EXTTRIG* pin at the I/O connector must be left unconnected, or driven high. If EXTTRIG* is held low, writing to this register has no effect.

Note: ***Several other pieces of NB-MIO-16 circuitry must be set up before a data acquisition run can occur. See*** *Programming Multiple A/D Conversions on a Single Input Channel* ***later in this chapter.***

Address: Slot starting address + 14 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map: Not applicable, no bits used

A/D Clear Register

Writing to the A/D Clear Register location clears the data acquisition circuitry. The following are the specific events that occur:

- Any data acquisition operation in progress is canceled.
- The A/D FIFO is emptied.
- The overrun flag is cleared.
- The overflow flag is cleared.
- Any pending CONV interrupt is cleared.
- Any pending RUN interrupt is cleared.
- Any pending DMA request is cleared.

Address: Slot starting address + 18 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map: Not applicable, no bits used

External Strobe Register

Writing to the External Strobe Register location generates an active low, approximately 100 ns strobe pulse at the EXTSTROBE output at the I/O connector. This action may be useful for several applications, including generating external general-purpose triggers and latching data into external devices (from the digital output port, for example).

Address: Slot starting address + 1C (hex)

Type: Write-only

Word Size: 16-bit

Bit Map: Not applicable, no bits used

Analog Output Register Group

The three registers making up the Analog Output Register Group allow the two DACs in the two analog output channels to be loaded. DAC0 controls analog output Channel 0. DAC1 controls analog output Channel 1. These DACs can be written to individually or simultaneously.

The bit descriptions for the Analog Output Register Group are identical. All three registers are as follows.

DAC0, DAC1, and DAC0 and DAC1 Registers

Writing to these registers loads the analog output channel DACs, thereby updating the voltages generated by the analog output channels.

Address:	Slot starting address + 20 (hex)	Load DAC0
	Slot starting address + 24 (hex)	Load DAC1
	Slot starting address + 28 (hex)	Load DAC0 and DAC1

Type: Write-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	D11 MSB	D10	D9	D8

7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0

Bit	Name	Description
15-12	X	Don't care bits.
11-0	D<11..0>	These twelve bits are loaded into the DAC, thereby updating the voltage generated by the analog output channel. See *Programming the Analog Output Circuitry* later in this chapter for a table mapping digital values to output voltage.

Analog Input Register Group

The three registers making up the Analog Input Register Group control the analog input circuitry and allow the A/D FIFO to be read from. The Mux-Counter Register allows the mux-gain memory to be addressed. The Mux-Gain Register controls the current multiplexer and gain settings and allows the mux-gain memory to be written to. Reading the A/D FIFO Register returns stored A/D conversion results.

Bit descriptions for the Analog Input Register Group registers are as follows.

Mux-Counter Register

The Mux-Counter Register loads the counter that sequences through the mux-gain memory.

Address: Slot starting address + 8 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
X	X	X	X	MC3	MC2	MC1	MC0

Bit	Name	Description
15-4	X	Don't care bits.
3-0	MC<3..0>	These four bits are loaded into the mux counter by writing to the Mux-Counter Register. The mux counter generates addresses for the mux-gain memory; therefore, writing to the Mux-Counter Register allows a specific location in the mux-gain memory to be addressed. The mux-gain memory contains a sequence of multiplexer addresses and gain settings. For example, writing 0004 hexadecimal to the Mux-Counter Register loads the mux counter with the value 4 and addresses mux-gain memory location 4. The analog circuitry is then controlled by the multiplexer address and gain settings in mux-gain memory location 4 (see the description of the Mux-Gain Register).

Mux-Gain Register

The Mux-Gain Register controls the multiplexer and gain settings, and, when used in conjunction with the Mux-Counter Register, allows a scan sequence to load into the mux-gain memory.

Address: Slot starting address + C (hex)

Type: Write-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
GAIN1	GAIN0	X	X	MA3	MA2	MA1	MA0

Bit	Name	Description
15-8	X	Don't care bits.
7-6	GAIN<1..0>	This 2-bit field controls the gain setting of the input instrumentation amplifier. The actual amplifier gains depend on the type of NB-MIO-16 board. The following gains can be selected on the NB-MIO-16H board:

GAIN<1..0>	Actual Gain
00	1
01	2
10	4
11	8

The following gains can be selected on the NB-MIO-16L board:

GAIN<1..0>	Actual Gain
00	1
01	10
10	100
11	500

Bit	Name	Description (continued)
5-4	X	Don't care bits.
3-0	MA<3..0>	This 4-bit field controls the multiplexer address setting of the input multiplexers, thereby allowing the analog input channel to be selected. In single-ended mode (NRSE or RSE), only one analog input channel is selected. In DIFF mode, two analog input channels are selected. A table showing the analog input channels selected for either mode is given below.

MA<3..0>	Selected Analog Input Channels	
	Single-Ended	DIFF (+) (-)
0000	0	0 & 8
0001	1	1 & 9
0010	2	2 & 10
0011	3	3 & 11
0100	4	4 & 12
0101	5	5 & 13
0110	6	6 & 14
0111	7	7 & 15
1000	8	0 & 8
1001	9	1 & 9
1010	10	2 & 10
1011	11	3 & 11
1100	12	4 & 12
1101	13	5 & 13
1110	14	6 & 14
1111	15	7 & 15

Writing to the Mux-Gain Register updates the current analog input channel selection and the current gain setting. The mux-gain memory is also loaded by writing to the Mux-Gain Register. The mux counter is written to in order to address a specific location in the mux-gain memory. Any subsequent value written to the Mux-Gain Register is then stored in that memory location as well as applied to the analog input multiplexer and gain circuitry.

A/D FIFO Register

Reading the A/D FIFO Register returns the oldest A/D conversion value stored in the A/D FIFO. Whenever the A/D FIFO is read, the value read is removed from the A/D FIFO, thereby freeing space for another A/D conversion value to be stored. Values are stored into the A/D FIFO by the ADC whenever an A/D conversion is complete.

The A/D FIFO is emptied when all values it contains are read. The Status Register should be read before the A/D FIFO Register is read. If the A/D FIFO contains one or more A/D conversion values, the CONVAVAIL bit is set in the Status Register and the A/D FIFO Register can be read to retrieve a value. If the CONVAVAIL bit is clear, the A/D FIFO is empty, in which case reading the A/D FIFO Register returns meaningless information.

The values returned by reading the A/D FIFO Register are available in two different binary formats: straight binary (which generates only positive numbers) or two's complement binary (which generates both positive and negative numbers). The binary format used is selected by the 2SCADC* bit in Command Register 1. The bit pattern returned for either format is given below.

Address: Slot starting address + 2C (hex)

Type: Read-only

Word Size: 16-bit

Bit Map: Straight binary mode

15	14	13	12	11	10	9	8
0	0	0	0	D11	D10	D9	D8

7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0

Bit	Name	Description
15-12		The bits are not used on the NB-MIO-016. *Always* write a zero to each of these bits.
11-0	D<11..0>	This is the straight binary result of a 12-bit A/D conversion. The most significant four bits are set to 0 in order to return a 16-bit result. Values read, therefore, range from 0 to 4095 decimal (0000 to 0FFF). Straight binary mode is useful for unipolar analog input readings because all values that are read reflect a positive polarity input signal.

A/D FIFO Register (continued)

Bit Map: Two's complement binary mode

15	14	13	12	11	10	9	8
D11	D11	D11	D11	D11	D10	D9	D8

7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0

Bit	Name	Description
15-0	D<11..0>	These bits are the two's complement result of a 12-bit A/D conversion. Bit D11 is inverted and extended out to bits D12 through D15. Values read, therefore, range from -2048 to +2047 decimal (F800 to 7FF hex). Two's complement mode is useful for bipolar analog input readings because the values read reflect the polarity of the input signal.

Counter/Timer (Am9513) Group

The three registers making up the Counter/Timer Register Group access the onboard Am9513 Counter/Timer. The Am9513 controls onboard data acquisition timing as well as general-purpose timing for the user.

The Am9513 registers described here are the Am9513 Data Register, the Am9513 Command Register, and the Am9513 Status Register. The Am9513 contains 18 additional internal registers. These internal registers are accessed through the Data Register. A detailed register description of all Am9513 registers is provided Appendix C, *AMD Data Sheet* in this manual.

Bit descriptions for each register in the Counter/Timer Register Group registers are as follows.

Am9513 Data Register

The Am9513 Data Register allows any of the 18 internal registers of the Am9513 to be written to or read from. The Am9513 Command Register must be written to in order to select the register to be accessed by the Data Register. The internal registers accessed by the Data Register are as follows:

- Counter Mode Registers for Counters 1, 2, 3, 4, and 5
- Counter Load Registers for Counters 1, 2, 3, 4, and 5
- Counter Hold Registers for Counters 1, 2, 3, 4, and 5
- The Master Mode Register
- The Compare Registers for Counters 1 and 2

All these registers are 16-bit registers. Bit descriptions for each of these registers are given in Appendix C, *AMD Data Sheet,* in this manual.

Address: Slot starting address + 30 (hex)

Type: Read-and-write

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
D15	D14	D13	D12	D11	D10	D9	D8
7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0

Bit	Name	Description
15-0	D<15..0>	These 16 bits are loaded into the Am9513 Internal Register currently selected. See Appendix C, *AMD Data Sheet*, for the detailed bit descriptions of the 18 registers accessed through the Am9513 Data Register.

Am9513 Command Register

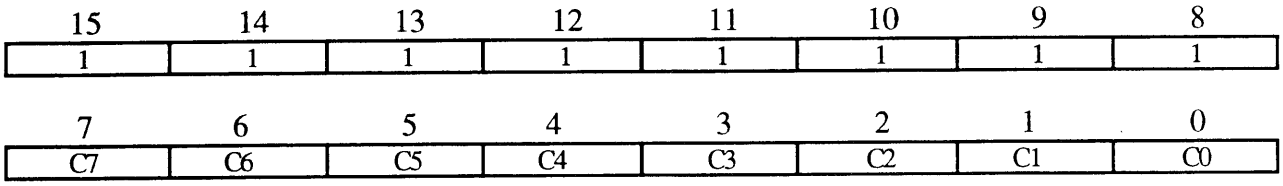
The Am9513 Command Register controls the overall operation of the Am9513 Counter/Timer and also controls selection of the internal registers that are accessed through the Am9513 Data Register.

Address: Slot starting address + 34 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map:



Bit	Name	Description
15-8		These bits must always be set to one when writing to the Am9513 Command Register.
7-0	C<7..0>	These eight bits are loaded into the Am9513 Command Register. See Appendix C, *AMD Data Sheet,* for a detailed bit description of the Am9513 Command Register.

Am9513 Status Register

The Am9513 Status Register provides information about the output pin status of each counter in the Am9513.

Address: Slot starting address + 34 (hex)

Type: Read-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
X	X	OUT5	OUT4	OUT3	OUT2	OUT1	BYTE POINTER

Bit	Name	Description
15-6	X	Don't care bits.
5-1	OUT<5..1>	Each of these five bits returns the logic state of the associated counter output pin. For example, if OUT4 is set, then the output pin of Counter 4 is at a logic high state.
0	BYTE POINTER	This bit represents the state of the Am9513 Byte Pointer Flip-Flop. This bit has no significance for NB-MIO-16 operation because the Am9513 should always be used in 16-bit mode on the NB-MIO-16.

Digital I/O Register Group

The two registers making up the Digital I/O Register Group monitor and control the NB-MIO-16 digital I/O lines. The Digital Input Register returns the digital state of the eight digital I/O lines. A pattern written to the Digital Output Register is driven onto the digital I/O lines when the digital output drivers are enabled (see Command Register 2).

Bit descriptions for the registers in the Digital I/O Register Group are as follows.

Digital Input Register

The Digital Input Register, when read, returns the logic state of the eight NB-MIO-16 digital I/O lines.

Address: Slot starting address + 38 (hex)

Type: Read-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
BDI3	BDI2	BDI1	BDI0	ADI3	ADI2	ADI1	ADI0

Bit	Name	Description
15-8	X	Don't care bits.
7-4	BDI<3..0>	These four bits represent the logic state of the digital lines BDIO<3..0>.
3-0	ADI<3..0>	These four bits represent the logic state of the digital lines ADIO<3..0>.

Digital Output Register

The Digital Output Register is written to in order to control the eight NB-MIO-16 digital I/O lines. The Digital Output Register controls both ports A and B. When either digital port is enabled, the pattern contained in the Digital Output Register is driven onto the lines of the digital port.

Address: Slot starting address + 38 (hex)

Type: Write-only

Word Size: 16-bit

Bit Map:

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
BDO3	BDO2	BDO1	BDO0	ADO3	ADO2	ADO1	ADO0

Bit	Name	Description
15-8	X	Don't care bits.
7-4	BDO<3..0>	These four bits control the digital lines BDIO<3..0>. The bit DOUTBEN in Command Register 2 must be set in order for BDO<3..0> to be driven onto the digital lines BDIO<3..0>.
3-0	ADO<3..0>	These four bits control the digital lines ADIO<3..0>. The bit DOUTAEN in Command Register 2 must be set in order for ADO<3..0> to be driven onto the digital lines ADIO<3..0>.

The RTSI Switch Register Group

The two registers making up the RTSI Switch Register Group allow the NB-MIO-16 RTSI switch to be programmed for routing of signals on the RTSI bus trigger lines to and from NB-MIO-16 signal lines. The RTSI switch is programmed by shifting a 56-bit routing pattern into the RTSI switch and then loading the internal RTSI control register. The routing pattern is shifted into the RTSI switch by writing one bit at a time to the RTSI Switch Shift Register. The RTSI control register is then loaded by writing to the RTSI Switch Strobe Register.

Bit descriptions for the registers in the RTSI Switch Register Group are as follows.

RTSI Switch Shift Register

The RTSI Switch Shift Register is written to in order to load the RTSI switch internal 56-bit control register with routing information for switching signals to and from the RTSI bus trigger lines. The Shift Register is a 1-bit register and must be written to 56 times in order to shift the 56 bits into the internal register.

Address: Slot starting address + C 0000 (hex)

Type: Write-only

Word Size: 8-bit

Bit Map:

7	6	5	4	3	2	1	0
X	X	X	X	X	X	X	RSI

Bit	Name	Description
7-1	X	Don't care bits.
0	RSI	RTSI switch Serial Input. This bit is the serial input to the RTSI switch. Each time the RTSI Switch Shift Register is written to, the value of this bit is shifted into the RTSI switch. See *Programming the RTSI Switch* later in this chapter for more information.

RTSI Switch Strobe Register

The RTSI Switch Strobe Register is written to in order to load the contents of the RTSI Shift Register into the RTSI Switch Control Register, thereby updating the RTSI switch routing pattern. The Strobe Register is written to after shifting the 56-bit routing pattern into the RTSI Switch Shift Register.

Address: Slot starting address + C 0004 (hex)

Type: Write-only

Word Size: 8-bit

Bit Map: Not applicable, no bits used

The Configuration EPROM

The Configuration EPROM on the NB-MIO-16 contains information pertinent to the NB-MIO-16 board and is required by the Macintosh. The Macintosh system Slot Manager reads the Configuration EPROM upon system start-up.

The Configuration EPROM is mapped to address offset locations E 1000 through F FFFC (hexadecimal). The EPROM is 8 bits (1 byte) wide and 8K bytes in length. Each byte of the EPROM is mapped to every fourth address location on the NB-MIO-16 board: the first byte is read from slot address + E 1000; the second byte is read from slot address + E 1004; the third byte is read from slot address + E 1008, and so on.

Programming Considerations

This section contains programming instructions for operating the circuitry on the NB-MIO-16 board. Programming the NB-MIO-16 involves writing to and reading from the various registers on the board. The programming instructions list the sequence of steps to take. The instructions are language independent; that is, they instruct the user to write a value to a given register, to set or clear a bit in a given register, or to detect whether a given bit is set or clear without presenting the actual code.

Register Programming Considerations

Registers in the Macintosh are memory mapped; that is, to write to a register, a value is stored in a memory location. To read a register, a memory location is read. Only memory location reads and writes can be performed on the NB-MIO-16 registers. Mathematical or logical operations *cannot* be applied directly to the NB-MIO-16 registers. Attempting to do so results in unpredictable program behavior.

Several write-only registers on the NB-MIO-16 contain bits that control independent pieces of the onboard circuitry. In the set or clear instructions provided, specific register bits are supposed to be set or cleared without changing the current state of the remaining bits in the register. However, writing to these registers affects all register bits simultaneously. It is not possible to read these registers to determine which bits have been set or cleared in the past; therefore, you should maintain a software copy of the write-only registers. This software copy can then be read to determine the status of the write-only registers. To change the state of a single bit without disturbing the remaining bits, set or clear the bit in the software copy and write the software copy to the register.

Initializing the NB-MIO-16 Board

The NB-MIO-16 hardware must be initialized for the NB-MIO-16 circuitry to operate properly. To initialize the NB-MIO-16 hardware, complete these steps:

1. Write 0 to Command Register 1 (16-bit write).
2. Write 0 to Command Register 2 (16-bit write).
3. Write 0 to the Mux-Gain Register.
4. Initialize the Am9513 (described as follows).
5. Write 0 to the A/D Clear Register (16-bit write).

This sequence leaves the NB-MIO-16 circuitry in the following state:

- DMA is disabled.
- All interrupts are disabled.
- Outputs of counter/timers are in a high-impedance state.
- Analog input circuitry is initialized.

- A/D FIFO is cleared.
- Analog input Channel 0 is selected.
- Gain of 1 is selected.

Initializing the Am9513

Follow the sequence below to initialize the Am9513 Counter/Timer. All writes are 16-bit write operations. All values are given in hexadecimal.

1. Issue a master reset by writing FFFF to the Am9513 Command Register.
2. Set up Am9513 16-bit mode by writing FFEF to the Am9513 Command Register.
3. Point to Am9513 Master Mode Register by writing FF17 to the Am9513 Command Register.
4. Load master mode value into Am9513 Master Mode Register by writing F000 to the Am9513 Data Register.
5. Initialize all five counters. For *ctr* = 1 to 5, follow these steps:
   - Write FF00 + *ctr* to the Am9513 Command Register (select the Counter Mode Register).
   - Write 0004 to the Am9513 Data Register (store the counter mode value).
   - Write FF08 + *ctr* to the Am9513 Command Register (select the Counter Load Register).
   - Write 3 to the Am9513 Data Register (store the inactive count value in the Counter Load Register).
6. Load all counters with their counter load register values by writing FF5F to the Am9513 Command Register.

After this sequence of writes, the Am9513 Counter/Timer is in the following state:

- 16-bit mode is enabled.
- BCD scalar division is selected.
- The FOUT signal is turned off.
- All counter OUT output pins are set to high-impedance output state.
- All counters are loaded with a non-terminal count value.

For additional details concerning the Am9513 Counter/Timer, see Appendix C, *AMD Data Sheet*.

Initializing the Analog Output Circuitry

The NB-MIO-16 powers up with the analog output circuitry at an unknown voltage. You may wish to initialize the analog output circuitry to 0 V. If the analog output channel is configured for unipolar operation, then write 0 to the DAC Register (16-bit write) for that channel.

If the analog output channel is configured for bipolar output, then write 2048 (07FF hexadecimal) to the DAC Register for that channel.

Programming the Analog Input Circuitry

Programming the analog input circuitry to obtain a single A/D conversion involves the following sequence of steps:

1. Select analog input channel and gain.
2. Initiate an A/D conversion.
3. Read the A/D conversion result.

In addition, the binary format of the A/D conversion result can be programmed and the analog input circuitry can be reset.

1. Select analog input channel and gain.

The analog input channel and gain are selected by writing to the Mux-Gain Register. Bits 7 and 6 control the gain, and bits 3 through 0 select the analog input channel. See the Mux-Gain Register bit description above for gain and analog input channel bit patterns. Set up the bits as given in the Mux-Gain Register bit description and write to the Mux-Gain Register.

Once the Mux-Gain Register is set up, it needs to be written to only if the analog input channel or gain setting needs to be changed.

2. Initiate an A/D conversion.

An A/D conversion can be initiated in one of two ways–a software-generated pulse or a hardware pulse.

To initiate an A/D conversion through software, write 0 to the A/D Convert Register (16-bit write).

To initiate an A/D conversion through hardware, apply an active low pulse to the EXTCONV* pin on the NB-MIO-16 I/O connector. See *Data Acquisition Timing Connections* in Chapter 2, *Configuration and Installation*, for EXTCONV* signal specifications.

Once an A/D conversion is initiated, the A/D converter automatically stores the result in the A/D FIFO at the end of its conversion cycle.

3. Read the A/D conversion result.

A/D conversion results are obtained by reading the A/D FIFO Register. Before reading the A/D FIFO, however, the Status Register must be read to determine whether the A/D FIFO contains any results.

To read the A/D conversion result, do the following:

- Read the Status Register (16-bit read).
- If the CONVAVAIL bit is set (bit 13), then read the A/D FIFO Register to obtain the result.

Reading the A/D FIFO Register removes the A/D conversion result from the A/D FIFO. The binary modes of the A/D FIFO output are explained below.

The CONVAVAIL bit indicates whether one or more A/D conversion results are stored in the A/D FIFO. If the CONV AVAIL bit is not set, the A/D FIFO is empty and reading the A/D FIFO Register returns meaningless data. Once an A/D conversion is initiated, the CONVAVAIL bit should be set within 100 µsec, indicating that the data conversion result can be read from the FIFO.

It is possible to cause an A/D FIFO overflow condition, which occurs if more than 16 conversions are initiated and stored in the A/D FIFO before the A/D FIFO Register is read. If this condition occurs, the OVERFLOW bit is set in the Status Register to alert the user that one or more A/D conversion results have been lost because of FIFO overflow. Writing to the A/D Clear Register clears this error flag and empties the A/D FIFO.

A/D FIFO Output Binary Formats

The A/D conversion result can be returned from the A/D FIFO as a two's complement or straight binary value by setting or clearing the 2SCADC* bit in Command Register 1. If the analog input circuitry is configured for the input range 0 to +10 V, straight binary format is recommended (set the 2SCADC* bit). Straight binary format returns numbers between 0 and 4095 (decimal) when the A/D FIFO Register is read. If the analog input circuitry is configured for the input ranges -5 to +5 V or -10 to +10 V, two's complement format is recommended (clear the 2SCADC* bit). Two's complement format returns numbers between -2048 and +2047 (decimal) when the A/D FIFO Register is read.

The factory default setting is the input range -10 to +10 V. Table 4-3 shows input voltage versus A/D conversion value for straight binary mode and 0 to +10 V input range. Table 4-4 shows input voltage versus A/D conversion value for two's complement mode for both -5 to +5 V and -10 to +10 V input ranges.

Table 4-3. Straight Binary Mode A/D Conversion Values

Input Voltage (Gain = 1)	A/D Conversion Result Range: 0 to +10 V	
	Decimal	Hex
0	0	0000
2.5	1024	0400
5.0	2048	0800
7.5	3072	0C00
9.9976	4095	0FFF

Table 4-4. Two's Complement Mode A/D Conversion Values

Input Voltage (Gain = 1)	A/D Conversion Result			
	Range: -5 to +5 V		Range: -10 to +10 V	
	Decimal	Hex	Decimal	Hex
-10.0	—	—	-2048	F800
-5.0	-2048	F800	-1024	FC00
-2.5	-1024	FC00	-512	FE00
0	0	0000	0	0000
2.5	1024	0400	512	0200
4.9976	2047	07FF	—	—
5.0	—	—	1024	0400
9.9951	—	—	2047	07FF

Clearing the Analog Input Circuitry

The analog input circuitry can be cleared by writing to the A/D Clear Register, which leaves the analog input circuitry in the following state:

- Analog Input Error Flags OVERFLOW and OVERRUN are cleared.
- Pending interrupt requests are cleared.
- A/D FIFO is emptied.

Empty the A/D FIFO before starting any A/D conversions. This action guarantees that the A/D conversion results read from the A/D FIFO are the results from the initiated conversions and not left-over results from previous conversions.

To clear the analog input circuitry and the A/D FIFO, write 0 to the A/D Clear Register (16-bit write).

Programming Multiple A/D Conversions on a Single Input Channel

The NB-MIO-16 board can be programmed to initiate multiple A/D conversions in the following ways:

- Conversions can be initiated either by the onboard sample-interval counter pulses or by pulses applied to the EXT_CONV input.
- The onboard sample-interval counter can be controlled either by the onboard sample counter or by a signal applied to the EXTGATE input.

The most commonly used configuration is for the onboard sample-interval and sample counters to control the entire data acquisition operation. Programming this configuration is explained here. The other timing configurations are explained under *External Timing Considerations for Multiple A/D Conversions* later in this chapter. Multiple-channel scanning is discussed under *Programming Multiple A/D Conversions with Channel Scanning* later in this chapter.

Programming multiple A/D conversions on a single channel requires the following steps:

1. Select analog input channel and gain.
2. Program the sample-interval counter.
3. Program the sample counter.
4. Clear the A/D circuitry.
5. Enable the data acquisition operation.
6. Apply a trigger.
7. Service the data acquisition operation.

In step 7, the term *service* refers to reading data out of the FIFO as it becomes available. Each of these programming steps is explained below.

1. Select analog input channel and gain.

The analog input channel and gain are selected by writing to the Mux-Gain Register. Bits 7 and 6 control the gain, and bits 3 through 0 select the analog input channel. See the Mux-Gain Register bit description above for gain and analog input channel bit patterns. Set up the bits as given in the Mux-Gain Register bit description and write to the Mux-Gain Register.

The Mux-Gain Register needs to be written to only when the analog input channel or gain setting needs to be changed.

2. Program the sample-interval counter.

Counter 3 of the Am9513 Counter/Timer is used as the sample-interval counter. Counter 3 can be programmed to generate a pulse once every *N* counts. *N* is referred to as the sample interval, that is, the time between successive A/D conversions. *N* can be between 2 and 65,536. One count is equal to the period of the timebase clock used by the counter. The following clocks are available internal to the Am9513: 1 MHz, 100 kHz, 10 kHz, 1 kHz, and 100 Hz. In addition, the sample-interval timer can use signals connected to any of the Am9513 SOURCE input pins.

To program the sample-interval counter, use the following programming sequence. All writes are 16-bit write operations. All values given are hexadecimal.

a. Write FF03 to the Am9513 Command Register (select the Counter 3 Mode Register).

b. Write the mode value to the Am9513 Data Register (store the Counter 3 mode value). Use one of the following mode values:

   8B25 – Selects 1-MHz clock.
   8C25 – Selects 100-kHz clock.
   8D25 – Selects 10-kHz clock.
   8E25 – Selects 1-kHz clock.
   8F25 – Selects 100-Hz clock.
   8525 – Selects signal at SOURCE5 input as clock (counts the rising edge of the signal, 6 MHz maximum).

c. Write FF0B to the Am9513 Command Register (select the Counter 3 Load Register).

d. Write 2 to the Am9513 Data Register (store the Counter 3 load value).

e. Write FF44 to the Am9513 Command Register (load Counter 3).

f. Write FFF3 to the Am9513 Command Register (step Counter 3 down to 1).

g. Write the desired sample interval to the Am9513 Data Register (store the Counter 3 load value):

   - If the sample interval is between 2 and FFFF (65,535 decimal), write the sample interval to the Am9513 Data Register.

   - If the sample interval is 10000 (65,536 decimal), write 0 to the Am9513 Data Register.

h. Write FF24 to the Am9513 Command Register (arm Counter 3).

After you apply this programming sequence, Counter 3 is configured to generate A/D conversion pulses as soon as application of a trigger causes it to be enabled.

3. Program the sample counter.

Counters 4 and 5 of the Am9513 Counter/Timer are used as the sample counter. The sample counter tallies the number of A/D conversions initiated by Counter 3 and stops Counter 3 when the desired sample count is reached. If the desired sample count is 65,536 or less, only Counter 4 needs to be used, making Counter 5 available for general-purpose timing applications. If the desired sample count is greater than 65,536, both Counters 4 and 5 must be used.

Sample Counts 2 through 65,536

To program the sample counter for sample counts up to 65,536, use the following programming sequence. The minimum permitted sample count is 2. All writes are 16-bit write operations. All values are hexadecimal.

a. Write FF04 to the Am9513 Command Register (select the Counter 4 Mode Register).

b. Write 1001 to the Am9513 Data Register (store the Counter 4 mode value).

c. Write FF0C to the Am9513 Command Register (select the Counter 4 Load Register).

d. Write the sample count value to the Am9513 Data Register (store the Counter 4 load value):

   - If the sample count is between 2 and FFFF (65,535 decimal), write the sample count to the Am9513 Data Register.
   - If the sample count is 10000 (65,536 decimal), write 0 to the Am9513 Data Register.

e. Write FF68 to the Am9513 Command Register (load and arm Counter 4).

f. Clear the 16*/32 CNT bit in Command Register 1 to notify the hardware that only Counter 4 will be used as the sample counter.

After you apply this programming sequence, Counter 4 is configured to count A/D conversion pulses generated by Counter 3 and turns off the data acquisition operation when it counts down to zero.

Sample Counts Greater than 65,536

To program the sample counter for sample counts greater than 65,536, use the following programming sequence. The lower 16 bits of the sample count are stored in Counter 4 and the upper 16 bits of the sample count are stored in Counter 5. All writes are 16-bit write operations. All values given are hexadecimal.

a. Write FF04 to the Am9513 Command Register (select the Counter 4 Mode Register).

b. Write 1021 to the Am9513 Data Register (store the Counter 4 mode value).

c. Write FF0C to the Am9513 Command Register (select the Counter 4 Load Register).

d. Write the least significant 16 bits of the sample count value to the Am9513 Data Register (store the Counter 4 load value).

e. Write FF48 to the Am9513 Command Register (load Counter 4).

f. Write 0 to the Am9513 Data Register (store 0 into the Load Register for Counter 4 reloading).

g. Write FF28 to the Am9513 Command Register (arm Counter 4).

h. Write FF05 to the Am9513 Command Register (select the Counter 5 Mode Register).

i. Write 1 to the Am9513 Data Register (store the Counter 5 mode value).

j. Write FF0D to the Am9513 Command Register (select the Counter 5 Load Register)

k. Take the most significant 16 bits of the sample count value, add 1, and write the result to the Am9513 Data Register (store the Counter 5 load value).

l. Write FF70 to the Am9513 Command Register (load and arm Counter 5).

m. Set the 16*/32 CNT bit in Command Register 1 to notify the hardware that both Counters 4 and 5 will be used as the sample counter.

After you complete this programming sequence, Counter 4 is configured to count A/D conversion pulses generated by Counter 3, and Counter 5 decrements every time Counter 4 reaches 0. The data acquisition operation terminates when they both reach 0.

4. Clear the A/D circuitry.

Before starting the data acquisition operation, the A/D FIFO must be emptied to clear out any old A/D conversion results. This emptying must be done after the counters are programmed in case any spurious edges were caused while programming the counters. Write 0 to the A/D Clear Register to empty the FIFO (16-bit write).

5. Enable the data acquisition operation.

To enable the data acquisition operation such that A/D conversions begin when a trigger is received, set the DAQ EN bit in Command Register 1.

6. Apply a trigger.

Once set up by following the above steps, the data acquisition operation is initiated when a trigger is received. A trigger can be sent in one of two ways: through software or through hardware.

To initiate the data acquisition operation through software, write 0 to the Start DAQ Register (16-bit write).

To initiate the data acquisition operation through hardware, apply an active low pulse to the EXTTRIG* pin on the NB-MIO-16 I/O connector. See *Data Acquisition Timing Connections* in Chapter 2, *Configuration and Installation*, for EXTTRIG* signal specifications.

Once the trigger is applied, Counter 3 generates pulses initiating A/D conversions once every sample interval until the sample counter reaches 0.

7. Service the data acquisition operation.

Once the data acquisition operation is started, the operation must be serviced by reading the A/D FIFO Register every time an A/D conversion result becomes available. To do this, perform the following sequence until the desired number of conversion results has been read:

a. Read the Status Register (16-bit read).

b. If the CONVAVAIL bit is set (bit 13), then read the A/D FIFO Register to obtain the result.

Interrupts or DMA can also be used to service the data acquisition operation. These topics are discussed later in this chapter.

Two error conditions may occur during a data acquisition operation: an overflow error or an overrun error. These error conditions are reported through the Status Register and should be checked every time the Status Register is read to check the CONVAVAIL bit.

An overflow condition occurs when more than 16 A/D conversions have been stored in the A/D FIFO without the A/D FIFO being read; that is, the A/D FIFO is full and cannot accept any more data. This situation occurs if the software loop reading the A/D FIFO Register is not fast enough to keep up with the A/D conversion rate. When an overflow occurs, at least one A/D conversion result is lost. An overflow condition has occurred if the OVERFLOW bit in the Status Register is set.

An overrun condition occurs if a second A/D conversion is initiated before the previous conversion is finished. This condition may result in one or more missing A/D conversions. This condition occurs if the sample interval is too small (sample rate is too high). An overrun condition has occurred if the OVERRUN bit in the Status Register is set. The NB-MIO-16(H/L)-9 has a maximum recommended single-channel data acquisition rate of 100 ksamples/sec. Appendix A, *Specifications*, contains more information about data acquisition rates.

Both the OVERFLOW and OVERRUN bits in the Status Register are cleared by writing to the A/D Clear Register.

External Timing Considerations for Multiple A/D Conversions

The case of controlled data acquisition operations using the onboard sample-interval and sample counters was given above. The two external timing cases are given here: using the EXTGATE input to control the sample-interval counter and applying pulses to the EXT_CONV input.

Gating the Sample-Interval Counter

In this case, the sample-interval counter is gated by a signal applied to the EXTGATE input on the NB-MIO-16 I/O connector. To gate the sample-interval counter, perform these programming steps:

1. Select analog input channel and gain.
2. Program the sample-interval counter.
3. Clear the A/D circuitry.
4. Service the data acquisition operation.

1. Select analog input channel and gain.

The analog input channel and gain are selected by writing to the Mux-Gain Register. Bits 7 and 6 control the gain, and bits 3 through 0 select the analog input channel. See the Mux-Gain Register bit description above for gain and analog input channel bit patterns. Set up the bits as given in the Mux-Gain Register bit description and write to the Mux-Gain Register.

Once the Mux-Gain Register is set up, it needs to be written to only when the analog input channel or gain setting needs to be changed.

2. Program the sample-interval counter.

Counter 3 of the Am9513 Counter/Timer is used as the sample-interval counter. Counter 3 can be programmed to generate a pulse once every *N* counts. *N* is referred to as the sample interval, that is, the time between successive A/D conversions. *N* can be between 2 and 65,536. One count is equal to the period of the timebase clock used by the counter. The following clocks are available internal to the Am9513: 1 MHz, 100 kHz, 10 kHz, 1 kHz, and 100 Hz. In addition, the sample-interval timer can use signals connected to any of the Am9513 SOURCE input pins.

To program the sample-interval counter, use the following programming sequence. All writes are 16-bit write operations. All values given are hexadecimal.

a. Write FF03 to the Am9513 Command Register (select the Counter 3 Mode Register).

b. Write the mode value to the Am9513 Data Register (store the Counter 3 mode value). Use one of the following mode values:

   4B25 – Selects 1-MHz clock.
   4C25 – Selects 100-kHz clock.
   4D25 – Selects 10-kHz clock.
   4E25 – Selects 1-kHz clock.
   4F25 – Selects 100-Hz clock.
   4525 – Selects signal at SOURCE5 input as clock (counts the rising edge of the signal, 6 MHz maximum).

c. Write FF0B to the Am9513 Command Register (select the Counter 3 Load Register).

d. Write 2 to the Am9513 Data Register (store the Counter 3 load value).

e. Write FF44 to the Am9513 Command Register (load Counter 3).

f. Write FFF3 to the Am9513 Command Register (step Counter 3 down to 1).

g. Write the desired sample interval to the Am9513 Data Register (store the Counter 3 load value):

   - If the sample interval is between 2 and FFFF (65,535 decimal) inclusive, write the sample interval to the Am9513 Data Register.
   - If the sample interval is 10000 (65,536 decimal), write 0 to the Am9513 Data Register.

h. Write FF24 to the Am9513 Command Register (arm Counter 3).

After you complete this programming sequence, Counter 3 is configured to generate A/D conversion pulses as soon as an active high signal EXTGATE is applied to the EXTGATE input.

3. Clear the A/D circuitry.

Before starting the data acquisition operation, the A/D FIFO must be emptied to clear out any old A/D conversion results. This emptying must be done after the counters are programmed in case any spurious edges were caused while programming the counters. Write 0 to the A/D Clear Register to empty the FIFO (16-bit write).

4. Service the data acquisition operation.

Once the data acquisition operation is started by application of an active high EXTGATE signal, the operation must be serviced by reading the A/D FIFO Register every time an A/D conversion result becomes available. To do this, perform the following sequence until the desired number of conversion results has been read:

a. Read the Status Register (16-bit read).

b. If the CONVAVAIL bit is set (bit 13), then read the A/D FIFO Register to obtain the result.

Interrupts or DMA can also be used to service the data acquisition operation. These topics are discussed later in this chapter.

Two error conditions may occur during a data acquisition operation: an overflow error or an overrun error. These error conditions are reported through the Status Register and should be checked every time the Status Register is read to check the CONVAVAIL bit.

An overflow condition occurs when more than 16 A/D conversions have been stored in the A/D FIFO without the A/D FIFO being read; that is, the A/D FIFO is full and cannot accept any more data. This situation occurs if the software loop reading the A/D FIFO register is not fast enough to keep up with the A/D conversion rate. When an overflow occurs, at least one A/D conversion result is lost. An overflow condition has occurred if the OVERFLOW bit in the Status Register is set.

An overrun condition occurs if a second A/D conversion is initiated before the previous conversion is finished. This condition may result in one or more missing A/D conversions. This condition occurs if the sample interval is too small (sample rate is too high). An overrun condition has occurred if the OVERRUN bit in the Status Register is set. See Table 3-2 for NB-MIO-16 maximum data acquisition rates.

Both the OVERFLOW and OVERRUN bits in the Status Register are cleared by writing to the A/D Clear Register.

Once steps 1, 2, and 3 are completed, Counter 3 is armed and begins generating pulses whenever the signal applied to the EXTGATE input is at a logic high level. The EXTGATE signal specifications are given in Chapter 2, *Configuration and Installation*. Service the data acquisition operation as given in step 4.

Controlling Multiple A/D Conversions with the EXTCONV* Signal

In this case, none of the onboard counters are used. Pulses applied to the EXTCONV* input initiate the A/D conversions. To control multiple A/D conversions with EXTCONV*, perform these steps:

1. Select analog input channel and gain.
2. Clear the A/D circuitry.
3. Service the data acquisition operation.

First, make certain that Counter 3 is reset as described under *Resetting the Hardware after a Data Acquisition Operation* later in this chapter. If Counter 3 is not reset, it may be driving the EXTCONV line and therefore preventing another signal from successfully driving the line high or low.

1. Select analog input channel and gain.

The analog input channel and gain are selected by writing to the Mux-Gain Register. Bits 7 and 6 control the gain, and bits 3 through 0 select the analog input channel. See the Mux-Gain Register bit description earlier in this chapter for gain and analog input channel bit patterns. Set up the bits as given in the Mux-Gain Register bit description and write to the Mux-Gain Register.

The Mux-Gain Register needs to be written to only when the analog input channel or gain setting needs to be changed.

2. Clear the A/D circuitry.

Before starting the data acquisition operation, the A/D FIFO must be emptied to clear out any old A/D conversion results. Write 0 to the A/D Clear Register to empty the FIFO (16-bit write).

3. Service the data acquisition operation.

Once an external trigger starts the data acquisition operation, the operation must be serviced by reading the A/D FIFO Register every time an A/D conversion result becomes available. To do this, perform the following sequence until the desired number of conversion results has been read:

a. Read the Status Register (16-bit read).

b. If the CONVAVAIL bit is set (bit 13), then read the A/D FIFO Register to obtain the result.

Interrupts or DMA can also be used to service the data acquisition operation. These topics are discussed later in this chapter.

Two error conditions may occur during a data acquisition operation: an overflow error or an overrun error. These error conditions are reported through the Status Register and should be checked every time the Status Register is read to check the CONVAVAIL bit.

An overflow condition occurs when more than 16 A/D conversions have been stored in the A/D FIFO without the A/D FIFO being read; that is, the A/D FIFO is full and cannot accept any more data. This situation occurs if the software loop reading the A/D FIFO Register is not fast enough to keep up with the A/D conversion rate. When an overflow occurs, at least one A/D conversion result is lost. An overflow condition has occurred if the OVERFLOW bit in the Status Register is set.

An overrun condition occurs if a second A/D conversion is initiated before the previous conversion is finished. This condition may result in one or more missing A/D conversions. This condition occurs if the sample interval is too small (sample rate is too high). An overrun condition has occurred if the OVERRUN bit in the Status Register is set. See Table 3-2 for NB-MIO-16 maximum data acquisition rates.

Both the OVERFLOW and OVERRUN bits in the Status Register are cleared by writing to the A/D Clear Register.

An A/D conversion is initiated and stored in the A/D FIFO every time a high-to-low edge is applied to the EXTCONV* input. See Chapter 2, *Configuration and Installation*, for EXTCONV* signal specifications.

Programming Multiple A/D Conversions with Channel Scanning

The data acquisition programming sequences given above program the NB-MIO-16 for multiple A/D conversions on a single input channel. The NB-MIO-16 is programmed for scanning analog input channels and switching gain settings during the data acquisition operation. Programming scanned multiple A/D conversions involves the following programming steps:

1. Set up the analog channel and gain selection sequence.
2. Program the sample-interval counter.
3. Program the sample counter.
4. Clear the A/D circuitry and reset the mux counter.
5. Enable the scanning data acquisition operation.
6. Apply a trigger.
7. Service the data acquisition operation.

Setting the SCANEN bit in Command Register 1 enables scanning during multiple A/D conversions. This bit must be set regardless of the type of timing used; otherwise, only a single channel is scanned. In addition, a channel and gain scan sequence must be stored in the mux-gain memory.

1. Set up the analog channel and gain selection sequence.

During a scanning data acquisition operation, each of the 16 locations in the mux-gain memory is clocked through. A new mux-gain memory location is selected after each A/D conversion. The first conversion is performed on the first channel and gain setting in memory. The second conversion is performed on the second channel and gain setting, and so on. After the 16th conversion is performed, the scan sequence starts over. Thus, in the data collected, every 16th conversion is performed on the same channel and gain setting.

The mux-gain memory must be loaded with the desired scan sequence before data acquisition begins. To load the mux-gain memory, perform the following write operations (16-bit writes).

For $i = 0$ to 15, do the following:

a. Write i to the Mux-Counter Register (this selects the mux-gain memory location).

b. Write the desired analog channel selection and gain setting to the Mux-Gain Register (this loads the mux-gain memory at the selected location).

It is possible to load the mux-gain memory such that only 1, 2, 4, 8, or 16 channels are scanned. For example, if the application requires that only 4 channels are scanned, simply repeat the scan sequence four times when loading the mux-gain memory. In this way, every fourth conversion will be performed on the same channel.

2. Program the sample-interval counter.

Counter 3 of the Am9513 Counter/Timer is used as the sample-interval counter. Counter 3 can be programmed to generate a pulse once every N counts. N is referred to as the sample interval, that is, the time between successive A/D conversions. N can be between 2 and 65,536. One count is equal to the period of the timebase clock used by the counter. The following clocks are available internal to the Am9513: 1 MHz, 100 kHz, 10 kHz, 1 kHz, and 100 Hz. In addition, the sample-interval timer can use signals connected to any of the Am9513 SOURCE input pins.

To program the sample-interval counter, use the following programming sequence. All writes are 16-bit write operations. All values given are hexadecimal.

a. Write FF03 to the Am9513 Command Register (select the Counter 3 Mode Register).

b. Write the mode value to the Am9513 Data Register (store the Counter 3 mode value). Use one of the following mode values:

   8B25 – Selects 1-MHz clock.
   8C25 – Selects 100-kHz clock.
   8D25 – Selects 10-kHz clock.
   8E25 – Selects 1-kHz clock.
   8F25 – Selects 100-Hz clock.
   8525 – Selects signal at SOURCE5 input as clock (counts the rising edge of the signal, 6 MHz maximum).

c. Write FF0B to the Am9513 Command Register (select the Counter 3 Load Register).

d. Write 2 to the Am9513 Data Register (store the Counter 3 load value).

e. Write FF44 to the Am9513 Command Register (load Counter 3).

f. Write FFF3 to the Am9513 Command Register (step Counter 3 down to 1).

g. Write the desired sample interval to the Am9513 Data Register (store the Counter 3 load value):

- If the sample interval is between 2 and 65,535, write the sample interval to the Am9513 Data Register.
- If the sample interval is 65,536, write zero to the Am9513 Data Register.

h. Write FF24 to the Am9513 Command Register (arm Counter 3).

After you complete this programming sequence, Counter 3 is configured to generate A/D conversion pulses as soon as application of a trigger causes it to be enabled.

3. Program the sample counter.

Counters 4 and 5 of the Am9513 Counter/Timer are used as the sample counter. The sample counter tallies the number of A/D conversions initiated by Counter 3 and stops Counter 3 when the desired sample count is reached. If the desired sample count is 65,536 or less, only Counter 4 needs to be used, making Counter 5 available for general-purpose timing applications. If the desired sample count is greater than 65,536, both Counters 4 and 5 must be used.

Sample Counts 2 through 65,536

To program the sample counter for sample counts up to 65,536, use the following programming sequence. The minimum permitted sample count is 2. All writes are 16-bit write operations. All values are hexadecimal.

a. Write FF04 to the Am9513 Command Register (select the Counter 4 Mode Register).

b. Write 1021 to the Am9513 Data Register (store the Counter 4 mode value).

c. Write FF0C to the Am9513 Command Register (select the Counter 4 Load Register).

d. Write the sample count value to the Am9513 Data Register (store the Counter 4 load value):

- If the sample interval is between 2 and 65,535, write the sample count to the Am9513 Data Register.
- If the sample count is 65,536, write zero to the Am9513 Data Register.

e. Write FF68 to the Am9513 Command Register (load and arm Counter 4).

f. Clear the 16*/32 CNT bit in Command Register 1 to notify the hardware that only Counter 4 will be used as the sample counter.

After you complete this programming sequence, Counter 4 is configured to count A/D conversion pulses generated by Counter 3 and turns off the data acquisition operation when it counts down to zero.

Sample Counts Greater than 65,536

To program the sample counter for sample counts greater than 65,536, use the following programming sequence. The lower 16 bits of the sample count are stored in Counter 4, and the upper 16 bits of the sample count are stored in Counter 5. All writes are 16-bit write operations. All values given are hexadecimal.

a. Write FF04 to the Am9513 Command Register (select the Counter 4 Mode Register).

b. Write 1001 to the Am9513 Data Register (store the Counter 4 mode value).

d. Write FF0C to the Am9513 Command Register (select the Counter 4 Load Register).

4. Write the least significant 16 bits of the sample count value to the Am9513 Data Register (store the Counter 4 load value).

e. Write FF48 to the Am9513 Command Register (load Counter 4).

f. Write zero to the Am9513 Data Register (store zero into the Load Register for Counter 4 reloading).

g. Write FF28 to the Am9513 Command Register (arm Counter 4).

h. Write FF05 to the Am9513 Command Register (select the Counter 5 Mode Register).

i. Write 1 to the Am9513 Data Register (store the Counter 5 mode value).

j. Write FF0D to the Am9513 Command Register (select the Counter 5 Load Register).

k. Take the most significant 16 bits of the sample count value, add one, and write the result to the Am9513 Data Register (store the Counter 5 load value).

l. Write FF70 to the Am9513 Command Register (load and arm Counter 5).

m. Set the 16*/32 CNT bit in Command Register 1 to notify the hardware that both Counters 4 and 5 will be used as the sample counter.

After you complete this programming sequence, Counter 4 is configured to count A/D conversion pulses generated by Counter 3, and Counter 5 is incremented every time Counter 4 reaches zero. The data acquisition operation terminates when Counters 4 and 5 both reach zero.

4. Clear the A/D circuitry and reset the mux counter.

Before starting the data acquisition operation, the A/D FIFO must be emptied to clear out any old A/D conversion results. This emptying must be done after the counters are programmed in case any spurious edges were caused while programming the counters. Write zero to the A/D Clear Register to empty the FIFO (16-bit write).

Write zero to the Mux-Counter Register to set the analog input circuitry to the first channel and gain setting of the scan sequence.

5. Enable the scanning data acquisition operation.

To enable the scanning data acquisition operation such that A/D conversions begin when a trigger is received, set the DAQEN bit and the SCANEN bit in Command Register 1.

6. Apply a trigger.

Once set up by the preceding steps, the data acquisition operation is initiated when a trigger is received. A trigger can be sent in one of two ways: through software or through hardware.

To initiate the data acquisition operation through software, write zero to the Start DAQ Register (16-bit write).

To initiate the data acquisition operation through hardware, apply an active low pulse to the EXTTRIG* pin on the NB-MIO-16 I/O connector. See *Data Acquisition Timing Connections* in Chapter 2, *Configuration and Installation*, for EXTTRIG* signal specifications.

Once the trigger is applied, Counter 3 generates pulses initiating A/D conversions once every sample interval until the sample counter reaches zero.

7. Service the data acquisition operation.

Once the data acquisition operation is started by application of a trigger, the operation must be serviced by reading the A/D FIFO Register every time an A/D conversion result becomes available. To do this, perform the following sequence until the desired number of conversion results has been read:

a. Read the Status Register (16-bit read).

b. If the CONVAVAIL bit is set (bit 13), then read the A/D FIFO Register to obtain the result.

Interrupts or DMA can also be used to service the data acquisition operation. These topics are discussed later in this chapter.

Two error conditions may occur during a data acquisition operation: an overflow error or an overrun error. These error conditions are reported through the Status Register and should be checked every time the Status Register is read to check the CONVAVAIL bit.

An overflow condition occurs when more than 16 A/D conversions have been stored in the A/D FIFO without the A/D FIFO being read; that is, the A/D FIFO is full and cannot accept any more data. This situation occurs if the software loop reading the A/D FIFO register is not fast enough to keep up with the A/D conversion rate. When an overflow occurs, at least one A/D conversion result is lost. An overflow condition has occurred if the OVERFLOW bit in the Status Register is set.

An overrun condition occurs if a second A/D conversion is initiated before the previous conversion is finished. This condition may result in one or more missing A/D conversions. This condition occurs if the sample interval is too small (sample rate is too high). An overrun condition has occurred if the OVERRUN bit in the Status Register is set.

Scanned data acquisition requires slower data acquisition rates than single-channel data acquisition because signals must settle each time channels are switched. See Table 3-2 for the maximum recommended multiple-channel data acquisition rates. Appendix A, *Specifications*, contains more information about data acquisition rates.

Both the OVERFLOW and OVERRUN bits in the Status Register are cleared by writing to the A/D Clear Register.

External Timing Considerations for Scanned Data Acquisition

Follow the programming instructions listed under *External Timing Considerations for Multiple A/D Conversions* earlier in this chapter; then complete these additional steps: set up the analog channel and gain sequence as given above, set the SCANEN bit in Command Register 1, and set the mux counter to zero before starting the data acquisition operation.

Resetting the Hardware after a Data Acquisition Operation

After a data acquisition operation is complete, the Am9513 counters used must be disarmed and reset and the A/D circuitry must be reset.

Resetting Counter 3

To reset Counter 3, use the following programming sequence. All writes are 16-bit write operations. All values given are hexadecimal.

1. Write FFC4 to the Am9513 Command Register (disarm Counter 3).
2. Write FF03 to the Am9513 Command Register (select the Counter 3 Mode Register).
3. Write four to the Am9513 Data Register (store the Counter 3 mode value such that counter output becomes high-impedance).
4. Write FF0B to the Am9513 Command Register (select the Counter 3 Load Register).
5. Write three to the Am9513 Data Register (store non-terminal count value in the Counter 3 Load Register).
6. Write FF44 to the Am9513 Command Register (load Counter 3).
7. Write FF44 to the Am9513 Command Register a second time (load Counter 3 again; this guarantees that Counter 3 is not left in a terminal count state).

Resetting Counter 4

To reset Counter 4, use the following programming sequence. All writes are 16-bit write operations. All values given are hexadecimal.

1. Write FFC8 to the Am9513 Command Register (disarm Counter 4).
2. Write FF04 to the Am9513 Command Register (select the Counter 4 Mode Register).

3. Write four to the Am9513 Data Register (store the Counter 4 mode value such that counter output becomes high-impedance).

4. Write FF0C to the Am9513 Command Register (select the Counter 4 Load Register).

5. Write three to the Am9513 Data Register (store non-terminal count value in the Counter 4 Load Register).

6. Write FF48 to the Am9513 Command Register (load Counter 4).

7. Write FF48 to the Am9513 Command Register a second time (load Counter 4 again to guarantee that Counter 4 is not left in a terminal count state).

Resetting Counter 5

To reset Counter 5, use the following programming sequence. All writes are 16-bit write operations. All values given are hexadecimal.

1. Write FFD0 to the Am9513 Command Register (disarm Counter 5).

2. Write FF05 to the Am9513 Command Register (select the Counter 5 Mode Register).

3. Write four to the Am9513 Data Register (store the Counter 5 mode value such that counter output becomes high-impedance).

4. Write FF0D to the Am9513 Command Register (select the Counter 5 Load Register).

5. Write three to the Am9513 Data Register (store non-terminal count value in the Counter 5 Load Register).

6. Write FF50 to the Am9513 Command Register (load Counter 5).

7. Write FF50 to the Am9513 Command Register a second time (load Counter 5 again; this guarantees that Counter 5 is not left in a terminal count state).

After resetting the counters, write 0 to the A/D Clear Register (16-bit write) to clear all error conditions and to empty the A/D FIFO.

Programming the Analog Output Circuitry

The voltage at the analog output circuitry output pins (pins DAC0 OUT and DAC1 OUT on the NB-MIO-16 I/O connector) is controlled by loading the DAC in the analog output channel with a 12-bit digital code. This loading is performed by writing the digital code to the DAC0, DAC1, and DAC0 and DAC1 Registers. Writing to the DAC0 Register updates the voltage at the DAC0 OUT pin on the NB-MIO-16 I/O connector. Writing to the DAC1 Register updates the voltage at the DAC1 OUT pin. Writing to the DAC0 and DAC1 Register updates both the DAC0 OUT and DAC1 OUT voltages simultaneously.

The output voltage generated from the digital code depends on the configuration, unipolar or bipolar, of the associated analog output channel. Unipolar or bipolar configuration is determined by configuration jumpers on the NB-MIO-16 board. The factory default is bipolar configuration. See *Analog Input Configuration* in Chapter 2, *Configuration and Installation*, for more information. Table 4-5 lists the output voltage versus digital code for a unipolar analog output configuration.

The formula for the voltage output versus digital code for a unipolar analog output configuration is as follows:

$$Vout = Vref * \frac{\text{digital code}}{4,096}$$

where V_{ref} is the reference voltage applied to the analog output channel. The digital code in the above formula is a decimal value ranging from 0 to 4,095.

Table 4-5. Analog Output Voltage Versus Digital Code (Unipolar Mode)

Digital Code		**Voltage Output**	
Decimal	**Hex**	**V_{ref}**	**V_{ref} = 10 V**
0	0	0	0 V
1	1	$\frac{Vref}{4,096}$	2.44 mV
1024	0400	$\frac{Vref}{4}$	2.5 V
2048	0800	$\frac{Vref}{2}$	5 V
3072	0C00	$\frac{Vref * 3}{4}$	7.5 V
4095	0FFF	$\frac{Vref * 4,095}{4,096}$	9.9976 V

The formula for the voltage output versus digital code for a bipolar analog output configuration is as follows:

$$Vout = Vref * \frac{(\text{digital code} - 2,048)}{2,048}$$

where V_{ref} is the reference voltage applied to the analog output channel. The digital code in the above formula is a decimal value ranging from 0 to 4,095.

Table 4-6 lists the voltage versus digital code for a bipolar analog output configuration.

Table 4-6. Analog Output Voltage Versus Digital Code (Bipolar Mode)

Digital Code		Voltage Output	
Decimal	**Hex**	V_{ref}	V_{ref} = 10 V
0	0	0	-10 V
1	1	$\frac{Vref * (-2,047)}{2,048}$	-9.9951 V
1024	0400	$\frac{-Vref}{2}$	-5 V
2047	07FF	$\frac{-Vref}{2,048}$	-2.44 mV
2048	0800	0	0 V
2049	0801	$\frac{Vref}{2,048}$	+2.44 mV
3072	0C00	$\frac{Vref}{2}$	+7.5 V
4095	0FFF	$\frac{Vref * 2,047}{2,048}$	+9.9951 V

Programming the Digital I/O Circuitry

The digital input circuitry is controlled and monitored using the Digital Input Register, the Digital Output Register, and the two bits DOUTAEN and DOUTBEN in Command Register 2. See the register bit descriptions above for more information.

To enable digital output port A, set the DOUTAEN bit in Command Register 2. To enable digital output port B, set the DOUTBEN bit in Command Register 2. When a digital output port is enabled, the contents of the Digital Output Register are driven onto the digital lines corresponding to that port.

The digital output for both ports A and B are updated by writing the desired pattern to the Digital Output Register.

In order for an external device to drive the digital I/O lines, the output ports must be enabled. Clear the DOUTAEN bit in Command Register 2 if an external device is driving digital I/O lines ADIO<3..0>. Clear the DOUTBEN bit in Command Register 2 if an external device is driving digital I/O lines BDIO<3..0>. The Digital Input Register can then be read to monitor the state of the digital I/O lines as driven by the external device.

The logic state of all eight digital I/O lines can be read from the Digital Input Register. If the digital output ports are enabled, the Digital Input Register serves as a read-back register; that is, it is possible to determine how the NB-MIO-16 is driving the digital I/O lines by reading the Digital Input Register.

If any digital I/O line is not driven, it floats to an indeterminate value. If more than one device is driving any digital I/O line, the voltage at that line may also be indeterminate. In these cases, the digital line has no meaningful logic value, and reading the Digital Input Register may return either one or zero for the state of the digital line.

Programming the Am9513 Counter/Timer

Counters 1, 2, and 5 of the Am9513 Counter/Timer are available for general-purpose timing applications. The programmable frequency output pin FOUT is also available as a timing signal source. These applications and a general description of the Am9513 Counter/Timer are given under *Data Acquisition Timing Connections* in Chapter 2, *Configuration and Installation*. *Timing I/O Circuitry* in Chapter 3, *Theory of Operation*, explains how the Am9513 is used on the NB-MIO-16 board.

Initialization of the Am9513 as required by the NB-MIO-16 and specific programming requirements for the sample-interval and sample counters are given earlier in this chapter. For general programming details for Counters 1, 2, and 5 and for information concerning the programmable frequency output, refer to Appendix C, *AMD Data Sheet*.

In programming the Master Mode Register, keep the following considerations in mind:

- The Am9513 must be used in 16-bit bus mode.
- The scalar control should be set to BCD division in order for the clocks to be correct as described under *Programming Multiple A/D Programming Conversions on a Single Input Channel* earlier in this chapter.

RTSI Bus Trigger Line Programming Considerations

The RTSI switch connects signals on the NB-MIO-16 to the seven RTSI bus trigger lines. The RTSI switch has seven pins labeled A<6..0> connected to NB-MIO-16 signals and seven pins labeled B<6..0> connected to the seven RTSI bus trigger lines. Table 4-7 shows the signals connected to each pin.

Table 4-7. RTSI Switch Signal Connections

Side	RTSI Switch Pin	Signal Name	Signal Direction
A	A0	GATE1	Bidirectional
	A1	FOUT	Output
	A2	OUT2	Output
	A2	EXTCONV*	Input
	A3	SOURCE4	Bidirectional
	A4	OUT5	Output
	A4	EXTGATE	Input
	A5	OUT1	Bidirectional
	A6	EXTTRIG*	Bidirectional
B	B0	TRIGGER6	Bidirectional
	B1	TRIGGER5	Bidirectional
	B2	TRIGGER4	Bidirectional
	B3	TRIGGER3	Bidirectional
	B4	TRIGGER2	Bidirectional
	B5	TRIGGER1	Bidirectional
	B6	TRIGGER0	Bidirectional

Figure 3-8 in Chapter 3, *Theory of Operation*, diagrams the NB-MIO-16 RTSI switch connections.

NB-MIO-16 RTSI Signal Connection Considerations

The NB-MIO-16 board has a total of nine signals connected to the seven A-side pins of the RTSI switch. These same signals also appear at the NB-MIO-16 I/O connector, with the exception of SOURCE4. SOURCE4 is connected to the SOURCE4 input pin of the Am9513. As shown in Table 4-7, two NB-MIO-16 signals are connected to pin A2, and two signals are connected to pin A4. The routing of these signals is further controlled by the bits A4 DRV, A4 RCV, A2 DRV, and A2 RCV in Command Register 2.

- To drive the RTSI switch pin A2 with the signal OUT2, set the A2 DRV bit in Command Register 2. Otherwise, clear the A2 DRV bit.

- To drive the signal EXTCONV* from pin A2 of the RTSI switch, set the A2 RCV bit in Command Register 2. Otherwise, clear the A2 RCV bit.

Note: ***If both the A2 DRV and A2 RCV bits are set, the EXTCONV* signal is driven by the signal OUT2, which is probably not desirable.***

- To drive the RTSI switch pin A4 with the signal OUT5, set the A4 DRV bit in Command Register 2. Otherwise, clear the A4 DRV bit.

- To drive the signal EXTGATE from pin A4 of the RTSI switch, set the A4 RCV bit in Command Register 2. Otherwise, clear the A4 RCV bit.

Note: ***If both the A4 DRV and A4 RCV bits are set, the EXTGATE signal is driven by the signal OUT5, which is probably not desirable.***

Programming the RTSI Switch

The RTSI switch can be programmed to connect any of the signals on the A side to any of the signals on the B side and vice versa. To do this, a 56-bit pattern is shifted into the RTSI switch by writing one bit at a time to the RTSI Switch Shift Register, and then writing to the RTSI Switch Strobe Register to load the pattern into the RTSI switch.

The 56-bit pattern is made up of two 28-bit patterns, one for side A and one for side B of the RTSI switch. The low-order 28 bits select the signal sources for the B-side pins. The high-order 28 bits select the signal sources for the A-side pins. Each of the 28-bit patterns is made up of seven 4-bit fields, one for each pin. The 4-bit field selects the signal source and the output enable for the pin. Figure 4-1 shows the bit map of the RTSI switch 56-bit pattern.

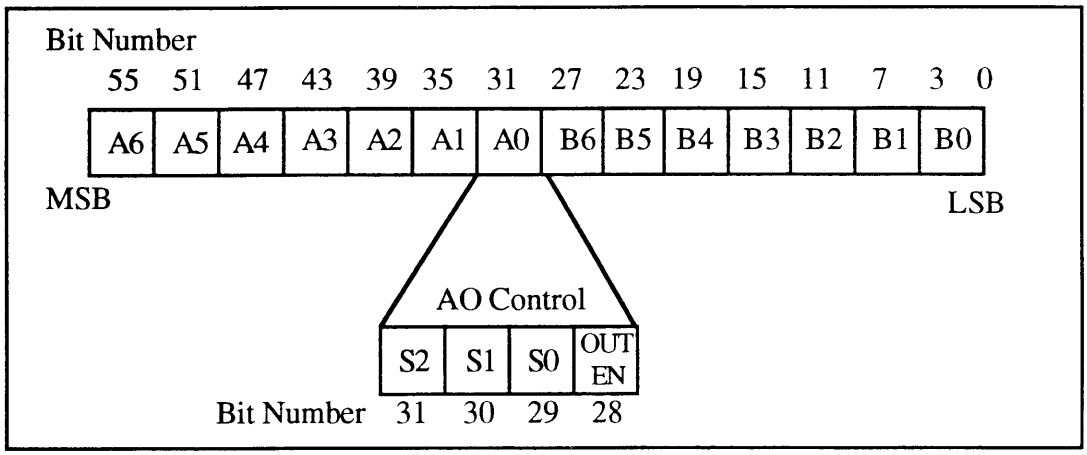


Figure 4-1. RTSI Switch Control Pattern

In Figure 4-1, the fields labeled A6 through A0 and B6 through B0 are the 4-bit control fields for each RTSI switch pin of the same name. The 4-bit control field for pin A0 is shown in Figure 4-1.

The bits labeled S2 through S0 are the signal source selection bits for the pin. One of seven source signals can be selected. Pins A6 through A0 can select any of the pins B6 through B0 as signal sources. Pins B6 through B0 can select any of the pins A6 through A0 as signal sources. For example, the pattern 011 for S2 through S0 in the A0 control field selects the signal connected to pin B3 as the signal source for pin A0.

The bit labeled OUTEN is the output enable bit for that pin. If the OUTEN bit is set, the pin is driven by the selected source signal (the pin acts as an output pin). If the OUTEN bit is cleared, the pin is not driven, regardless of the source signal selected; instead, the pin can be used as an input pin.

If the A0 control field above contained the pattern 0111, the signal connected to pin B3 (Trigger Line 3) would appear at pin A0. On the NB-MIO-16 board, this would allow the GATE1 signal to be driven by Trigger Line 3. Conversely, if the B4 control field contains the pattern 1011, the signal connected to pin A5 appears at pin B4. This configuration allows Trigger Line 4 to be driven by the NB-MIO-16 OUT1 signal. In this way, boards connected via the RTSI bus can send signals to each other over the RTSI bus trigger lines.

To program the RTSI switch, complete these steps:

1. Calculate the 56-bit pattern based on the desired signal routing.
   a. Clear the OUTEN bit for all input pins and for all unused pins.
   b. Specify the signal source pin for all output pins by setting bits S2 through S0 to the source pin number.
   c. Set the OUTEN bit for all output pins.
2. For $i = 0$ to 55, do the following:
   a. Copy bit i of the 56-bit pattern to bit 0 of an 8-bit temporary variable.
   b. Write the temporary variable to the RTSI Switch Shift Register (8-bit write).
3. Write 0 to the RTSI Switch Strobe Register (8-bit write). This action loads the 56-bit pattern into the RTSI switch. At this point, the new signal routing goes into effect.

Step 2 above can be completed by simply writing the low-order 8 bits of the 56-bit pattern to the RTSI Switch Shift Register, shifting the 56-bit pattern right once, and repeating this two-step operation a total of 56 times. Only bit 0 of the word written to the RTSI Switch Shift Register is used. The higher-order bits are ignored.

Programming DMA Operations

DMA operations can be used for servicing the A/D FIFO during a data acquisition operation if the DMA board is used in the system and if it is connected with the NB-MIO-16 board over the RTSI bus.

The NB-MIO-16 can be programmed such that the A/D FIFO generates a DMA request signal every time one or more A/D conversion values are stored in the A/D FIFO. To program the NB-MIO-16 for DMA operation, perform the following steps after the circuitry on the

NB-MIO-16 is set up for a data acquisition operation and before the data acquisition operation begins:

1. Set the DMAA<2..0> bits in Command Register 2 to the DMA channel to be used. DMA Channels 0, 1, 2, 3, 5, 6, and 7 are available. DMA Channel 4 is not available over the RTSI bus.

2. Set the DMA EN bit in Command Register 1 to enable DMA request generation.

3. Program the DMA board DMA controller to service DMA requests from the NB-MIO-16 board.

Once you have followed these steps, the DMA controller automatically reads the A/D FIFO Register whenever an A/D conversion result is available and stores the result in a buffer in memory.

Programming instructions for a DMA board are included in the manual that came with your DMA board. You need the following information in order to program the DMA Controller on a DMA board:

- The requestor is the NB-MIO-16 board.
- The requestor device type is an input/output device.
- The requestor hold bit should be set to hold.
- The requestor address is the A/D FIFO Register NuBus address, as shown in the following table.

Slot Number	NB-MIO-16 Requestor Address (Hex)
1	F9F0 002C
2	FAF0 002C
3	FBF0 002C
4	FCF0 002C
5	FDF0 002C
6	FEF0 002C

- Transfer cycles is two-cycle.
- Data transfer mode is single transfer mode.
- The requestor bus size is 16-bit.
- The transfer type is write transfer (write to target).

- The target device is a memory buffer (and therefore a memory device).
- The target address is the program address of the memory buffer that is to be written to.
- The target address bit should be set to increment.
- The target device bus size should be set to a 32-bit bus (which is more efficient).
- The byte count is the desired number of samples (sample count) multiplied by two, minus one.

Interrupt Programming

Interrupts can be used for servicing the A/D FIFO during a data acquisition operation. Two different interrupts are generated by the NB-MIO-16 board: an interrupt whenever a conversion is available to be read from the A/D FIFO and an interrupt whenever the sample counter terminates a data acquisition operation. These two interrupts are individually enabled.

To use the conversion interrupt, set the CONVINTEN bit in Command Register 1. A conversion interrupt has occurred if the following three conditions are met: the CONVINTEN bit is set, an interrupt occurs from the NB-MIO-16 board, and the CONVAVAIL bit in the Status Register is set. Reading from the A/D FIFO Register clears this interrupt condition. Writing to the A/D Clear Register also clears the conversion interrupt.

To use the data acquisition completion interrupt, set the DAQINTEN bit in Command Register 1. A data acquisition completion interrupt has occurred if the following three conditions are met: the DAQINTEN bit is set, an interrupt occurs from the NB-MIO-16 board, and the DAQCMPL bit in the Status Register is set. Writing to the A/D Clear Register clears the conversion interrupt. Writing to the A/D Clear Register also empties the A/D FIFO; therefore, read all remaining A/D conversion results from the A/D FIFO Register before doing so.

The NINTDIS bit in Command Register 2 must be cleared for these interrupts to be driven onto the NuBus.

Refer to your Macintosh documentation for information about initializing and servicing interrupts in the Macintosh.

Chapter 5
Calibration Procedures

This chapter discusses the calibration procedures for the NB-MIO-16 analog input and analog output circuitry.

The NB-MIO-16 is calibrated at the factory before shipment. In order to maintain the 12-bit accuracy of the NB-MIO-16 analog input and analog output circuitry, recalibration at six-month intervals is recommended.

Factory calibration is performed with the NB-MIO-16 in its default factory configuration:

- DIFF analog input mode
- -10 to +10 V analog input range (bipolar)
- -10 to +10 V analog output range (bipolar with internal reference selected)

Recalibration of your NB-MIO-16 board is recommended any time you change your board configuration.

Calibration Equipment Requirements

For best measurement results, the NB-MIO-16 needs to be calibrated so that its measurement accuracy is within ±0.012% of its input range (±1/2 LSB). According to standard practice, the equipment used to calibrate the NB-MIO-16 should be 10 times as accurate, that is, have ±0.001% rated accuracy. Practically speaking, calibration equipment with four times the accuracy of the item under calibration is generally considered acceptable. Four times the accuracy of the NB-MIO-16 is 0.003%. To calibrate the NB-MIO-16 board you need the following equipment.

For analog input calibration, a precision variable DC voltage source (usually a calibrator):

Accuracy: ±0.001% standard
±0.003% sufficient

Range: greater than ±10 V

Resolution: 100 µV in ±10 V range (5 1/2 digits)

For analog output calibration, a voltmeter:

Accuracy: ±0.001% standard
±0.003% sufficient

Range: greater than ±10 V

Resolution: 100 µV in ±10 V range (5 1/2 digits)

Calibration Trimpots

The NB-MIO-16 has eight trimpots for calibration. The location of these trimpots on the NB-MIO-16 board is shown in the partial diagram of the board in Figure 5-1.

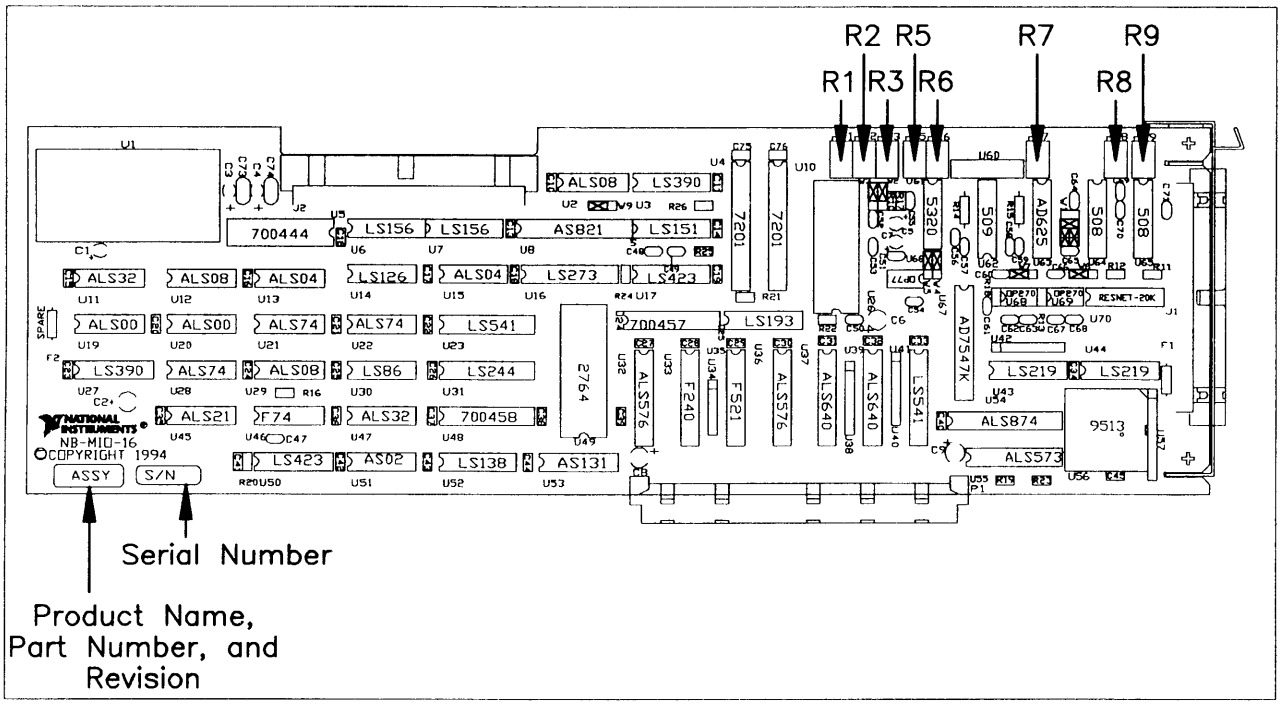


Figure 5-1. Calibration Trimpot Location Diagram

The following trimpots are used to calibrate the analog input circuitry:

- R1 – Gain trim, analog input
- R2 – Bipolar offset trim, analog input
- R3 – Unipolar offset trim, analog input
- R7 – Instrumentation amplifier input offset trims

The following trimpots are used to calibrate the analog output circuitry:

- R5 – Gain trim, analog output Channel 0
- R6 – Gain trim, analog output Channel 1
- R8 – Offset trim, analog output Channel 0
- R9 – Offset trim, analog output Channel 1

Analog Input Calibration

To null out error sources that compromise the quality of measurements, you must calibrate the analog input circuitry by adjusting the following potential sources of error:

- Offset error at the input of the instrumentation amplifier
- Offset error at the input of the ADC
- Gain error of analog input circuitry

Offsets at the input to the instrumentation amplifier contribute gain-dependent error to the analog input system. This offset is multiplied by the gain of the instrumentation amplifier. To calibrate this offset, you must ground the analog input, read it at two different gain settings, and then adjust a trimpot until the readings match at the two different gain settings.

Offset error at the input of the ADC is the total of the voltage offsets contributed by the circuitry from the output of the instrumentation amplifier to the ADC input (including the ADC's own offsets). Offset errors appear as a voltage added to the input voltage being measured. To calibrate this offset, you must apply V_{-fs} +1/2 LSB to the analog input circuitry and adjust a trimpot until the ADC returns readings that flicker between its most negative count and the most negative count plus one. The voltages corresponding to V_{-fs} and 1 LSB are given below.

All the stages up to and including the input to the ADC contribute to the gain error of the analog input circuitry. With the instrumentation amplifier set to a gain of one, the gain of analog input circuitry is ideally one. The gain error is the deviation of the gain from one and appears as a multiplication of the input voltage being measured. To calibrate this offset, you must apply V_{+fs} -3/2 LSB to the analog input circuitry and adjust a potentiometer until the ADC returns readings that flicker between its most positive count and the most positive count minus one. The voltages corresponding to V_{+fs} and 1 LSB are given in the following table.

The voltages corresponding to V_{-fs}, which is the most negative voltage that the ADC can read, V_{+fs} - 1, which is the most positive voltage the ADC can read, and 1 LSB, which is the voltage corresponding to one count of the ADC, are dependent on the input range selected. The value of these voltages for each input range is given in the following table.

Input Range	V_{-fs}	V_{+fs} - 1	1 LSB	1/2 LSB
-10 to +10 V	-10 V	+9.99512 V	4.88 mV	2.44 mV
-5 to +5 V	-5 V	+4.99756 V	2.44 mV	1.22 mV
0 to 10 V	0 V	+9.99756 V	2.44 mV	1.22 mV

Board Configuration

Calibration procedure differs depending on input ranges selected and input configuration modes selected. Two analog input calibration procedures are given below: one for the two bipolar input configurations (-10 to +10 V and -5 to +5 V), and one for the unipolar input configuration (0 to +10 V).

The calibration procedures presented here assume that your NB-MIO-16 board is configured for DIFF input. If necessary, reconfigure your board for DIFF input before using the following calibration procedures.

If you want to calibrate your board with a non-differential input setting, the procedure is similar to the procedures outlined below with the following exception. The procedures given below apply the input calibration voltages across the positive (+) and negative (-) inputs for differential Channel 0. For single-ended input, apply your calibration voltages between the Channel 0 positive (+) input and whichever ground system you are using (refer to Chapter 2, *Configuration and Installation*, for instructions on using single-ended input connections).

Bipolar Input Calibration Procedure

If your board is configured for bipolar input, which provides the ranges -5 to +5 V or -10 to +10 V, then complete the following procedure in the order given. This procedure assumes that ADC readings are in the range -2048 to +2047.

1. Adjusting the Amplifier Input Offset.

To adjust the amplifier input offset:

1. Connect both ACH0 (pin 3 on the I/O connector) and ACH8 (pin 4) to AISENSE (pin 19).
2. Take analog input readings from channel 0 at the following gains:
   - Both 1 and 500 for the NB-MIO-16L
   - Both 1 and 8 for the NB-MIO-16H
3. Adjust trimpot R7 until the readings match to within one count at both gain settings.

2. Adjusting the ADC Input Offset.

Adjust the ADC input offset by applying an input voltage across ACH0 and ACH8. This input voltage is V_{-fs} + ½ LSB and depends on the input range selected:

Input Range	Calibration Voltage
-10 to +10 V	-9.99756 V
- 5 to +5 V	-4.99878 V

1. Connect the calibration voltage across ACH0 (pin 3 on the I/O connector) and ACH8 (pin 4). Connect the ground point on the calibration voltage source to AI SENSE (pin 19).

2. Take analog input readings from Channel 0 at a gain of one, and adjust trimpot R2 until the ADC readings flicker evenly between -2048 and -2047.

3. Adjusting the Analog Input Gain.

Adjust the analog input gain by applying an input voltage across ACH0 and ACH8. This input voltage is V_{+fs} - 3/2 LSB and depends on the input range selected:

Input Range	Calibration Voltage
-10 to +10 V - 5 to +5 V	+9.99268 V +4.99634 V

1. Connect the calibration voltage across ACH0 (pin 3 on the I/O connector) and ACH8 (pin 4). Connect the ground point on the calibration voltage source to AI SENSE (pin 19).

2. Take analog input readings from Channel 0 at a gain of one and adjust trimpot R1 until the ADC readings flicker evenly between 2046 and 2047.

Unipolar Input Calibration Procedure

If your board is configured for unipolar input, which provides an input range of 0 to +10 V, then complete the following steps in the order given. This procedure assumes that ADC readings are in the range 0 to 4095.

1. Adjusting the Amplifier Input Offset.

To adjust the amplifier input offset:

1. Connect both ACH0 (pin 3 on the I/O connector) and ACH8 (pin 4) to AI SENSE (pin 19).

2. Take analog input readings from Channel 0 at a gain of one and adjust trimpot R3 until a reading of roughly six counts is returned.

3. Take analog input readings from Channel 0 at the following gains:

   - Both 1 and 500 for the NB-MIO-16L
   - Both 1 and 8 for the NB-MIO-16H

4. Adjust trimpot R7 until the readings at each gain setting match to within one count of each other.

2. Adjusting the ADC Input Offset.

Adjust the ADC input offset by applying an input voltage across ACH0 and ACH8. This input voltage is 1.22 mV or 0 V + 1/2 LSB.

1. Connect the calibration voltage (1.22 mV) across ACH0 (pin 3 on the I/O connector) and ACH8 (pin 4). Connect the ground point on the calibration voltage source to AISENSE (pin 19).

2. Take analog input readings from Channel 0 at a gain of one and adjust trimpot R3 until the ADC readings flicker evenly between zero and one.

3. Adjusting the Analog Input Gain.

Adjust the analog input gain by applying an input voltage across ACH0 and ACH8. This input voltage is +9.99634 V or V_{+fs} - 3/2 LSB.

1. Connect the calibration voltage (+9.99634 V) across ACH0 (pin 3 on the I/O connector) and ACH8 (pin 4). Connect the ground point on the calibration voltage source to AISENSE (pin 19).

2. Take analog input readings from Channel 0 at a gain of one and adjust trimpot R1 until the ADC readings flicker evenly between 4,094 and 4,095.

Analog Output Calibration

To null out error sources that affect the accuracy of the output voltages generated, you must calibrate the analog output circuitry by adjusting the following potential sources of error:

- Analog output offset error

- Analog output gain error

Offset error in the analog output circuitry is the total of the voltage offsets contributed by each component in the circuitry. This error appears as voltage difference between the desired voltage and the actual output voltage generated and is independent of D/A setting. To correct this offset gain error, set the D/A to negative fullscale and adjust a trimpot until the output voltage is the negative fullscale value ±1/2 LSB.

Gain error in the analog output circuitry is the product of the gains contributed by each component in the circuitry. This error appears as voltage difference between the desired voltage and the actual output voltage generated, which depends on the D/A setting. This gain error is corrected by setting the D/A to positive fullscale and adjusting a trimpot until the output voltage corresponds to the positive fullscale value ±1/2 LSB.

Board Configuration

The calibration procedure differs if you select either bipolar or unipolar output configuration. A procedure for each configuration is given below. The calibration procedures presented in this chapter assume that the internal voltage reference (+10 V) is selected for the analog output channel to be calibrated.

If you want to calibrate your board to an external reference input (DC only), you must recalculate the desired output voltages to calibrate to the following values:

For bipolar output:

$$1\ LSB = \frac{V_{extref}}{2,048} \quad (\text{therefore } 1/2\ LSB = \frac{V_{extref}}{4,096})$$

$$V_{-fs} = -V_{extref}$$

$$V_{+fs} = V_{extref} - 1\ LSB$$

For unipolar output:

$$1\ LSB = \frac{V_{extref}}{4,096} \quad (\text{therefore } 1/2\ LSB = \frac{V_{extref}}{8,192})$$

$$V_{-fs} = 0\ V$$

$$V_{+fs} = V_{extref} - 1\ LSB$$

In calibrating to your own external reference, we recommend that you write your own procedure using the following procedure as a guide. Substitute your calculated voltages for those given.

Bipolar Output Calibration Procedure

If your board is configured for bipolar output, which provides an output range of -10 to +10 V, then complete the following procedures in the order given.

1. Adjusting the Analog Output Offset.

Adjust the analog output offset by measuring the output voltage generated with the DAC set at negative fullscale(0). This output voltage should be $V_{-fs} \pm 1/2$ LSB. For bipolar output, $V_{-fs} = -10$ V, and 1/2 LSB = 2.44 mV.

For analog output Channel 0:

1. Connect the voltmeter between DAC0 OUT (I/O connector pin 20) and AOGND (pin 23).
2. Set the analog output channel to -10 V by writing zero to the DAC.
3. Adjust trimpot R8 until the output voltage read is -10 V ±2.44 mV, that is, between -10.00244 and -9.99756 V.

For analog output Channel 1:

1. Connect the voltmeter between DAC1 OUT (I/O connector pin 21) and AOGND (pin 23).
2. Set the analog output channel to -10 V by writing -2048 to the DAC.
3. Adjust trimpot R9 until the output voltage read is -10 V ±2.44 mV, that is, between -10.00244 and -9.99756 V.

2. Adjusting the Analog Output Gain.

Adjust the analog output gain by measuring the output voltage generated with the DAC set at positive fullscale (4,095). This output voltage should be V_{+fs} ±1/2 LSB. For bipolar output, V_{+fs} = +9.99512 V, and 1/2 LSB = 2.44 mV.

For analog output Channel 0:

1. Connect the voltmeter between DAC0 OUT (pin 20 on the I/O connector) and AOGND (pin 23).
2. Set the analog output channel to +9.99512 V by writing 2,047 to the DAC.
3. Adjust trimpot R5 until the output voltage read is +9.99512 V ±2.44 mV, that is, between 9.99756 and 9.99268 V.

For analog output Channel 1:

1. Connect the voltmeter between DAC1 OUT (pin 21 on the I/O connector) and AOGND (pin 23).
2. Set the analog output channel to +9.99512 V by writing 4,095 to the DAC.
3. Adjust trimpot R6 until the output voltage read is +9.99512 V ±2.44 mV, that is, between 9.99756 and 9.99268 V.

Unipolar Output Calibration Procedure

If your analog output channel is configured for unipolar output, which provides an output range of 0 to +10 V, then calibrate your board by completing the following procedure.

1. Adjusting the Analog Output Offset.

Adjust the analog output offset by measuring the output voltage generated with the DAC set at zero. This output voltage should be V_{-fs} ±1/2 LSB. For unipolar output, V_{-fs} = 0 V, and 1/2 LSB = 1.22 mV.

For analog output Channel 0:

1. Connect the voltmeter between DAC0 OUT (pin 20 on the I/O connector) and AOGND (pin 23).
2. Set the analog output channel to 0 V by writing zero to the DAC.
3. Adjust trimpot R8 until the output voltage read is 0 V ±1.22 mV.

For analog output Channel 1:

1. Connect the voltmeter between DAC1 OUT (pin 21 on the I/O connector) and AOGND (pin 23).
2. Set the analog output channel to 0 V by writing zero to the DAC.
3. Adjust trimpot R9 until the output voltage read is 0 V ±1.22 mV.

2. Adjusting the Analog Output Gain.

Adjust the analog output gain by measuring the output voltage generated with the DAC set at positive fullscale (4,095). This output voltage should be V_{+fs} ±1/2 LSB. For unipolar output, V_{+fs} = +9.99756 V, and 1/2 LSB = 1.22 mV.

For analog output Channel 0:

1. Connect the voltmeter between DAC0 OUT (pin 20 on the I/O connector) and AOGND (pin 23).
2. Set the analog output channel to +9.99756 V by writing 4,095 to the DAC.
3. Adjust trimpot R5 until the output voltage read is +9.99756 V ±1.22 mV, that is, between 9.99878 and 9.99634 V.

For analog output Channel 1:

1. Connect the voltmeter between DAC1 OUT (pin 21 on the I/O connector) and AOGND (pin 23).
2. Set the analog output channel to +9.99756 V by writing 4,095 to the DAC.
3. Adjust trimpot R6 until the output voltage read is +9.99756 V ±1.22 mV, that is, between 9.99878 and 9.99634 V.

Appendix A
Specifications

This appendix lists the specifications of the NB-MIO-16. These specifications are typical at 25° C unless otherwise stated. The operating temperature range is 0° to 70° C.

Analog Input

Number of input channels	16 single-ended, 8 differential
Analog resolution	12-bit, 1 in 4,096
Type of ADC	Successive-approximation
Relative accuracy (nonlinearity + quantization error, see explanation of specifications)	±1 LSB maximum over temperature, ±3/4 LSB typical
Integral nonlinearity	±1/2 LSB maximum
Differential nonlinearity	±1 LSB maximum (no missing codes over temperature); typical ±1/2 LSB
Differential analog input ranges	±10 V, ±5 V, or 0 to +10 V, jumper-selectable
Analog input range	±12 V
Common mode range	±7 V, ±9.5 V, or ±7 V, for respective differential analog input ranges
Instrumentation amplifier	
Common mode rejection ratio	75 dB minimum, DC through 100 Hz
Input bias current	±25 nA maximum
Input offset current	±15 nA maximum
Input impedance	1 GΩ
Gain ranges	1, 2, 4, and 8 for NB-MIO-16H, 1, 10, 100, and 500 for NB-MIO-16L, software-selectable
Gain accuracy (includes pot adjustment range) gain = 1	±0.83% of full scale, adjustable to zero

gain > 1	±0.85% of full scale, ±0.08% of full scale maximum when gain error adjusted to zero at gain = 1
temperature drift	36 ppm/ °C
Input offset voltage (includes pot adjustment range)	±50 mV for gain 1, adjustable to zero ±25 mV for gain 2 ±15 mV for gain 4 ±10 mV for gain 8 ±5 mV for gain 10 ±2 mV for gain 100 ±1.5 mV for gain 500
temperature drift	160 µV/ °C + 6 µV/ °C * gain
Other system offset voltage (includes pot adjustment range)	±85 mV for ±10 V range, adjustable to zero ±45 mV for ±5 V range ±30 mV for 0 to +10 V range
System noise (figures are for 20 V range; multiply by two for 10 V range)	0.15 LSB for gains 1 to 10 0.25 LSB for gain 100 0.5 LSB for gain 500

Explanation of Analog Input Specifications

Relative accuracy is a measure of the linearity of an ADC. However, relative accuracy is a tighter specification than a *nonlinearity* specification. Relative accuracy indicates the maximum deviation from a straight line for the analog-input-to-digital-output transfer curve. If an ADC has been calibrated perfectly, then this straight line is the ideal transfer function, and the relative accuracy specification indicates the worst deviation from the ideal that the ADC permits.

A relative accuracy specification of ±1 LSB is roughly equivalent to (but not the same as) a ±1/2 LSB nonlinearity or integral nonlinearity specification because relative accuracy encompasses both nonlinearity and variable quantization uncertainty, a quantity often mistakenly assumed to be exactly ±1/2 LSB. Although quantization uncertainty is ideally ±1/2 LSB, it can be different for each possible digital code and is actually the analog width of each code. Thus, it is more specific to use relative accuracy as a measure of linearity than it is to use what is normally called nonlinearity, because relative accuracy ensures that the *sum* of quantization uncertainty and A/D conversion error does not exceed a given amount.

Integral nonlinearity in an ADC is an often ill-defined specification that is supposed to indicate a converter's overall A/D transfer linearity. The manufacturers of the ADC chips used by National Instruments specify their integral nonlinearity by stating that the analog center of any code will not deviate from a straight line by more than ±1/2 LSB. This specification is misleading because although a particularly wide code's center may be found within ±1/2 LSB of the ideal, one of its edges may be well beyond ±1 LSB; thus, the ADC would have a relative accuracy of that amount. National Instruments tests its boards to ensure that they meet all three linearity specifications defined in this appendix; specifications for integral nonlinearity are included primarily to maintain compatibility with a convention of specifications used by other board manufacturers. Relative accuracy, however, is much more useful.

Differential nonlinearity is a measure of deviation of code widths from their theoretical value of 1 LSB. The width of a given code is the size of the range of analog values that can be input to produce that code, ideally 1 LSB. A specification of ±1 LSB differential nonlinearity ensures that no code has a width of 0 LSBs (that is, no missing codes) and that no code width exceeds 2 LSBs.

System noise is the amount of noise seen by the ADC when there is no signal present at the input of the board. The amount of noise that is reported directly (without any analysis) by the ADC is not necessarily the amount of real noise present in the system, unless the noise is ≥ 0.5 LSB rms. Noise that is less than this magnitude produces varying amounts of flicker, and the amount of flicker seen is a function of how near the real mean of the noise is to a code transition. If the mean is near or at a transition between codes, the ADC flickers evenly between the two codes, and the noise is seen as very nearly 0.5 LSB. If the mean is near the center of a code and the noise is relatively small, very little or no flicker is seen, and the noise is reported by the ADC as nearly 0 LSB. From the relationship between the mean of the noise and the measured rms magnitude of the noise, the character of the noise can be determined. National Instruments has determined that the character of the noise in the NB-MIO-16 is fairly Gaussian, and so the noise specifications given are the amounts of pure Gaussian noise required to produce our readings.

Analog Data Acquisition Rates

Single-Channel Acquisition Time

The maximum data acquisition rate for the NB-MIO-169(H/L)-9 is 100 kS/s typical, 91 kS/s worst case.

Permissible data acquisition rates are determined by the minimum A/D conversion time of the system. This minimum conversion time is the sum of the conversion time of the ADC and the settling time of the analog input front end. When data acquisition is performed on a single analog input channel, the time required for the input sample-and-hold amplifier to acquire the input signal and settle to 12-bit accuracy (0.01%) is added to the conversion time of the ADC. The sample-and-hold amplifier in the NB-MIO-16 takes 1 µs typical and 1.5 µs maximum to settle to 0.01% for a 10 V step. The data acquisition rates shown in the preceding table are the best rates for single-channel acquisition. These rates take into account the specified typical and maximum (worst-case) conversion times of the ADC plus 2 µs to allow for sample-and-hold settling time.

Multiple-Channel Scanning Acquisition Time

The following are the maximum scan rates allowed by each version of the NB-MIO-16:

Gain	Data Acquisition Rate
1, 2, 4, 8	100 kS/s, typical 91 kS/s, worst case
10	50 kS/s
100	25 kS/s
500	12.5 kS/s

Multiple-channel scanning rates are limited by scan timing circuitry on the NB-MIO-16. This circuitry is designed to wait for the analog input to recover from the effects of channel and/or gain switching before allowing an A/D conversion to start. The scan timing circuitry on the NB-MIO-16 waits a minimum of 10 µs for gains 1 through 8, 20 µs for a gain of 10, 40 µs for a gain of 100, and 80 µs for a gain of 500. Thus, scanned data acquisition rates are limited by the scan timing circuitry wait time or by the A/D conversion time of the system (explained under *Single-Channel Acquisition Rates* earlier in this appendix), whichever is longer.

For the maximum scanning rates allowed, the following settling accuracies are typical:

Gain	Maximum Acquisition Rate	Settling Accuracy	
		20V Step	10V Step
1	100 kbytes/s	±2.5 LSB (±0.06%)	±1.2 LSB (±0.03%)
2	100 kbytes/s	±1.5 LSB (±0.04%)	±0.7 LSB (±0.02%)
4	100 kbytes/s	±1.0 LSB (±0.02%)	±0.7 LSB (±0.02%)
8	100 kbytes/s	±1.0 LSB (±0.02%)	±1.0 LSB (±0.02%)
10	50 kbytes/s	±0.5 LSB (±0.01%)	±0.5 LSB (±0.01%)
100	25 kbytes/s	±0.5 LSB (±0.01%)	±0.5 LSB (±0.01%)
500	12.5 kbytes/s	±0.5 LSB (±0.01%)	±0.5 LSB (±0.01%)

The larger the voltage difference between two analog input channels, the longer it takes for the NB-MIO-16 circuitry to settle within a given accuracy of the new channel voltage. A fullscale difference between input channels is the worst-case switching condition for channel scanning settling time, with one channel at the positive end of the fullscale range and the other channel at the negative end of the fullscale range. At a gain of 1, the fullscale voltage difference is 20 V and the ½ fullscale voltage difference is 10 V.

The lower the analog input source impedance, the better the settling time performance. The preceding measurements for settling accuracy were made using a TL071 general-purpose low noise op-amp to buffer the voltage source.

Analog Output

Number of output channels	Two
Type of DAC	12-bit, multiplying
Relative accuracy (nonlinearity)	±1/2 LSB maximum, ±1/4 LSB typical
Differential nonlinearity	±1 LSB maximum (monotonic over temperature), ±1/5 LSB typical
Gain error (includes pot adjustment range, but excludes reference)	±0.77% of full scale, adjustable to zero
Voltage offset (includes pot adjustment range)	±64 mV bipolar mode, ±32 mV unipolar mode, adjustable to zero
Internal voltage reference	10 V (±100 mV maximum); 25 ppm/°C drift
Output voltage ranges (jumper-selectable)	0 to +10 V, unipolar mode; ±10 V, bipolar mode
Current drive capability	±2 mA
Output settling time to 0.01%	20 µs for 10 V step 40 µs for 20 V step
Output slew rate	2.5 V/µs
Output noise	500 µV rms, DC to 20 MHz
Output Impedance	0.1 Ω maximum

Explanation of Analog Output Specifications

Relative accuracy in a D/A system is the same as nonlinearity, because no uncertainty is added due to code width. Unlike an ADC, every digital code in a D/A system represents a specific analog value rather than a range of values. The relative accuracy of the system is therefore limited to the worst-case deviation from the ideal correspondence (a straight line), excepting noise. If a D/A system has been calibrated perfectly, then the relative accuracy specification reflects its worst-case absolute error.

Differential nonlinearity in a D/A system is a measure of deviation of code width from 1 LSB. In this case, code width is the difference between the analog values produced by consecutive digital codes. A specification of ±1 LSB differential nonlinearity ensures that the code width is always greater than 0 LSBs (guaranteeing monotonicity) and is always less than 2 LSBs.

Digital I/O

Compatibility	TTL compatible
Output current source capability	Can source 2.6 mA and maintain V_{OH} at 2.4 V
Output current sink capability	Can sink 24 mA and maintain V_{OL} at 0.5 V

Timing I/O

Number of channels output	Four: three counter/timers and one frequency
Resolution	16-bit for 3 counter/timers 4-bit for frequency output channel
Base clock available	1 MHz, 100 kHz, 10 kHz, 1 kHz, 100 Hz
Base clock accuracy	±0.01%
Compatibility	TTL-compatible inputs and outputs. Counter gate and source inputs are pulled up with 4.7-kΩ resistors onboard
Counter input frequency	6.9 MHz maximum (145 ns period) with a minimum pulse width of 70 ns

Power Requirement (from Macintosh NuBus)

Power consumption	1.5 A typical at +5 VDC

Physical

Board dimensions	12.8 x 4.0 in.
I/O connector	50-pin male ribbon cable connector

Operating Environment

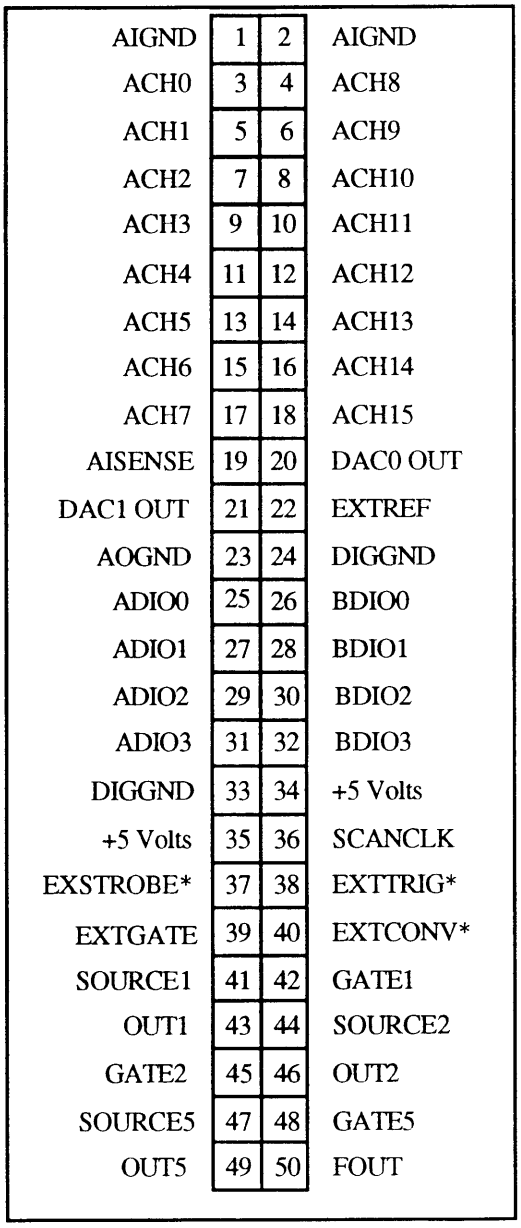
Component temperature	0° to 70° C
Relative humidity	5% to 90% noncondensing

Storage Environment

Temperature	-55° to 150° C
Relative humidity	5% to 90% noncondensing

Appendix B
I/O Connector

This appendix shows the pinout and signal names for the NB-MIO-16 50-pin I/O connector.



AIGND	1	2	AIGND
ACH0	3	4	ACH8
ACH1	5	6	ACH9
ACH2	7	8	ACH10
ACH3	9	10	ACH11
ACH4	11	12	ACH12
ACH5	13	14	ACH13
ACH6	15	16	ACH14
ACH7	17	18	ACH15
AISENSE	19	20	DAC0 OUT
DAC1 OUT	21	22	EXTREF
AOGND	23	24	DIGGND
ADIO0	25	26	BDIO0
ADIO1	27	28	BDIO1
ADIO2	29	30	BDIO2
ADIO3	31	32	BDIO3
DIGGND	33	34	+5 Volts
+5 Volts	35	36	SCANCLK
EXSTROBE*	37	38	EXTTRIG*
EXTGATE	39	40	EXTCONV*
SOURCE1	41	42	GATE1
OUT1	43	44	SOURCE2
GATE2	45	46	OUT2
SOURCE5	47	48	GATE5
OUT5	49	50	FOUT

Figure B-1. NB-MIO-16 I/O Connector

Detailed signal specifications are provided in Chapter 2, *Configuration and Installation.*

Appendix C
AMD Data Sheet*

This appendix contains a manufacturer data sheet for the Am9513A/Am9513 System Timing Controller (Advanced Micro Devices, Inc.) integrated circuit. This circuit is used on the NB-MIO-16 board.

Advanced Micro Devices, Inc. 1985 Data Book *MOS Microprocessors and Peripherals.*

Am9513A/AmZ8073A

Am9513A/AmZ8073A

System Timing Controller

DISTINCTIVE CHARACTERISTICS

- Five independent 16-bit counters
- High speed counting rates
- Up/down and binary/BCD counting
- Internal oscillator frequency source
- Tapped frequency scaler
- Programmable frequency output
- 8-bit or 16-bit bus interface
- Time-of-day option
- Alarm comparators on counters 1 and 2
- Complex duty cycle outputs
- One-shot or continuous outputs
- Programmable count/gate source selection
- Programmable input and output polarities
- Programmable gating functions
- Retriggering capability
- +5 volt power supply
- Standard 40-pin package

GENERAL DESCRIPTION

The Am9513A System Timing Controller is an LSI circuit designed to service many types of counting, sequencing and timing applications. It provides the capability for programmable frequency synthesis, high resolution programmable duty cycle waveforms, retriggerable digital one-shots, time-of-day clocking, coincidence alarms, complex pulse generation, high resolution baud rate generation, frequency shift keying, stop-watching timing, event count accumulation, waveform analysis, etc. A variety of programmable operating modes and control features allow the Am9513A to be personalized for particular applications as well as dynamically reconfigured under program control.

The STC includes five general-purpose 16-bit counters. A variety of internal frequency sources and external pins may be selected as inputs for individual counters with software selectable active-high or active-low input polarity. Both hardware and software gating of each counter is available. Three-state outputs for each counter provide pulses or levels and can be active-high or active-low. The counters can be programmed to count up or down in either binary or BCD. The host processor may read an accumulated count at any time without disturbing the counting process. Any of the counters may be internally concatenated to form any effective counter length up to 80 bits.

The AmZ8073A* is functionally equivalent to the Am9513A with timing enhancements which allow it to be fully speed compatible with the AmZ8001 and AmZ8002 microprocessors.

BLOCK DIAGRAM

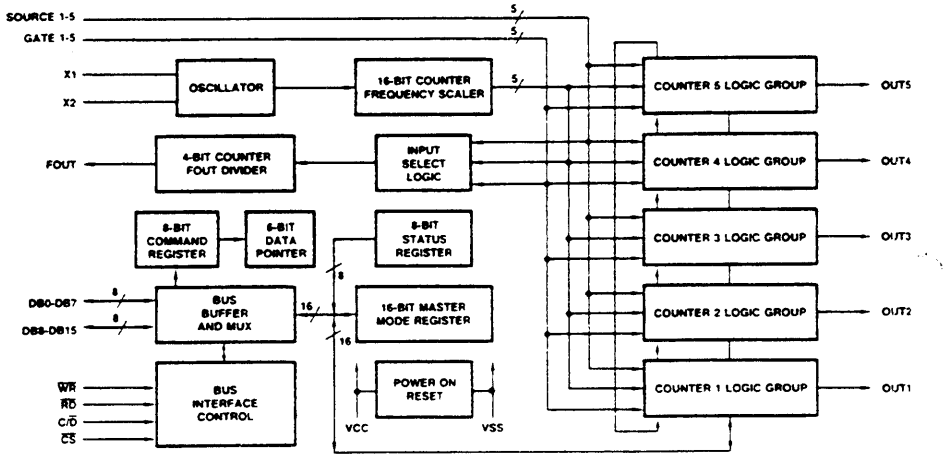


Figure 1-1.

*Z8000 is a trademark of Zilog, Inc.

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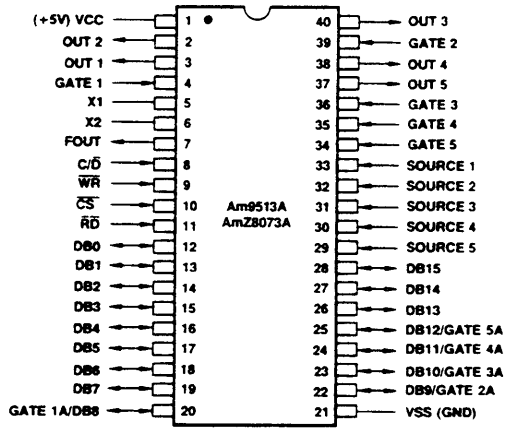
CONNECTION DIAGRAM
Top View

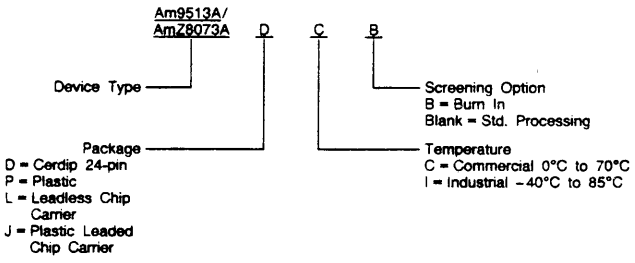


CD005210

Note: Pin 1 is marked for orientation

ORDERING INFORMATION

AMD products are available in several packages and operating ranges. The order number is formed by a combination of the following: Device number, speed option (if applicable), package type, operating range and screening option (if desired).



Valid Combinations	
Am9513A/ AmZ8073A	DC, DCB, DI, DIB, PC, PCB, PI, PIB, LC, LCB, LI, LIB, /BQA

Valid Combinations

Consult the local AMD sales office to confirm availability of specific valid combinations, check for newly released valid combinations and/or obtain additional data on AMD's standard military grade product.

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Refer to page 7-1 for Essential Information on Military Devices

Am9513A/AmZ8073A

PIN DESCRIPTION

Pin No.	Name	I/O	Description
1	V_{CC}		+5V Power Supply.
21	V_{SS}		Ground.
5, 6	X1, X2	O, I	(Crystal). X1 and X2 are the connections for an external crystal used to determine the frequency of the internal oscillator. The crystal should be a parallel-resonant, fundamental-mode type. An RC or LC or other reactive network may be used instead of a crystal. For driving from an external frequency source, X1 should be left open and X2 should be connected to a TTL source and a pull-up resistor.
7	FOUT	O	(Frequency Out). The FOUT output is derived from a 4-bit counter that may be programmed to divide its input by any integer value from 1 through 16 inclusive. The input to the counter is selected from any of 15 sources, including the internal scaled oscillator frequencies. FOUT may be gated on and off under software control and when off will exhibit a low impedance to ground. Control over the various FOUT options resides in the Master Mode register. After power-up, FOUT provides a frequency that is 1/16 that of the oscillator. The input source on power-up is F1.
4, 39, 36-34	GATE1 - GATE5	I	(Gate). The Gate inputs may be used to control the operations of individual counters by determining when counting may proceed. The same Gate input may control up to three counters. Gate pins may also be selected as count sources for any of the counters and for the FOUT divider. The active polarity for a selected Gate input is programmed at each counter. Gating function options allow level-sensitive gating or edge-initiated gating. Other gating modes are available including one that allows the Gate input to select between two counter output frequencies. All gating functions may also be disabled. The active Gate input is conditioned by an auxiliary input when the unit is operating with an external 8-bit data bus. See Data Bus description. Schmitt-trigger circuitry on the GATE inputs allows slow transition times to be used.
33-29	SRC1 - SRC5	I	(Source).The Source inputs provide external signals that may be counted by any of the counters. Any Source line may be routed to any or all of the counters and the FOUT divider. The active polarity for a selected SRC input is programmed at each counter. Any duty cycle waveform will be accepted as long as the minimum pulse width is at least half the period of the maximum specified counting frequency for the part. Schmitt-trigger circuitry on the SRC inputs allows slow transition times to be used.
3, 2, 40, 38, 37	OUT1 - OUT5	O	(Counter). Each 3-state OUT signal is directly associated with a corresponding individual counter. Depending on the counter configuration, the OUT signal may be a pulse, a square wave, or a complex duty cycle waveform. OUT pulse polarities are individually programmable. The output circuitry detects the counter state that would have been all bits zero in the absence of a reinitialization. That information is used to generate the selected waveform type. An optional output mode for Counters 1 and 2 overrides the normal output mode and provides a true OUT signal when the counter contents match the contents of an Alarm register.
12-19, 20, 22-28	DB0 - DB7, DB8 - DB15	I/O	(Data Bus). The 16 bidirectional Data Bus lines are used for information exchanges with the host processor. HIGH on a Data Bus line corresponds to one and LOW corresponds to zero. These lines act as inputs when $\overline{WR}$ and $\overline{CS}$ are active and as outputs when $\overline{RD}$ and $\overline{CS}$ are active. When $\overline{CS}$ is inactive, these pins are placed in a high-impedance state. After power-up or reset, the data bus will be configured for 8-bit width and will use only DB0 through DB7. DB0 is the least significant and DB7 is the most significant bit position. The data bus may be reconfigured for 16-bit width by changing a control bit in the Master Mode register. This is accomplished by writing an 8-bit command into the low-order DB lines while holding the DB13 - DB15 lines at a logic high level. Thereafter, all 16 lines can be used, with DB0 as the least significant and DB15 as the most significant bit position. When operating in the 8-bit data bus environment, DB8 - DB15 will never be driven active by the Am9513A. DB8 through DB12 may optionally be used as additional Gate inputs (see Figure 1-3). If unused, they should be held HIGH. When pulled LOW, a GATENA signal will disable the action of the corresponding counter N gating. DB13 - DB15 should be held HIGH in 8-bit bus mode whenever $\overline{CS}$ and $\overline{WR}$ are simultaneously active.
10	$\overline{CS}$	I	(Chip Select). The active-low Chip Select input enables Read and Write operations on the data bus. When Chip Select is HIGH, the Read and Write inputs are ignored. The first Chip Select signal after power-up is used to clear the power-on reset circuitry. If Chip Select is tied to ground permanently, the power-on reset circuitry may not function. In such a configuration, the software reset command must be issued following power-up to reset the Am9513A.
11	$\overline{RD}$	I	(Read). The active-low Read signal is conditioned by Chip Select and indicates that internal information is to be transferred to the data bus. The source will be determined by the port being addressed and, for Data Port reads, by the contents of the Data Pointer register. $\overline{WR}$ and $\overline{RD}$ should be mutually exclusive.
9	$\overline{WR}$	I	(Write). The active-low Write signal is conditioned by Chip Select and indicates that data bus information is to be transferred to an internal location. The destination will be determined by the port being addressed and, for Data Port writes, by the contents of the Data Pointer register. $\overline{WR}$ and $\overline{RD}$ should be mutually exclusive.
8	C/$\overline{D}$	I	(Control/Data). The Control/Data signal selects source and destination locations for Read and Write operations on the data bus. Control Write operations load the Command register and the Data Pointer. Control Read operations output the Status register. Data Read and Data Write transfers communicate with all other internal registers. Indirect addressing at the data port is controlled internally by the Data Pointer register.

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Refer to page 7-1 for Essential Information on Military Devices

Signal	Abbreviation	Type	Pins
+ 5 Volts	VCC	Power	1
Ground	VSS	Power	1
Crystal	X1, X2	O, I	2
Read	$\overline{RD}$	Input	1
Write	$\overline{WR}$	Input	1
Chip Select	$\overline{CS}$	Input	1
Control/Data	C/$\overline{D}$	Input	1
Source N	SRC	Input	5
Gate N	GATE	Input	5
Data Bus	DB	I/O	16
Frequency Out	FOUT	Output	1
Out N	OUT	Output	5

Figure 1-2. Interface Signal Summary

Figure 1-2 summarizes the interface signals and their abbreviations for the STC.

Package Pin	Data Bus Width (MM14)	
	16 Bits	8 Bits
12	DB0	DB0
13	DB1	DB1
14	DB2	DB2
15	DB3	DB3
16	DB4	DB4
17	DB5	DB5
18	DB6	DB6
19	DB7	DB7
20	DB8	GATE 1A
22	DB9	GATE 2A
23	DB10	GATE 3A
24	DB11	GATE 4A
25	DB12	GATE 5A
26	DB13	(VIH)
27	DB14	(VIH)
28	DB15	(VIH)

Figure 1-3. Data Bus Assignments

Interface Considerations

All of the input and output signals for the Am9513A are specified with logic levels compatible with those of standard TTL circuits. In addition to providing TTL compatible voltage levels, other output conditions are specified to help configure non-standard interface circuitry. The logic level specifications take into account all worst-case combinations of the three variables that affect the logic level thresholds: ambient temperature, supply voltage and processing parameters. A change in any of these toward nominal values will improve the actual operating margins and will increase noise immunity.

Unprotected open gate inputs of high quality MOS transistors exhibit very high resistances on the order of perhaps 10^{14} ohms. It is easy, therefore, in some circumstances, for charge to enter the gate node of such an input faster than it can be discharged and consequently, for the gate voltage to rise high enough to break down the oxides and destroy the transistor. All inputs to the Am9513A include protection networks to help prevent damaging accumulations of static charge. The protection circuitry is designed to slow the transitions of incoming current surges and to provide low-impedance discharge paths for voltages beyond the normal operating levels. Note, however, that input energy levels can nonetheless be too high to be successfully absorbed. Conventional design, storage, and handling precautions should be observed so that the protection networks themselves are not overstressed.

Within the limits of normal operation, the input protection circuitry is inactive and may be modeled as a lumped series RC as shown in Figure 1-4(a). The functionally active input connection during normal operation is the gate of a MOS transistor. No active sources or drains are connected to the inputs so that neither transient nor steady-state currents are impressed on the driving signals other than the charging or discharging of the input capacitance and the accumulated leakage associated with the protection network and the input circuit.

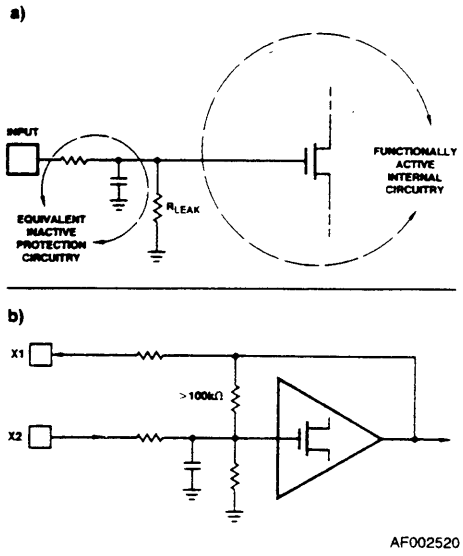

Figure 1-4. Input Circuitry

The only exception to the purely capacitive input case is the X2 crystal input. As shown in Figure 1-4(b) an internal resistor connects X1 and X2 in addition to the protection network. The resistor is a modestly high value of more than 100kohms.

Fanout from the driving circuitry into the Am9513A inputs will generally be limited by transition time considerations rather than DC current limitations when the loading is dominated by conventional MOS circuits. In an operating environment, all inputs should be terminated so they do not float and therefore will not accumulate stray static charges. Unused inputs should be tied directly to Ground or VCC, as appropriate. An input in use will have some type of logic output driving it, and termination during operation will not be a problem. Where inputs are driven from logic external to the card containing this chip, however, on-board termination should be provided to protect the chip when the board is unplugged (the input would otherwise float). A pull-up resistor or a simple inverter or gate will suffice.

DETAILED DESCRIPTION

The Am9513A System Timing Controller (STC) is a support device for processor oriented systems that is designed to enhance the available capability with respect to counting and timing operations. It provides the capability for programmable frequency synthesis, high resolution programmable duty cycle waveforms, retriggerable digital timing functions, time-of-day clocking, coincidence alarms, complex pulse generation, high resolution baud rate generation, frequency shift keying, stop-watching timing, event count accumulation, waveform analysis and many more. A variety of programmable operating modes and control features allow the Am9513A to be personalized for particular applications as well as dynamically reconfigured under program control.

The STC includes five general-purpose 16-bit counters. A variety of internal frequency sources and external pins may be selected as inputs for individual counters with software selectable active-high or active-low input polarity. Both hardware and software gating of each counter is available. Three-state outputs for each counter provide either pulses or levels. The counters can be programmed to count up or down in either binary or BCD. The accumulated count may be read without disturbing the counting process. Any of the counters may be internally concatenated to form an effective counter length of up to 80 bits.

The Am9513A block diagrams indicate the interface signals and the basic flow of information. Internal control lines and the internal data bus have been omitted. The control and data registers are all connected to a common internal 16-bit bus. The external bus may be 8- or 16-bits wide; in the 8-bit mode, the internal 16-bit information is multiplexed to the low order data bus pins DB0 through DB7.

An internal oscillator provides a convenient source of frequencies for use as counter inputs. The oscillator's frequency is controlled at the X1 and X2 interface pins by an external reactive network such as a crystal. The oscillator output is divided by the Frequency Scaler to provide several sub-frequencies. One of the scaled frequencies (or one of ten input signals) may be selected as an input to the FOUT divider and then comes out of the chip at the FOUT interface pin.

The STC is addressed by the external system as two locations: a Control port and a Data port. The Control port provides direct access to the Status and Command registers, as well as allowing the user to update the Data Pointer register. The Data port is used to communicate with all other addressable internal locations. The Data Pointer register controls the Data port addressing.

Among the registers accessible through the Data port are the Master Mode register and five Counter Mode registers, one for each counter. The Master Mode register controls the programmable options that are not controlled by the Counter Mode registers.

Each of the five general-purpose counters is 16-bits long and is independently controlled by its Counter Mode register. Through this register, a user can software select one of 16 sources as the counter input, a variety of gating and repetition modes, up or down counting in binary or BCD and active-high or active-low input and output polarities.

Associated with each counter are a Load register and a Hold register, both accessible through the Data port. The Load register is used to automatically reload the counter to any predefined value, thus controlling the effective count period. The Hold register is used to save count values without disturbing the count process, permitting the host processor to read intermediate counts. In addition, the Hold register may be used as a second Load register to generate a number of complex output waveforms.

All five counters have the same basic control logic and control registers. Counters 1 and 2 have additional Alarm registers and comparators associated with them, plus the extra logic necessary for operating in a 24-hour time-of-day mode. For real-time operation, the time-of-day logic will accept 50Hz, 60Hz or 100Hz input frequencies.

Each general counter has a single dedicated output pin. It may be turned off when the output is not of interest or may be configured in a variety of ways to drive interrupt controllers, Darlington buffers, bus drivers, etc. The counter inputs, on the other hand, are specifically not dedicated to any given interface line. Considerable versatility is available for configuring both the input and the gating of individual counters. This not only permits dynamic reassignment of inputs under software control, but also allows multiple counters to use a single input and a single gate pin to control more than one counter. Indeed, a single pin can be the gate for one counter and, at the same time, the count source for another.

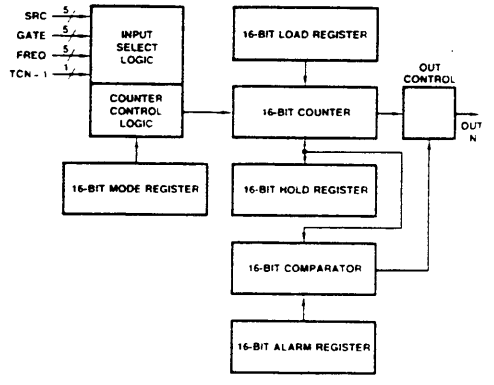

Figure 1-5. Counter Logic Groups 1 and 2

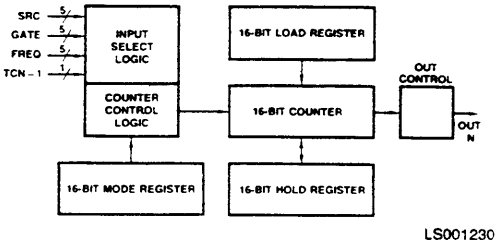

Figure 1-6. Counter Logic Groups 3, 4 and 5

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Refer to page 7-1 for Essential Information on Military Devices

A powerful command structure simplifies user interaction with the counters. A counter must be armed by one of the ARM commands before counting can commence. Once armed, the counting process may be further enabled or disabled using the hardware gating facilities. The ARM and DISARM commands permit software gating of the count process in some modes.

The LOAD command causes the counter to be reloaded with the value in either the associated Load register or the associated Hold register. It will often be used as a software retrigger or as counter initialization prior to active hardware gating.

The DISARM command disables further counting independent of any hardware gating. A disarmed counter may be reloaded using the LOAD command, may be incremented or decremented using the STEP command and may be read using the SAVE command. A count process may be resumed using an ARM command.

The SAVE command transfers the contents of a counter to its associated Hold register. This command will overwrite any previous Hold register contents. The SAVE command is designed to allow an accumulated count to be preserved so that it can be read by the host CPU at some later time.

Two combinations of the basic commands exist to either LOAD AND ARM or to DISARM AND SAVE any combination of counters. Additional commands are provided to: step an individual counter by one count; set and clear an output toggle; issue a software reset; clear and set special bits in the Master Mode register; and load the Data Pointer register.

Note: Separate LOAD and ARM commands should be used for asynchronous operations.

Power Supply

The Am9513A requires only a single 5V power supply. Maximum supply currents are specified in the electrical specification at the high end of the voltage tolerance and the low end of the temperature range. In addition, the current specifications take into account the worstcase distribution of processing parameters that may be encountered during the manufacturing life of the product. Typical supply current values, on the other hand, are specified at a nominal +5.0 volts, a nominal ambient temperature of 25°C, and nominal processing parameters. Supply current always decreases with increasing ambient temperature: thermal run-away is not a problem.

Supply current will vary somewhat from part to part, but a given unit at a given operating temperature will exhibit a nearly constant power drain. There is no functional operating region that will cause more than a few percent change in the supply current. Decoupling of VCC, then, is straightforward and will generally be used to isolate the Am9513A from VCC noise originating externally

CONTROL PORT REGISTERS

The STC is addressed by the external system as only two locations: a Control port and a Data port. Transfers at the Control port (C/$\overline{D}$ = HIGH) allow direct access to the Command register when writing and the Status register when reading. All other available internal locations are accessed for both reading and writing via the Data port (C/$\overline{D}$ = LOW). Data port transfers are executed to and from the location currently addressed by the Data Pointer register. Options available in the Master Mode register and the Data Pointer control structure allow several types of transfer sequencing to be used. See Figure 1-7.

Transfers to and from the Control port are always 8-bits wide. Each access to the Control port will transfer data between the Command register (writes) or Status register (reads) and Data Bus pins DB0-DB7, regardless of whether the Am9513A is in 8- or 16-bit bus mode. When the Am9513A is in 8-bus mode, Data Bus pins DB13-DB15 should be held at a logic high whenever $\overline{CS}$ and WR are both active.

Command Register

The Command register provides direct control over each of the five general counters and controls access through the Data port by allowing the user to update the Data Pointer register. The "Command Description" section of this data sheet explains the detailed operation of each command. A summary of all commands appears in Figure 1-20. Six of the command types are used for direct software control of the counting process. Each of these six commands contains a 5-bit S field. In a linear-select fashion, each bit in the S field corresponds to one of the five general counters (S1 = Counter 1, S2 = Counter 2, etc.). When an S bit is a one, the specified operation is performed on the counter so designated; when an S bit is a zero, no operation occurs for the corresponding counter.

Data Pointer Register

The 6-bit Data Pointer register is loaded by issuing the appropriate command through the Control port to the Command register. As shown in Figure 1-7, the contents of the Data Pointer register are used to control the Data port multiplexer, selecting which internal register is to be accessible through the Data port.

The Data Pointer consists of a 3-bit Group Pointer, a 2-bit Element Pointer and a 1-bit Byte Pointer, depicted in Figure 1-8. The Byte Pointer bit indicates which byte of a 16-bit register is to be transferred on the next access through the Data port. Whenever the Data Pointer is loaded, the Byte Pointer bit is set to one, indicating a least-significant byte is expected. The Byte Pointer toggles following each 8-bit data transfer with an 8-bit data bus (MM13 = 0), or it always remains set with the 16-bit data bus option (MM13 = 1). The Element and Group pointers are used to select which internal register is to be accessible through the Data port. Although the contents of the Element and Group Pointer in the Data Pointer register cannot be read by the host processor, the Byte Pointer is available as a bit in the Status register.

Random access to any available internal data location can be accomplished by simply loading the Data Pointer using the command shown in Figure 1-9 and then initiating a data read or data write. This procedure can be used at any time, regardless of the setting of the Data Pointer Control bit (MM14). When the 8-bit data bus configuration is being used (MM13 = 0), two bytes of data would normally be transferred following the issuing of the "Load Data Pointer" command.

To permit the host processor to rapidly access the various internal registers, automatic sequencing of the Data Pointer is provided.

Am9513A/AmZ8073A

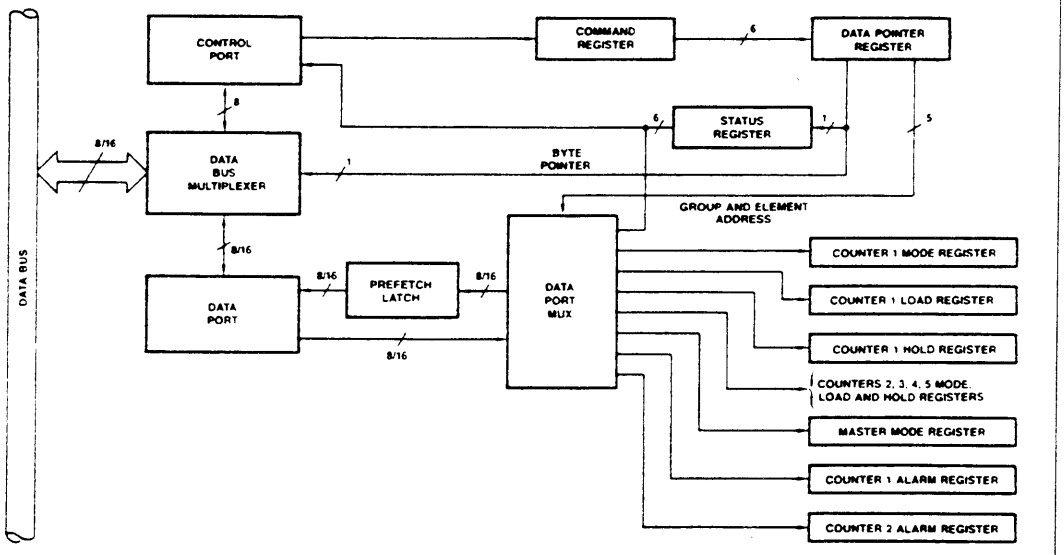

Figure 1-7. Am9513A Register Access

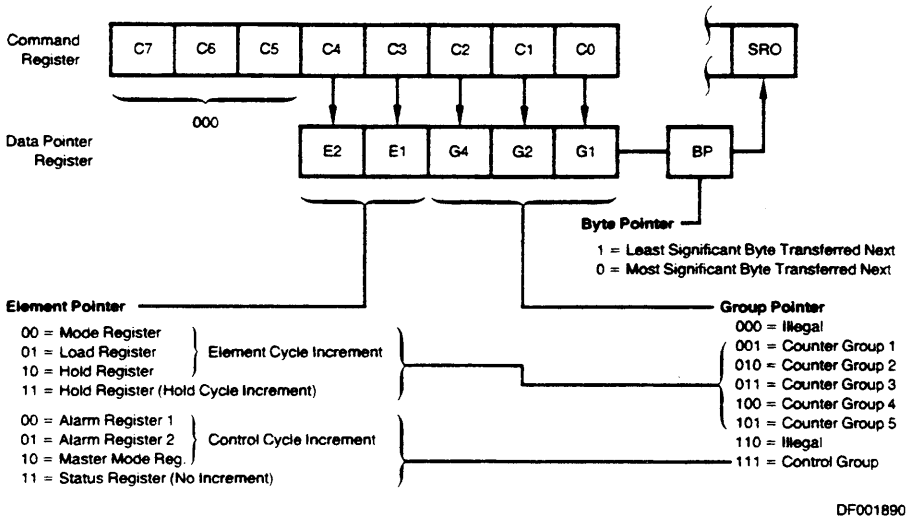

Figure 1-8. Data Pointer Register

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	Element Cycle			Hold Cycle
	Mode Register	Load Register	Hold Register	Hold Register
Counter 1	FF01	FF09	FF11	FF19
Counter 2	FF02	FF0A	FF12	FF1A
Counter 3	FF03	FF0B	FF13	FF1B
Counter 4	FF04	FF0C	FF14	FF1C
Counter 5	FF05	FF0D	FF15	FF1D

Master Mode Register = FF17
Alarm 1 Register = FF07
Alarm 2 Register = FF0F
Status Register = FF1F

Notes:
1. All codes are in hex.
2. When used with an 8-bit bus, only the two low order hex digits should be written to the command port; the 'FF' prefix should be used only for a 16-bit data bus interface.

Figure 1-9. Load Data Pointer Commands

Sequencing is enabled by clearing Master Mode bit 14 (MM14) to zero. As shown in Figure 1-10 several types of sequencing are available depending on the data bus width being used and the initial Data Pointer value entered by command.

When E1 = 0 or E2 = 0 and G4, G2, G1 points to a Counter Group, the Data Pointer will proceed through the Element cycle. The Element field will automatically sequence through the three values 00, 01 and 10 starting with the value entered. When the transition from 10 to 00 occurs, the Group field will also be incremented by one. Note that the Element field in this case does not sequence to a value of 11. The Group field circulates only within the five Counter Group codes.

If E2, E1 = 11 and a Counter Group are selected, then only the Group field is sequenced. This is the Hold cycle. It allows the Hold registers to be sequentially accessed while bypassing the Mode and Load registers. The third type of sequencing is the Control cycle. If G4, G2, G1 = 111 and E2, E1 ≠ 11, the Element Pointer will be incremented through the values 00, 01 and 10, with no change to the Group Pointer.

When G4, G2, G1 = 111 and E2, E1 = 11, no incrementing takes place and only the Status register will be available through the Data port. Note that the Status register can also always be read directly through the Control port.

For all these auto-sequencing modes, if an 8-bit data bus is used, the Byte pointer will toggle after every data transfer to allow the least and most significant bytes to be transferred before the Element or Group fields are incremented.

Prefetch Circuit

To minimize the read access time to internal Am9513A registers, a prefetch circuit is used for all read operations through the Data port. Following each read or write operation through the Data port, the Data Pointer register is updated to point to the next register to be accessed. Immediately following this update, the new register data is transferred to a special prefetch latch at the interface pad logic. When the user performs a subsequent read of the Data port, the data bus drivers are enabled, outputting the prefetched data on the bus. Since the internal data register is accessed prior to the start of the read operation, its access time is transparent to the user. To keep the prefetched data consistent with the Data Pointer, prefetches are also performed after each write to the Data port and after execution of the "Load Data Pointer" command. The following rules should be kept in mind regarding Data port Transfers.

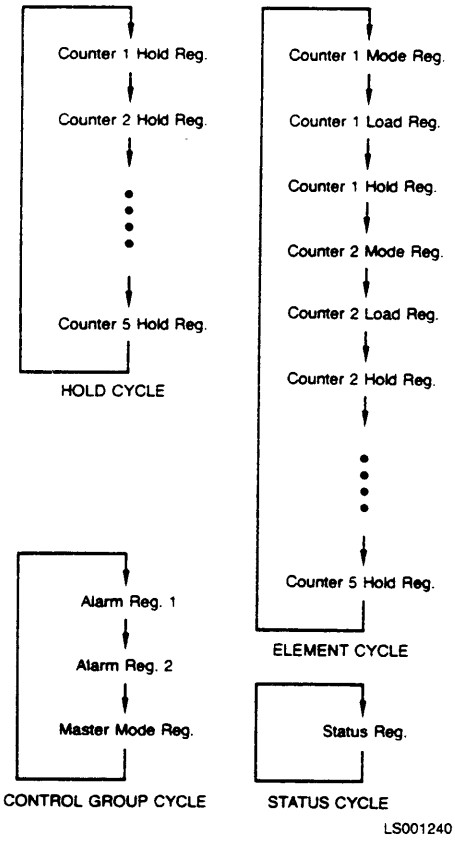


Figure 1-10. Data Pointer Sequencing

1. The Data Pointer register should always be reloaded before reading from the Data port if a command, other than "Load Data Pointer," was issued to the Am9513A following the last Data port read or write. The Data Pointer does not have to be loaded again if the first Data port transaction after a command entry is a write, since the Data port write will automatically cause a new prefetch to occur.

2. Operating modes N, O, Q, R and X allow the user to save the counter contents in the Hold register by applying an active-going gate edge. If the Data Pointer register had been pointing to the Hold register in question, the prefetched value will not correspond to the new value saved in the Hold Register. To avoid reading an incorrect value, a new "Load Data Pointer" command should be issued before attempting to read the saved data. A Data port write (to another register) will also initiate a prefetch; subsequent reads will access the recently saved Hold register data. Many systems will use the "saving" gate edge to interrupt the host CPU. In systems such as this, the interrupt service routine should issue a "Load Data Pointer" command prior to reading the saved data.

Status Register

The 8-bit read-only Status register indicates the state of the Byte Pointer bit in the Data Pointer register and the state of the OUT signal for each of the general counters. See Figures 1-11 and 1-18. The OUT signals reported are those internal to the

chip after the polarity-select logic and just before the 3-state interface buffer circuitry. Bits SR6 and SR7 may be 0 or 1.

The Status register OUT bit reflects an active-high or active-low TC output, or a TC Toggled output, as programmed in the Output Control Field of the Counter Mode register. That is, it reflects the exact state of the OUT pin. When the low-impedance to Ground Output option (CM2-CM0 = 000) is selected, the Status register will reflect an active-high TC Output. When a high-impedance Output option (CM2-CM0 = 100) is selected, the Status register will reflect an active-low TC output.

For Counters 1 and 2, the OUT pin will reflect the comparator output if the comparators are enabled. The Status register bit and OUT pin are active-high if CM2 = 0 and active-low if CM2 = 1. When the high-impedance option is selected and the comparator is enabled, the status register bit will reflect an active-high comparator output. When the low-impedance to Ground option is selected and the comparator is enabled, the status register bit will reflect an active-low comparator output.

The Status register is normally accessed by reading the Control port (see Figure 1-7) but may also be read via the Data port as part of the Control Group.

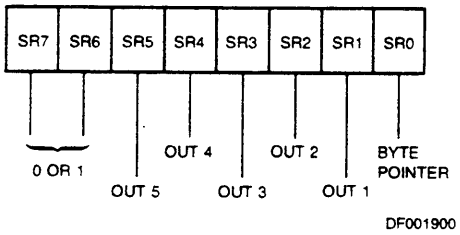


Figure 1-11. Status Register Bit Assignments

DATA PORT REGISTERS

Counter Logic Groups

As shown in Figures 1-5 and 1-6, each of the five Counter Logic Groups consists of a 16-bit general counter with associated control and output logic, a 16-bit Load register, a 16-bit Hold register and a 16-bit Mode register. In addition, Counter Groups 1 and 2 also include 16-bit Comparators and 16-bit Alarm registers. The comparator/alarm functions are controlled by the Master Mode register. The operation of the Counter Mode registers is the same for all five counters. The host CPU has both read and write access to all registers in the Counter Logic Groups through the Data port. The counter itself is never directly accessed.

Load Register

The 16-bit read/write Load register is used to control the effective length of the general counter. Any 16-bit value may be written into the Load register. That value can then be transferred into the counter each time the Terminal Count (TC) occurs. "Terminal Count" is defined as that period of time when the counter contents would have been zero if an external value had not been transferred into the counter. Thus, the terminal count frequency can be the input frequency divided by the value in the Load register. In all operating modes, either the Load or Hold register will be transferred into the counter when TC occurs. In cases where values are being accumulated in the counter, the Load register action can become transparent by filling the Load register with all zeros.

Hold Register

The 16-bit read/write Hold register is dual-purpose. It can be used in the same way as the Load register, thus offering an alternate source for module definition for the counter. The Hold register may also be used to store accumulated counter values for later transfer to the host processor. This allows the count to be sampled while the counting process proceeds without interruption. Transfer of the counter contents into the Hold register is accomplished by the hardware interface in some operating modes or by software commands at any time.

Counter Mode Register

The 16-bit read/write Counter Mode register controls the gating, counting, output and source select functions within each Counter Logic Group. The "Counter Mode Control Options" section of this document describes the detailed control options available. Figure 1-17 shows the bit assignments for the Counter Mode registers.

Alarm Registers and Comparators

Added functions are available in the Counter Logic Groups for Counters 1 and 2 (see Figure 1-5). Each contains a 16-bit Alarm register and a 16-bit Comparator. When the value in the counter reaches the value in the Alarm register, the Comparator output will go true. The Master Mode register contains control bits to individually enable/disable the comparators. When enabled, the comparator output appears on the OUT pin of the associated counter in place of the normal counter output. The output will remain true as long as the comparison is true, that is, until the next input causes the count to change. The polarity of the Comparator output will be active-high if the Output Control field of the Counter Mode register is 001 or 010 and active-low if the Output Control field is 101.

MASTER MODE CONTROL OPTIONS

The 16-bit Master Mode (MM) register is used to control those internal activities that are not controlled by the individual Counter Mode registers. This includes frequency control, Time-of-Day operation, comparator controls, data bus width and data pointer sequencing. Figure 1-12 shows the bit assignments for the Master Mode register. This section describes the use of each control field.

Master Mode register bits MM12, MM13 and MM14 can be individually set and reset using commands issued to the Command register. In addition, they can all be changed by writing directly to the Master Mode register.

After power-on reset or a Master Reset command, the Master Mode register is cleared to an all zero condition. This results in the following configuration:

Time-of-Day disabled
Both Comparators disabled
FOUT Source is frequency F1
FOUT Divider set for divide-by-16
FOUT gated on
Data Bus 8 bits wide
Data Pointer Sequencing enabled
Frequency Scaler divides in binary

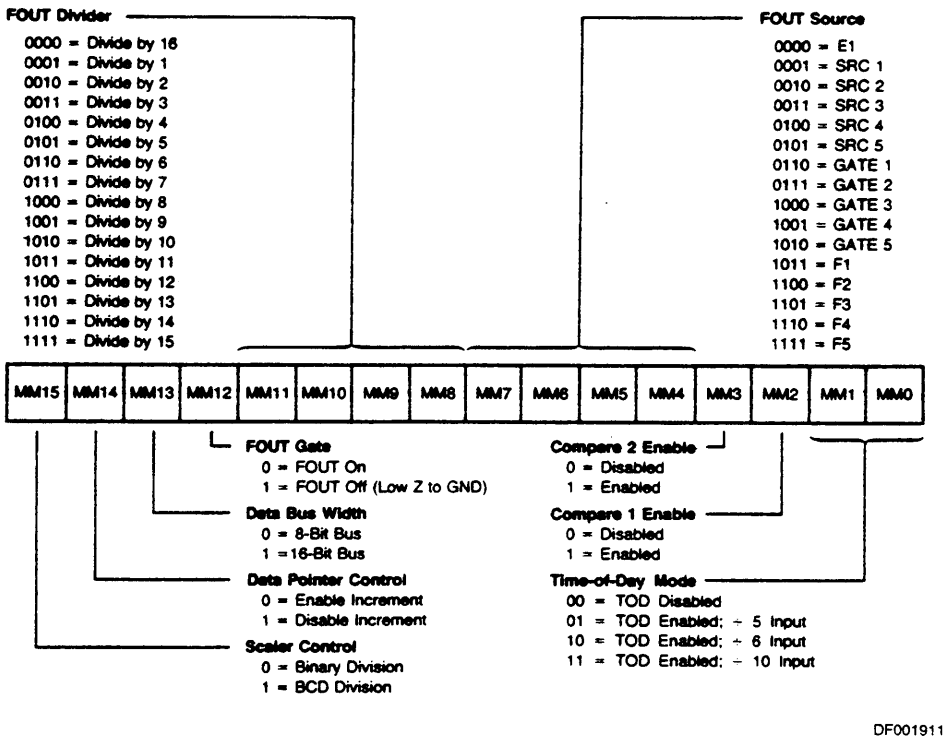


Figure 1-12. Master Mode Register Bit Assignments

Time-of-Day

Bits MM0 and MM1 of the Master Mode register specify the Time-of-Day (TOD) options. When MM0 = 0 and MM1 = 0, the special logic used to implement TOD is disabled, and Counters 1 and 2 will operate in exactly the same way as Counters 3, 4 and 5. When MM0 = 1 or MM1 = 1, additional counter decoding and control logic is enabled on Counters 1 and 2, which causes their decades to turn over at the counts that generate appropriate 24-hour TOD accumulations. For additional information, see the Time-of-Day chapter in the 9513A System timing controller technical manual.

Comparator Enable

Bits MM2 and MM3 control the Comparators associated with Counters 1 and 2. When a Comparator is enabled, its output is substituted for the normal counter output on the associated OUT1 or OUT2 pin. The comparator output will be active-high if the output control field of the Counter Mode register is 001 or 010 and active-low for a code of 101. Once the compare output is true, it will remain so until the count changes and the comparison therefore goes false.

The two Comparators can always be used individually in any operating mode. One special case occurs when the Time-of-Day option is revoked and both Comparators are enabled. The operation of Comparator 2 will then be conditioned by Comparator 1 so that a full 32-bit compare must be true in order to generate a true signal on OUT2. OUT1 will continue, as usual, to reflect the state of the 16-bit comparison between Alarm 1 and Counter 1.

FOUT Source

Master Mode bits MM4 through MM7 specify the source input for the FOUT divider. Fifteen inputs are available for selection, and they include the five Source pins, the five Gate pins and the five internal frequencies derived from the oscillator. The 16th combination of the four control bits (all zeros) is used to assure that an active frequency is available at the input to the FOUT divider following reset.

FOUT Divider

Bits MM8 through MM11 specify the dividing ratio for the FOUT Divider. The FOUT source (selected by bits MM4 through MM7) is divided by an integer value between 1 and 16, inclusive, and is then passed to the FOUT output buffer. After power-on or reset, the FOUT divider is set to divide-by-16.

FOUT Gate

Master Mode bit MM12 provides a software gating capability for the FOUT signal. When MM12 = 1, FOUT is off and in a low-impedance state to ground. MM12 may be set or cleared in conjunction with the loading of the other bits in the Master Mode register; alternatively, there are commands that allow MM12 to be individually set or cleared directly without changing any other Master Mode bits. After power-up or reset, FOUT is gated on.

When changing the FOUT divider ratio or FOUT source, transient pulses as short as half the period of the FOUT source may appear on the FOUT pin. Turning the FOUT gate on or off can also generate a transient. This should be considered when using FOUT as a system clock source.

Bus Width

Bit MM13 controls the multiplexer at the data bus interface in order to configure the part for an 8-bit or 16-bit external bus. The internal bus is always 16-bits wide. When MM13 = 1, 16-bit data is transferred directly between the internal bus and all 16 of the external bus lines. In this configuration, the Byte Pointer bit in the Data Pointer register remains set at all times. When MM13 = 0, 16-bit internal data is transferred a byte at a time to and from the eight low-order external data bus lines. The Byte Pointer bit toggles with each byte transfer in this mode.

When the Am9513A is set to operate with an 8-bit data bus width, pins DB8 through DB15 are not used for the data bus and are available for other functions. Pins DB13 through DB15 should be tied high. Pins DB8 through DB12 are used as auxiliary gating inputs and are labeled GATE1A through GATE5A respectively. The auxiliary gate pin, GATENA, is logically ANDed with the gate input to Counter N, as shown in Figure 1-13. The output of the AND gate is then used as the gating signal for Counter N.

Data Pointer Sequencing

Bit MM14 controls the Data Pointer logic to enable or disable the automatic sequencing functions. When MM14 = 1, the contents of the Data Pointer can be changed only directly by entering a command. When MM14 = 0, several types of automatic sequencing of the Data Pointer are available. These are described in the Data Pointer register section of this document.

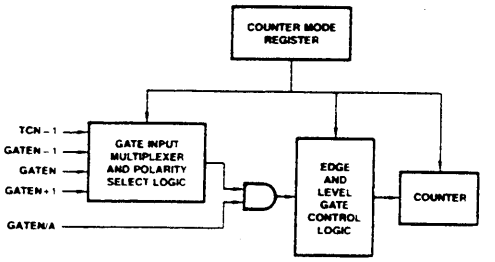
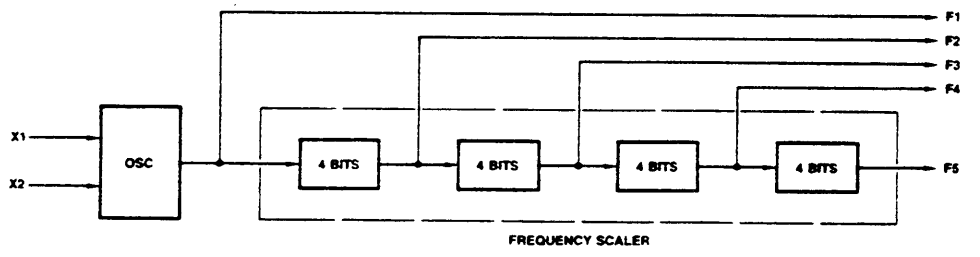


Figure 1-13. Gating Control

Thus, the host processor, by controlling MM14, may repetitively read/write a single internal location, or may sequentially read/write groups of locations. Bit MM14 can be loaded by writing to the Master Mode register or can be set or cleared by software command.

Scaler Ratios

Master Mode bit MM15 controls the counting configuration of the Frequency Scaler counter. When MM15 = 0, the Scaler divides the oscillator frequency in binary steps so that each subfrequency is 1/16 of the preceding frequency. When MM15 = 1, the Scaler divides in BCD steps so that adjacent frequencies are related by ratios of 10 instead of 16 (see Figure 1-14).



Frequency	BCD Scaling MM15 = 1	Binary Scaling MM15 = 0
F1	OSC	OSC
F2	F1 ÷ 10	F1 ÷ 16
F3	F1 ÷ 100	F1 ÷ 256
F4	F1 ÷ 1,000	F1 ÷ 4,096
F5	F1 ÷ 10,000	F1 ÷ 65,536

Figure 1-14. Frequency Scaler Ratios

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Refer to page 7-1 for Essential Information on Military Devices

Counter Mode	A	B	C	D	E	F	G	H	I	J	K	L
Special Gate (CM7)	0	0	0	0	0	0	0	0	0	0	0	0
Reload Source (CM6)	0	0	0	0	0	0	1	1	1	1	1	1
Repetition (CM5)	0	0	0	1	1	1	0	0	0	1	1	1
Gate Control (CM15-CM13)	000	LEVEL	EDGE	000	LEVEL	EDGE	000	LEVEL	EDGE	000	LEVEL	EDGE
Count to TC once, then disarm	X	X	X									
Count to TC twice, then disarm							X	X	X			
Count to TC repeatedly without disarming				X	X	X				X	X	X
Gate input does not gate counter input	X			X			X			X		
Count only during active gate level		X			X			X			X	
Start count on active gate edge and stop count on next TC			X			X						
Start count on active gate edge and stop count on second TC									X			X
No hardware retriggering	X	X	X	X	X	X	X	X	X	X	X	X
Reload counter from Load register on TC	X	X	X	X	X	X						
Reload counter on each TC, alternating reload source between Load and Hold registers							X	X	X	X	X	X
Transfer Load register into counter on each TC that gate is LOW, transfer Hold register into counter on each TC that gate is HIGH.												
On active gate edge transfer counter into Hold register and then reload counter from Load register												

Counter Mode	M	N	O	P	Q	R	S	T	U	V	W	X
Special Gate (CM7)	1	1	1	1	1	1	1	1	1	1	1	1
Reload Source (CM6)	0	0	0	0	0	0	1	1	1	1	1	1
Repetition (CM5)	0	0	0	1	1	1	0	0	0	1	1	1
Gate Control (CM15-CM13)	000	LEVEL	EDGE	000	LEVEL	EDGE	000	LEVEL	EDGE	000	LEVEL	EDGE
Count to TC once, then disarm		X	X									
Count to TC twice, then disarm							X					
Count to TC repeatedly without disarming					X	X				X		X
Gate input does not gate counter input							X			X		
Count only during active gate level		X			X							
Start count on active gate edge and stop count on next TC			X			X						X
Start count on active gate edge and stop count on second TC												
No hardware retriggering							X			X		X
Reload counter from Load register on TC		X	X		X	X						X
Reload counter on each TC, alternating reload source between Load and Hold registers.												
Transfer Load register into counter on each TC that gate is LOW, transfer Hold register into counter on each TC that gate is HIGH.							X			X		
On active gate edge transfer counter into Hold register and then reload counter from Load register		X	X		X	X						
On active gate edge transfer counter into Hold register, but counting continues												X

Notes: 1. Counter modes M, P, T, U and W are reserved and should not be used.
2. Mode X is available for Am9513A only.

Figure 1-15 Counter Mode Operating Summary

COUNTER MODE DESCRIPTIONS

Counter Mode register bits CM15-CM13 and CM7-CM5 select the operating mode for each counter (see Figure 1-15). To simplify references to a particular mode, each mode is assigned a letter from A through X. Representative waveforms for the counter modes are illustrated in Figures 1-16a through 1-16v. (Because the letter suffix in the figure number is keyed to the mode, Figures 1-16m, 1-16p, 1-16t, 1-16u and 1-16w do not exist.) The figures assume down counting on rising source edges. Those modes which automatically disarm the counter (CM5 = 0) are shown with the $\overline{WR}$ plus entering the required ARM command; for modes which count repetitively (CM5 = 1), the ARM command is omitted. The retriggering modes (N, O, Q and R) are shown with one retrigger operation. Both a TC output waveform and a TC Toggled output waveform are shown for each mode. The symbols L and H are used to represent count values equal to the Load and Hold register contents, respectively. The symbols K and N represent arbitrary count values. For each mode, the required bit pattern in the Counter Mode register is shown; "don't care" bits are marked "X." These figures are designed to clarify the mode descriptions; the Am9513A Electrical Specification should be used as the authoritative reference for timing relationships between signals.

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To keep the following mode descriptions concise and to the point, the phrase "source edges" is used to refer to active-going source edges only, not to inactive-going edges. Similarly, the phrase "gate edges" refers only to active-going gate edges. Also, again to avoid verbosity and euphuism, the descriptions of some modes state that a counter is stopped or disarmed "on a TC, inhibiting further counting." As is fully explained in the TC section of this document, for these modes the counter is actually stopped or disarmed following the active-going source edge which drives the counter out of TC. In other words, since a counter in the TC state always counts, irrespective of its gating or arming status, the stopping or disarming of the count sequence is delayed until TC is terminated.

MODE A

Software-Triggered Strobe with No Hardware Gating

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
0	0	0	X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	0	0	X	X	X	X	X

Mode A, shown in Figure 1-16a, is one of the simplest operating modes. The counter will be available for counting source edges when it is issued an ARM command. On each TC, the counter will reload from the Load register and automatically disarm itself, inhibiting further counting. Counting will resume when a new ARM command is issued.

MODE B

Software-Triggered Strobe with Level Gating

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
LEVEL			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	0	0	X	X	X	X	X

Mode B, shown in Figure 1-16b, is identical to Mode A except that source edges are counted only when the assigned Gate is active. The counter must be armed before counting can occur. Once armed, the counter will count all source edges which occur while the Gate is active and disregard those edges which occur while the Gate is inactive. This permits the Gate to turn the count process on and off. On each TC the counter will reload from the Load register and automatically disarm itself, inhibiting further counting unitl a new ARM command is issued.

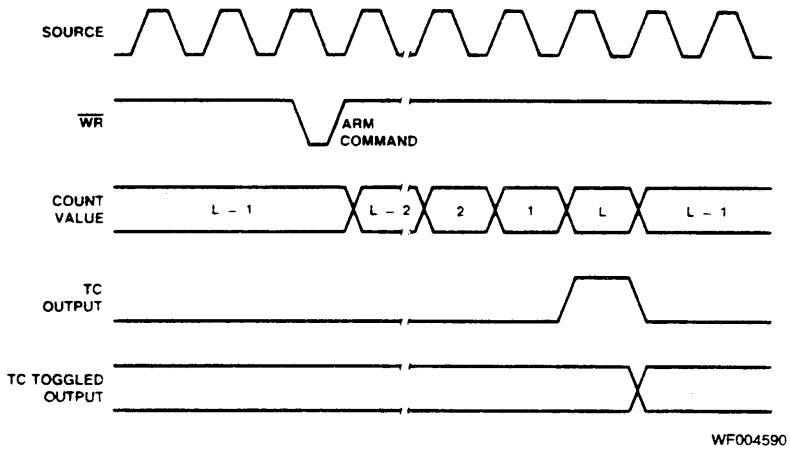

Figure 1-16a. Mode A Waveforms

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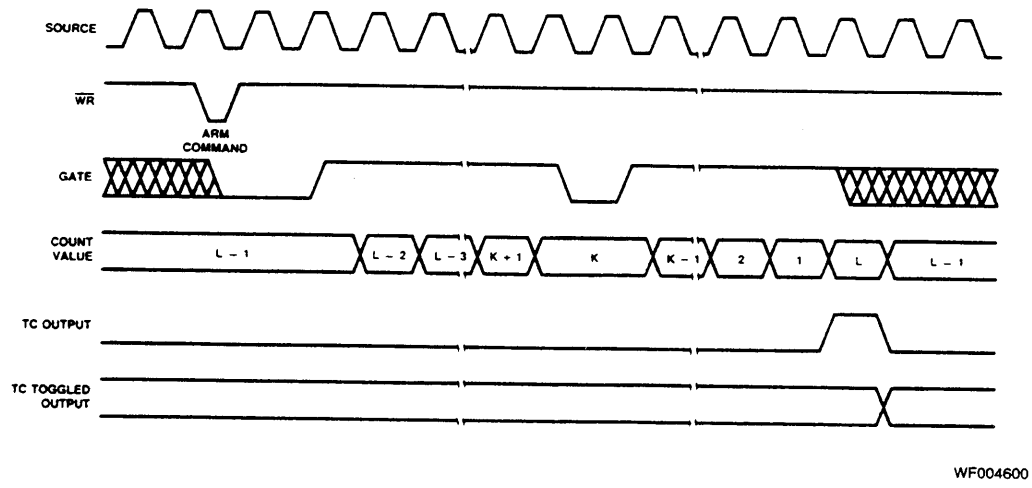

Figure 1-16b. Mode B Waveforms

MODE C

Hardware-Triggered Strobe

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
EDGE			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	0	0	X	X	X	X	X

Mode C, shown in Figure 1-16c, is identical to Mode A, except that counting will not begin until a Gate edge is applied to the armed counter. The counter must be armed before application of the triggered Gate edge; Gate edges applied to a disarmed counter are disregarded. The counter will start counting on the first source edge after the triggering Gate edge and will continue counting until TC. At TC, the counter will reload from the Load register and automatically disarm itself. Counting will then remain inhibited until a new ARM command and a new Gate edge are applied in that order. Note that after application of a triggered Gate edge, the Gate input will be disregarded for the remainder of the count cycle. This differs from Mode B, where the Gate can be modulated throughout the count cycle to stop and start the counter.

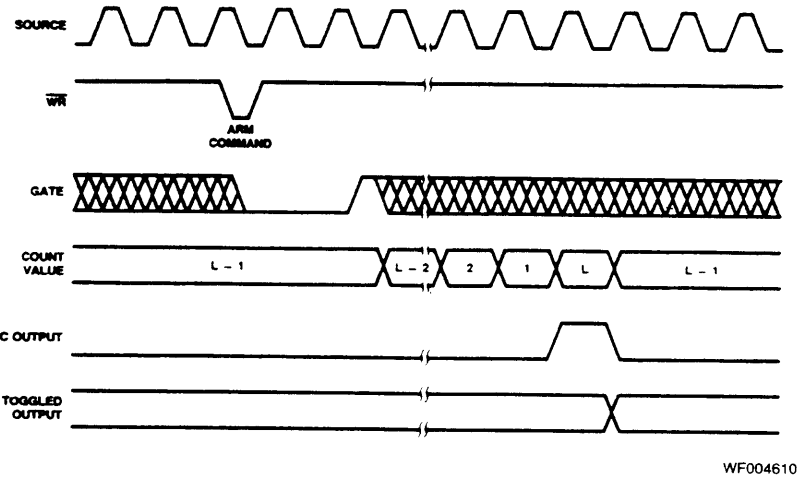

Figure 1-16c. Mode C Waveforms

MODE D

Rate Generator with No Hardware Gating

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
0	0	0	X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	0	1	X	X	X	X	X

Mode D, shown in Figure 1-16d, is typically used in frequency generation applications. In this mode, the Gate input does not affect counter operation. Once armed, the counter will count to TC repetitively. On each TC, the counter will reload itself from the Load register; hence, the Load register value determines the time between TCs. A square wave rate generator may be obtained by specifying the TC Toggled output mode in the Counter Mode register.

MODE E

Rate Generator with Level Gating

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
LEVEL			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	0	1	X	X	X	X	X

Mode E, shown in Figure 1-16e, is identical to Mode D, except the counter will only count those source edges which occur while the Gate input is active. This feature allows the counting process to be enabled and disabled under hardware control. A square wave rate generator may be obtained by specifying the TC Toggled output mode.

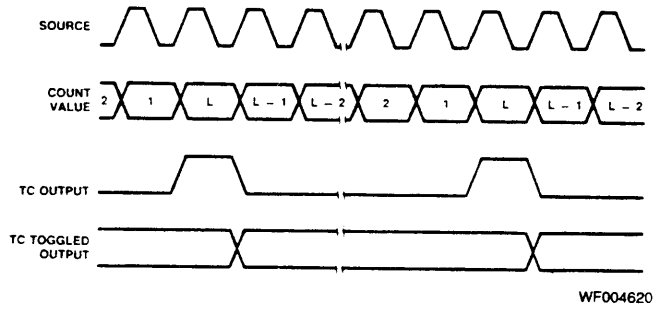

Figure 1-16d. Mode D Waveforms

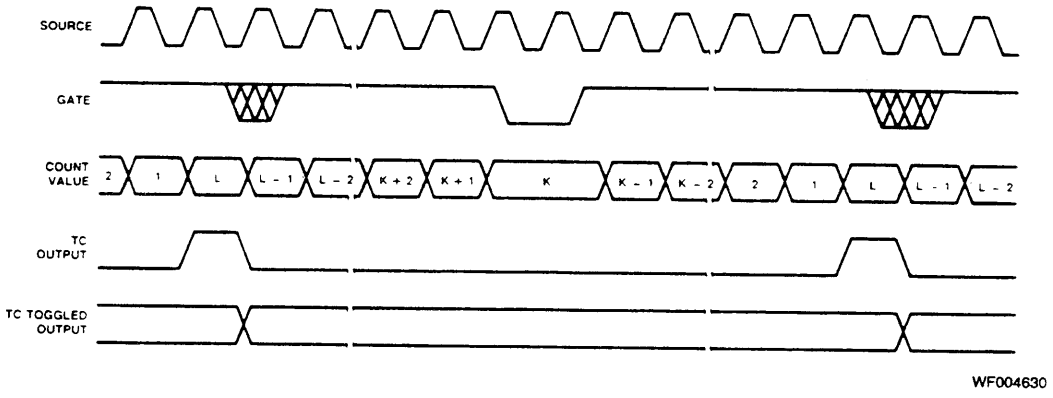

Figure 1-16e. Mode E Waveforms

MODE F

Non-Retriggerable One-Shot

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
EDGE			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	0	1	X	X	X	X	X

Mode F, shown in Figure 1-16f, provides a non-retriggerable one-shot timing function. The counter must be armed before it will function. Application of a Gate edge to the armed counter will enable counting. When the counter reaches TC, it will reload itself from the Load register. The counter will then stop counting, awaiting a new Gate edge. Note that unlike Mode C, a new ARM command is not needed after TC, only a new Gate edge. After application of a triggering Gate edge, the Gate input is disregarded until TC.

MODE G

Software-Triggered Delayed Pulse One-Shot

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
0	0	0	X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	1	0	X	X	X	X	X

In Mode G, the Gate does not affect the counter's operation. Once armed, the counter will count to TC twice and then automatically disarm itself. For most applications, the counter will initially be loaded from the Load register either by a LOAD command or by the last TC of an earlier timing cycle. Upon counting to the first TC, the counter will reload itself from the Hold register. Counting will proceed until the second TC, when the counter will reload itself from the Load register and automatically disarm itself, inhibiting further counting. Counting can be resumed by issuing a new ARM command. A software-triggered delayed pulse one-shot may be generated by specifying the TC Toggled output mode in the Counter Mode register. The initial counter contents control the delay from the ARM command until the output pulse starts. The Hold register contents control the pulse duration. Mode G is shown in Figure 1-16g.

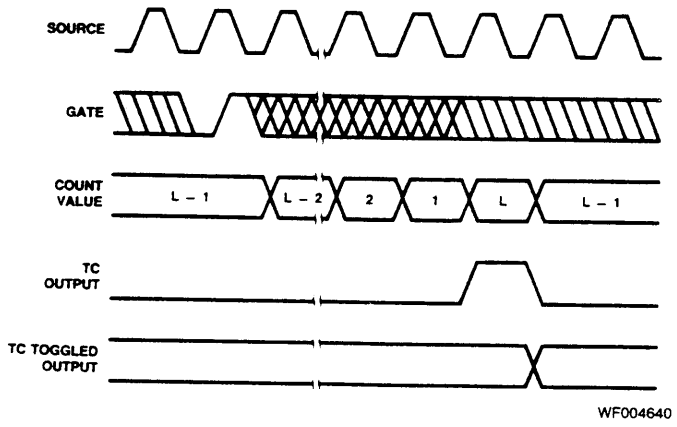

Figure 1-16f. Mode F Waveforms

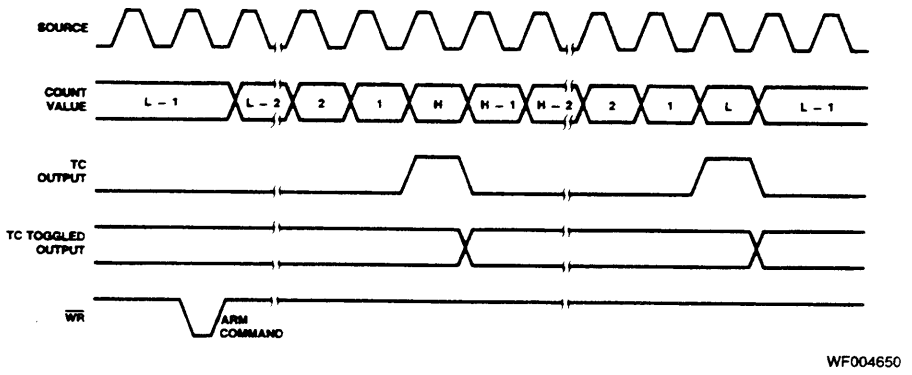

Figure 1-16g. Mode G Waveforms

MODE H

Software-Triggered Delayed Pulse One-Shot with Hardware Gating

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
LEVEL			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	1	0	X	X	X	X	X

Mode H, shown in Figure 1-16h, is identical to Mode G except that the Gate input is used to qualify which source edges are to be counted. The counter must be armed for counting to occur. Once armed, the counter will count all source edges that occur while the Gate is inactive. This permits the Gate to turn the count process on and off. As with Mode G, the counter will be reloaded from the Hold register on the first TC and reloaded from the Load register and disarmed on the second TC. This mode allows the Gate to control the extension of both the initial output delay time and the pulse width.

MODE I

Hardware-Triggered Delayed Pulse Strobe

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
EDGE			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	1	0	X	X	X	X	X

Mode I, shown in Figure 1-16i, is identical to Mode G, except that counting will not begin until a Gate edge is applied to an armed counter. The counter must be armed before application of the triggering Gate edge; Gate edges applied to a disarmed counter are disregarded. An armed counter will start counting on the first source edge after the triggering Gate edge. Counting will then proceed in the same manner as in Mode G. After the second TC, the counter will disarm itself. An ARM command and Gate edge must be issued in this order to restart counting. Note that after application of a triggering Gate edge, the Gate input will be disregarded until the second TC. This differs from Mode H, where the Gate can be modulated throughout the count cycle to stop and start the counter.

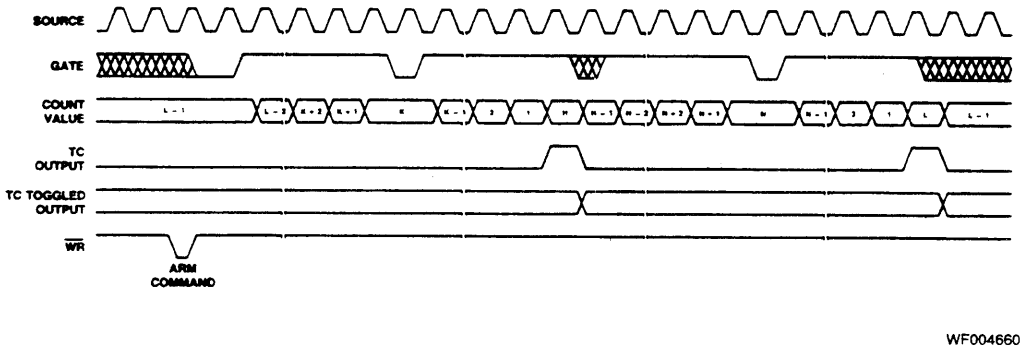

Figure 1-16h. Mode H Waveforms

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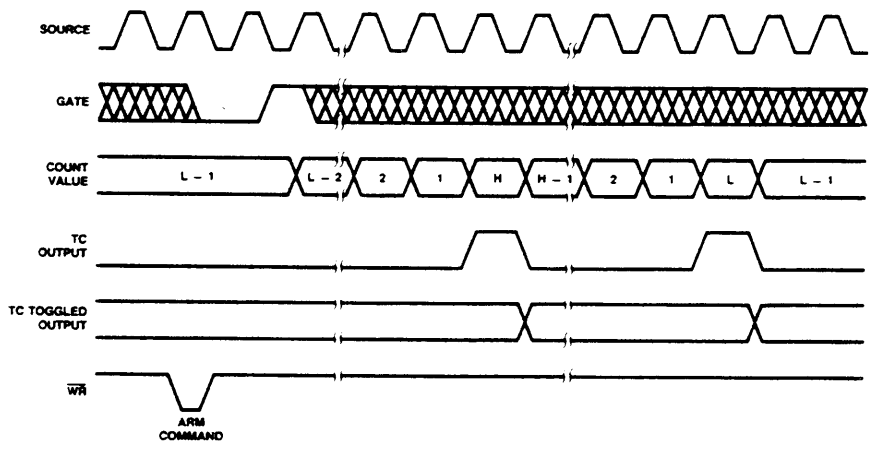

Figure 1-16i. Mode I Waveforms

MODE J

Variable Duty Cycle Rate Generator with No Hardware Gating

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
0	0	0	X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	1	1	X	X	X	X	X

Mode J, shown in Figure 1-16i, will find the greatest usage in frequency generation applications with variable duty cycle requirements. Once armed, the counter will count continuously until it is issued a DISARM command. On the first TC, the counter will be reloaded from the Hold register. Counting will then proceed until the second TC at which time the counter will be reloaded from the Load register. Counting will continue, with the reload source alternating on each TC, until a DISARM command is issued to the counter. (The third TC reloads from the Hold register, the fourth TC reloads from the Load register, etc.) A variable duty cycle output can be generated by specifying the TC Toggled output in the Counter Mode register. The Load and Hold values then directly control the output duty cycle, with high resolution available when relatively high count values are used.

MODE K

Variable Duty Cycle Rate Generator with Level Gating

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
LEVEL			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	1	1	X	X	X	X	X

Mode K, shown in Figure 1-16k, is identical to Mode J, except that source edges are only counted when the Gate is active. The counter must be armed for counting to occur. Once armed, the counter will count all source edges which occur while Gate is active and disregard those source edges which occur while the Gate is inactive. This permits the Gate to turn the count process on and off. As with Mode J, the reload source used will alternate on each TC, starting with the Hold register on the first TC after any ARM command. When the TC Toggled output is used, this mode allows the Gate to modulate the duty cycle of the output waveform. It can affect both the HIGH and LOW portions of the output waveform.

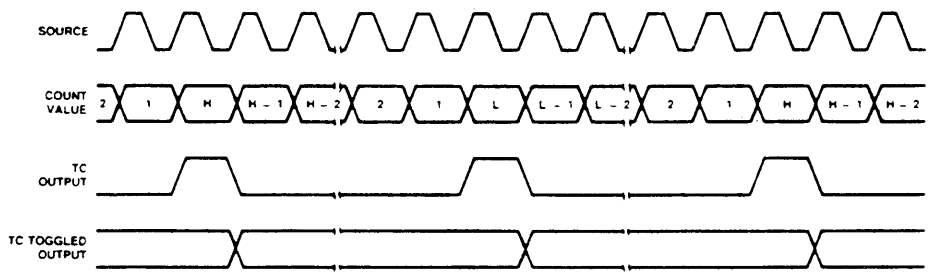

Figure 1-16j. Mode J Waveforms

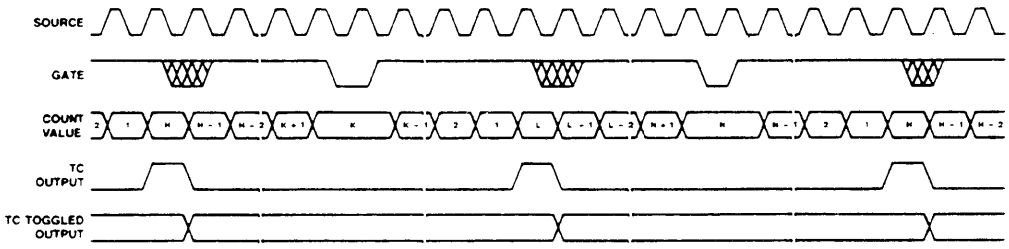

Figure 1-16k. Mode K Waveforms

MODE L

Hardware-Triggered Delayed Pulse One-Shot

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
EDGE			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
0	1	1	X	X	X	X	X

Mode L, shown in Figure 1-16l, is similar to Mode J except that counting will not begin until a Gate edge is applied to an armed counter. The counter must be armed before application of the triggering Gate edge; Gate edges applied to a disarmed counter are disregarded. The counter will start counting source edges after the triggering Gate edge, and counting will proceed until the second TC. Note that after application of a triggering Gate edge, the Gate input will be disregarded for the remainder of the count cycle. This differs from Mode K, where the gate can be modulated throughout the count cycle to stop and start the counter. On the first TC after application of the triggering Gate edge, the counter will be reloaded from the Hold register. On the second TC, the counter will be reloaded from the Load register, and counting will stop until a new gate edge is issued to the counter. Note that unlike Mode K, new Gate edges are required after every second TC to continue counting.

MODE N

Software-Triggered Strobe with Level Gating and Hardware Retriggering

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
LEVEL			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
1	0	0	X	X	X	X	X

Mode N, shown in Figure 1-16n, provides a software-triggered strobe with level gating that is also hardware retriggerable. The counter must be issued an ARM command before counting can occur. Once armed, the counter will count all source edges which occur while the gate is active and disregard those source edges which occur while the Gate is inactive. This permits the Gate to turn the count process on and off. After the issuance of the ARM command and the application of an active Gate, the counter will count to TC. Upon reaching TC, the counter will reload from the Load register and automatically disarm itself, inhibiting further counting. Counting will resume upon the issuance of a new ARM command. All active-going Gate edges issued to an armed counter will cause a retrigger operation. Upon application of the Gate edge, the counter contents will be saved in the Hold register. On the first qualified source edge after application of the retriggering gate edge, the contents of the Load register will be transferred into the counter. Counting will resume on the second qualified source edge after the retriggering Gate edge. Qualified source edges are active-going edges which occur while the Gate is active.

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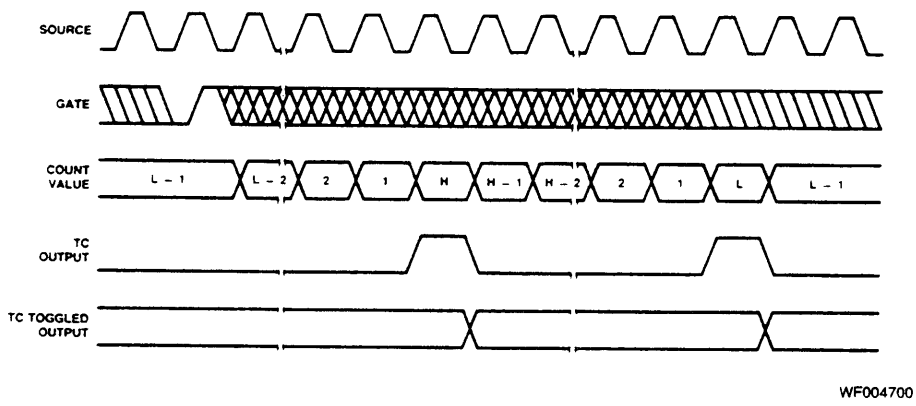

Figure 1-16l. Mode L Waveforms

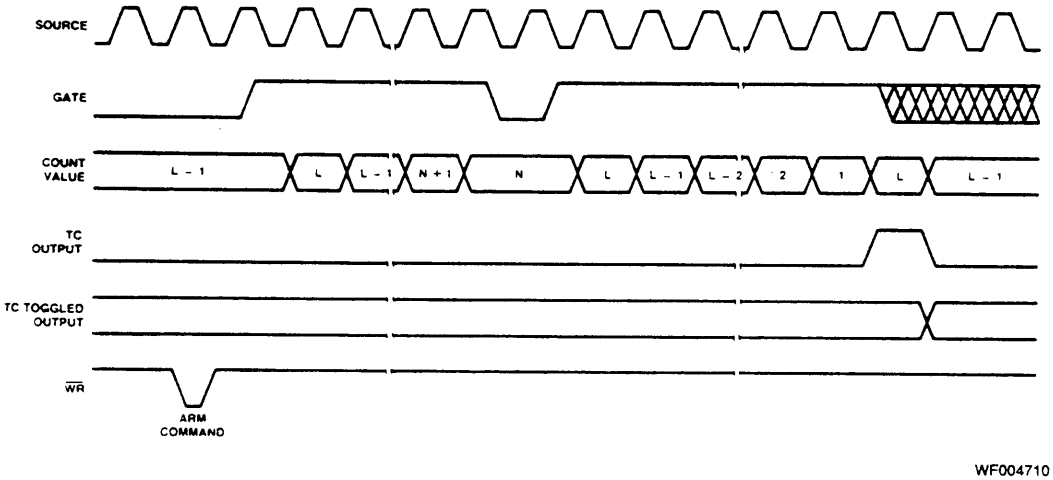

Figure 1-16n. Mode N Waveforms

MODE O

Software-Triggered Strobe with Edge Gating and Hardware Retriggering

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
EDGE			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
1	0	0	X	X	X	X	X

Mode O, shown in Figure 1-16o, is similar Mode N, except that counting will not begin until an active-going Gate edge is applied to an armed counter and the Gate level is not used to modulate counting. The counter must be armed before application of the triggering Gate edge; Gate edges applied to a disarmed counter are disregarded. Irrespective of the Gate level, the counter will count all source edges after the triggering Gate edge until the first TC. On the first TC,the counter will be reloaded from the Load register and disarmed. A new ARM command and a new Gate edge must be applied in that order to initiate a new counting cycle. Unlike Modes C, F, I and L, which disregard the Gate input once counting starts, in Mode O the count process will be retriggered on all active-going Gate edges, including the first Gate edge used to start the counter. On each retriggering Gate edge, the counter contents will be transferred into the Hold register. On the first source edge after the retriggering Gate edge, the Load register contents will be transferred into the counter. Counting will resume on the second-source edge after a retrigger.

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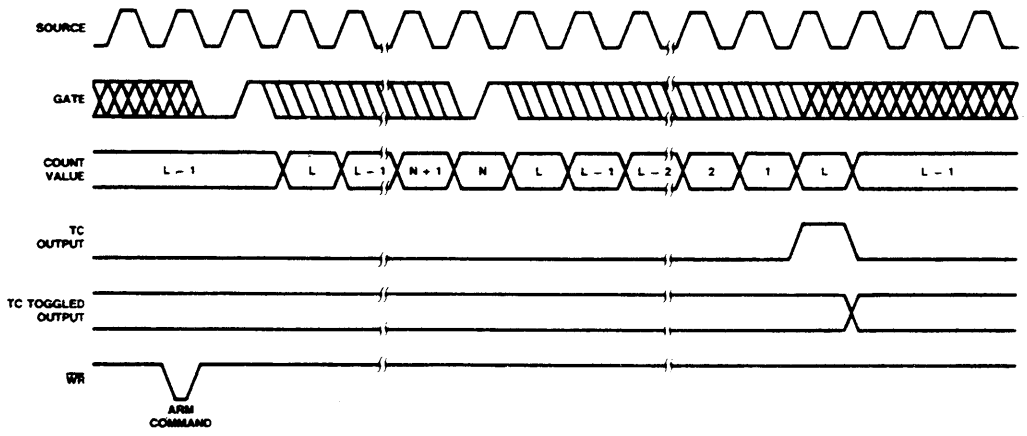

Figure 1-16o. Mode O Waveforms

MODE Q

Rate Generator with Synchronization (Event Counter with Auto-Read/Reset)

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
LEVEL			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
1	0	1	X	X	X	X	X

Mode Q, shown in Figure 1-16q, provides a rate generator with synchronization or an event counter with auto-read/reset. The counter must first be issued an ARM command before counting can occur. Once armed, the counter will count all source edges which occur while the Gate is active and disregard those edges which cccur while the Gate is inactive. This permits the Gate to turn the count process on and off. After the issuance of an ARM command and the application of an active Gate, the counter will count to TC repetitively. On each TC,the counter will reload itself from the Load register. The counter may be retriggered at any time by presenting an active-going Gate edge to the Gate input. The retriggering Gate edge will transfer the contents of the counter into the Hold register. The first qualified source edge after the retriggering Gate edge will transfer the contents of the Load register into the Counter. Counting will resume on the second qualified source edge after the retriggering Gate edge. Qualified source edges are active-going edges which occur while the Gate is active.

MODE R

Retriggerable One-Shot

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
EDGE			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
1	0	1	X	X	X	X	X

Mode R, shown in Figure 1-16r, is similar to Mode Q, except that edge gating rather than level gating is used. In other words, rather than use the Gate level to qualify which source edges to count, Gate edges are used to start the counting operation. The counter must be armed before application of the triggering Gate edge; Gate edges applied to a disarmed counter are disregarded. After application of a Gate edge, an armed counter will count all source edges until TC, irrespective of the Gate level. On the first TC, the counter will be reloaded from the Load register and stopped. Subsequent counting will not occur until a new Gate edge is applied. All Gate edges applied to the counter, including the first used to trigger counting, initiate a retrigger operation. Upon application of a Gate edge, the counter contents are saved in the Hold register. On the first source edge after the retriggering Gate edge, the Load register contents will be transferred into the counter. Counting will resume on the second source edge after the retriggering Gate edge.

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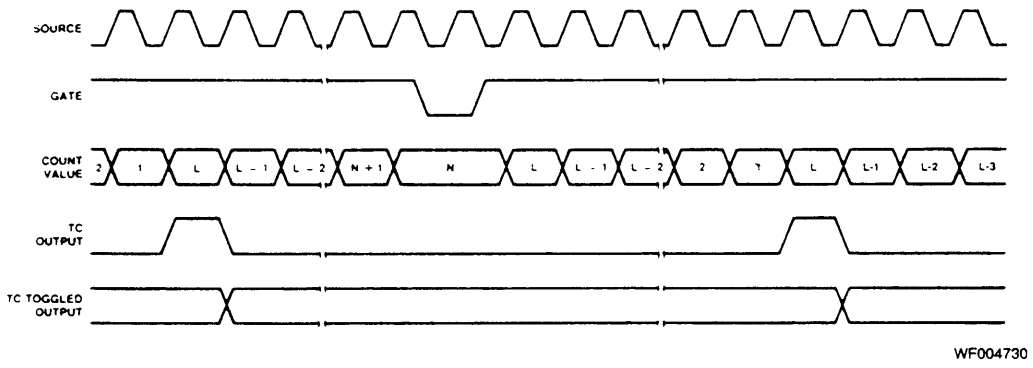

Figure 1-16q. Mode Q Waveforms

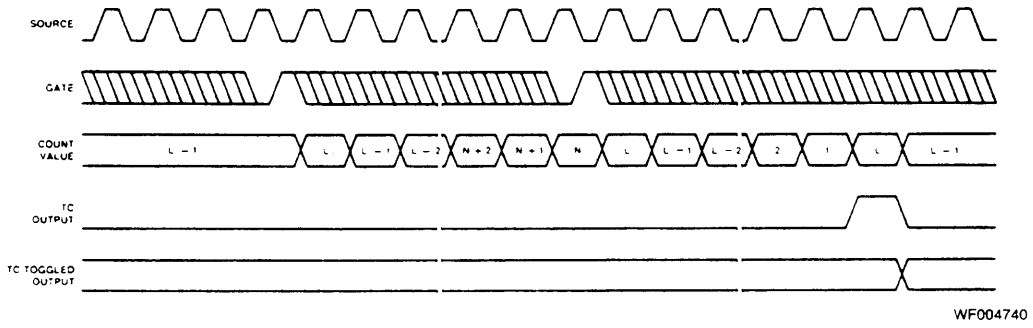

Figure 1-16r. Mode R Waveforms

MODE S

RELOAD SOURCE

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
0	0	0	X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
1	1	0	X	X	X	X	X

In this mode, the reload source for LOAD commands (irrespective of whether the counter is armed or disarmed) and for TC-initiated reloads is determined by the Gate input. The Gate input in Mode S is used only to select the reload source, not to start or modulate counting. When the Gate is Low, the Load register is used; when the Gate is High, the Hold register is used. Note the Low-Load, High-Hold mnemonic convention. Once armed, the counter will count to TC twice and then disarm itself. On each TC, the counter will be reloaded from the reload source selected by the Gate. Following the second TC, an ARM command is required to start a new counting cycle. Mode S is shown in Figure 1-16s.

MODE V

Frequency-Shift Keying

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
0	0	0	X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
1	1	1	X	X	X	X	X

Mode V, shown in Figure 1-16v, provides frequency-shift keying modulation capability. Gate operation in this mode is identical to that in Mode S. If the Gate is Low, a LOAD command or a TC-induced reload will reload the counter from the Load register. If the Gate is HIGH, LOADs and reloads will occur from the Hold register. The polarity of the Gate only selects the reload source; it does not start or modulate counting. Once armed, the counter will count repetitively to TC. On each TC, the counter will reload itself from the register determined by the polarity of the Gate. Counting will continue in this manner until a DISARM command is issued to the counter. Frequency shift keying may be obtained by specifying a TC Toggled output mode in the Counter Mode register. The switching of frequencies is achieved by modulating the Gate.

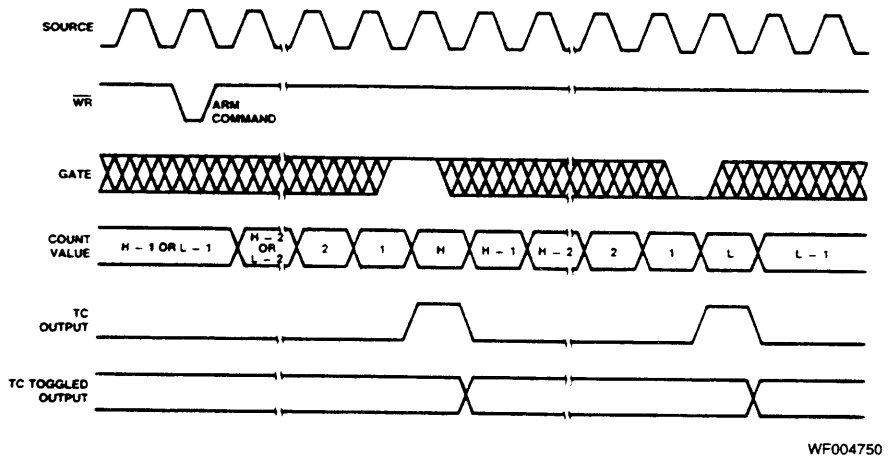

Figure 1-16s. Mode S Waveforms

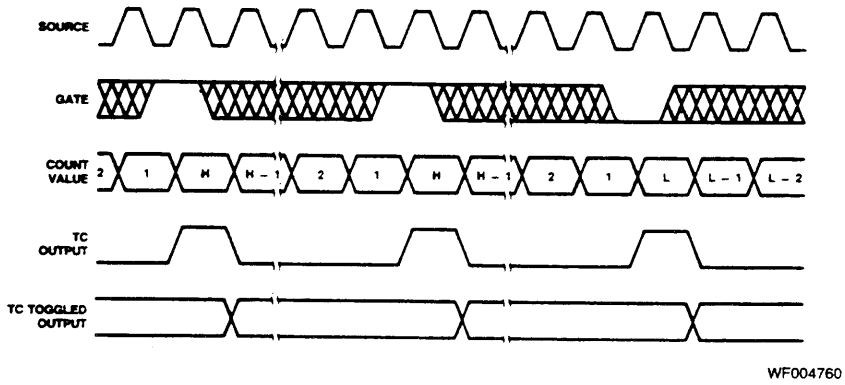

Figure 1-16v. Mode V Waveforms

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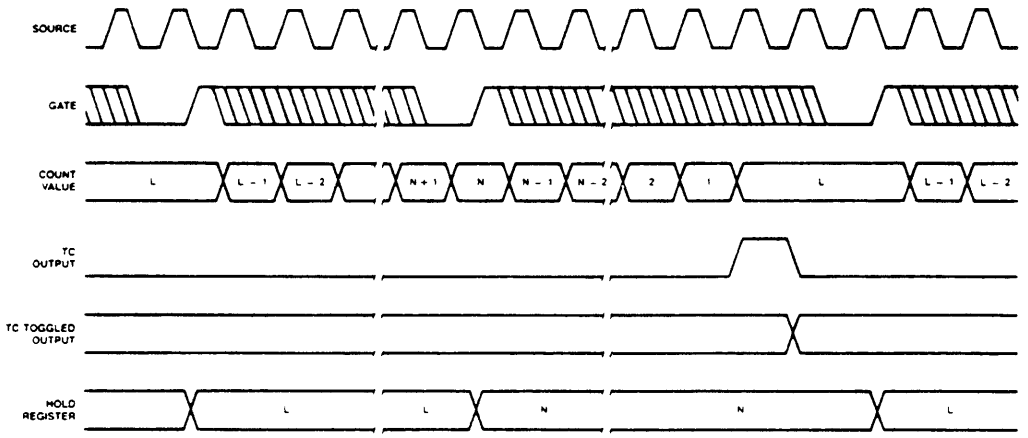


Figure 1-16x. Mode X Waveforms

MODE X

Hardware Save (available in Am9513A only)

CM15	CM14	CM13	CM12	CM11	CM10	CM9	CM8
Edge			X	X	X	X	X

CM7	CM6	CM5	CM4	CM3	CM2	CM1	CM0
1	1	1	X	X	X	X	X

Mode X, as shown in Figure 1-16x, provides a hardware sampling of the counter contents without interrupting the count. A LOAD AND ARM command or a LOAD command followed by an ARM command is required to initialize the counter. Once armed, a Gate edge starts the counting operation; Gate edges applied to a disarmed counter are disregarded. After application of the Triggering Gate edge, the counter will count all qualified source edges until the first TC, irrespective of the gate level. All gate edges applied during the counting sequence will store the current count in the Hold register, but they will not interrupt the counting sequence. On each TC, the counter will be reloaded from the Load register and stopped. Subsequent counting requires a new triggering Gate edge; counting resumes on the first source edge following the triggering Gate edge.

Note: Mode X is only available in the Am9513'A' devices.

COUNTER MODE CONTROL OPTIONS

Each Counter Logic Group includes a 16-bit Counter Mode (CM) register used to control all of the individual options available with its associated general counter. These options include output configuration, count control, count source and gating control. Figure 1-17 shows the bit assignments for the Counter Mode registers. This section describes the control options in detail. Note that generally each counter is independently configured and does not depend on information outside its Counter Logic Group. The Counter Mode register should be loaded only when the counter is Disarmed. Attempts to load the Counter Mode register when the counter is armed may result in erratic counter operation.

After power-on reset or a Master Reset command, the Counter Mode registers are initialized to a preset condition. The value entered is 0B00 hex and results in the following control configuration:

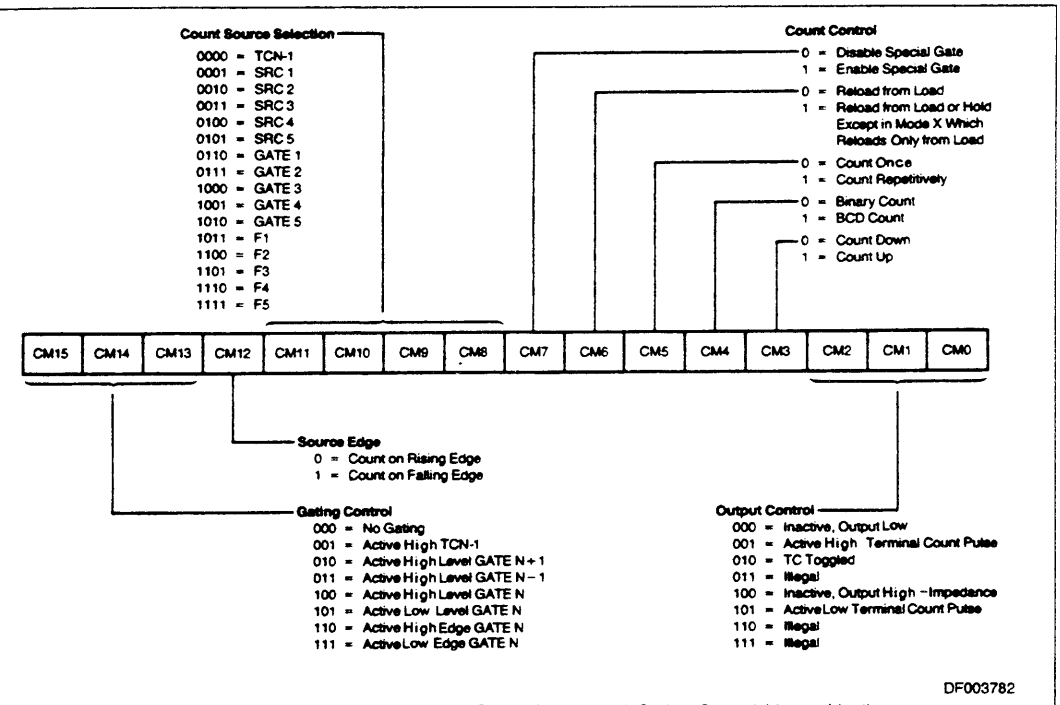
Output low-impedance to ground
Count down
Count binary
Count once
Load register selected
No retriggering
F1 input source selected
Positive-true input polarity
No gating

Output Control

Counter mode bits CM0 through CM2 specify the output control configuration. Figure 1-18 shows a schematic representation of the output control logic. The OUT pin may be off (a high-impedance state), or it may be inactive with a low-impedance to ground. The three remaining valid combinations represent the active-high, active-low or TC Toggle output waveforms.

One output form available is called Terminal Count (TC) and represents the period in time that the counter reaches an equivalent value of zero. TC will occur on the next count when the counter is at 0001 for down counting, at 9999 (BCD) for BCD up counting or at FFFF (hex) for binary up counting. Figure 1-19 shows a Terminal Count pulse and an example context that generated it. The TC width is determined by the period of the counting source. Regardless of any gating input or whether the counter is Armed or Disarmed, the terminal count will go active for only one clock cycle. Figure 1-19 assumes active-high source polarity, counter armed, counter decrementing and an external reload value of K.

The counter will always be loaded from an external location when TC occurs; the user can choose the source location and the value. If a non-zero value is picked, the counter will never really attain a zero state, and TC will indicate the counter state that would have been zero had no parallel transfer occurred.



Note: See Figure 1-16 for restrictions on Count Control and Gating Control bit combinations.

Figure 1-17. Counter Mode Register Bit Assignments

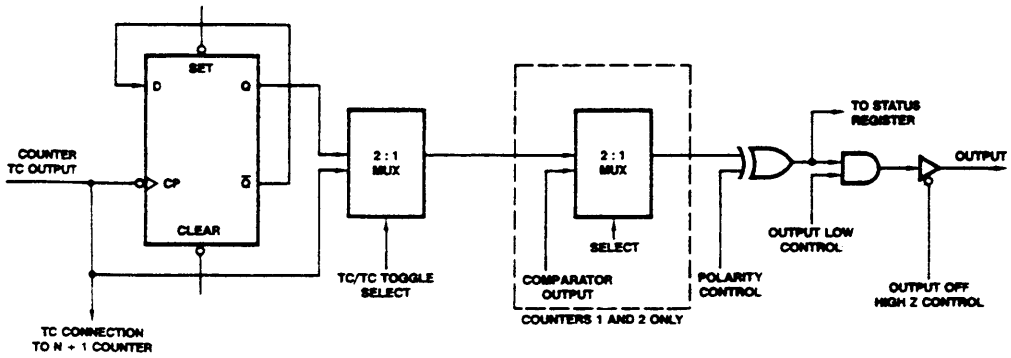


Figure 1-18. Output Control Logic

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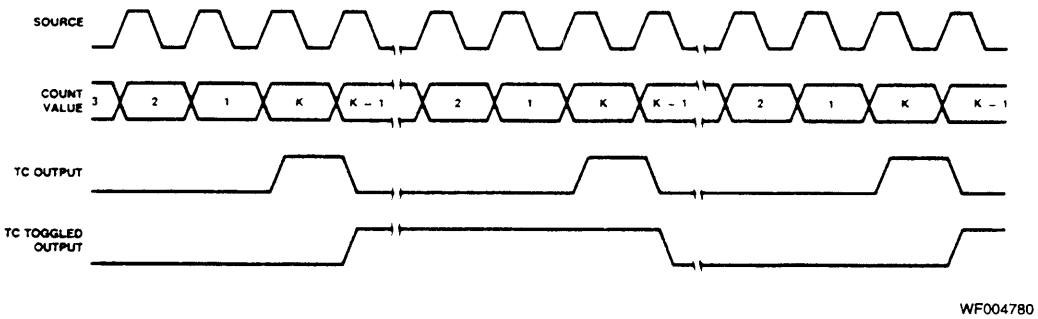

Figure 1-19. Counter Output Waveforms

The other output form, TC Toggled, uses the trailing edge of TC to toggle a flip-flop to generate an output level instead of a pulse. The toggle output is 1/2 the frequency of TC. The TC Toggled output will frequently be used to generate variable duty-cycle square waves in Operating Modes G through K.

In Mode L the TC Toggled output can be used to generate a one-shot function, with the delay to the start of the output pulse and the width of the output pulse separately programmable. With selection of the minimum delay to the start of the pulse, the output will toggle on the second source pulse following application of the triggering Gate edge.

Note that the TC Toggled output form contains no implication about whether the output is active-high or active-low. Unlike the TC output, which generates a transient pulse which can clearly be active-high or active-low, the TC Toggled output waveform only flips the state of the output on each TC. The sole criterion of whether the TC Toggled output is active-high or active-low is the level of the output at the start of the count cycle. This can be controlled by the Set and Clear Output commands. (See Figure 1-20.)

TC (Terminal Count)

On each Terminal Count (TC), the counter will reload itself from the Load or Hold register. TC is defined as that period of time when the counter contents would have been zero had no reload occurred. Some special conditions apply to counter operation immediately before and during TC.

1. In the clock cycle before TC, an internal signal is generated that commits the counter to go to TC on the next count, and retriggering by a hardware Gate edge (Modes N, O, Q and R) or a software LOAD or LOAD AND ARM command will not extend the time to TC. Note that the "next count" driving the counter to TC can be caused by the application of a count source edge (in level gating modes, the edge must occur while the gate is active, or it will be disregarded), by the application of a LOAD or LOAD AND ARM command (see 2 below) or by the application of a STEP command.
2. If a LOAD or LOAD AND ARM command is executed during the cycle preceding TC, the counter will immediately go to TC. If these commands are issued during TC, the TC state will immediately terminate.
3. When TC is active, the counter will always count the next source edge issued to it, even if it is disarmed or gated off during TC. This means that TC will never be active for longer than one count period and it may, in fact, be shorter if a STEP command or a LOAD or LOAD AND ARM command is applied during TC (see item 2 above). This also means that a counter that is disarmed or stopped on TC is actually disarmed/stopped immediately following TC.

This may cause count sequences different from what a user might expect. Since the counter is always reloaded at the start of TC and since it always counts at the end of TC, the counter contents following TC will differ by one from the reloaded value, irrespective of the operating mode used.

If the reloaded value was 0001 for down counting, 9999 (BCD) for BCD up counting or FFFF (hex) for binary up counting, the count at the end of TC will drive the counter into TC again regardless of whether the counter is gated off or disarmed. As long as these values are reloaded, the TC output will stay active. If a TC Toggled output is selected, it will toggle on each count. Execution of a LOAD, LOAD AND ARM or STEP command with these counter contents will act the same as application of a source pulse, causing TC to remain active and a TC Toggled output to toggle.

Count Control

Counter Mode bits CM3 through CM7 specify the various options available for direct control of the counting process. CM3 and CM4 operate independently of the others and control up/down and BCD/binary counting. They may be combined freely with other control bits to form many types of counting configurations. The other three bits and the Gating Control field interact in complex ways. Bit CM5 controls the repetition of the count process. When CM5 = 1, counting will proceed in the specified mode until the counter is disarmed. When CM5 = 0, the count process will proceed only until one full cycle of operation occurs. This may occur after one or two TC events. The counter is then disarmed automatically. The single or double TC requirement will depend on the state of other control bits. Note that even if the counter is automatically disarmed upon a TC, it always counts the count source edge which generates the trailing TC edge.

When TC occurs, the counter is always reloaded with a value from either the Load register of the Hold register. Bit CM6 specifies the source options for reloading the counter. When CM6 = 0, the contents of the Load register will be transferred into the counter at every occurrence of TC. When CM6 = 1, the counter reload location will be either the Load or Hold Register. The reload location in this case may be controlled externally by using a Gate pin (Modes S and V) or may alternate on each TC (Modes G through L). With alternating sources and with the TC Toggled output selected, the duty cycle of the output waveform is controlled by the relative Load and Hold values and very fine resolution of duty cycles ratios may be achieved.

Bit CM7 controls the special gating functions that allow retriggering and the selection of Load or Hold sources for counter reloading. The use and definition of CM7 will depend on the status of the Gating Control field and bits CM5 and CM6.

Hardware Retriggering

Whenever hardware retriggering is enabled (Modes N, O, Q, and R), all active-going Gate edges initiate retrigger operations. On application of the Gate edge, the counter contents will be transferred to the Hold register. On the first qualified source edge after application of the retriggering Gate edge, the Load register contents will be transferred into the counter. (Qualified source edges are edges which occur while the counter is gated on and Armed.)

This means that, if level gating is used, the edge occurring on active-going gate transitions will initiate a retrigger. Similarly, when edge gating is enabled, an edge used to start the counter will also initiate a retrigger. The first count source edge applied after the Gate edge will not increment/decrement the counter but retrigger it.

If a LOAD, LOAD AND ARM, or a STEP Command occurs between the retriggering Gate edge and the first qualified source edge, it will be interpreted as a source edge and transfer the Load register contents into the counter. Thereafter, the counter will count all qualified source edges.

When some form of Gating is specified, CM7 controls hardware retriggering. In this case, when CM7 = 0, hardware retriggering does not occur; when CM7 = 1, the counter is retriggered any time an active-going Gate edge occurs. Retriggering causes the counter value to be saved in the Hold register and the Load register contents to be transferred into the counter.

When No Gating is specified, the definition of CM7 changes. In this case, when CM7 = 0, the Gate input has no effect on the counting; when CM7 = 1, the Gate input specifies the source (selecting either the Load or Hold register) used to reload the counter when TC occurs. Figure 1-15 shows the various available control combinations for these interrelated bits.

Count Source Selection

Counter Mode bits CM8 through CM12 specify the source used as input to the counter and the active edge that is counted. Bit CM12 controls the polarity for all the sources; logic zero counts rising edges and logic one counts falling edges. Bits CM8 through CM11 select 1 of 16 counting sources to route to the counter input. Five of the available inputs are internal frequencies derived from the internal oscillator (see Figure 1-14 for frequency assignments). Ten of the available inputs are interface pins; five are labeled SRC and five are labeled GATE.

The 16th available input is the TC output from the adjacent lower-numbered counter. (The Counter 5 TC wraps around to the Counter 1 input.) This option allows internal concatenating that permits very long counts to be accumulated. Since all five counters may be concatenated, it is possible to configure a counter that is 80-bits long on one Am9513A chip. When TCN-1 is the source, the count ripples between the connected counters. External connections can also be made, and can use the toggle bit for even longer counts. This is easily accomplished by selecting a TC Toggled output mode and wiring OUTN to one of the SRC inputs.

Gating Control

Counter Mode bits CM15, CM14, CM13 specify the hardware gating options. When "no gating" is selected (000),the counter will proceed unconditionally as long as it is armed. For any other gating mode, the count process is conditioned by the specified gating configuration.

For a code of 100 in this field, counting can proceed only when the pin labeled GATEN associated with Counter N is at a logic high level. When it goes LOW, counting is simply suspended until the Gate goes HIGH again. A code of 101 performs the same function with an opposite active polarity. Codes 010 and 011 offer the same function as 100, but specify alternate input pins as Gating Sources. This allows any of three interface pins to be used as gates for a given counter. On Counter 4, for example, pin 34, pin 35 or pin 36 may be used to perform the gating function. This also allows a single Gate pin to simultaneously control up to three counters. Counters 1 and 5 are considered adjacent when using TCN - 1 (001), Gate N + 1 (010) and Gate N – 1 (011) controls.

For codes of 110 or 111 in this field, counting proceeds after the specified active Gate edge until one or two TC events occur. Within this interval, the Gate input is ignored, except for the retriggering option. When repetition is selected, a cycle will be repeated as soon as another Gate edge occurs. With repetition selected, any Gate edge applied after TC goes active will start a new count cycle. Edge gating is useful when implementing a digital single-shot since the gate can serve as a convenient firing trigger.

A 001 code in this field selects the TC (not TOGGLE) output from the adjacent lower-numbered counter as the gate. This is useful for synchronous counting when adjacent counters are concatenated.

COMMAND DESCRIPTIONS

The command set for the Am9513A allows the host processor to customize and manage the operating modes and features for particular applications, to initialize and update both the internal data and control information, and to manipulate operating bits during operation. Commands are entered directly into the 8-bit Command register by writing into the Control port (see Figure 1-7).

All available commands are described in the following text. Figure 1-20 summarizes the command codes and includes a brief description of each function. Figure 1-21 shows all the unused code combinations; unused codes should not be entered into the Command register since undefined activities may occur.

Six of the command types are used for direct software control of the counting process and they each contain a 5-bit S field. In a linear-select fashion, each bit in the S field corresponds to one of five general counters (S1 = Counter 1, S2 = Counter 2, etc.). When an S bit is a one, the specified operation is performed on the counter so designated; when an S bit is a zero, no operation occurs for the corresponding counter. This type of command format has three basic advantages. It saves host software by allowing any combination of counters to be acted on by a single command. It allows simultaneous action on multiple counters where synchronization of commands is important. It allows counter-specific service routines to control individual counters without needing to be aware of the operating context of other counters.

Three of the commands use a 3-bit binary code (N4, N2, N1) to identify the affected counter (a 001 programs counter 1, etc.). Unlike the previously mentioned commands, these commands allow you to program only one counter at a time.

Command Code								Command Description
C7	C6	C5	C4	C3	C2	C1	C0	
0	0	0	E2	E1	G4	G2	G1	Load Data Pointer register with contents of E and G fields. (G ≠ 000, G ≠ 110)
0	0	1	S5	S4	S3	S2	S1	Arm counting for all selected counters
0	1	0	S5	S4	S3	S2	S1	Load contents of specified source into all selected counters
0	1	1	S5	S4	S3	S2	S1	Load and Arm all selected counters*
1	0	0	S5	S4	S3	S2	S1	Disarm and Save all selected counters
1	0	1	S5	S4	S3	S2	S1	Save all selected counters in Hold register
1	1	0	S5	S4	S3	S2	S1	Disarm all selected counters
1	1	1	0	1	N4	N2	N1	Set Toggle out (HIGH) for counter N (001 ≤ N ≤ 101)
1	1	1	0	0	N4	N2	N1	Clear Toggle out (LOW) for counter N (001 ≤ N ≤ 101)
1	1	1	1	0	N4	N2	N1	Step counter N (001 ≤ N ≤ 101)
1	1	1	0	1	0	0	0	Set MM14 (Disable Data Pointer Sequencing)
1	1	1	0	1	1	1	0	Set MM12 (Gate off FOUT)
1	1	1	0	1	1	1	1	Set MM13 (Enter 16-bit bus mode)
1	1	1	0	0	0	0	0	Clear MM14 (Enable Data Pointer Sequencing)
1	1	1	0	0	1	1	0	Clear MM12 (Gate on FOUT)
1	1	1	0	0	1	1	1	Clear MM13 (Enter 8-bit bus mode)
1	1	1	1	1	0	0	0	Enable Prefetch for Write operations (Am9513'A' only)
1	1	1	1	1	0	0	1	Disable Prefetch for Write operations (Am9513'A' only)
1	1	1	1	1	1	1	1	Master reset

*Not to be used for asynchronous operations.

Figure 1-20. Am9513A Command Summary

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	1	0	0	0	0
1	1	1	1	0	1	1	0
1	1	1	1	0	1	1	1
0	0	0	X	X	1	1	0
0	0	0	X	X	0	0	0
*1	1	1	1	1	X	X	X

*Unused except when XXX = 111, 001 or 000.

Figure 1-21. Am9513A Unused Command Codes

Arm Counters

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
0	0	1	S5	S4	S3	S2	S1

Description: Any combination of counters, as specified by the S field, will be enabled for counting. A counter must be armed before counting can commerce. Once armed, the counting process may be further enabled or disabled using the hardware gating facilities. This command can only arm or do nothing for a given counter; a zero in the S field does not disarm the counter.

ARM and DISARM commands can be used to gate counter operation on and off under software control. DISARM commands entered while a counter is in the TC state will not take effect until the counter leaves TC. This ensures that the counter never latches up in a TC state. (The counter may leave the TC state because of application of a count source edge, execution of a LOAD or LOAD AND ARM command, or execution of a STEP command.)

In modes which alternate reload sources (Modes G-L), the ARMing operation is used as a reset for the logic which determines which reload source to use on the upcoming TC. Following each ARM or LOAD AND ARM command, a counter in one of these modes will reload from the Hold register on the first TC and alternate reload sources thereafter (reload from the Load register on the second TC, the Hold register on the third, etc.).

Load Counters

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
0	1	0	S5	S4	S3	S2	S1

Description: Any combination of counters, as specified in the S field, will be loaded with previously entered values. The source of information for each counter will be either the associated Load register or the associated Hold register, as determined by the operating configuration in the Mode register. The Load/Hold contents are not changed. This command will cause a transfer independent of any current operating configuration for the counter. It will often be used as a software retrigger or as counter initialization prior to active hardware gating.

If a LOAD or LOAD AND ARM command is executed during the cycle preceding TC, the counter will go immediately to TC. This occurs because the LOAD operation is performed by generating a pseudo-count pulse internal to the Am9513A, and the Am9513A is expecting to go into TC on the next count pulse. The reload source used to reload the counter will be the same as that which would have been used if the TC were generated by a source edge rather than by the LOAD operation.

Execution of a LOAD or LOAD AND ARM command while the counter is in TC will cause the TC to end. For Armed counters in all modes except S or V, the LOAD source used will be that to be used for the upcoming TC. (The LOADing operation will not alter the selection of reload source for the upcoming TC.) For Disarmed counters in modes except S or V, the reload sources used will be the LOAD register. For modes S or V, the reload source will be selected by the GATE input, regardless of whether the counter is Armed or Disarmed.

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Special considerations apply when modes with alternating reload sources are used (Modes G-L). If a LOAD command drives the counter to TC in these modes, the reload source for the next TC will be from the opposite reload location. In other words, the LOAD-generated TC will cause the reload sources to alternate just as a TC generated by a source edge would. Note that if a second LOAD command is issued during the LOAD-generated TC (or during any other TC, for that matter), the second LOAD command will terminate the TC and cause a reload from the source designated for use with the next TC. The second LOAD will not alter the reload source for the next TC since the second LOAD does not generate a TC; reload sources alternate on TCs only, not on LOAD commands.

Load and Arm Counters*

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
0	1	1	S5	S4	S3	S2	S1

Description: Any combination of counters, as specified in the S field, will be first loaded and then armed. This command is equivalent to issuing a LOAD command and then an ARM command.

A LOAD AND ARM command which drives a counter to TC generates the same sequence of operations as execution of a LOAD command and then an ARM command. In modes which disarm on TC (Modes A-C and N-O, and Modes G-I and S if the current TC is the second in the cycle), the ARM part of the LOAD AND ARM command will re-enable counting for another cycle. In modes which alternate reload sources (Modes G-L), the ARMing operation will cause the next TC to reload from the HOLD register, irrespective of which reload source the current TC used.

*This command should not be used during asynchronous operations.

Disarm Counters

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	0	S5	S4	S3	S2	S1

Description: Any combination of counters, as specified by the S field, will be disabled from counting. A disarmed counter will cease all counting independent of other conditions. The only exception to this is that a counter in the TC state will always count once, in order to leave TC, before DISARMing. This count may be generated by a source edge, by a LOAD or LOAD AND ARM command (the LOAD AND ARM command will negate the DISARM command) or by a STEP command. A disarmed counter may be updated using the LOAD command and may be read using the SAVE command. A count process may be resumed using an ARM command. See the ARM command description for further details.

Save Counters

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	0	1	S5	S4	S3	S2	S1

Description: Any combination of counters, as specified by S field, will have their contents transferred into their associated Hold register. The transfer takes place without interfering with any counting that may be underway. This command will overwrite any previous Hold register contents. The SAVE command is designed to allow an accumulated count to be preserved so that it can be read by the host CPU at some later time.

Disarm and Save Counters

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	0	0	S5	S4	S3	S2	S1

Description: Any combination of counters, as specified by the S field, will be disarmed, and the contents of the counter will be transferred into the associated Hold registers. This command is identical to issuing a DISARM command followed by a SAVE command.

Set TC Toggle Output

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	1	N4	N2	N1

(001 ≤ N ≤ 101)

Description: The initial output level for TC Toggle mode is set (HIGH) for counter N selected by N4, N2, N1 = 001 (Counter 1) thru 101 (Counter 5) respectively. This command conditions the TC Toggle flip-flop (see Figure 1-18), but does not appear at the counter output unless TC Toggle mode (CM2, CM1, CM0 = 010) is selected.

Clear TC Toggle Output

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	0	N4	N2	N1

(001 ≤ N ≤ 101)

Description: The initial output level for TC Toggle mode is Cleared (LOW) for counter N selected by N4, N2, N1 = 001 (Counter 1) thru 101 (Counter 5) respectively. This command conditions the TC Toggle flip-flop (see Figure 1-18, but does not appear at the counter output unless TC Toggle mode (CM2, CM1, CM0 = 010) is selected.

Step Counter

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	1	0	N4	N2	N1

(001 ≤ N ≤ 101)

Description: Counter N is incremented or decremented by one, depending on its operating configuration. If the Counter Mode register associated with the selected counter has its CM3 bit cleared to zero, this command will cause the counter to decrement by one. If CM3 is set to a logic high, this command will increment the counter by one. The STEP command will take effect even on a disarmed counter.

Load Data Pointer Register

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
0	0	0	E2	E1	G4	G2	G1

(G4, G2, G1 ≠ 000, ≠ 110)

Description: Bits in the E and G fields will be transferred into the corresponding Element and Group fields of the Data Pointer register as shown in Figure 1-8. The Byte Pointer bit in the Data Pointer register is set. Transfers into the Data Pointer only occur for G field values of 001, 010, 011, 100, 101 and 111. Values of 000 and 110 for G should not be used. See the "Setting the Data Pointer Register" section of this document for additional details.

Disable Data Pointer Sequencing

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	1	0	0	0

Description: This command sets Master Mode bit 14 without affecting other bits in the Master Mode register. MM14 controls the automatic sequencing of the Data Pointer register. Disabling the sequencing allows repetitive host processor access to a given internal location without repetitive updating of the Data Pointer. MM14 may also be controlled by loading a full word into the Master Mode register.

Enable Data Pointer Sequencing

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	0	0	0	0

Description: This command clears Master Mode bit 14 without affecting other bits in the Master Mode register. MM14 controls the automatic sequencing of the Data Pointer register. Enabling the sequencing allows sequential host processor access to several internal locations without repetitive updating of the Data Pointer. MM14 may also be controlled by loading a full word into the Master Mode register. See the "Data Pointer Register" section of this document for additional information on Data Pointer sequencing

Enable 16-Bit Data Bus

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	1	1	1	1

Description: This command sets Master Mode bit 13 without affecting other bits in the Master Mode register. MM13 controls the multiplexer in the data bus buffer. When MM13 is set, no multiplexing takes place and all 16 external data bus lines are used to transfer information into and out of the STC. MM13 may also be controlled by loading the full Master Mode register in parallel.

Enable 8-Bit Data Bus

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	0	1	1	1

Description: This command clears Master Mode bit 13 without affecting other bits in the Master Mode register. MM13 controls the multiplexer in the data bus buffer. When MM13 is cleared, the multiplexer is enabled and 16-bit internal information is transferred eight bits at a time to the eight low-order external data bus lines. MM13 may also be controlled by loading the full Master Mode register in parallel.

Gate Off FOUT

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	1	1	1	0

Description: This command sets Master Mode bit 12 without affecting other bits in the Master Mode register. MM12 controls the output state of the FOUT signal. When gated off, the FOUT line will exhibit a low-impedance to ground. MM12 may also be controlled by loading the full Master Mode register in parallel.

Gate On FOUT

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	0	0	1	1	0

Description: This command clears Master Mode bit 12 without affecting other bits in the Master Mode register. MM12 controls the output status of the FOUT signal. When MM12 is cleared, FOUT will become active and will drive out the selected and divided FOUT signal. MM12 may also be controlled by loading the full Master Mode register in parallel. When FOUT is gated on or off, a transient pulse may be generated on the FOUT signal.

Disable Prefetch for Write Operations

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	1	1	0	0	1

Description: This command disables the prefetch circuitry during Write operations (if does not affect Read operations). This reduces the write recovery time and allows the user to use block move instructions for initialization of the Am9513A registers. Once prefetch is disabled for writing, an Enable Prefetch for Write or a Reset command is necessary to re-enable the prefetch circuitry for writing. Note: This command is only available in Am9513'A' devices; it is an illegal command in the "non-A Am9513" device.

Enable Prefetch for Write Operations

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	1	1	0	0	0

Description: This command re-enables the prefetch circuitry for Write operations. It is used only to terminate the Disable Prefetch Command. Note: This command is only available in Am9513'A' devices; it is an illegal command in the "non-A Am9513" device.

Master Reset

Coding:

C7	C6	C5	C4	C3	C2	C1	C0
1	1	1	1	1	1	1	1

Description: The Master Reset command duplicates the action of the power-on reset circuitry. It disarms all counters, enters 0000 in the Master Mode, Load and Hold registers and enters 0B00 (hex) in the Counter Mode registers.

Following either a power-up or software reset, the LOAD command should be applied to all the counters to clear any that may be in a TC state. The Data Pointer register should also be set to a legal value, since reset does not initialize it. A complete reset operation follows.

1. Using the procedure given in the "Command Initiation" section of this document, enter the FF (hex) command to perform a software reset.
2. Using the "Command Initiation" procedure, enter the LOAD command for all counters, opcode 5F (hex).
3. Using the procedure given in the "Setting the Data Pointer Register" section of this document, set the Data Pointer to a valid code. The legal Data Pointer codes are given in Figure 1-9.

The Master Mode, Counter Mode, Load and Hold registers can now be initialized to the desired values.

Am9513A/Am8073A

ABSOLUTE MAXIMUM RATINGS

Storage Temperature ..... −65°C to +150°C
VCC with Respect to VSS ..... −0.5V to +7.0V
All Signal Voltages
with Respect to VSS ..... −0.5V to +7.0V
Power Dissipitation (Package Limitation) 1.5W

Stresses above those listed under ABSOLUTE MAXIMUM RATINGS may cause permanent device failure. Functionality at or above these limits is not implied. Exposure to absolute maximum ratings for extended periods may affect device reliability.

OPERATING RANGES

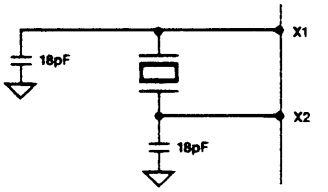
Grade	T_A	V_{CC}	V_{SS}
Commercial	0°C to 70°C	5V ±5%	0V
Industrial	−40°C to 85°C	5V ±10%	0V

Operating ranges define those limits over which the functionality of the device is guaranteed.

DC CHARACTERISTICS over operating range unless otherwise specified

Parameters	Description		Test Conditions	Min	Typ	Max	Units
VIL	Input Low Voltage	All Inputs Except X2		VSS − 0.5		0.8	Volts
		X2 Input		VSS − 0.5		0.8	
VIH	Input High Voltage	All Input Except X2		2.2V		VCC	Volts
		X2 Input		3.8		VCC	
VITH	Input Hysteresis (SRC and GATE Inputs Only)			0.2	0.3		Volts
VOL	Output Low Voltage		IOL = 3.2mA			0.4	Volts
VOH	Output High Voltage		IOH = −200μA	2.4			Volts
IIX	Input Load Current (Except X2)		VSS ≤ VIN ≤ VCC			±10	μA
IIX	Input Load Current X2					±100	μA
IOZ	Output Leakage Current (Except X1)		VSS+0.4 ≤ VOUT ≤ VCC High-Impedance State			±25	μA
ICC	VCC Supply Current (Steady State)		T_A = −55°C			275	mA
			T_A = 0°C			255	
			T_A = +25°C		190	235	
CIN	Input Capacitance		f = 1MHz, T_A = +25°C. All pins not under test at 0V.			10	pF
COUT	Output Capacitance					15	
CIO	IN/OUT Capacitance					20	

SWITCHING TEST INPUT/OUTPUT WAVEFORMS



Crystal is fundamental mode parallel resonant 32pF load capacitance less than 100Ω ESR C_0 less than 100pF.

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SWITCHING CHARACTERISTICS over operating range unless otherwise specified (Notes 2, 3, 4)

Parameters	Description		Figure	Am9513A Min	Am9513A Max	AmZ8073A Min	AmZ8073A Max	Units
TAVRL	C/$\overline{D}$ Valid to Read Low		23	25		25		ns
TAVWH	C/$\overline{D}$ Valid to Write High		23	170		170		ns
TCHCH	X2 High to X2 High (X2 Period)		24	145		145		ns
TCHCL	X2 High to X2 Low (X2 High Pulse Width)		24	70		70		ns
TCLCH	X2 Low to X2 High (X2 Low Pulse Width)		24	70		70		ns
TDVWH	Data In Valid to Write High		23	80		80		ns
TEHEH	Count Source High to Count Source High (Source Cycle Time) (Note 10)		24	145		145		ns
TEHEL TELEH	Count Source Pulse Duration (Note 10)		24	70		70		ns
TEHFV	Count Source High to FOUT Valid (Note 10)		24		500		500	ns
TEHGV	Count Source High to Gate Valid (Level Gating Hold Time) (Notes 10, 12, 13)		24	10		10		ns
TEHRL	Count Source High to Read Low (Set-up Time) (Notes 5, 10)		23	190		190		ns
TEHWH	Count Source High to Write High (Set-up Time) (Notes 6, 10)		23	-100		-100		ns
TEHYV	Count Source High to Out Valid (Note 10)	TC Output	24		300		300	ns
		Immediate or Delayed Toggle Output	24		300		300	
		Comparator Output	24		350		350	
TFN	FN High to FN + 1 Valid (Note 14)		24		75		75	ns
TGVEH	Gate Valid to Count Source High (Level Gating Set-up Time) (Notes 10, 12, 13)		24	100		100		ns
TGVGV	Gate Valid to Gate Valid (Gate Pulse Duration) (Notes 11, 13)		24	145		145		ns
TGVWH	Gate Valid to Write High (Notes 6, 13)		23	-100		-100		ns
TRHAX	Read High to C/$\overline{D}$ Don't Care		23	0		0		ns
TRHEH	Read High to Count Source High (Notes 7, 10)		23	0		0		ns
TRHQX	Read High to Data Out Invalid		23	10		10		ns
TRHQZ	Read High to Data Out at High-Impedance (Data Bus Release Time)		23		85		85	ns
TRHRL	Read High to Read Low (Read Recovery Time)		23	1000		1000		ns
TRHSH	Read High to $\overline{CS}$ High (Note 15)		23	0		0		ns
TRHWL	Read High to Write Low (Read Recovery Time)		23	1000		1000		ns
TRLQV	Read Low to Data Out Valid		23		110		110	ns
TRLQX	Read Low to Data Bus Driven (Data Bus Drive Time)		23	20		20		ns
TRLRH	Read Low to Read High (Read Pulse Duration) (Note 15)		23	160		160		ns
TSLRL	$\overline{CS}$ Low to Read Low (Note 15)		23	20		20		ns
TSLWH	$\overline{CS}$ Low to Write High (Note 15)		23	170		170		ns
TWHAX	Write High to C/$\overline{D}$ Don't Care		23	20		20		ns
TWHDX	Write High to Data In Don't Care		23	20		20		ns
TWHEH	Write High to Count Source High (Notes 8, 10, 17)		23	550		550		ns
TWHGV	Write High to Gate Valid (Notes 8, 13, 17)		23	475		475		ns
TWHRL	Write High to Read Low (Write Recovery Time)		23	1500*		1000		ns
TWHSH	Write High to $\overline{CS}$ High (Note 15)		23	20		20		ns
TWHWL	Write High to Write Low (Write Recovery Time)		23	1500*		1000		ns
TWHYV	Write High to Out Valid (Note 9, 17)		23		650		650	ns
TWLWH	Write Low to Write High (Write Pulse Duration) (Note 15)		23	150		150		ns

*In short data write mode TWHRL and TWHWL minimun = 1000ns.

Notes:

1. Typical values are for T_A = 25°C, nominal supply voltage and nominal processing parameters.
2. Test conditions assume transition times of 10ns or less, timing reference levels of 0.8V and 2.0V and output loading of one TTL gate plus 100pF, unless otherwise noted.
3. Abbreviations used for the switching parameter symbols are given as the letter T followed by four or five characters. The first and third characters represent the signal names on which the measurements start and end. Signal abbreviations used are:

A (Address) = C/$\overline{D}$
C (Clock) = X2
D (Data In) = DB0-DB15
E (Enabled counter source input) = SRC1-SRC5, GATE1-GATE5, F1-F5,TCN-1
F = FOUT
G (Counter gate input) = GATE1-GATE5, TCN-1
Q (Data Out) = DB0-DB15
R (Read) = $\overline{RD}$
S (Chip Select) = $\overline{CS}$
W (Write) = $\overline{WR}$
Y (Output) = OUT1-OUT5

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Refer to page 7-1 for Essential Information on Military Devices

The second and fourth letters designate the reference states of the signals named in the first and third letters respectively, using the following abbreviations.

H = HIGH
L = LOW
V = VALID
X = Unknown or Don't care
Z = High-Impedance

4. Switching parameters are listed in alphabetical order.

5. Any input transition that occurs before this minimum setup requirement will be reflected in the contents read from the status register.

6. Any input transition that occurs before this minimum setup requirement will act on the counter before the execution of the operation initiated by the write and the counter may be off by one count.

7. Any input transition that occurs after this minimum hold time is guaranteed to not influence the contents read from the status register on the current read operation.

8. Any input transition that occurs after this minimum hold time is guaranteed to be seen by the counter as occurring after the action initiated by the write operation and the counter may be off by one count.

9. This parameter applies to cases where the write operation causes a change in the output bit.

10. The enabled count source is one of F1-F5, TCN-1 SRC1-SRC5 or GATE1-GATE 5, as selected in the applicable Counter Mode register. The timing diagram assumes the counter counts on rising source edges. The timing specifications are the same for falling-edge counting.

11. This parameter applies to edge gating (CM15-CM13 = 110 or 111) and gating when both CM7 = 1 and CM15-CM13 ≠ 000. This parameter represents the minimum GATE pulse width needed to ensure that the pulse initiates counting or counter reloading.

12. This parameter applies to both edge and level gating (CM15-CM13 = 001 through 111) and gating when both CM7 = 1 and CM15-CM13 = 000. This parameter represents the minimum setup or hold times to ensure that the Gate input is seen at the intended level on the active source edge and the counter may be off by one count.

13. This parameter assumes that the GATENA input is unused (16-bit bus mode) or is tied high. In cases where the GATENA input is used, this timing specification must be met by both the GATE and GATENA inputs.

14. Signals F1-F5 cannot be directly monitored by the user. The phase difference between these signals will manifest itself by causing counters using two different F signals to count at different times on nominally simultaneous transitions in the F signals. F1 = X2.

15. This timing specification assumes that $\overline{CS}$ is active whenever $\overline{RD}$ or $\overline{WR}$ are active. $\overline{CS}$ may be held active indefinitely.

16. This parameter assumes X2 is driven from an external gate with a square wave.

17. This parameter assumes that the write operation is to the command register.

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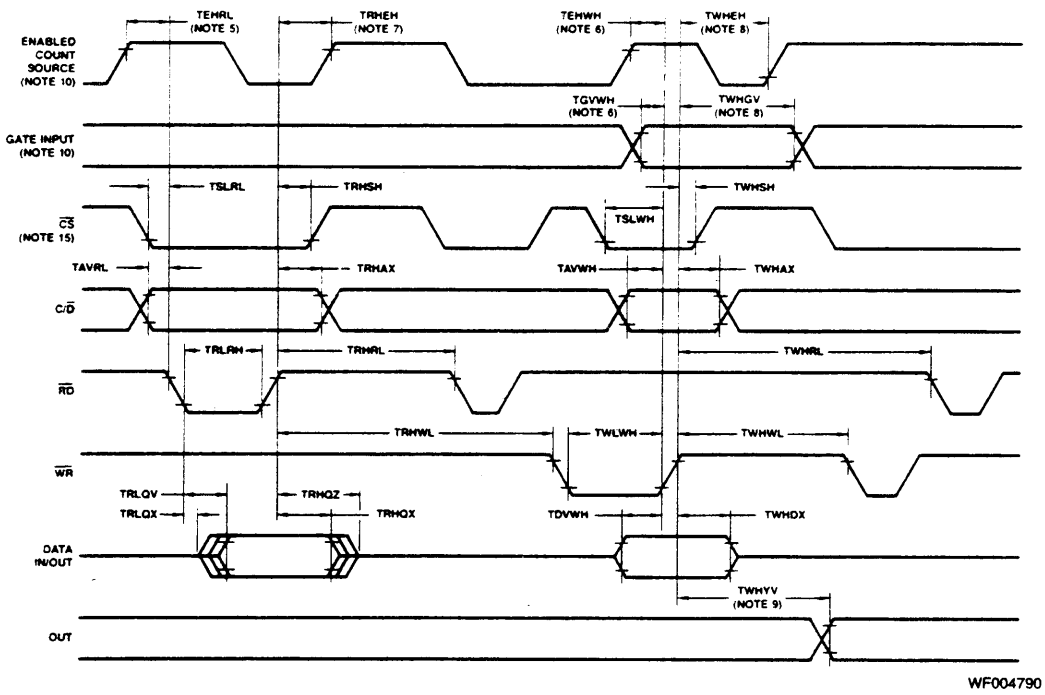
Refer to page 7-1 for Essential Information on Military Devices

BUS TRANSFER SWITCHING WAVEFORMS



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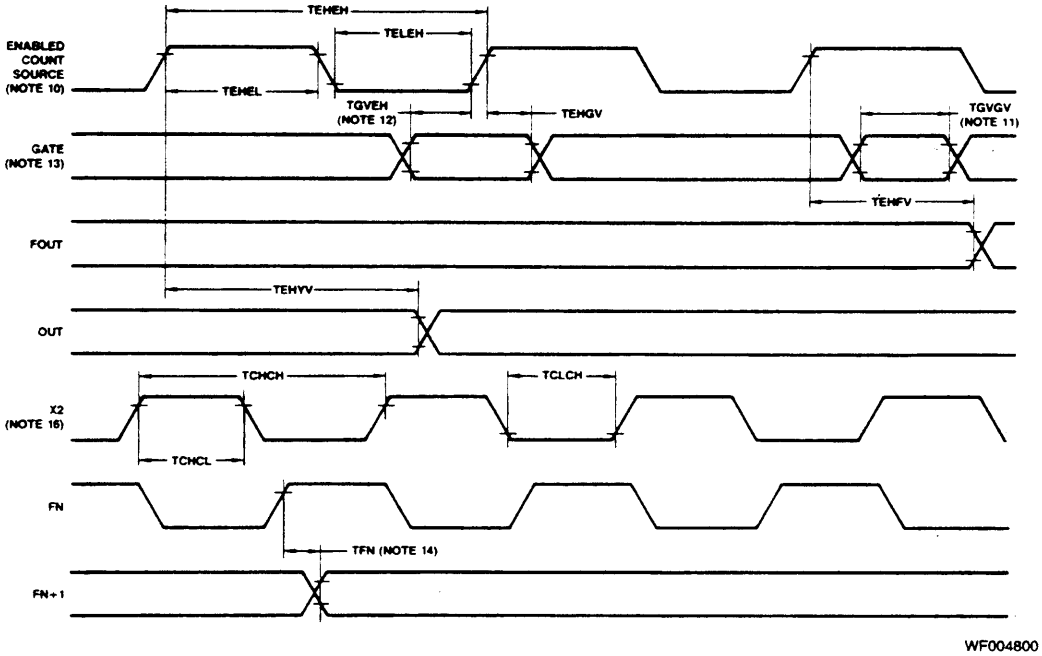
COUNTER SWITCHING WAVEFORMS



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Refer to page 7-1 for Essential Information on Military Devices

Appendix D
Customer Communication

For your convenience, this appendix contains forms to help you gather the information necessary to help us solve technical problems you might have as well as a form you can use to comment on the product documentation. Filling out a copy of the *Technical Support Form* before contacting National Instruments helps us help you better and faster.

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(512) 794-5678

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Belgium	02/757.00.20	02/757.03.11
Denmark	45 76 26 00	45 76 71 11
Finland	(90) 527 2321	(90) 502 2930
France	(1) 48 14 24 00	(1) 48 14 24 14
Germany	089/741 31 30	089/714 60 35
Italy	02/48301892	02/48301915
Japan	(03) 3788-1921	(03) 3788-1923
Netherlands	03480-33466	03480-30673
Norway	32-848400	32-848600
Spain	(91) 640 0085	(91) 640 0533
Sweden	08-730 49 70	08-730 43 70
Switzerland	056/20 51 51	056/20 51 55
U.K.	0635 523545	0635 523154

Technical Support Form

Photocopy this form and update it each time you make changes to your software or hardware, and use the completed copy of this form as a reference for your current configuration. Completing this form accurately before contacting National Instruments for technical support helps our applications engineers answer your questions more efficiently.

If you are using any National Instruments hardware or software products related to this problem, include the configuration forms from their user manuals. Include additional pages if necessary.

Name _____

Company _____

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Computer brand _____ Model _____ Processor _____

Operating system _____

Speed _____ MHz RAM _____ MB Display adapter _____

Mouse _____ yes _____ no Other adapters installed _____

Hard disk capacity _____ MB Brand _____

Instruments used _____

National Instruments hardware product model _____ Revision _____

Configuration _____

National Instruments software product _____ Version _____

Configuration _____

The problem is _____

_____

_____

_____

_____

List any error messages _____

_____

_____

_____

_____

The following steps will reproduce the problem _____

_____

_____

_____

NB-MIO-16 Hardware and Software Configuration Form

Record the settings and revisions of your hardware and software on the line to the right of each item. Complete a new copy of this form each time you revise your software or hardware configuration, and use this form as a reference for your current configuration. Completing this form accurately before contacting National Instruments for technical support helps our applications engineers answer your questions more efficiently.

National Instruments Products

- Revision Level of NB-MIO-16 _____
- Slot (Base I/O Address) of NB-MIO-16 _____
- Input Configuration (DIFF, NRSE, or RSE) _____
- ADC Input Range (±10, 0 - 10, ±5) _____
- DMA Server (NB-DMA-8-G, NB-DMA2800) _____
- LabVIEW, LabWindows, or NI-DAQ Version _____

Other Products

- Computer Make and Model _____
- Amount of Memory _____
- Type of Video Board Installed _____
- System and Finder Versions _____
- Programming Language _____
- Programming Language Version _____
- Other Boards in System _____
- Slots (Base I/O Addresses) of Other Boards _____

Documentation Comment Form

National Instruments encourages you to comment on the documentation supplied with our products. This information helps us provide quality products to meet your needs.

Title: **NB-MIO-16 User Manual**

Edition Date: **September 1994**

Part Number: **320295B-01**

Please comment on the completeness, clarity, and organization of the manual.

If you find errors in the manual, please record the page numbers and describe the errors.

Thank you for your help.

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Glossary

Prefix	Meaning	Value
p-	pico-	10^{-12}
n-	nano-	10^{-9}
µ-	micro-	10^{-6}
m-	milli-	10^{-3}
k-	kilo-	10^{3}
M-	mega-	10^{6}
G-	giga-	10^{12}

°	degrees
Ω	ohms
%	percent
A	amperes
A/D	analog-to-digital
AC	alternating current
ADC	A/D converter
AWG	American Wire Gauge
BCD	binary-coded decimal
C	Celsius
CMOS	complementary metallic oxide semiconductor
D/A	digital-to-analog
DAC	D/A converter
dB	decibels
DC	direct current
DMA	direct memory access
EPROM	electrical programmable read-only memory
FIFO	first-in-first-out
ft	feet
hex	hexadecimal
Hz	hertz
I/O	input/output
in.	inches
kbytes	1,000 bytes
kS	1,000 samples
LSB	least significant bit
MB	megabytes of memory
NMR	nonmaskable interrupt request
NRSE	NRSE refers to non-referenced single-ended input configuration.
ppm	parts per million
rms	root mean square
ROM	read-only memory
RSE	RSE refers to referenced single-ended input configuration.
RTSI	Real-Time System Integration

s	seconds
TTL	transistor-transistor logic
V	volts
VDC	volts direct current
V_{extref}	external reference voltage
VI	virtual instrument
V_{IH}	volts, input high
V_{IL}	volts, input low
V_{in}	volts in
V_{OH}	volts, output high
V_{OL}	volts, output low
V_{out}	volts out
V_{ref}	reference voltage
Vrms	volts, root mean square

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