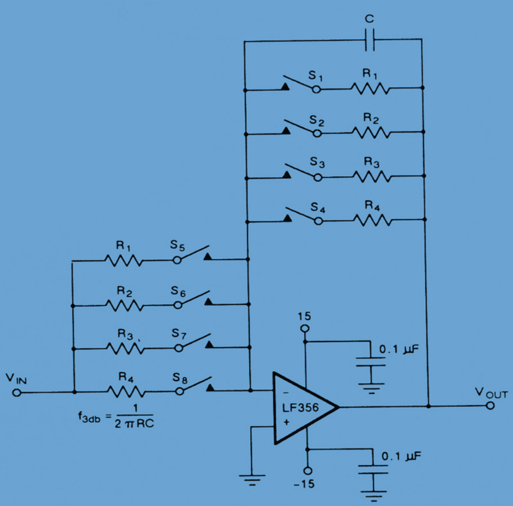
Designing with Analog Switches



	CODE TO SHIFT REGISTER								
C = 10,000 pF	1	2	3	4	5	6	7	8	f_{3db}
R_1 = 1.6 KΩ	1	0	0	0	1	0	0	0	10 KHz
R_2 = 800 Ω	0	1	0	0	0	1	0	0	20 KHz
R_3 = 530 Ω	0	0	1	0	0	0	1	0	30 KHz
R_4 = 400 Ω	0	0	0	1	0	0	0	1	40 KHz

Steve Moore

Designing with Analog Switches

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Designing with Analog Switches

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Micro Linear Corporation
San Jose, California

Marcel Dekker, Inc. New York · Basel · Hong Kong

Library of Congress Cataloging--in--Publication Data

Moore, Steve
Designing with analog switches / Steve Moore.
p. cm. -- -- (Electrical engineering and electronics; 68)
Includes bibliographical references and index.
ISBN 0-8247-8421-9
1. Switching circuits. 2. Analog electronic systems-- --Design and construction. I. Title. II. Series
TK7868.S9M55 1990
621.381'5372-- --dc20 90--23802
CIP

This book is printed on acid-free paper.

MARCEL DEKKER, INC.
270 Madison Avenue, New York, New York 10016

Current printing (last digit):
10 9 8 7 6 5 4 3 2 1

PRINTED IN THE UNITED STATES OF AMERICA

Preface

Analog switches are an often-neglected, yet essential part of any electronic system that combines analog and digital circuitry. More and more electrical engineers come out of college with training in digital circuitry, but very little, if any, training in analog switches. Frequently they are required to design with these devices, but have to rely on the wisdom of their more experienced compatriots, if they are fortunate enough to find them.

This book will help the design engineer to understand how analog switches and multiplexers operate, how to design with them, and how to select the best device for his or her application. Practical circuit diagrams are included as examples of how analog switches and multiplexers are best applied, considering the trade-offs of system cost, function and performance. General principles for using these devices are presented with examples using the latest state-of-the-art switch technology and products.

The book begins with generic analog switch and multiplexer applications, to give the reader a feeling for the kinds of tasks these devices have been selected for in the past. It then moves into more specific details about switching products and specifications. Specific classes of applications are covered chapter by chapter, including practical circuit suggestions and ways of achieving optimal circuit performance at minimum cost.

The switching devices covered in this book have been limited to those that handle a 44 volt maximum signal range. Devices with voltage ratings above 44 volts are not covered, because they are generally considered to be "solid-state relays," and are useful for a different class of applications known as "power switching." This book limits the discussion to "signal switching," with typical power supplies of ±15 volts or below.

The target audience for this book includes

- Analog design engineers who interface digital circuits
- Digital design engineers who interface analog circuits
- Electronics technicians who troubleshoot circuits with mixed analog and digital signals
- Component engineers who specify analog switches
- Component purchasing managers who buy analog switches
- Engineering managers who develop mixed analog/digital systems
- Hobbyists who use switches in electronics projects
- Quality managers in mixed-signal systems
- Analog semiconductor sales and marketing management

Steve Moore

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Designing with Analog Switches

Chapter 1

An Overview of Analog Switch Uses

1.1 THE CATEGORIES OF APPLICATIONS FOR ANALOG SWITCHES

An analog switch is a useful circuit building block that is capable of performing many different functions in a wide variety of system applications. This chapter looks at some of the systems that use analog switches and the basic functions that switches perform in these systems. This will help the reader to gain general insight into circuits, systems and applications where analog switches have traditionally been used, and possibly inspire ideas for solutions in other areas. In the system application examples presented in this chapter, the reader is directed to the other sections in the book where the specific technical details of a function or device are explained in detail.

The common denominator for all analog switch applications is a requirement for digital control of analog signals. Almost any system that combines analog and digital circuitry will require analog switches. Such electronic systems fall into broad categories of classification, in "strategic marketing" lingo known as "application market segments", including:

- Computers and Computer Peripherals
- Instrumentation
- Communications Equipment
- Consumer Electronics
- Military Systems

Each of the above categories has many types of systems requiring a mixture of analog and digital circuitry. Each major application group uses analog switches to perform one or more of the following functions:

- Signal Conditioning
- Sampling
- Level Translation
- Signal Routing

Each application group has its own unique set of requirements that the devices must meet. For example, the computer peripheral devices will generally require specification for operation with a single 12 V power supply, with 5 V logic compatibility. Military devices usually require extended temperature range operation, and consumer electronics devices must have a very low selling price.

1.2 ANALOG SWITCHES IN COMPUTERS AND COMPUTER PERIPHERALS

The term "computer peripherals" encompasses a broad group of products that are connected to computers or microprocessors.

Computers are generally considered to be purely digital functions, with the exception of "analog computers", which were used before the digital computer, and are now experiencing a revival of sorts with "neural network" computer systems. Because of this, it is the peripheral electronics that uses analog switches. These electronic systems include disk drives, data acquisition systems, workstation monitors and displays, and add-on boards for personal computer systems. Computer systems use analog switches for all four of the above-mentioned applications.

1.2.1 Disk Drives

Analog circuitry is found in three subsystems of the hard disk drive, two of which are shown in Figure 1.1. One is the "data path", where the data that are stored on the disk are conditioned for reading by the controller, or for writing to the read/write head. The other is the servo loop, which controls head positioning. Analog switches have also been found in the motor control portion of the system.

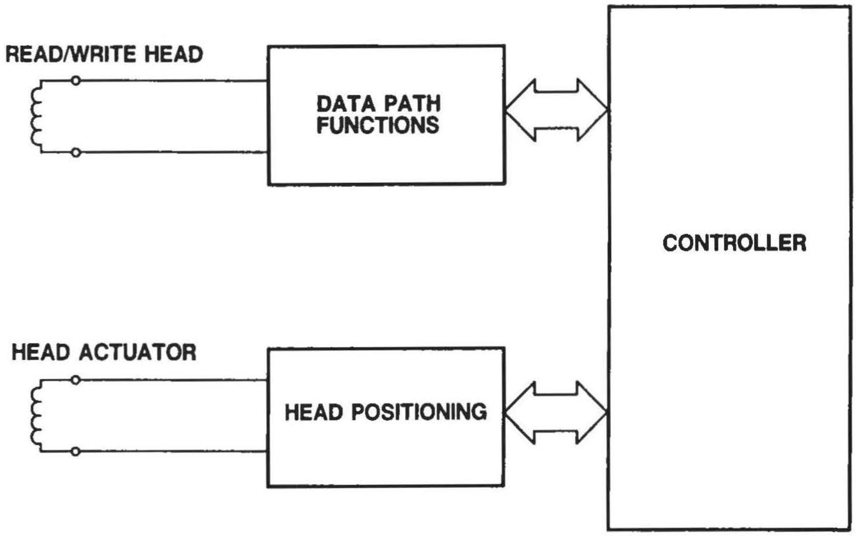

Figure 1.1 Block diagram of the analog portion of a disk drive.

1.2.1.1 Data Path Functions

In the data path of a disk drive, analog switches are used for signal conditioning and routing. A typical signal conditioning application is shown in Figure 1.2, where the signal from the read/write head is being amplified by the head amplifier. In this circuit, the gain of the read amplifier is set by the digital disk drive controller. The feedback resistors, which determine the gain of the amplifier, are switched in and out as various gain values (or ranges) are required. As one may imagine, there are many ways to perform this "gain ranging" function. This subject is developed in detail in Chapter 7, Section 1.

This circuit requires analog switches that will operate with a 12 V supply. While there are many such types of analog switches, few are optimized for this kind of operation. The low-voltage CD4000 series devices lack TTL or 5 V logic compatibility when given a 12 V supply. High-voltage DG200 series devices are specified for ±15 V operation. Switches such as the DG601 quad analog switch are optimized for 12 V, TTL-compatible operation, having been designed and specified for computer peripheral applications. The subject of power supply voltage specifications is developed in Chapter 3, Section 7. A discussion of low-voltage CMOS analog switch technology is found in Appendix 1, Section 1.

Signal routing is another analog switch function that is commonly found in the data path of a disk drive, especially those designed for very high data storage density, such as multi-platter magnetic and optical drives. An example of signal routing is shown in Figure 1.3.

Figure 1.3 shows an analog switch in a "zone switching" application, where the read/write data is recorded on the disk media at two different data rates, one low rate in the inner tracks, and one higher rate on the outer tracks of the disk where the linear velocity is higher. Two low-pass filters are required to accommodate the two data rates, and the analog switches route the data through the appropriate one. A one of two selector is also known as a single-pole double-throw, or SPDT switch. The various switch functions are discussed in Chapter 2, Section 1.

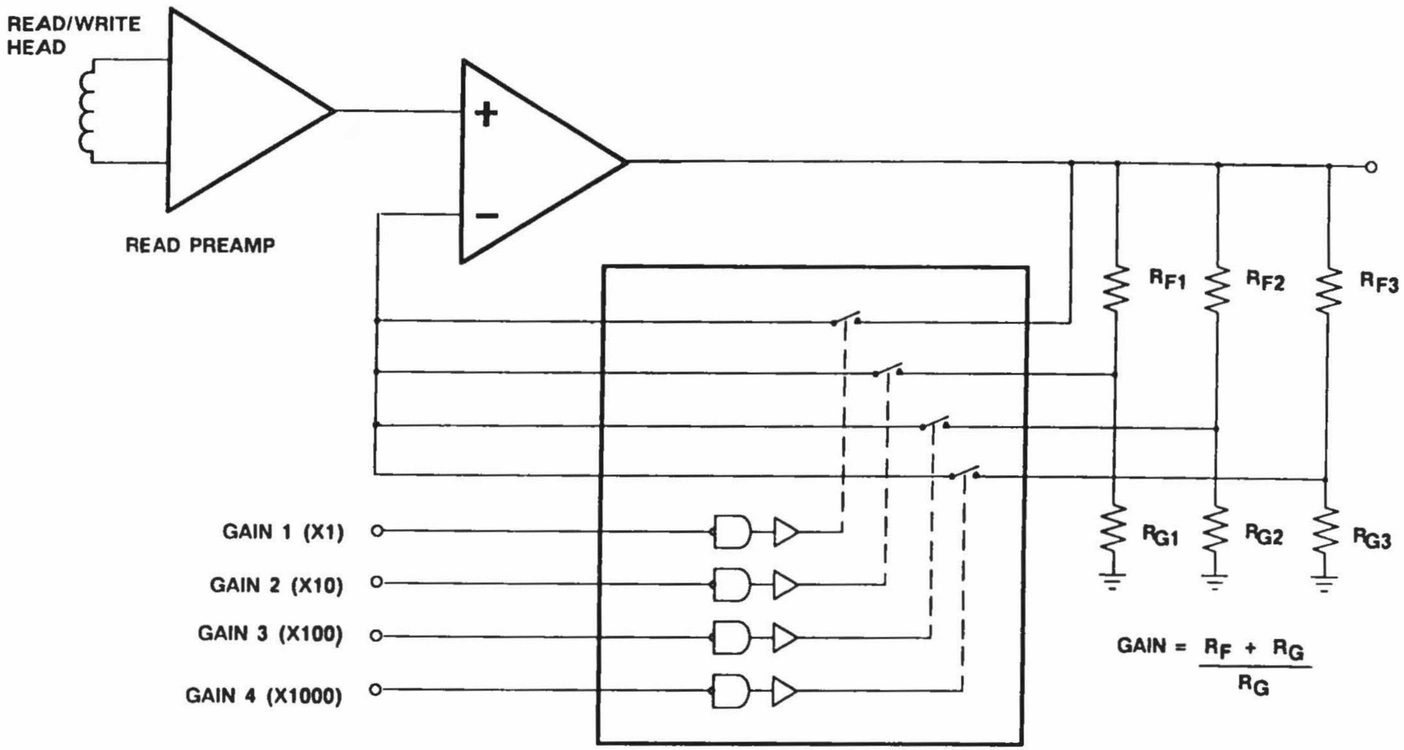

Figure 1.2 Gain ranging in the read amplifier of a disk drive.

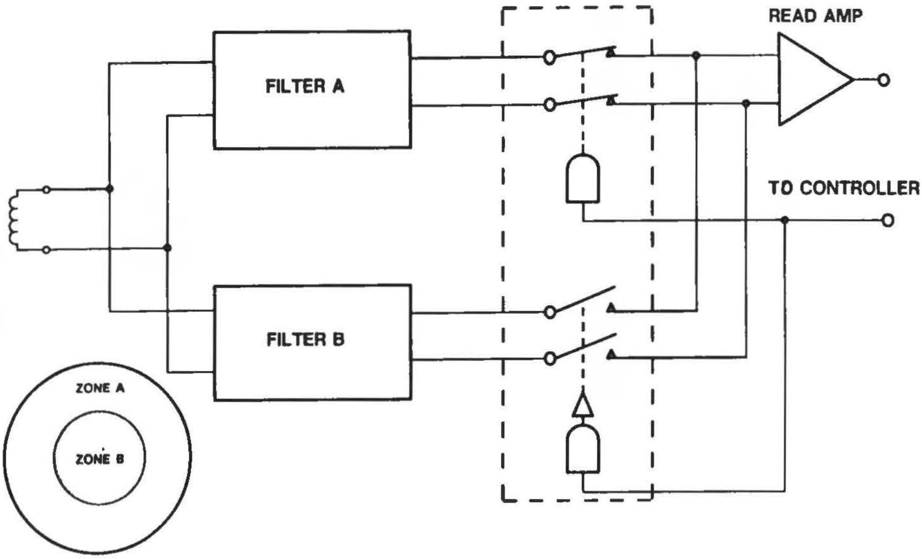

Figure 1.3 Zone switching, or zone density recording, is used to increase data storage density and requires a wideband switch.

The read/write data are handled differentially for improved rejection of common-mode noise. This requires two sets of SPDT switches, hence a dual SPDT analog switch function is selected for zone switching. The bandwidth of the head signals in the example ranges from 15 MHz to 90 MHz, hence a wideband D/CMOS switch is selected. The DG542 is a dual SPDT "T" switch, which provides adequate bandwidth (500 MHz) and crosstalk rejection for the system. Wideband switching techniques are examined in Chapter 10.

Another example of signal routing in a disk drive uses a multiplexer to select which disk is accessed in a multi-platter system, as shown in Figure 1.4.

The wideband multiplexer in Figure 1.4 connects one of the four heads to the read amplifier. The multiplexer function (covered in detail in Chapter 2, Section 2), decodes binary input code to select one switch (or set of switches) to a common output.

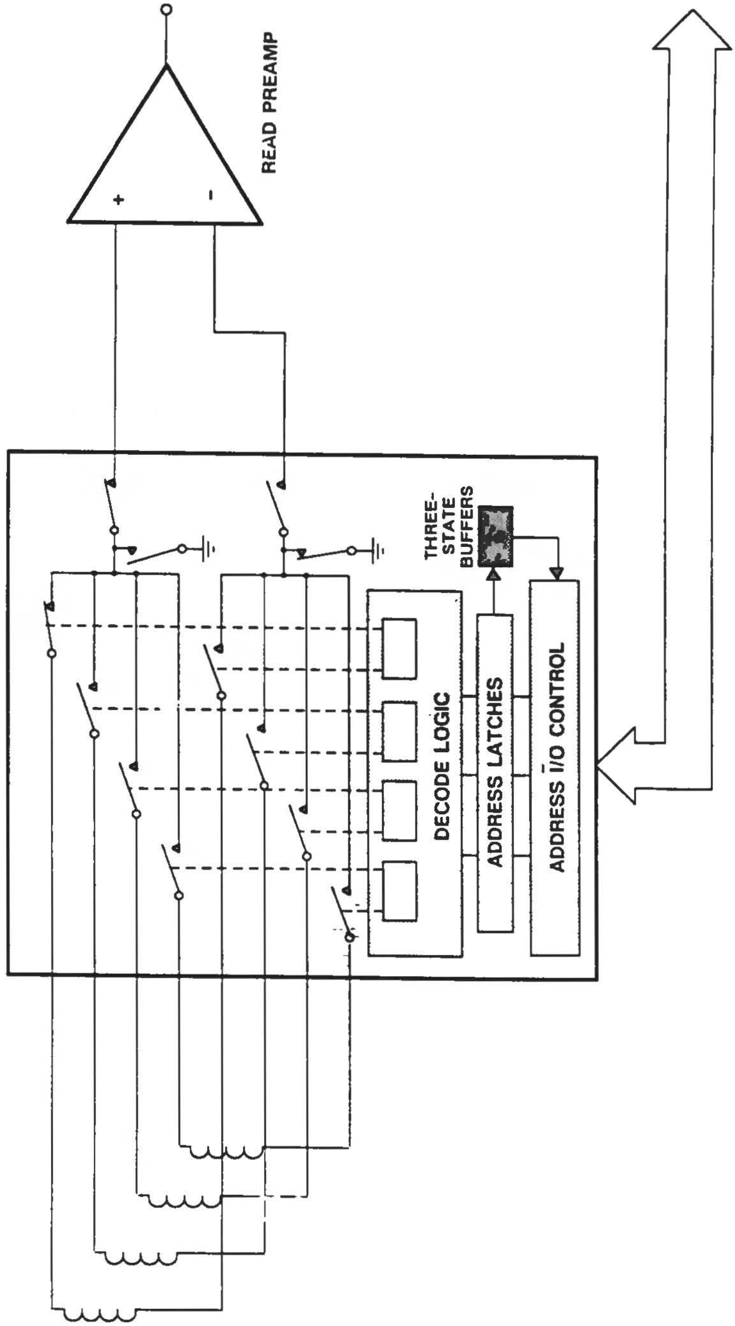

Figure 1.4 A wideband multiplexer (DG538) selects one of four read/write heads in a multi-platter data storage system.

This reduces the number of read amplifiers that are required in the system. As in the zone switcher, wideband "T" switches are required in the multiplexer to provide adequate bandwidth and isolation.

1.2.1.2 Head Positioning Functions

Level translation and signal conditioning functions are found in the servo control section of the drive. An analog switch provides level translation to drive the MOSFETs that drive the head actuators, as shown in Figure 1.5. The increased gate drive voltage reduces the on resistance of the MOSFET, resulting in reduced power dissipation in the motor drive, compared to direct drive from the 5 V logic. Level translation applications are covered in more detail in Chapter 8.

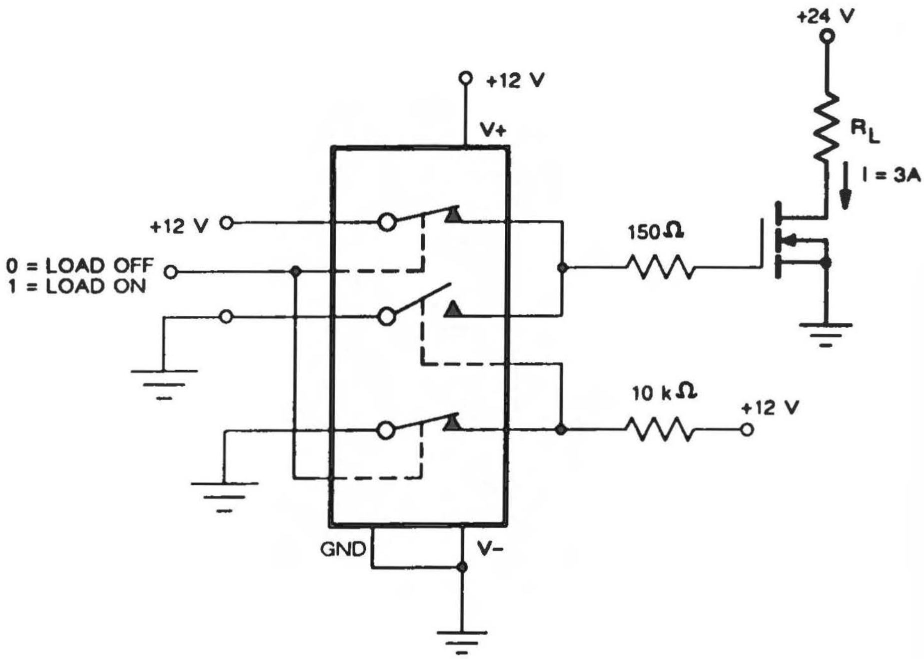

Figure 1.5 MOSFET drive is an example of level translation in a disk drive.

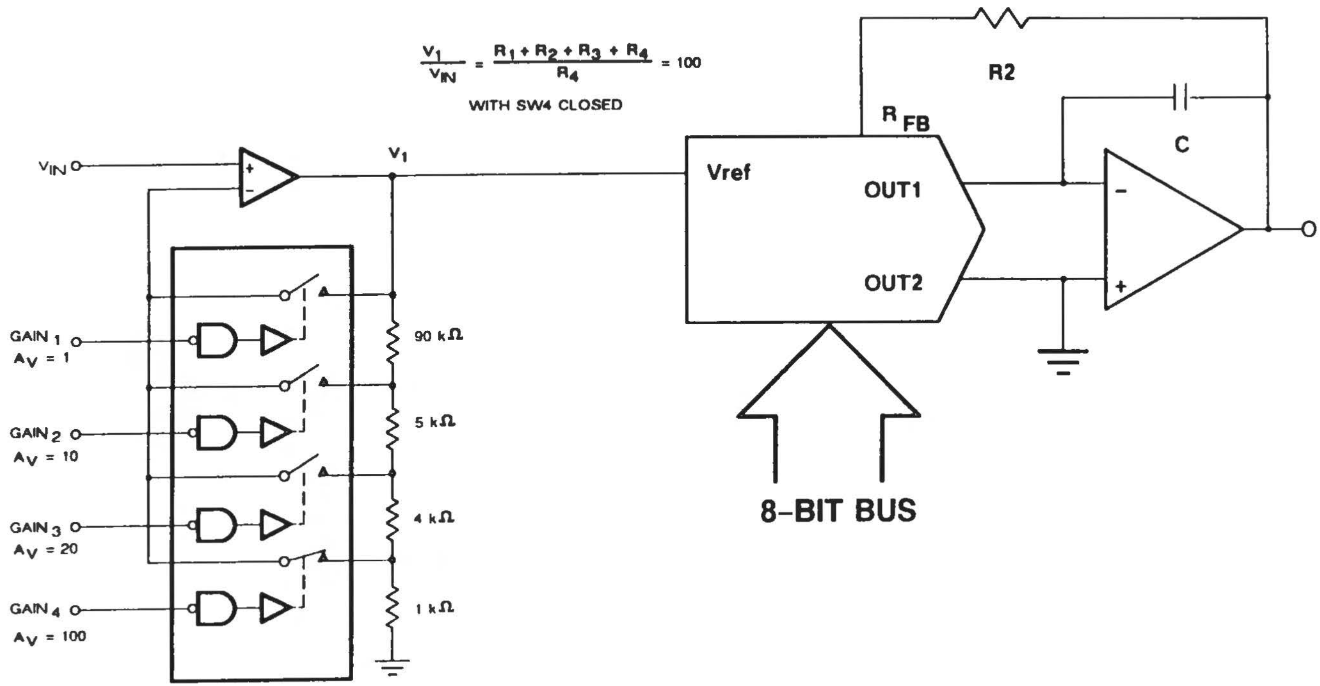

Figure 1.6 Gain ranging increases the resolution of the head positioning servo loop for improved track search, thereby increasing the density of accessible tracks on the magnetic or optical media.

Another signal conditioning function for analog switches in the disk drive is for gain ranging on a digital to analog converter (DAC) that controls head position. The addition of gain ranging increases the resolution of the servo loop. For example, a low-cost 8-bit DAC gives resolution of only one out of 256 voltage levels. A quad analog switch can provide four gain ranges for the reference input of the DAC, increasing the resolution by a factor of four, as shown in Figure 1.6.

1.2.2 Data Acquisition Systems

The term "data acquisition system" (or DAS) has many connotations. A manufacturer of data converters may call a single-chip A/D converter with an on-board multiplexer a monolithic DAS. A research lab may consider a high resolution digital multimeter to be the front end of the DAS. What these systems have in common is the ability to acquire analog signals and convert them to a format (usually a binary digital code) which can be used for processing of the signal or storage of the data collected for subsequent evaluation. Figure 1.7 shows the block diagram of a typical DAS.

The typical DAS begins with a multiplexer at the front end to provide input channel selection. A sample-and-hold amplifier follows, a function that "freezes" the analog signal at a constant level, long enough to allow the A/D converter to make an accurate conversion. Analog switches are used in all three of these stages. Multiplexers are covered in Chapter 2, Section 2, and their applications in sampled-data systems, along with sample-and-hold applications, are covered in Chapter 5.

As a computer peripheral, the data acquisition system has emerged as a board-level add-on to the personal computer. These systems give the PC the ability to listen to the "real world" of analog levels, ranging from slowly changing temperature measurements from a thermocouple to high speed waveforms from an audio or video source. Data acquisition boards are generally optimized according to one or the other performance constraints, that is either precision or speed.

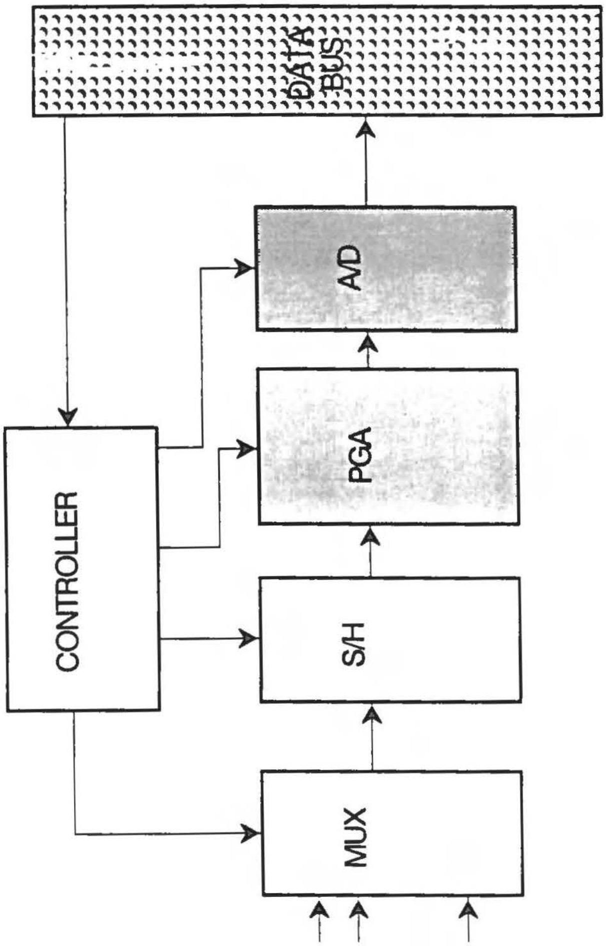

Figure 1.7 A Data Acquisition System (DAS) converts analog information to a binary digital code.

1.2.2.1 Data Acquisition Systems Emphasizing Precision

To be considered "precision", data acquisition systems are generally expected to resolve at least 12 bits. For a 10 V full scale range, this means that the smallest step size (or least significant bit, or LSB) in a 12-bit system is 10 V × (1/4096), or 2.44 millivolts. Sixteen-bit systems are not uncommon today, requiring resolution of one part in 65,536, resulting in a 156 microvolt step size for a 10 V full scale value. The errors that are contributed by each of the analog input stages in a DAS must be accounted for in an "error budget" that meets the accuracy requirements of the system. For example, if a DAS is to be 12-bit accurate, then the worst-case sum of errors from all of the analog input stages must not exceed 1/2 LSB. Thus, for a 10 V full scale range, the sum of the errors contributed by the input stages of a 12-bit accurate DAS must not exceed 1.22 millivolts.

The input stages generally use buffers and amplifiers, analog switches and multiplexers, sample/holds, and A/D converters in the signal path. Each of these analog components will contribute offset, drift, nonlinearity and gain errors to the system. The errors caused by analog switches are attributed to the ON resistance, leakage currents and charge injection of the switches, and all of these specifications must be considered when using a switch in a precision application. Precision switching is covered in detail in Chapter 9.

1.2.2.2 High Speed Data Acquisition Systems

High speed data acquisition systems find applications in digital signal processing systems such as video frame grabbers and music synthesis/emulation. In these systems, the dynamic properties of the DAS are more important than the DC accuracy. For example, the system bandwidth must be high enough to allow the highest frequency information to be acquired without attenuation or distortion. Also, the sampling time interval of the system must be small enough to allow accurate acquisition of fast-slewing signals. The analog switches in these systems must have a low enough capacitance and ON resistance to achieve the required system bandwidth, and they also must have short enough transition times (or switching times) to facilitate high speed sampling. Examples of wideband switching applications are given in Chapter 10.

1.2.3 Workstation Monitors

Another computer peripheral device that uses analog switches is the workstation monitor. High resolution color monitors have very wide operating bandwidths for their input signals. Wideband analog switches are required for routing the monitor input signals to multiple monitors in workstation networks. The monitor signals are often handled in component video format, using a separate signal path for the red, green, blue and sync waveforms. This is often referred to as RGB switching. A wideband RGB switch that selects between two component video channels is shown in Figure 1.8.

1.3 INSTRUMENTATION APPLICATIONS

Most modern electronic instruments combine digital control circuits with analog inputs and outputs, and thus analog switches are frequently used in these systems. These instruments are found in scientific and engineering labs, where high levels of precision are often required and the ability to measure very fast moving events is needed. Production or automatic test equipment (ATE) also uses analog switches, often requiring hundreds in a single system to handle the large number of test points in the system. Similar types of applications for analog switches are found in medical instrumentation, such as ultrasound, NMR, EKG and CAT scanners. Industrial processes use electronic instrumentation for measuring and controlling various process variables such as temperature, pressure, humidity, strain, etc. Again, analog switches help provide the sampling, routing, level shifting and multiplexing functions for the digitally-controlled analog subsystems in these instruments.

1.3.1 Lab/Bench Equipment

Lab and bench instrumentation includes the familiar oscilloscopes, DVMs, power supplies, signal generators, voltage

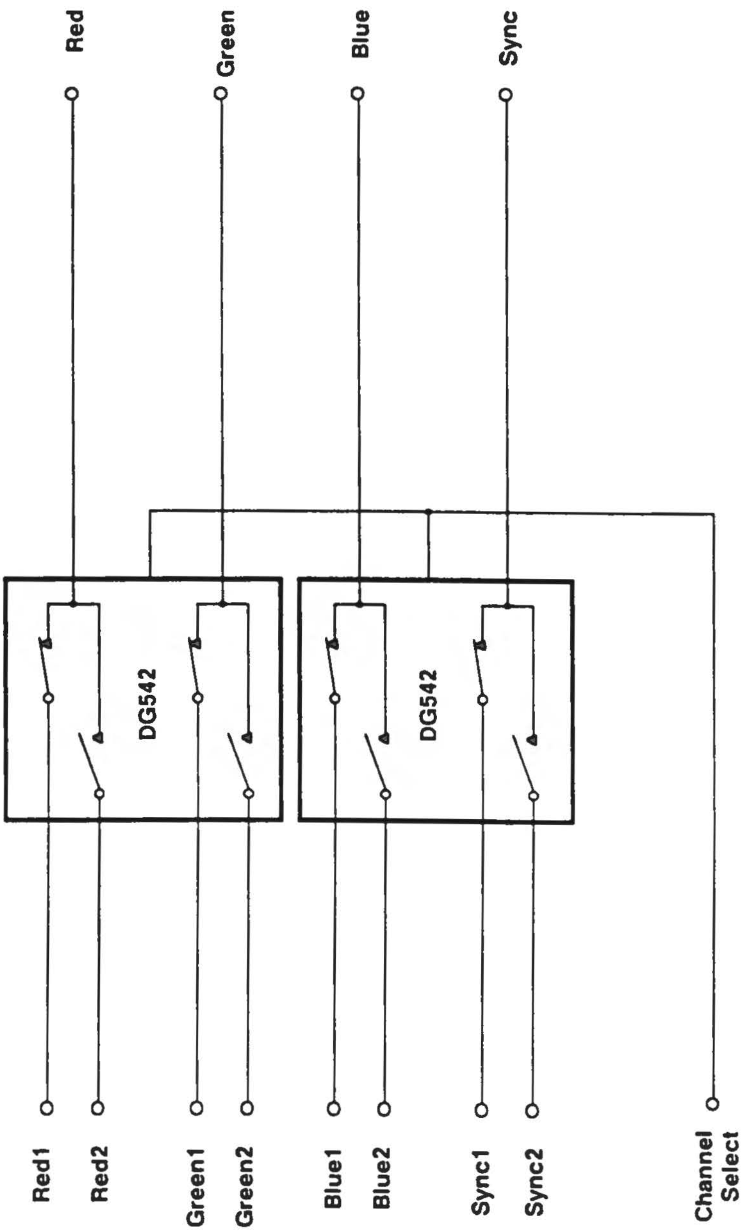

Figure 1.8 Two Dual SPDT DMOS "T" switches form a dual RGB selector switch for a workstation monitor application.

references and other rack equipment that a scientific or engineering lab technician requires to evaluate the performance of an electronic circuit or component. One of the trends in lab equipment is to improve speed and measurement accuracy. Another is to provide more automation features via microprocessor control. These trends have resulted in a requirement for analog switches that are more precise, provide faster switching, and are easier to interface to a microprocessor bus.

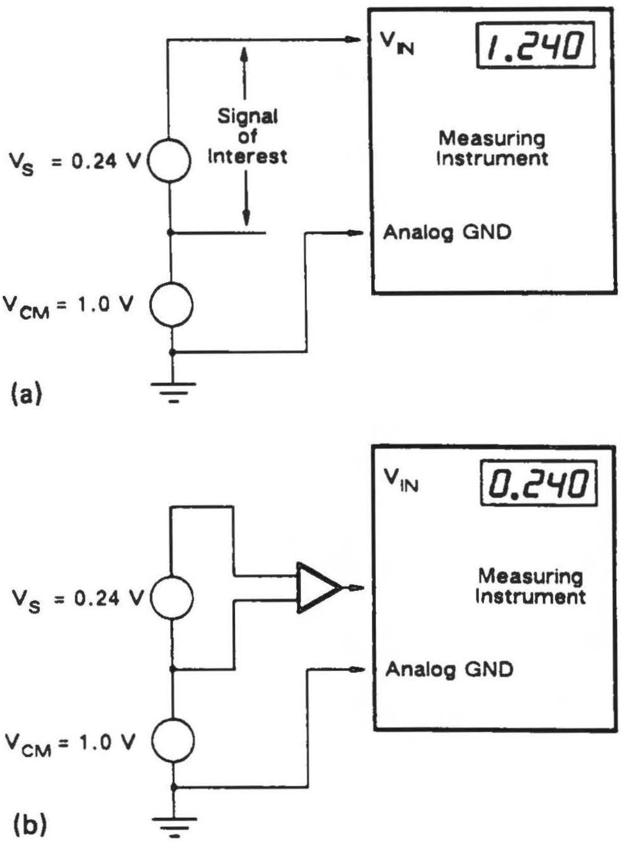

Figure 1.9 Differential input multiplexing for precision lab instrumentation requires a dual 4-channel multiplexer and an instrumentation amplifier.