

AOM5

Analog Output Module

Introduction

The AOM5 is a high-speed analog output module providing four independent channels of D/A conversion. A system strobe feature, supported by two levels of data latching in the D/A converter, allows all D/A channels to be updated simultaneously.

The AOM5 D/A converters offer 13-bit resolution (12 data bits plus a sign bit). Four output ranges can be independently selected through software for each channel: 10V, 5V, 2V, and 1V. The sign bit switches the converter output either positive or negative, so the effective full-scale resolution for a bipolar range is 8192 steps. Programming +0V or -0V results in the same output. Maximum nonlinearity is $\pm 0.024\%$.

The AOM5 analog output circuitry has a 5 μ s settling time, and can theoretically achieve output update speeds of 200kHz. However, the speed of the computer limits the rate at which successive output values can be written to the module, with a typical speed being about 60kHz for a 10MHz 80286-based computer.

High-speed operation is supported in Keithley's KDAC500 software by the ANOUTQ (ANalog OUTput Quick) command. The AOM5 analog output circuitry also offers an "auto-sequence" mode which can be implemented through PEEK and POKE commands or assembler language. This feature makes it possible to write optimized high-speed analog output routines. It is described later in this manual.

Hardware Compatibility

The AOM5 can be operated in slots 2 through 10 of the 500A, 500P, or 556 mainframe. Up to nine AOM5 modules can be used in these systems for a maximum of 36 analog output channels. The AOM5 can also be used in the option slot of the Model 570 or 575 for up to 6 analog output channels.

The AOM5 uses the voltage reference which is a part of the system A/D converter circuitry. In the 500-series systems and Model 575, the reference is located on the AMM analog master measurement module plugged into slot 1 of the system. Where analog input measurements are not needed, an AOM5 can also be plugged into slot 1 of these systems. This requires that the optional on-board voltage reference be populated on the AOM5. This reference circuitry is explained later in this manual under the topic "Using the On-board Voltage Reference".

Software Compatibility

Keithley's KDAC500 software fully supports the AOM5. If you are using third-party software, be certain that the software is compatible with the AOM5.

The AOM5 can also be programmed by accessing its command registers. This can be done through any high- or low-level language by writing directly to the AOM5 Command A (CMDA), Command B (CMDDB), and Global Strobe registers which are explained later in this manual.

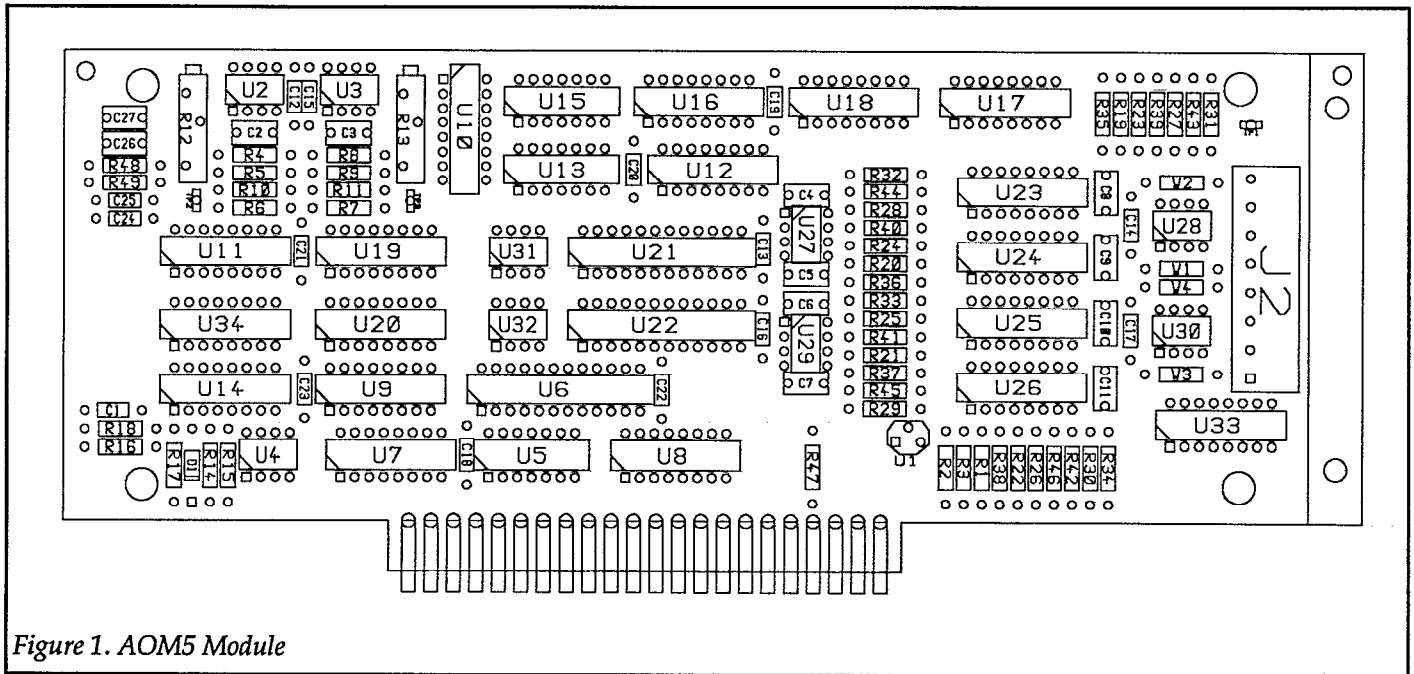


Figure 1. AOM5 Module

Specifications

Channel capacity: 4

Resolution: 13 bits (12 data bits plus polarity bit).

Full-scale Output Ranges: $\pm 10V$, $\pm 5V$, $\pm 2V$, $\pm 1V$

Output updating: Instantaneous update or global strobe.

Maximum output load: $2k\Omega$ minimum. $100pF$ maximum.

Settling time: $5\mu s$ to $0.01\% \pm 1LSB$ for any step size.

Maximum output update frequency: $200kHz$

Non-linearity: ± 1 LSB

Accuracy: $\pm 10V$ range - $\pm 0.15\% \pm 5mV$. Other ranges, $\pm 0.2\% \pm 4mV$.

Temperature coefficient: $\pm 0.0025\%$ per degree C.

Installation

All features and operating modes of the AOM5 module are programmable; there are no hardware switches to be set.

CAUTION

Turn off power to the data acquisition system before you insert or remove any module. To minimize the possibility of EMI radiation, always operate the data acquisition system with the cover in place and properly secured.

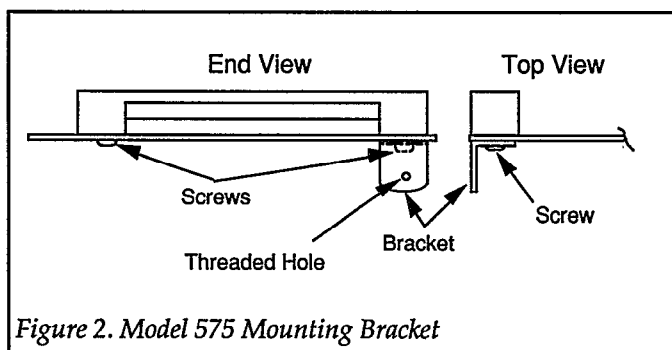
CAUTION

Make sure you have discharged any static charges on your body before handling the module. You can do this most easily by simply touching the chassis of a computer or data acquisition mainframe which is plugged into a grounded, 3-wire outlet. Avoid touching components or the card edge connector of the module.

For a compatible multi-slot data acquisition system (e.g. Model 500A, 500P, or 556), remove the top cover of the system by loosening the cover retaining screws located in the upper corners of the rear panel. Slide the cover back about one inch and then lift it off. Insert the module in the desired slot with the component side facing the system power supply. Replace the system cover.

For a Model 570, install the module in the option slot with the component side of the board facing upward. Close and secure the cover.

For a Model 575, first attach the supplied right-angle bracket to the module (see Figure 2). Plug the AOM5 into the option slot with the components facing upward, and secure the bracket to the rear panel of the system. Close and secure the cover.



Connections

The four channels on the AOM5 are accessed through the quick connect terminals of J2. Each of the four outputs has two terminal screws: one screw for analog output and one for analog ground. The channel connections are listed in Table 1.

Table 1. J2 Connections

Channel Number	Output Terminal	Ground Terminal
0	1	2
1	3	4
2	5	6
3	7	8

A quick-disconnect terminal block can be removed from the module to facilitate making connections. Pull the block straight off the board with a firm, even pressure. Do not pry the terminals with a screwdriver or sharp object, or you may damage the circuit board.

Each individual terminal on a terminal block consists of a small metal block with a hole and metal compression tab within the hole. To make connections to a terminal block, first strip 3/16 of insulation from the end of the wire which you want to attach. Loosen the desired terminal screw on

the block and insert the bare end of the wire into the corresponding hole. Tighten the screw securely to compress the tab against the wire.

After you have attached all the desired signal wires to a terminal block, replace the terminal block by lining it up with the mating pins on the module and pressing it back into place.

NOTE

For analog output connections, use shielded cable to minimize the possibility of EMI radiation. Connect the shield to module analog ground. Leave the other end of the shield disconnected.

Output Limitations

The output circuitry of the AOM5 is designed for fast output settling time. Because of the design, there are restrictions as to the output capabilities of each channel. Generally, there is an upper limit on the amount of capacitance and a lower limit to the resistance that can be connected across the output. To avoid possible oscillation, output capacitance must be less than 100pF.

If it is necessary to drive a capacitive load larger than 100pF, a 100Ω or larger resistor must be placed in series with the output. This will slow down the settling time somewhat, depending on the value of the capacitive load. A wire jumper is installed on the AOM5 circuit board in series with each output. The jumper may be removed and replaced by a series resistor if desired. The jumpers are labelled W1 through W4 on the component layout, and correspond to output channels 0 through 3 respectively.

Similar restrictions apply to the output current, which is determined largely by the resistive component of the load connected across the output. If the resistance is too small, accuracy will suffer. To maintain rated accuracy, the load resistance should be at least 2kΩ at the maximum output of ±10V. Maximum current output is 5mA or less.

If an analog output channel must drive a load with both low resistance and high capacitance, the output must be buffered by an external voltage amplifier.

AOM5 Commands and Command Locations

The AOM5 is controlled by writing to the Command A (CMDA), Command B (CMDB), and Strobe addresses for the slot in which the module is mounted. Programmable parameters include selection of channel and range, loading of data, auto-sequencing control, and strobe. There are no READ modes for the AOM5. Refer to your data acquisition system hardware manual for the addresses associated with the slot where the AOM5 is mounted.

Table 2. Slot-Dependent Memory Locations (hex)

SLOT	500, 570, 575		GPIB	
	CMDA	CMDB	CMDA	CMDB
1*	xxx80	xxx81	0	1
2	xxx82	xxx83	2	3
3*	xxx84	xxx85	4	5
4	xxx86	xxx87	6	7
5	xxx88	xxx89	8	9
6	xxx8A	xxx8B	A	B
7	xxx8C	xxx8D	C	D
8**	xxx8E	xxx8F	E	F
9	xxx90	xxx91	10	11
10	xxx92	xxx93	12	13

* = Model 575 Physical Slots
 ** = Model 570 Option Slot
 xxx = First three digits of IBIN address, e.g. "CFF"

Table 3. AOM5 Command Locations and Functions

Read Functions:	
COMMAND	FUNCTION
CMDA	None
CMDB	None
Write Functions:	
COMMAND	FUNCTION
CMDA	Data register select, D/A Control
CMDB	D/A Data and Range
xxx9D	Strobe (update all outputs)

SLOT-DEPENDENT CMDA, DATA REGISTER SELECT AND D/A CONTROL

Writing to the Command A location controls the register selection, auto sequencing, and global strobe updating of the D/A converter in the analog output circuitry.

D/A control must precede any change in range register data. This write resets the register auto-sequencing circuit to the proper register. The lower four bits represent the register to be written first. Bits D5 and D6 represent the last channel for auto sequencing of the data written to the output data registers (registers 0 through 7). Setting bit D7 enables global strobe (see below) to update analog outputs simultaneously.

SLOT-DEPENDENT, CMDB, D/A DATA AND RANGE DATA

Through the use of register auto sequencing, the various D/A control registers can be filled by writing repeatedly to the CMDB register. Range registers are filled first, in descending order from 3 to 0. After filling the range registers, the DAC data bytes are written for each channel, LSB first. The DAC requires two write operations to supply the 13 bits necessary for data and polarity information. The range registers are only set once, until a write to CMDA points to the range registers again, and the data registers are continuously updated to allow variable output. When the global strobe update feature is not enabled, the output channel is automatically updated upon receipt of the second byte of data. When the global strobe update feature is enabled, data is not latched into the conversion register of the D/A converter until receipt of the global strobe signal. Twelve of the available 16 registers are implemented in this circuitry.

Initially, a D/A control is issued which must select one of the four range registers, register 12, 13, 14, or 15 for channel 3, 2, 1, or 0 range, respectively. Additionally, the D/A control must select the last channel for auto sequencing, and either enable or disable the global strobe update feature.

After the D/A control is issued, the D/A data is loaded. The command circuitry selects the appropriate range register, and register control is relinquished to the auto-sequencer. The range registers are filled with the proper range data. The auto sequencer drops to the output data

registers. D/A output data is written, and the sequencer automatically "points to" the next register to be written. The data is written LSB first, then MSB, going from channel 0 to channel 1, then 2, then 3. If the global strobe update feature is disabled (in the D/A control word) the output of the D/A converter is updated immediately upon receipt of the MSB of data (including the polarity bit). If the strobe input is enabled, the data is not latched into the output registers of the D/A converter until receipt of the active low strobe input.

To determine the digital value corresponding to a given voltage, it is necessary to know the output range setting of the DAC. Since the AOM5's 13-bit converters are organized as 12 data bits plus sign bit, there are actually 4096 possible voltage levels to be programmed, specified with digital values of 0-4095. 13-bit resolution results from setting the polarity bit for positive or negative output. The full-scale value is the nominal full-scale value minus 1 LSB, and the resolution is 1 part in 4096, or about 2.44mV on the 10 volt range. The DAC counts for a particular output can be calculated as:

$$\text{COUNTS} = \text{ABS} [(\text{VOLTS} / \text{RANGE}) \times 4096]$$

where counts = DAC data, volts = desired voltage output, and range = the output range setting for the particular channel. The digital data must be adjusted to include the sign bit (the D7 bit in the MSB of the data). This may be accomplished by adding 128 to the MSB if negative voltage output is desired.

**xxx9D (STROBE)
GLOBAL ANALOG OUTPUT UPDATE**

The strobe command is used to synchronously update all analog output channels. The strobe feature is global, affecting all D/A channels in a system whose global strobe feature has been enabled. Any analog output whose global strobe has been enabled, and whose data has not been changed since the last global strobe was issued, will not change its output voltage.

Writing to the global strobe command location causes the STROBE line to go active low, and allows global update of all DAC outputs if the analog output circuit is so configured.

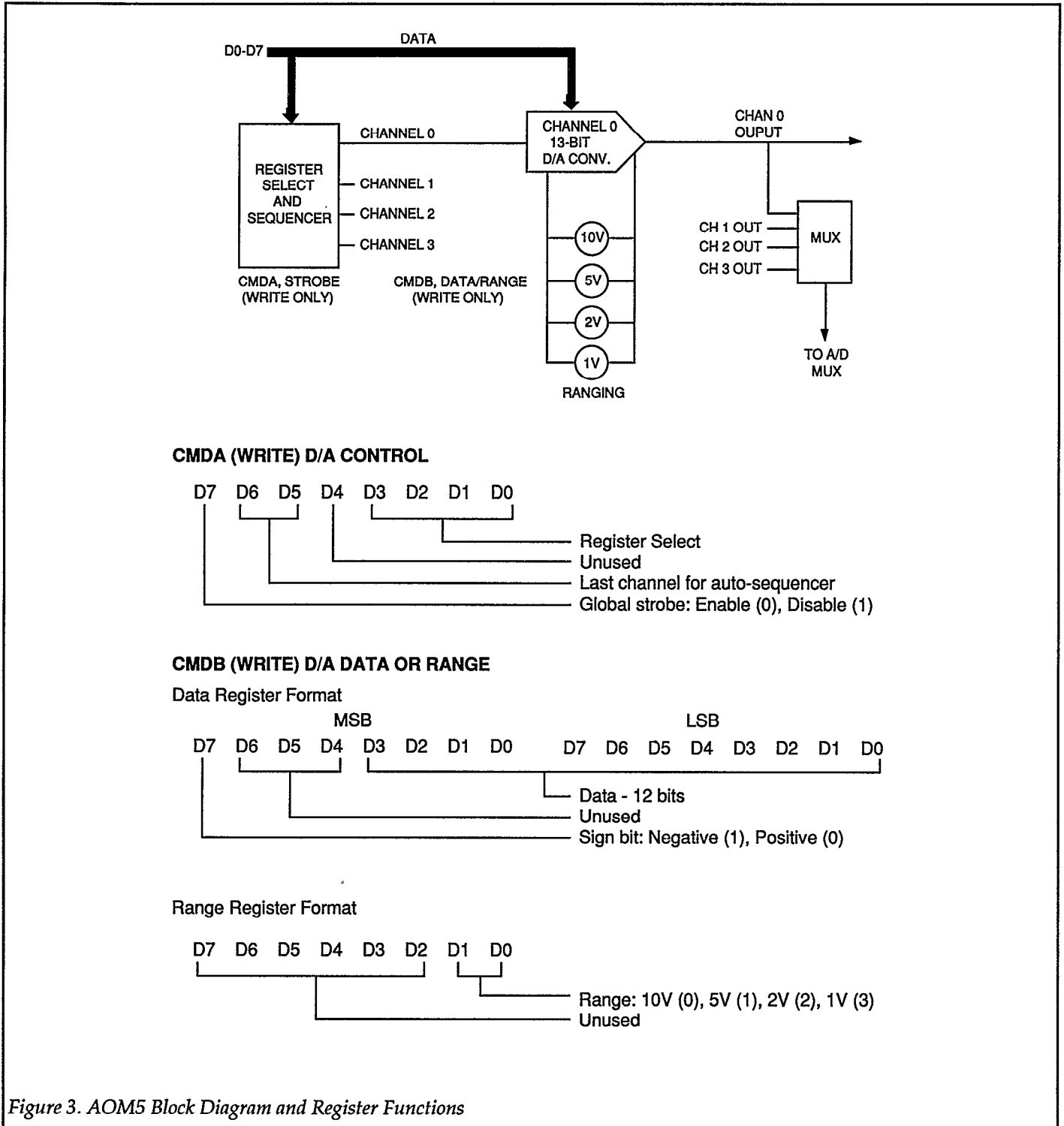
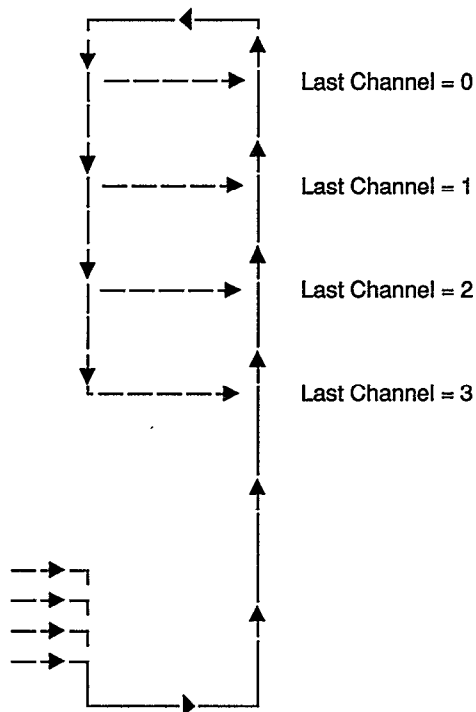


Figure 3. AOM5 Block Diagram and Register Functions

CMDB WRITE REGISTER TABLE

REGISTER NUMBER	DISCRIPTION
0	Channel 0 LSB
1	Channel 0 MSB
2	Channel 1 LSB
3	Channel 1 MSB
4	Channel 2 LSB
5	Channel 2 MSB
6	Channel 3 LSB
7	Channel 3 MSB
8	Not Used
9	Not Used
10	Not Used
11	Not Used
12	Channel 3 Range
13	Channel 2 Range
14	Channel 1 Range
15	Channel 0 Range

COUNT SEQUENCE



STROBE (WRITE) UPDATE OF OUTPUTS, ADDRESS = xxx9D

The GLOBAL STROBE can be used to simultaneously update all D/A outputs in the system. This includes all output channels on all D/A cards in the system which have been programmed to respond to GLOBAL STROBE.

To enable the AOM5 to respond to GLOBAL STROBE, write a 1 to bit 7 of the AOM5 CMDA register.

OUTPUT DATA

Calculate the data value (number of bits) for a desired output voltage as follows:

$$\text{DATA VALUE} = (\text{ABSOLUTE VALUE (VOLTAGE)} / \text{RANGE}) \times 4096$$

Set bit 13 to 0 for positive output, or 1 for negative output. See CMDB for information on writing data to AOM5 data registers.

Automatic Register Sequencing

The AOM5 analog output circuitry includes an automatic incrementing circuit for the analog output range and data registers. The incrementing circuitry aids in high-speed output programming. The following information will be useful for generating analog output by directly accessing the CMDA and CMDB registers. These operations are normally handled by KDAC500.

Generally, standard (non-auto sequenced) analog output is generated by first writing register select information to CMDA, followed by writing the corresponding data to CMDB. These steps are repeated until all the necessary range and output data have been written for a desired channel. For channel 0, a typical sequence might be as follows:

1. Write "15" to CMDA to select the channel 0 range register.
2. Write the desired range to CMDB.
3. Write "0" to CMDA to indicate that the following data will be analog output low-order byte for channel 0.
4. Write the channel 0 low-order data byte to CMDB.
5. Write "1" to CMDA to indicate that the following data will be analog output high-order byte for channel 0.
6. Write the channel 0 high-order data byte to CMDB. (Note that bit D7 governs the polarity of the output.)
7. Write to the GLOBAL STROBE location (xxx9D) to update the channel 0 output.

Automatic register sequencing automates several of the write operations listed above. It first requires that a control byte be written to CMDA (see Tables 2, 3, and 4). This byte must include the register selection and last channel desired for auto sequencing. The most significant bit (MSB) of the byte must be 1 to disable the global strobe function.

Next, data must be written to CMDB. This data may be range data or the output low-order or high-order data byte, according to the information written to CMDA. The information written to CMDA also sets the "entry point" in the auto-sequencing loop, thus establishing the expected order of subsequent bytes written to CMDB. The auto sequence logic assumes that the next bytes will conform to the following sequence:

Table 4. AOM5 Automatic Sequencing

Register No.	Description	Sequence
0	Channel 0 LSB data	
1	Channel 0 MSB data	
2	Channel 1 LSB data	
3	Channel 1 MSB data	
4	Channel 2 LSB data	
5	Channel 2 MSB data	
6	Channel 3 LSB data	
7	Channel 3 MSB data	
12	Channel 3 range	
13	Channel 2 range	
14	Channel 1 range	
15	Channel 0 range	

Note that entry points in the loop may be range information or output data. As an example, if the initial write to CMDA is "14", the analog output circuitry would assume that the next byte is the channel 1 range, followed by the channel 0 range, the channel 0 least significant data byte, the channel 0 most significant data byte, and so on. Once the sequence moves out of the range registers, it will cycle continuously through the channel registers without returning to registers 12 through 15.

If the first control byte written to CMDA is 0 through 7, the auto sequence logic will expect that the next bytes written to CMDB will be data. The loop will not enter the range selection registers at all.

If the first control byte written to CMDA specifies that channel 0 is the last channel for auto sequencing, then the loop will run only through registers 0 and 1 (channel 0 LSB and MSB data) and not include registers 2 through 7. This path will confine output to channel 0 and permit the maximum output speed from channel 0.

The GLOBAL STROBE is typically disabled for auto sequencing. This enables the output of a channel to be updated as soon as the MSB data for the channel is written to the channel MSB register.

Calibration

This section contains general field calibration information for the AOM5. The procedures given are not necessarily as accurate as factory calibration. Also, the procedures given assume a certain amount of expertise on the part of the user. If you are not familiar with calibrating equipment, do not attempt calibration. The procedures in this section assume that you are familiar with general module operation. Refer to the appropriate manual for details on calibrating each module.

The only calibration necessary on the AOM5 is to adjust the +10 and -10 volt reference voltage buffer amplifiers. The voltage reference used by the AOM5 is the system +10 volt reference, which is typically provided by the AMM2 or AMM1A A/D converter modules. The output voltage accuracy of the AOM5 is affected by the accuracy of this reference, so it may be desirable to calibrate the AMM2 or AMM1A module first.

The calibration of the AOM5 proceeds as follows:

1. Measure the 10 volt system reference on the AMM2 or AMM1A by attaching the voltmeter (+) lead to TP7, and the voltmeter (-) lead to the analog ground test point TP4. Note this voltage reading for use later.
2. Connect the voltmeter (+) lead to TP1 on the AOM5, and the (-) lead to TP2 on the AOM5. Adjust pot R12 for a voltmeter reading identical to the reading obtained in step 1.
3. Connect the voltmeter (-) lead to TP1 on the AOM5, and the (+) lead to TP3 on the AOM5. Adjust pot R13 for a voltmeter reading identical to the reading obtained in step 1.

Please note that R12 must be adjusted first, as it affects both the voltage at TP2 and TP3.

Using the On-board Voltage Reference

The AOM5 is supplied from the factory without a built-in voltage reference because the AOM5 is typically used in a system containing either an AMM1A or AMM2 A/D converter module. The AMM1A and AMM2 provide a very high quality reference voltage to the system, so an on-board AOM5 reference is unnecessary.

Using the same reference voltage for generating and metering test voltages also has error canceling advantages. For example, if the reference voltage is slightly off, both the output voltage to an experiment and the resulting voltage reading by the A/D will both be off by the same percentage including the polarity of the error. Calculations which ratio the drive voltage to the measured voltage will cancel the error terms due to inaccurate reference voltage, and result in a more accurate experiment result. The system reference must be used where it is present, i.e. when an A/D module is in the system.

For cases where no A/D is used in the system, a reference voltage must be provided to the AOM5 for proper operation. The user may install components U1, R1, R2, and R3 on the AOM5 to generate a +10 volt reference. If more than one AOM5 is to be installed into a system, only one AOM5 needs these parts installed. This one reference circuit will provide the 10 volt reference for any other AOM5 in the system. These parts must be removed if an A/D module is later installed in the system, since the two references will conflict.

These parts may be ordered from Keithley Instruments Repair Department by requesting the following Keithley part numbers (see Table 5):

Table 5. Components, On-board Voltage Reference

Keithley Desig.	Part No.	Description
U1	IC-677	IC, TL431CLP Adjustment Shunt Regulator
R1	R-76-1K	Resistor
R2	R-263-6K	Resistor
R3	R-263-2K	Resistor

Theory of Operation

Refer to schematic drawing 501-236 for the following discussion:

Each of the four outputs function identically, and only the channel 0 output part references to the schematic are included below. The analog portion of the circuitry on the second sheet of the schematic drawing is described first.

The development of a specific output voltage begins with the selection of either the +10 volt or -10 volt reference voltage by the analog switch U19. If a positive output voltage is desired, the -10 volt reference voltage is used, and vice versa. U19A is turned on by a low logic level on its pin 1 when a negative output voltage is desired, and U19D is turned on by a low logic level on its pin 8 when a positive output voltage is desired. The selected reference voltage is buffered by amplifier U31A and fed into the reference input of the multiplying D/A converter U21. The multiplying D/A converter functions by multiplying the 10 volt reference input by the digital number programmed by the computer. The digital value programmed represents a number between 0 and 0.99976. Amplifier U27A is part of the multiplying circuit, and the overall output of the multiplying D/A converter circuit is at pin 1 of U27A. The voltage at this point always has a span of 0 to +9.9976 or 0 to -9.9976 volts. The resistor divider formed by R19, R23, R27, and R31 and analog switches U23A through U23D form the range selection circuitry. One of the four analog switches is on at a time, and selects a tap on the resistor divider which divides the output of U27A by 1, 2, 5, or 10. This results in a span of 0 to 10, 5, 2 or 1 volts, respectively, at the input of U28A, the output amplifier. Capacitor C8, combined with the voltage divider impedance and R35, R39, and R43, provides filtering for the signal to help remove glitches when the D/A converter output voltage is changed. The output of U28A drives the output connector directly. A wire jumper, W1, on the circuit board provides a location for connecting a resistor in series with the output, if needed.

The +10 and -10 volt references for all four output channels come from a common set of reference amplifiers, U2 and U3. Refer to sheet 1 of the schematic. The 10 volt system reference (10VREF), and system ground reference (AN_COM) come from the system baseboard on J1, and go to a differential amplifier circuit comprised of U2, R4, R5, R6, R7, 10, and R12. This amplifier inverts the reference voltage to provide the AOM5 -10 volt reference, and isolates the baseboard AN_COM ground reference from the AOM5 output ground reference. C24 provides a low AC output impedance. Components C2, C26, and R48 stabilize the feedback loop around U2. An inverting amplifier comprised of U3, C3, C25, C27, R8, R9, R11, R13, and R49 makes the +10 volt reference signal.

A power-up reset circuit made up of U4 and the associated components resets all the bits in the D/A converter registers to 0 when the power is first applied, which results in an output of 0 volts on all channels.

The command decoding circuitry is on sheet 1 of the schematic. U5 buffers some of the data and control lines to prevent excessive bus loading. The output of the 4-bit counter U8 represents the number of the control register which will be used on the next data write to CMDB. The output of U8 is decoded into the various write enable pulses for the data latches of the schematic by U6 and U10. When data is written to CMDA, bits D0, 1, 2, and 3 load the counter U8 and bits D4, 5, 6, and 7 are stored in U7. Every time a write is performed to CMDB, magnitude comparator U9 compares the output of counter U8 with the data previously latched into D5 and D6 of U7 to determine if the last register has been filled. If a match is determined, the output of U9 causes the counter U8 to be cleared, thus resetting the CMDB register pointer to the Channel 0 LSB register. This reset occurs at the conclusion of the CMDB write pulse.

Components U1, R1, R2, and R3 are not installed at the factory, and are normally not needed. Please refer to the section of this manual, "Using the Onboard Voltage Reference".

Calibration of the analog output circuit is not necessary other than the calibration of the +10 volt and ± 10 volt reference voltages (described in the AOM5 calibration procedure).

Troubleshooting

Any observed or suspected problem with a system or module may be the result of malfunctions in any part of the system. A hierarchy of possible problem areas is listed below. The list should help you apply an organized approach to troubleshooting, starting with software and working toward a specific module. It assumes that your system and software have both worked properly in the past. If you have spares, you can most quickly verify a system component through simple substitution. Check your data acquisition system manual or computer documentation — they may contain additional instructions on troubleshooting.

Faulty software or applications programs - If you have completed a new program which does not work as anticipated, review the program design and be certain that it actually functions as you assume. If a program which had been running properly begins to behave erratically, either the supporting software package or the application pro-

gram may have been corrupted. This may occur through disk media failures, power supply problems, hardware failures, or operator error.

Verify your software package against a back-up copy or the original diskettes. If the software is questionable, you should reinstall the software from the original diskettes or known-good copies. Likewise, your applications program should be restored from backups if a problem develops. Note that it is crucial to back up important software and programs. Ideally, you should make at least two copies, and store one in a location away from your work site. Application programs should be backed up regularly as they are being developed. Printouts of program listings may also be desirable.

Faulty computer system - A malfunctioning computer or peripheral can affect the data acquisition software and hardware, ranging from minor problems to total failure. These problems may be continuous or intermittent. If you suspect your computer, remove the data acquisition interface and run any diagnostics which came with the system to verify its performance. Also try running other software with which you are familiar. Pay close attention for any erratic behavior of the software which may indicate hardware problems.

Defective interface - A malfunctioning data acquisition interface can prevent the computer from booting up and operating properly, or it can affect only the data acquisition system. Some graphics, mouse, and networking adapters conflict with data acquisition interfaces as a result of both using the same addresses or interrupts. The system operates properly with one of the cards in place, but diagnostic error messages or other problems result with both cards plugged in. You can usually determine incompatibility by trying each suspected card individually, and then together. Such incompatibility can often be overcome through switch settings, configuration changes, or minor modifications to the hardware.

Defective data acquisition interface cable - The cable carries essential power, control, or data signals. Open conductors in a cable will disrupt the process. Cable shorts, especially in lines carrying system power supply voltages, may cause a total shutdown of the computer or data acquisition mainframe. If these problems exist, try disconnecting the interface cable from the computer and data acquisition system.

There is a maximum permissible length specified for interface cables. Exceeding the length will also introduce problems. You may note erratic operation of the computer, corrupt data, or a failure of the indicator lamps on the data acquisition system to light.

Defective data acquisition mainframe - A mainframe defect can affect any and all data acquisition functions. Main areas include the motherboard logic and connectors, the expansion slots, and the power supply. In the case of a completely dead acquisition system, always check any fuses and cabling which carry power.

An individual slot may also be bad. A known good module can be tried in various slots to determine the condition of individual mainframe slots.

Defective module(s) in general - A failure in a module's address, data, or control circuitry can affect other modules if the malfunctions ultimately reach the data acquisition motherboard or power supply. You may be able to locate a faulty module by removing modules individually until the problem clears.

The master A/D module in slot 1 is a special case because it processes data from all analog input channels. Any analog input involves its global multiplexer, programmable gain amplifier, and A/D converter. If only the analog input functions are faulty, you should also consider the master A/D module. Use a known-good A/D module, or first verify your A/D module for proper operation before troubleshooting another analog module.

Analog output normally relies only on circuitry within an analog output module unless documentation for the module states otherwise. The AOM5 modules use the 10V precision reference on the AMM module. If you note inaccurate output levels from the AOM5, the AMM module may need to be calibrated. Digital input and output are also performed wholly on a single module, with the exception of the PIM1 and PIM2 power control modules. The PIM modules use an external board and solid state relays. These should also be considered in situations where PIM modules are suspected of being faulty.

In troubleshooting modules, use a software package with which you are familiar to write a few simple test programs for the suspected module. Elaborate programs should

generally not be used. They may contain their own errors which mask problems with the hardware.

If a suspected module does not respond as expected, you may assume that the module requires calibration or is defective. If a module has no calibratable components, a problem at this point will normally indicate a failure within the module.

Defective AOM5 module - An AOM5 can be checked by running a few simple programs which test individual features of the module. The CMDA and CMDB registers can also be exercised to determine correct operation of the module. See information elsewhere in this manual.

A skilled technician who has access to electronic test equipment may be able to troubleshoot individual circuits on a module to isolate the faulty parts. A full parts list and diagram set are included with each module to aid the technician.

If a defective component is found, replacement parts may be obtained from Keithley. If factory service is desired, the module may be returned for repair. All Keithley-manufactured systems and modules are warranted against defects in material and workmanship for a period of one year. For information on replacement parts or factory service, see the Parts List section of the appropriate manual.

NOTE

If a calibratable module which had been working accurately suddenly becomes inaccurate by more than a few percent, the problem is more likely a malfunction and not a calibration problem. If you cannot calibrate the hardware after two attempts, you should return it to Keithley for repair or calibration at the factory.

List of Replaceable Parts

Table 6 contains replacement parts information. Parts are listed alphanumerically in order of their circuit designations. A component location drawing and schematic diagram for the AOM5 are found at the end of the manual.

Ordering Information

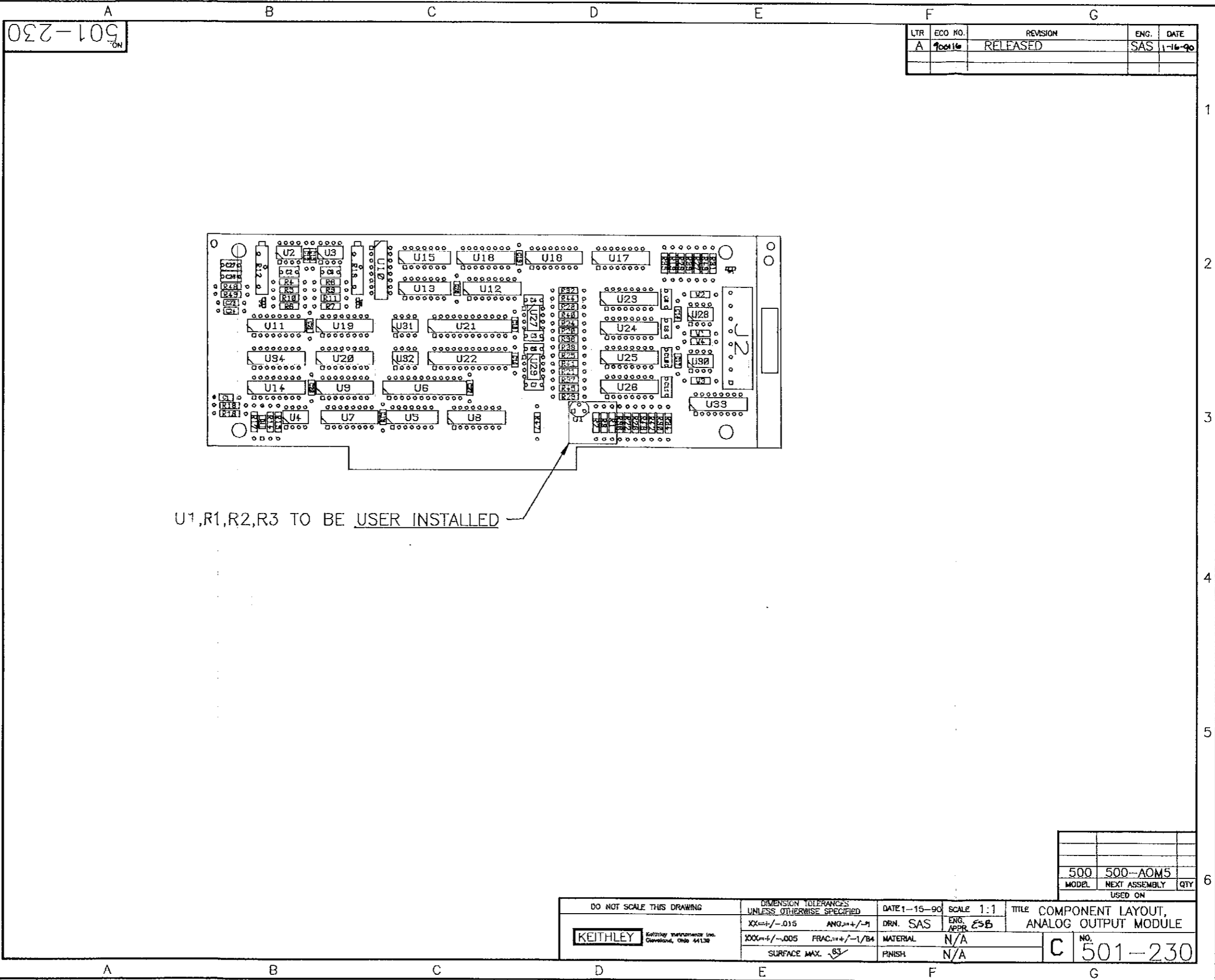
To place an order, or obtain information concerning replacement parts, first contact the Keithley customer service department: (216) 248-0400. When ordering parts, include the following information:

1. Model Number
2. Serial Number
3. Part Description
4. Circuit Designation (if applicable)
5. Keithley Part Number

If an additional instruction manual is required, order the manual package (Keithley Part Number 501-920-00 Rev *). The manual package contains an instruction manual and any applicable addenda.

Table 6. Parts List - Model AOM5 Analog Output Module

Part No.	Quantity	Title	Designation
C-365-.1	14	Cap, .1 μ F, 20%, 50V, Ceramic	C1, C12...C25
C-64-100P	4	100pF, 10%, 1000V, Ceramic	C2, C3, C27, C28
C-64-22P	8	Cap, 22pF, 10%, 1000V, Ceramic	C4...C11
CS-521-4	1	Conn, Strip, 8 Pin	J2
CS-553	3	Conn, Test Point	TP1...TP3
IC-173	1	IC, Voltage Comparator, LM311N	U4
IC-182	1	IC, Decoder/Demux, 74LS138	U10
IC-186	2	IC, Hex Inverter, 74LS04	U13, U15
IC-190	3	IC, 2 to 4 Line Decoder/Demux,	74LS139 U17, U18
IC-203	2	IC, 18V OP-Amp, 308AN	U2, U3
IC-215	1	IC, Quad 2 Input Pos AND, 74LS08	U5
IC-246	2	IC, 18V OP-Amp, 353	U31, U32
IC-267	1	IC, 8 Ch CMOS Analog Multi, 6108	U33
IC-272	1	IC, 4-Bit Counter, 74LS163A	U8
IC-320	6	IC, SPST CMOS Analog Switch, DG211	U19, U20, U23...U26
IC-366	5	IC, 4 Bit Bistable Latch, 74LS75	U7, U11, U12, U14,
IC-389	1	IC, 4-BIT Magnitude Comparators, 74LS85	U9
IC-504	4	IC, Dual JFET OP-Amp, 412	U27...U30
IC-678	2	IC, 12-Bit DAC, AD7537JN	U21, U22
IC-724	1	AOM5 PAL, MMI20L10	U6
J-3	4	Jumper, Circuit	W1...W4
R-176-10.7K	1	Res, 10.7K, .1%, 1/8W, Metal Film, T2	R47
R-263-10K	10	Res, 10K, .1%, 1/10W, Metal Film	R4...R9, R19...R22
R-263-2K	8	Res, 2K, .1%, 1/10W, Metal Film	R27...R34
R-263-6K	4	Res, 6K, .1%, 1/10W, Metal Film	R23...R26
R-76-39K	1	Res, 39K, 5%, 1/4W, Composition or Film	R14
R-76-4.7K	1	Res, 4.7K, 5%, 1/4W, Composition or Film	R18
R-76-470K	1	Res, 470K, 5%, 1/4W, Composition or Film	R17
R-88-1.82K	4	Res, 1.82K, 1%, 1/8W, Metal Film	R39...R42
R-88-22.1	2	Res, 22.1, 1%, 1/8W, Metal Film	R10, R11
R-88-3.16K	4	Res, 3.16K, 1%, 1/8W, Metal Film	R43...R46
R-88-37.4K	1	Res, 37.4K, 1%, 1/8W, Metal Film	R15
R-88-4.99K	5	Res, 4.99K, 1%, 1/8W, Metal Film	R16, R35...R38
R-88-470	2	Res, 470, 1%, 1/8W, Metal Film	R48, R49
RF-28	1	Diode, Silicon, 1N4148 (DO-35)	D1
RP-89-200	2	Pot, 200, 10%, .75W, Non-Wirewound	R12, R13
MC-334	1	Warning Label	
501-920-00	1	Manual Package	



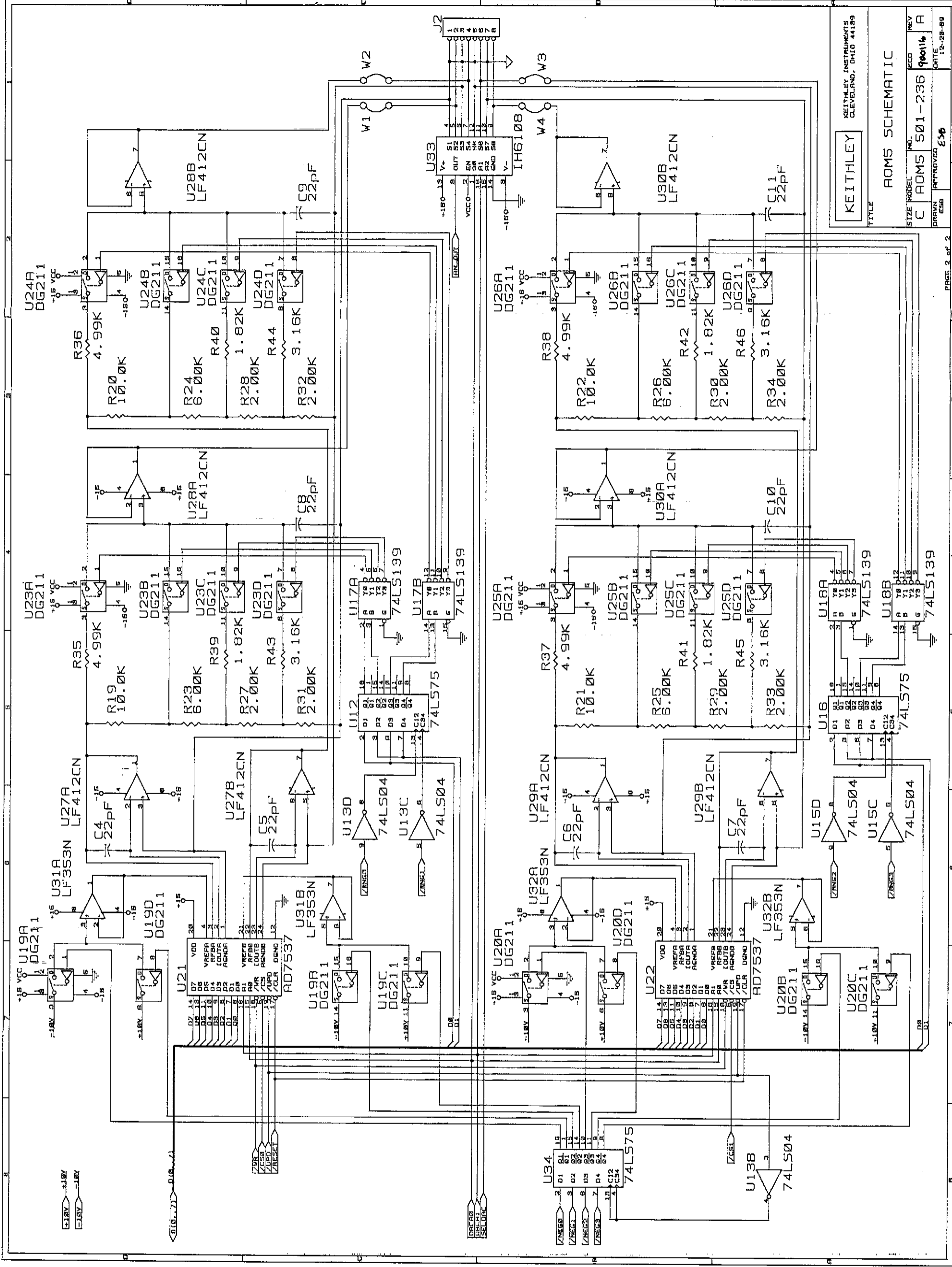
501-230
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LTR	ECO NO.	REVISION	ENG.	DATE
A	100116	RELEASED	SAS	1-16-90

U1,R1,R2,R3 TO BE USER INSTALLED

MODEL	NEXT ASSEMBLY	QTY
500	500-AOM5	

DO NOT SCALE THIS DRAWING		DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED		DATE 1-15-90	SCALE 1:1	TITLE COMPONENT LAYOUT, ANALOG OUTPUT MODULE	
KEITHLEY <small>Keithley Instruments Inc. Cleveland, Ohio 44132</small>	XX±/-0.15	ANG±±±/-0.1	DRN. SAS	ENG. APPR. ESB	NO. 501-230		
	XXX±±/-0.005	FRAC.±±±/-1/64	MATERIAL N/A	C			
	SURFACE MAX. √63		FINISH N/A				



KEITHLEY		KEITHLEY INSTRUMENTS CLEVELAND, OHIO 44139	
TITLE ROMS SCHEMATIC			
SIZE MODEL	NO.	ECO	REV
C	ROMS 501-236	900116	A
DRAWN	ESB	APPROVED	DATE
		ESB	12-28-80

Using the AOM5 Module with KDAC500

The following notes describe general techniques for using the AOM5 Analog Output Module. The AOM5 will normally be used to apply a voltage to some other electrical, electronic, or electro-mechanical device. Typical uses include biasing, excitation, or driving equipment whose function, position, or other performance parameters change in response to a control voltage.

The supplied program examples for these applications are oriented around BASIC and the foreground/background output commands in Keithley's KDAC500/I software. A foreground output command writes a single value, previously stored as a variable, to a chosen AOM5 channel. A background output command sequentially writes the elements of a memory-resident KDAC500 array to the desired channel at a rate set by KDAC500's programmable interrupts.

The channel input/output names (IONAMES) must be set up in the KDAC500 hardware configuration

(CONFIG) table according to the AOM5's slot position and the channel being used. The AOM5 output channel name used in the example programs is "OUTCHAN". Likewise, the analog input channel name used in Example 4 is "INCHAN".

If you are using another software package, consult your software documentation for operating modes and commands. In most programming languages, it is also possible to get the equivalent of foreground commands by writing directly to the AOM5 CMDA, CMDB, and STROBE command registers.

Output Current Compliance

The AOM5 has a maximum output drive current of five milliamperes. Where an application requires greater drive power, connect the AOM5 output to a suitable current amplifier or programmable analog power supply. In this case, the AOM5 drives the amplifier, which drives the load.

Using the AOM5 Module with KDAC500

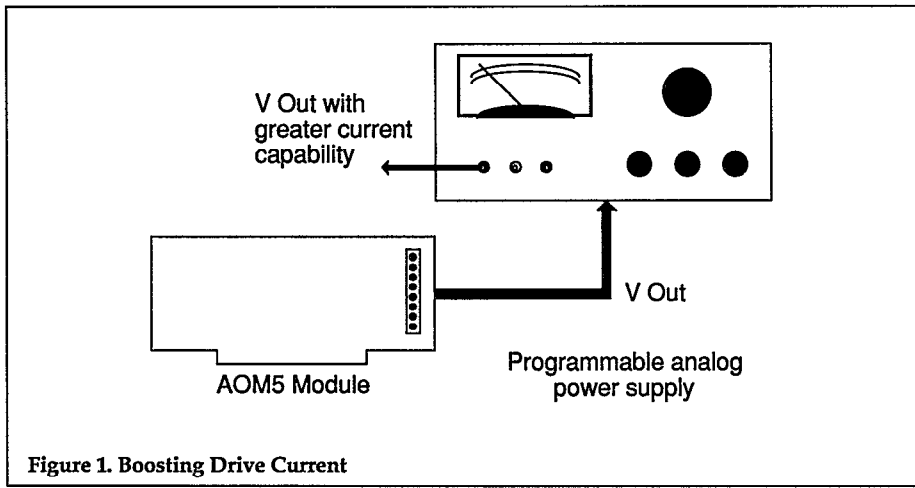


Figure 1. Boosting Drive Current

Initializing the AOM5

The AOM5 outputs will automatically initialize to 0 volts when a system containing the module is switched on. The KDAC500 HARDINIT utility, which can be executed through the computer's AUTOEXEC.BAT file, is not required to initialize the AOM5 at power-up. However, HARDINIT may be used to initialize other digital or analog output modules that lack a power-on reset.

The KDAC500 command KDINIT will return all AOM5 outputs to 0 volts anytime it is called within a program. This is an easy method for resetting all analog and digital outputs to 0 immediately before terminating a program.

Programming a Continuous Voltage

Many applications will require the AOM5 to be programmed and held at a specific voltage level while other tests are conducted. This may be accomplished most easily by executing a foreground output (FGWRITE) command. After the foreground write, the AOM5 output will remain constant until another

voltage is programmed, or until the system is reinitialized. Other I/O commands may be executed earlier or later in the program without affecting the AOM5 output level.

Note that where the desired output voltage does not fall exactly on a bit boundary, the actual output voltage will be a maximum of 1 D/A bit lower than programmed. For instance, programming 6.43V will result in 6.428V.

Ramped Output

Output ramps can be programmed by using the background output (BGWRITE) command to write a KDAC500 array to the desired AOM5 channel.

First, the ARMAKE must be used to allocate the array. A FOR-NEXT loop is then set up to:

- (a) linearly increment a data value and an array position index,
- (b) place the data into the KDAC500 array at the corresponding index with ARPUT,
- (c) repeat until the array is full.

The loop may also apply scaling or offset calculations to the data to achieve a desired offset and slope for the ramp. Further, the data values may be calculated as voltage, current, percent of full scale, or raw D/A counts so long as the appropriate engineering unit flag is used in ARPUT. The maximum resolution

```
10 'Program 6.43V output with foreground write
20 'Set AOM5 for +/-10V range
30 CALL KDINIT
   :
   : (BASIC and/or KDAC500 commands)
   :
400 DIM VOUT!(1)
410 VOUT!(0)=6.43
420 CALL FGWRITE("outchan",vout!(),"c.volts","nt")
   :
   : (BASIC and/or KDAC500 commands)
   :
900 CALL KDINIT
1000END
```

Example 1. KDAC500/I Foreground Write

Using the AOM5 Module with KDAC500

the AOM5 is 8192 steps for any bipolar output range. Careful selection of AOM5 range will provide optimum resolution for any output signal.

After the array has been created, a BGWRITE command must be set up for the desired AOM5 channel. Any other background commands should also be inserted at this point in the program.

To write the array to the AOM5, set up an INTON command, being careful that the specified interrupt interval is adequate for the computer type and number of background tasks. When the program runs, the output ramp will begin when the INTON command is executed. The BGWRITE command may be given a cycling parameter for continuous output or *n* repeats.

Output of Periodic or Complex Waveforms

Periodic and complex waveforms are handled in a fashion similar to ramps, except that the FOR-NEXT loop contains a mathematical equation to calculate the output data. The equation may be linear or non-linear in order to generate ramps, curves, periodic waves, random patterns, or combinations thereof. Synthesizing a single cycle of the wave form is usually adequate. The BGWRITE command cycling parameter can be set to output a specific number of cycles, or for continuous recycling.

Output of Data Acquired with an AMM1A or AMM2

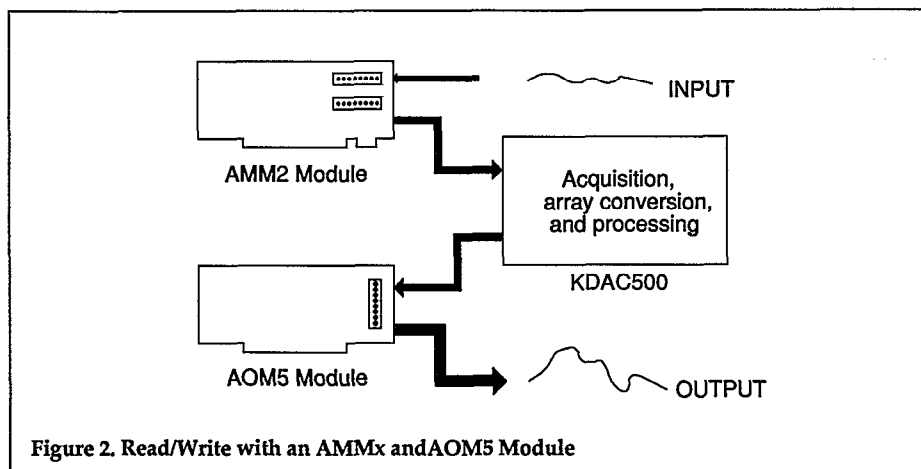
Data can also be acquired through an analog input channel, and then sent back out through an AOM5 output channel. This technique is useful for process control, sampling, or output of waveforms which cannot be synthesized easily through calculation. Foreground and background modes may both be used, although the basic techniques and applications will differ. Foreground commands will provide operation in real-time at the expense of speed, while background commands will be faster, but require input of all data before it can be output.

Before exploring these techniques, note that the AOM5 provides 13 bits of D/A resolution for four bipolar ranges. The AMM2 uses a 16-bit A/D converter, while the AMM1A uses a 12-bit A/D converter, and both

```
10 ' Output a ramp from 0-10V in 4.096 sec
20 CALL KDINIT
   :
   : (BASIC and/or KDAC500 commands)
   :
100 CALL ARMAKE("outarray%", 4096., "outchan")
110 DIM BITVAL%(1)
120 '
130 FOR D!=1 TO 4096!
140 BITVAL%(0)=D!
150 CALL ARPOT("outarray%", D!, D!, "outchan", 1, bitval%),
   "c.raw.int")
160 NEXT D!
   :
   : (BASIC and/or KDAC500 commands)
   :
200 CALL BGWRITE("outarray%", "outchan", 1, 1, "nt", "done")
210 '
220 CALL INTON(1,"mil")
230 '
240 STAT%=-1
250 CALL BGSTATUS("done", stat%)
260 IF STAT%<>0 GOTO 250
270 CALL INTOFF
   :
   : (BASIC and/or KDAC500 commands)
   :
900 CALL KDINIT
1000END
```

Example 2. Ramp with KDAC500/I Background Write

Using the AOM5 Module with KDAC500



```

10 ' Do foreground read and write in a loop
20 CALL KDINIT
   :
   : (BASIC and/or KDAC500 commands)
   :
100 DIM VIN!(1)
110 DIM VOUT!(1)
120 '
200 CALL FGREAD'("inchan", "none", vin!(), "c.volts", "nt")
210 VOUT!(0)=1.25*VIN!(0)+.3
220 CALL FGWRITE'("outchan", vout!(), "c.volts", "nt")
230 I$=INKEY$:IF I$="" GOTO 200
   :
   : (BASIC and/or KDAC500 commands)
   :
900 CALL KDINIT
1000END

```

Example 3. KDAC500/I Foreground Read/Write

modules can be set for unipolar or bipolar operation. Further, the AMM1A actually provides 16-bit results in which the four lowest order bits are permanently wired low. Therefore, the data formats of the AMM and AOM5 modules are not 1-to-1 compatible. Passing an array from an AMMx module directly to the AOM5 as unprocessed, binary data will not give a reconstruction of the input

signal. Fortunately, KDAC500's engineering unit conversion flags (EUF) make it possible to convert data using ARGET and ARPUT commands, without complex conversions.

For a foreground read/write using an AMMx and AOM5, first execute a KDAC500 foreground read (FGREAD) command to read an analog input value. The reading

should be returned as a voltage by setting the EUF in the FGREAD command for voltage. Next, apply any necessary conversions, offset, or scaling to the voltage value. Finally, write the value to the AOM5, also using a voltage EUF in the FGWRITE command. This process may be included in a loop as a form of process control. The loop will run at maximum speed in a compiler version of KDAC500.

For background-oriented operations, a BGREAD or ANINQ command is first used to acquire data with the AMM module and place it in a KDAC500 array. The next step depends on how large the array is, and whether additional processing of the array is necessary. If the acquired data will fit a 64k BASIC array, and if there is no need for additional calculations on the data, the ARGET command can be used to convert the entire KDAC500 array to a BASIC array. Appropriate voltage or current EUFs can be used in the ARGET command. Next, an ARPUT command converts the BASIC array back to a KDAC500 array. This second KDAC500 array must have been allocated previously with an ARMAKE command. Once converted, the new KDAC500 array can be sent out through an AOM5 channel by setting up a BGWRITE command and turning on interrupts.

If the data will not fit into a BASIC array, or if additional calculations are needed, a FOR-NEXT loop containing ARGET and ARPUT commands must be set up. The ARGET command sequentially reads each data value in the first KDAC500 array and returns it as a BASIC variable; engineering unit flags can be used to express the values as voltage, current, etc. The

Using the AOM5 Module with KDAC500

loop may also include calculations to offset or scale each value. Next, the ARPUT command writes the value to the second KDAC500 array. This second array must have been allocated previously with an

ARMAKE command. When the FOR-NEXT loop is complete, the array can then be sent out through an AOM5 channel by setting up a BGWRITE command and turning on interrupts.

```
10 ' Sample and output a waveform using background commands
20 ' AOM5 output range should match the AMM input range
30 CALL KDINIT
   :
   : (BASIC and/or KDAC500 commands)
   :
100 CALL BGREAD("inarray%", 5000., "inchan", 1, "none", 1, "nt",
    "readjob")
110 CALL INTON(1,"mil")
120 STAT%=-1
130 CALL BGSTATUS("readjob", stat%)
140 IF STAT%<>0 GOTO 130
150 CALL INTOFF
200 '
300 DIM BASICARRAY!(5000)
310 CALL ARMAKE("outarray%", 5000., "outchan")
320 CALL ARGET("inarray%", 1., 5000., "inchan", 1, basicarray!),
    "c.volts")
330 CALL ARPUT("outarray%", 1., 5000., "outchan", 1, basicarray!),
    "c.volts")
400 '
500 CALL BGWRITE("outarray%", "outchan", 1, 1, "nt", "writejob")
510 CALL INTON(1,"mil")
520 STAT%=-1
530 CALL BGSTATUS("writejob", stat%)
540 IF STAT%<>0 GOTO 530
550 CALL INTOFF
   :
   : (BASIC and/or KDAC500 commands)
   :
900 CALL KDINIT
1000END
```

Example 4. Ramp with KDAC500/I Background Write

KEITHLEY DAC

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