APPENDIX 1

STATE SPACE MODEL

The nonlinear equations are linearised to find the state space form as

\[
\frac{dx}{dt} = ax + bu
\]

\[y = cx\]

where the state \(x\), input \(u\) and output \(y\) are in deviation form

\[
\begin{bmatrix}
  a - a_s \\
  b - b_s
\end{bmatrix}
\]

\[
\begin{bmatrix}
  F \\
  V - \frac{F_s}{V}
\end{bmatrix}
\]

\[
\begin{bmatrix}
  a - a_s \\
  b - b_s
\end{bmatrix}
\]

The elements of the state-space matrix \(A\) is found by

\[
a_{ij} = -\frac{\partial f_i}{\partial x_j}
\]

\[
a_{11} = -\frac{\partial f_1}{\partial x_1} = \frac{F}{V} - k_1 - 2k_1a,
\]
\[ a_{12} = \frac{\partial f_1}{\partial x_2} \bigg|_{x_1} = \frac{\partial f_1}{\partial (b - b_s)} \bigg|_{b} = \frac{\partial f_1}{\partial b} = 0 \]

\[ a_{21} = \frac{\partial f_2}{\partial x_1} \bigg|_{x_1} = \frac{\partial f_2}{\partial (a - a_s)} \bigg|_{a} = \frac{\partial f_2}{\partial a} = k_1 \]

\[ a_{22} = \frac{\partial f_2}{\partial x_2} \bigg|_{x_2} = \frac{\partial f_2}{\partial (b - b_s)} \bigg|_{b} = \frac{\partial f_2}{\partial b} = \frac{F}{V} - k_2 \]

\[ b_{11} = \frac{\partial f_1}{\partial u_1} \bigg|_{u_1} = \frac{\partial f_1}{\partial \left( \frac{F}{V} \right)} \bigg|_{F} = \frac{\partial f_1}{\partial F} = a_i - a_s \]

\[ b_{21} = \frac{\partial f_2}{\partial u_1} \bigg|_{u_1} = \frac{\partial f_2}{\partial \left( \frac{F}{V} \right)} \bigg|_{F} = \frac{\partial f_2}{\partial F} = -b_s \]

The state space model is

\[
\begin{bmatrix}
-\frac{F}{V} - k_i - 2k_a a_s & 0 \\
\frac{F}{V} - k_2 & \frac{F}{V} - k_2
\end{bmatrix}
\]

\[
\begin{bmatrix}
a_s - a_s \\
-b_s
\end{bmatrix}
\]

\[
\begin{bmatrix}
0 & 1
\end{bmatrix}
\]
APPENDIX 2

HEAT EXCHANGER

A 2.1 Heat Exchanger

Make : VI Micro systems Pvt. Ltd, Chennai-600 096, India
Type : Shell and tube
No. of Shell and tube : 37 Numbers
Diameter : 150 mm
Length : 750 mm
End Connection : ½” BSP
Tube inner/outer diameter : 6 mm/ 9.7 mm

A 2.2 Temperature Transmitter

Input : RTD-Platinum-100-3 Wire
Output : (4-20) mA
Range : (0-100) °C
Supply volt : 24V DC

A 2.3 Rotameter

Model : MG11
Direction of Connection : Bottom to top vertical
Cover : Transparent Acrylic flow with needle valve
A 2.4  **Pump**

Flow rate : (800-1600) lph  
Total head : (12-24) in m  
RPM : 6500  

A 2.5  **Electro Pneumatic converter**

Input signal : (4-20) mA, two wire, @psi  
Output signal : (3-15) psi, (0.2-1) bar  
Characteristics : linear, pressure proportional to signal  
Operating temperature : -20 to +70°C  

A 2.6  **Control valve**

Type/ Valve action : Air to Open  
Flow rate maximum : 500/100 lph  
Trim material : SS 316  
Characteristics : Equal percentage  
Body material : CS body  
Spring Range : (0.2-1) Kg/ cm
APPENDIX 3

DATA ACQUISITION MODULES

A 3.1 INTRODUCTION

The ADAM Series is a set of intelligent sensor-to-computer interface modules containing built-in microprocessor. They are remotely controlled through a simple set of commands issued in ASCII format and transmitted in RS-485 protocol. They provide signal conditioning, isolation, ranging, ADC and DAC, data comparison, and digital communication functions. Some modules provide digital I/O lines for controlling relays and TTL devices. Software Configuration and Calibration ADAM modules contain no pots or switches to set. By merely issuing a command from the host computer, you can change an analog input module to accept several ranges of voltage input, thermocouple input or RTD input. All the module’s configuration parameters including I/O address, speed, parity, HI and LOW alarm, calibration parameters settings may be set remotely. Remote configuration can be done by using either the provided menu-based software or the command set’s configuration and calibration commands. By storing configuration and calibration parameters in a nonvolatile EEPROM, modules are able to retain these parameters in case of power failure. A watchdog timer supervisory function will automatically reset the ADAM modules in the event of system failure. Maintenance is thus simplified.
A 3.1.1 Power Requirements

Although the modules are designed for standard industrial unregulated 24 V DC power supply, they accept any power unit that supplies power within the range of +10 to +30 V DC. The power supply ripple must be limited to 5 V peak-to-peak, and the immediate ripple voltage should be maintained between +10 and +30 V DC.

A 3.1.2 RS-485 Network

The RS-485 network provides lower-noise sensor readings, as modules can be placed much closer to the source. Up to 256 ADAM modules may be connected to an RS-485 multi-drop network by using the ADAM RS-485 repeater, extending the maximum communication distance to 4,000 ft. The host computer is connected to the RS-485 network with one of its COM ports through the ADAM RS-232/RS-485 converter. To boost the network’s throughput, the ADAM RS-485 repeaters use a logical RTS signal to manage the repeater’s direction. Only two wires are needed for the RS-485 network: DATA+ and DATA-. Inexpensive shielded twisted pair wiring is employed. In ADAM series, the baud rate can be configured from 1200 bps to 38.4 kbps and the baud rate of all modules in an RS-485 network must be the same.

A 3.2 ADAM ISOLATED RS-232/RS-485 CONVERTER

When the host computer or terminal has only a RS-232 port, an ADAM Isolated RS-232/RS-485 Converter, connected to the host’s RS-232 port as shown in Figure A 3.1 is required. Since this module is not addressable by the host, the baud rate must be set using a switch inside the module. The factory default setting is 9600 baud.
A 3.2.1 Configuration with the ADAM command set

ADAM modules can be configured by issuing direct commands from within a terminal emulation program that is part of the ADAM utility software. Before the module is reconfigured, it is first requested to send its default settings.

To avoid communication conflicts when several devices try to send data at the same time, all actions are instigated by the host computer. The basic form is a command/response protocol with the host initiating the sequence. When modules are not transmitting they are in listen mode. The host issues a command to a module with a specified address and waits a certain amount of time for the module to respond. If no response arrives, a timeout aborts the sequence and returns control to the host. Changing
ADAM’s configuration might require the module to perform auto calibration before changes can take effect. Especially when changing the range, the module has to perform all stages of auto calibration that it also performs when booted. When this process is under way, the module does not respond to any other commands. The command set includes the exact delays that might occur when modules are reconfigured.

Syntax

(delimiter character)[address][command][data][checksum] [carriage return]

Every command begins with a delimiter character. There are four valid characters: a dollar sign $, pound sign #, a percentage sign % and an at sign @. The delimiter character is followed by a two-character address (hexadecimal) that specifies the target module. The actual two character command follows the address. Depending on the command, an optional data segment follows the command string. An optional two character checksum may be appended to the total string. Every command is terminated by a carriage return (cr). All commands should be issued in uppercase characters.

A 3.3 ADAM-4019 8-CHANNEL ANALOG INPUT MODULE

If there are different types of analog input, such as V, mV, mA, or thermocouple signals, there is a need of preparing individual modules for data acquisition. Now Advantech announces the ADAM-4019 universal analog input module to integrate the various AI modules as one. It not only reduces hardware cost, but also simplifies wiring engineering. Figure A 3.2 shows the front view of ADAM 4019 module and Table A 3.1 has technical specification of ADAM-4019
Table A 3.1 Technical specification of ADAM-4019

<table>
<thead>
<tr>
<th>Channel</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input type</td>
<td>V, mV, mA, T/C</td>
</tr>
</tbody>
</table>
| Input type | V: +/-1V, +/-2.5V, +/-5V, +/-10V  
mV: +/-100mV, +/-500mV  
mA: +/-20mA (w/125ohms) |
| Temperature range | Thermocouple:  
J 0 to 760 C  
K 0 to 1370 C  
T -100 to 400 C  
E 0 to 1400 C  
R 500 to 1750 C  
S 500 to 1750 C  
B 500 to 1800 C |
| Isolation voltage | 3000 V<sub>DC</sub> |
| Sampling rate | 6 samples per sec (total) |
| Input impedance | 20 MW |
| Accuracy | +/- 0.1% or better |
| Power consumption | 1 W |
| I/O connector type | 13-pin plug-terminal |
A 3.3.1 Command set for Analog Input Module (4019)

Configuration: Sets address, input range, baud rate, data format, checksum status, and/or integration time for an analog input module.

Syntax: %AANNTTCCFF(cr)

% is a delimiter character. AA(range 00-FF) represents the 2-character hexadecimal address of the analog input module. NN represents the new hexadecimal address of the analog input module. Range is from 00h to FFh. TT represents the type (input range) code. CC represents the baud rate code.

FF is a hexadecimal number that equals the 8-bit parameter representing the data format, checksum status and integration time. The layout of the 8-bit parameter is shown in Figure A 3.3. Bits 2 through 5 are not used and are set to 0. (cr) is the terminating character, carriage return (0Dh). Table A 3.2 has ADAM-4019 command codes against input ranges table.

<table>
<thead>
<tr>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration time</td>
<td>Not used</td>
<td>Data Format</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0:50 ms (operation under 60 Hz power)</td>
<td>0:Enabled</td>
<td>00:Engineering units</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: 60 ms (operation under 50 Hz power)</td>
<td>1: Disabled</td>
<td>01:% FSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10:two’s compliment of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>hexadecimal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11: ohms (for 4013) and 4015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Checksum status
0:Disabled
1: Enabled

Figure A 3.3 Format for 8-bit parameter for ADAM-4019
**TABLE A 3.2 ADAM-4019 Command codes against input ranges.**

<table>
<thead>
<tr>
<th>Command Code (Hex)</th>
<th>Input Type</th>
<th>Input Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>mV</td>
<td>-100mA</td>
</tr>
<tr>
<td>03</td>
<td>mV</td>
<td>-500 mA</td>
</tr>
<tr>
<td>04</td>
<td>V</td>
<td>-1 V</td>
</tr>
<tr>
<td>05</td>
<td>V</td>
<td>-2.5 V</td>
</tr>
<tr>
<td>08</td>
<td>V</td>
<td>-10 V</td>
</tr>
<tr>
<td>09</td>
<td>V</td>
<td>-5 V</td>
</tr>
<tr>
<td>0D</td>
<td>mV</td>
<td>-20mA</td>
</tr>
<tr>
<td>0E</td>
<td>Thermocouple, J</td>
<td>0 C to 760 C</td>
</tr>
<tr>
<td>0F</td>
<td>Thermocouple, K</td>
<td>0 to 1370 C</td>
</tr>
<tr>
<td>10</td>
<td>Thermocouple, T</td>
<td>-100 to 400 C</td>
</tr>
<tr>
<td>11</td>
<td>Thermocouple, E</td>
<td>0 to 1400 C</td>
</tr>
<tr>
<td>12</td>
<td>Thermocouple, R</td>
<td>500 to 1750 C</td>
</tr>
<tr>
<td>13</td>
<td>Thermocouple, S</td>
<td>500 to 1750 C</td>
</tr>
<tr>
<td>14</td>
<td>Thermocouple, B</td>
<td>500 to 1800 C</td>
</tr>
</tbody>
</table>

Analog Data In: The command will return the input value from a specified (AA) module in the currently configured data format.

**Syntax:**  #AA(cr)

# is a delimiter character. AA (range 00-FF) represents the 2-character hexadecimal address of an analog input module. (cr) is the terminating character, carriage return (0Dh).

**Response** > (data)(cr). There is no response if the module detects a syntax error or communication error or if the specified address does not exist.

> is a delimiter character. (data) is the input value in the configured data format of the interrogated module. (cr) is the terminating character, carriage return (0Dh).
A 3.4 ADAM-4021 ANALOG OUTPUT MODULE

Analog output module receives their digital input through an RS-485 interface from the host computer. The format of the data is either engineering units, twos complement hexadecimal format or percentage of full-scale range (FSR), depending on the module’s configuration. It then uses its microprocessor-controlled DAC converter to convert the digital data into output signals. One can specify slew rates and start up currents through the configuration software. The Analog Output Module can supply single-channel analog output in a range of voltages or currents. They protect your equipment from ground loops and power surges by providing opto-isolation of the DAC output and transformer based isolation up to 3000 V DC. The slew rate is defined as the discrepancy between the number of mA (or Volts) per second of the present and the required output currents (or voltages). An ADAM analog output module may be configured for a specific slew rate. Figure A 3.4 shows the front view of ADAM-4021.

Depending on its configuration settings the module accepts the following formats from the host computer:- Engineering units, Percent of Full-Scale Range (FSR), Two’s complement hexadecimal format.

Output types: Voltage: 0 to 10 V (Slew rate: 0.0625 to 64 V/sec), Currents: 0 to 20 mA, or 4 to 20 mA. (Slew rate: 0.125 to 128 mA/sec)
A 3.4.1 Command set for Analog output Module (4021)

Configuration: Sets address, input range, baud rate, data format, checksum status, and/or integration time for an analog output module.

Syntax: \%AANNTTCCFF(cr)

\% is a delimiter character. AA (range 00-FF) represents the 2-character hexadecimal address of the analog output module to be configured. NN represents the new hexadecimal address of the analog output module. Range is from 00h to FFh. TT represents the type (output range) code. CC represents the baud rate code. FF is a hexadecimal number that equals the 8-bit parameter representing the status of data format, slew rate, and check-sum.

The layout of the 8-bit parameter is shown in Figure A 3.5. Bit 7 is not used and must be set to 0. (cr) is the terminating character, carriage return (0Dh).
**Figure A 3.5 Format for 8-bit parameter for ADAM-4021**

Analog Data Out: Send a value to the addressed analog output module. Upon receipt, the analog output module will output this value.

Syntax:  `#AA(data)(cr)`

# is a delimiter character. AA (range 00-FF) represents the 2-character hexadecimal address of an analog output module. (data) is the value that has to be output through the analog output module. Range and value depend on the module’s configured data format.
APPENDIX 4

THREE TANK

A 4.1 Three tank system

Make : VI Micro systems Pvt. Ltd, Chennai-600 096, India

Tank area : 0.0154 m²

Cross section area of interconnecting pipe : 0.005 m²

Height of the tank : 0.63 m

Nominal value of h₁ : 0.32 m

Nominal value of h₃ : 0.20 m

Output : 4 to 20 mA

Accuracy : ± 0.1%

Input : 0 to 0.6 m

Power supply : 12 to 45 V DC

A 4.2 Pump

Speed : 20 to 200 rpm

Flow rate : 3.3×10⁻⁷ to 5.0×10⁻⁵ m³/s

Tube diameter : 12 mm

Pressure : 2 kg / sq. cm (Maximum)

Power supply : 230 V, 50 Hz, AC

A 4.3 DPT specifications

Upper Range Limit : 750 inches of WC (186.4 kPa)

Minimum span : 2 inches of WC (0.5 kPa)