Keep it Cheap: EPICS Devices for the Small Laboratory

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Motivation

- Mainly use EPICS on beamlines (or to run large detectors)
  - Beamlines typically VME based
  - Initial investment in VME crate and CPU is nearly $8,000.
- Small laboratory
  - No VME crates
  - Want to keep costs low
- All of the devices I'll talk about today can be used on beamlines too!

Example Applications
GSECARS Laboratory EPICS systems

- Micro-Raman and ruby fluorescence system.
  - 4 stepper motors
- Laser heating and laser machining system.
  - 8 stepper motors
  - Berkeley Nucleonics BNC-505 pulse generator
  - IPG Photonics 100 W laser
- Gas loading system for diamond anvil cells
  - 4 stepper motors
  - Koyo PLC for safety system.
  - Laser system interlocks
  - Omega panel meter for pressure reading and pressure interlock setpoints
- Want to automate an x-ray lab at the University of Chicago
  - Diffractometer
  - Bede scintillation detector with scaler

Devices to be Presented

- ACS MCB-4B motor controller
- Koyo PLCs with Modbus
- Measurement Computing USB devices
  - USB-4303 Counter/timer module
  - USB-1608GX-2AO analog input/output module
- Plus brief mention of some other RS-232 devices

8-Axis Stepper Motor System Cost

	MAXv and Step-Pak	**Newport XPS**	**Delta Tau GeoBrick LV IMS-II**	**ACS MCB-4B**
	MAXv $2,800	XPS-C8 $7,652	GeoBrick $7,015	MCB-4B ($915*2) = $1,830
	ACS Chassis, Transformer, Interface $3,225	DRV-01 driver ($571*8) $4,568	Power supply $522	Power supply+frames $265+$400=$665
	SPD-6U driver ($565*8) = $4,520			Moxa 2-channel terminal server $175
	VME slot (varies!) $1,000			Chassis, connectors $300
$ Total	$11,545	$12,220	$7,537	$2,970
$ per axis	**$1,440**	**$1,530**	**$942**	**$370**

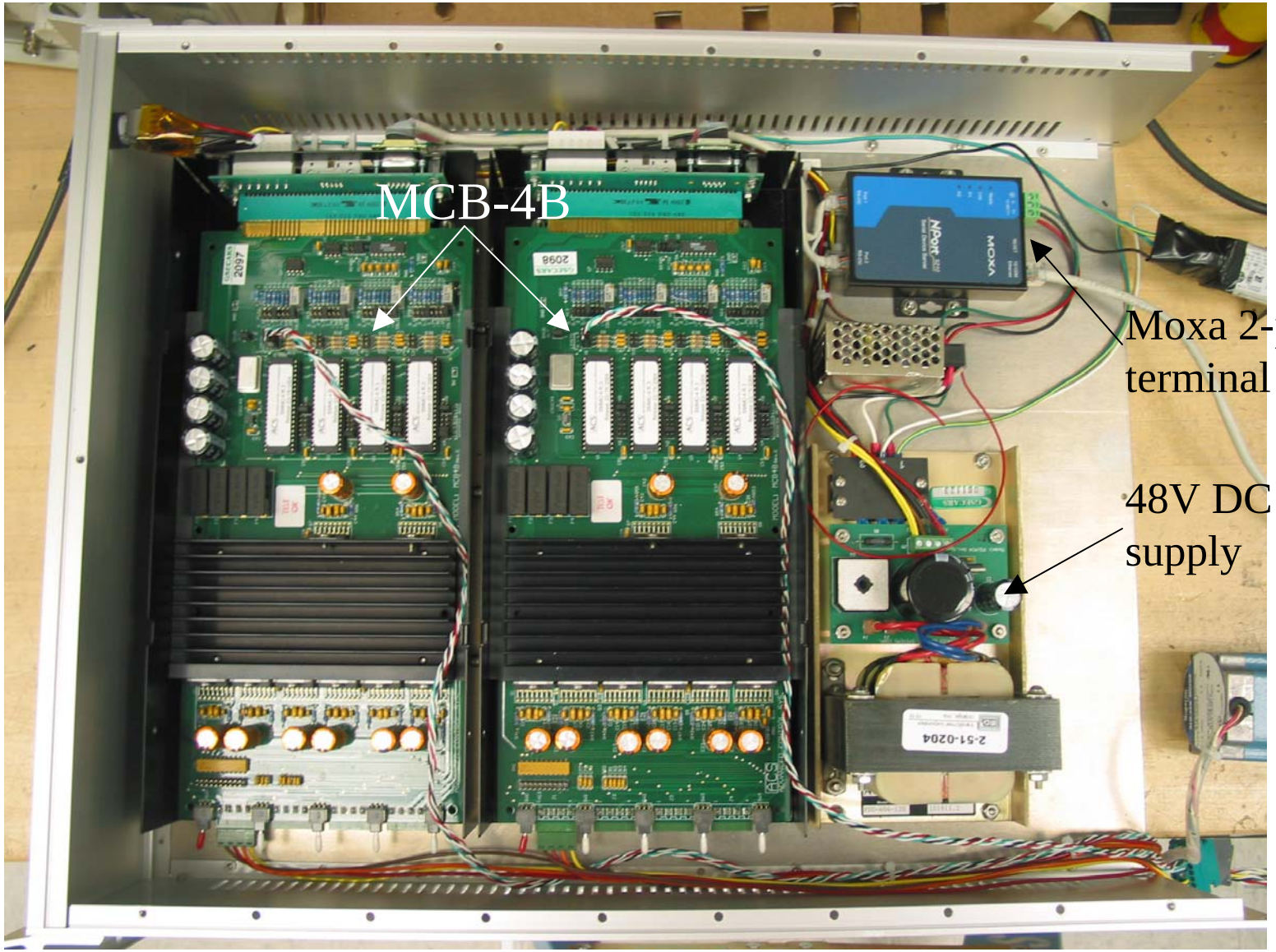
ACS MCB-4B

- MAXv, XPS, and GeoBrick are all much more sophisticated
  - Can control servos and steppers
  - Auxilliary I/O, complex motions, etc.
- But for simple stepper control with currents up to 3A then the MCB-4B is 3 to 4 times cheaper
- MCB-4B Features:
  - 4-axis controller and driver
  - RS-232 or RS-485 interface
  - Bipolar driver
  - 0.25A to 3A drive current
  - Full, 1/2, 1/4, 1/8 step
  - Limits and home inputs
- EPICS support for motor record is in “motor” module, has been used for over 8 years.

ACS MCB-4B in GSECARS 19” rack-mount enclosure

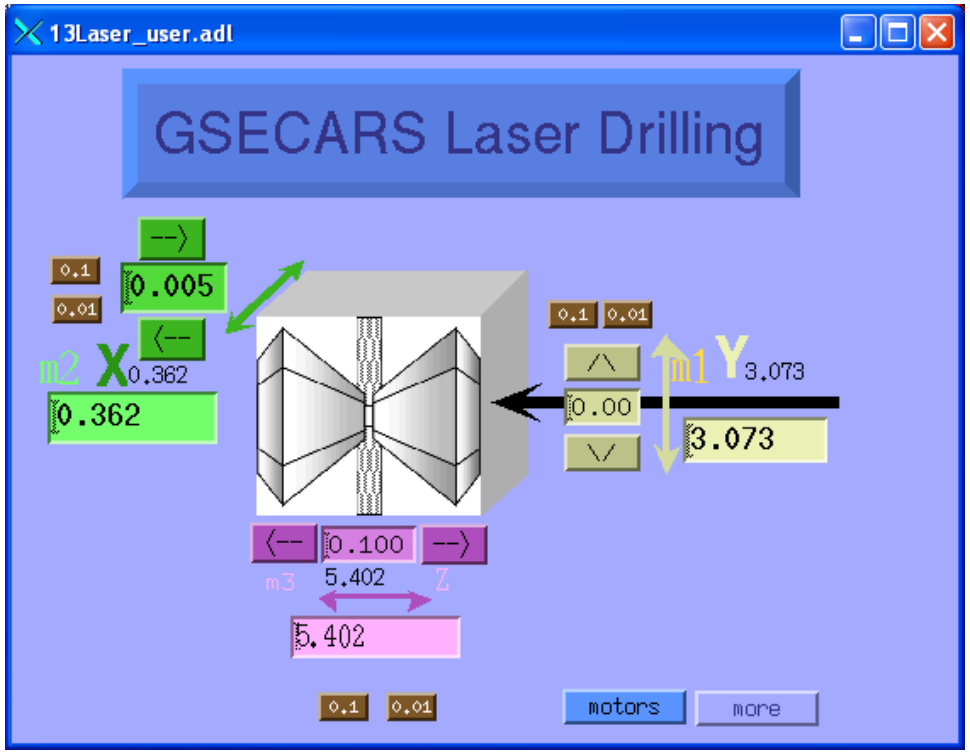
Front panel: Power button/indicator

Rear panel: Power plug, Ethernet RJ-45, 8 Elco connectors



Offline Laser Heating and Laser Machining System

- 8 stepper motors
- IPG Photonics 100 W near-IR laser
- Berkeley Nucleonics BNC-505 pulse generator for laser pulse-width modulation



Laser Machining System

IPG_YLR_laser.adl

IPG YLR Laser
13Laser:Laser1

Power (W): 5.00

Laser Emission
On
Off On

Diode Current
Percent Amps
14.150 1.12
1.000

Power filter time (s): 0.4 0.40
Temperature (C): 18.7 OK
Back Reflection: OK
Emission starting: Not starting
Connection: Connected
Failure: OK
Laser enabled: Enabled
Modules enabled: Enabled
Power supply: On
Collimator: Connected
Control: OK
Key switch: Remote
Modulation: Enabled Enable Disable
Analog Control: Disabled Enable Disable
Aiming beam control: RS-232 TTL RS-232
Aiming beam: Off On Off
Status: 0x205004
Reset errors: Reset
Firmware: 1.0.103
Communications: OK
Status rate: 1 second
more

BNC_505.adl

BNC 505 Pulse/Delay Generator
13Laser:BNC1:

Main setup
Run Stop Run
Period 8.0000e-005 < 1.000e-005 >
Mode Normal
Burst count 4
Pulse count 3
Off count 2

External input
Mode Disabled
Level 2.5000
Edge Rising
Polarity High

Output pulse setup
Output pulses

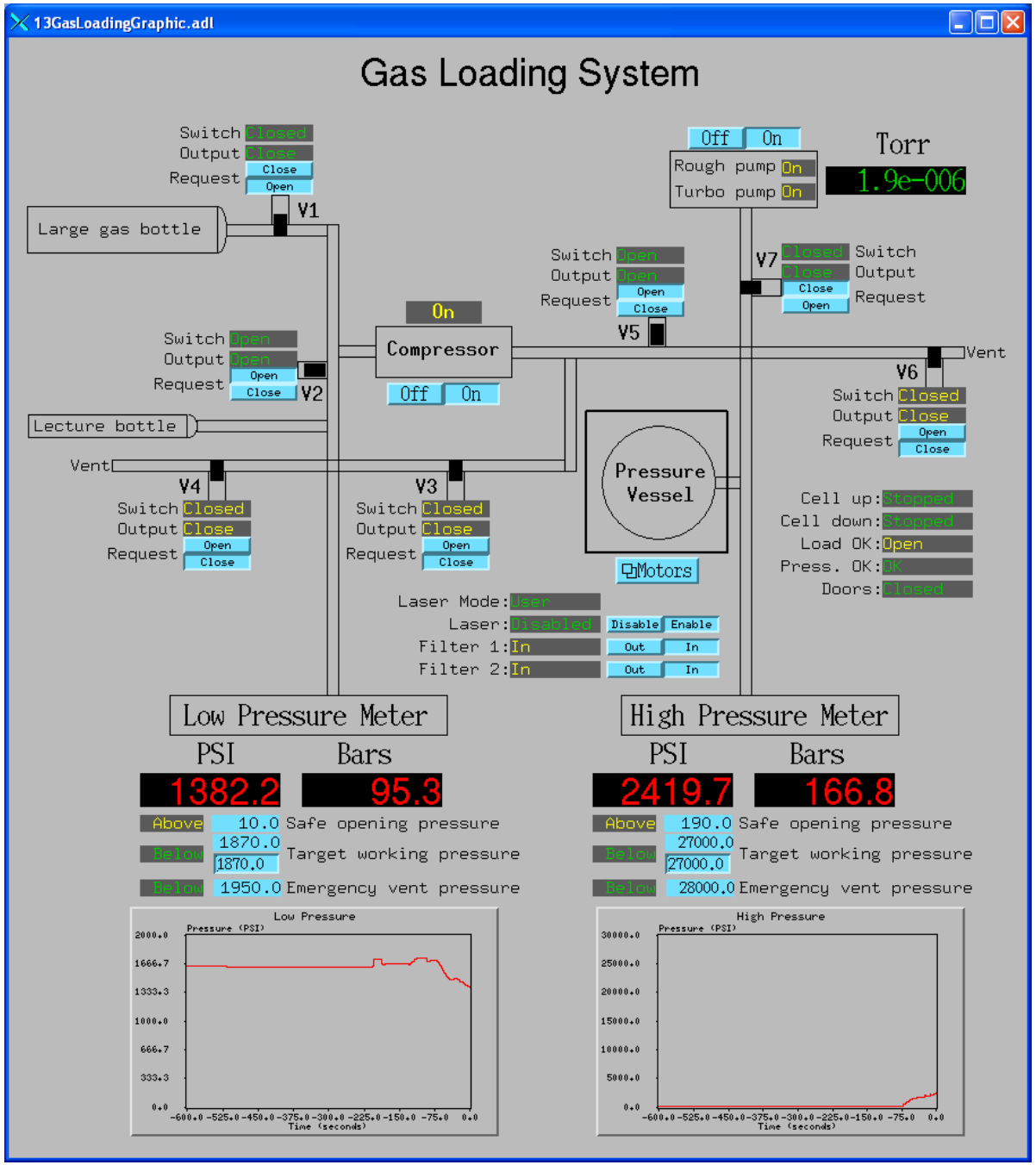
GSECARS Gas Loading System

- Load gases (He, Ne, etc.) in diamond anvil cell at pressures up to 30,000 PSI (2 kbar)
- Safety is critically important. Must be safe in hands of inexperienced user.
- Interlocked heavy-duty enclosure (3/8”” aluminum, ¾” plywood). All high-pressure components inside enclosure
- Gas loaded from lecture bottle to limit total mass (energy) that can be compressed in pressure vessel.
  - Protects against user forgetting to load cell or filler parts.

GSECARS Gas Loading System

- Air-operated high-pressure valves under PLC control
- Pressure meters on both low and high pressure systems which will vent before rupture disk fails
- Koyo PLC handles interlocks (valves, compressor, laser)
- EPICS makes requests to PLC and reads status via Modbus
- EPICS controls motors, reads Omega pressure gauges, vacuum gauge, etc.

Gas Loading System in Cabinet



GSECARS Gas Loading System

EPICS Control System Screen

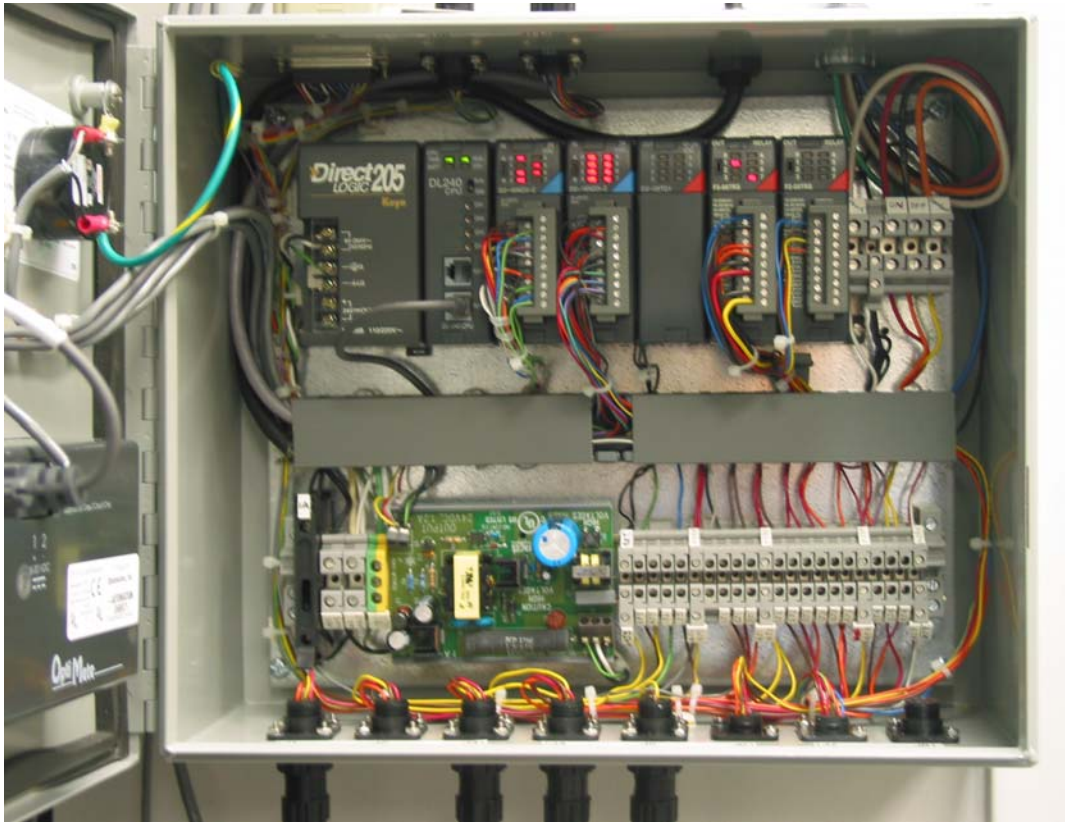
- EPICS IOC runs on Windows PC.
  - Controls 4 serial devices
    - 2 Omega panel meters
    - Vacuum pump and gauge
    - ACS MCB-4B motors
  - Controls and reads PLC through Modbus over Ethernet

Koyo PLC

Koyo PLC in GSECARS laser lab. Implements laser safety interlocks.

Gas loading system is the same, except it has Ethernet communications module for Modbus communications.

Both have OptiMate panel for local control and display.



Koyo PLC

- Digital input, digital output, relay output, analog to digital, digital to analog, many others
- Typically used for dedicated control systems like safety
- Modbus communications module allows it to be used simply as an EPICS I/O platform, quite inexpensive

6-slot base	$167
CPU D2-240	$219
Ethernet Communication Module	$299
32-channel digital input module	$120
32-channel digital output module	$122
8-channel 12-bit analog input	$264
8-channel 12-bit analog out	$269
TOTAL	**$1,460**

Modbus

- Communications protocol initially developed for communications with PLCs.
- Very simple communication model
  - *Modbus client* sends a *request message* to a *Modbus server*. The server replies with a *response message*.
  - All I/O is addressed to single bits or 16-bit registers
  - Blocks of up to ~125 registers or 2000 single bits can be read or written in a single operation

Modbus Communication Links	
Link type	**Description**
TCP	TCP/IP using standard port 502.
Serial RTU	Serial protocol, using RS-232, RS-422, or RS-485. The protocol directly transmits each byte as 8 data bits, so uses "binary" rather than ASCII encoding. The start and end of message frames is detected by timing rather than by specific characters.
Serial ASCII	Serial protocol, using RS-232, RS-422, or RS-485. The protocol encodes each byte as 2 ASCII characters. The start and end of message frames is detected by specific characters (":" to start a message and CR/LF to end a message). This protocol is less efficient than RTU, but may be more reliable in some environments.

Modbus

Modbus Data Types			
Primary tables	**Object type**	**Access**	**Comments**
Discrete Inputs	Single bit	Read-Only	This type of data can be provided by an I/O system.
Coils	Single bit	Read-Write	This type of data can be alterable by an application program.
Input Registers	16-bit word	Read-Only	This type of data can be provided by an I/O system.
Holding Registers	16-bit word	Read-Write	This type of data can be alterable by an application program.

Modbus Function Codes		
Access	**Function description**	**Function code**
Bit access	Read Coils	1
Bit access	Read Discrete Inputs	2
Bit access	Write Single Coil	5
Bit access	Write Multiple Coils	15
16-bit word access	Read Input Registers	4
16-bit word access	Read Holding Registers	3
16-bit word access	Write Single Register	6
16-bit word access	Write Multiple Registers	16

Modbus addresses for Koyo PLCs

- Important point: can directly access inputs and outputs via Modbus
  Don't need ladder logic program
  Not all PLC vendors use this model
  In safety system OK to directly read inputs, but outputs should be requests written to memory bits which the PLC only honors if it is safe!

Modbus Addresses for Koyo DL05/06/240/250/260/430/440/450 PLCs		
PLC Memory Type	**Modbus start address Decimal (octal)**	**Function codes**
Discrete inputs and coils		
Inputs (X)	2048 (04000)	2
Special Relays (SP)	3072 (06000)	2
Outputs (Y)	2048 (04000)	1, 5, 15
Control Relays (C)	3072 (06000)	1, 5, 15
Timer Contacts (T)	6144 (014000)	1, 5, 15
Counter Contacts (CT)	6400 (014400)	1, 5, 15
Stage Status Bits (S)	6144 (012000)	1, 5, 15
Input registers and holding registers (V memory)		
Timer Current Values (TA)	0 (00)	4
Counter Current Values (CTA)	512 (01000)	4
Global Inputs (VGX)	16384 (040000)	4
Global Outputs (VGY)	16512 (040200)	3, 6, 16
Inputs (VX)	16640 (040400)	4
Outputs (VY)	16704 (040500)	3, 6, 16
Control Relays (VC)	16768 (040600)	3, 6, 16
Stage Status Bits (VS)	16896 (041000)	3, 6, 16
Timer Contacts (VT)	16960 (041100)	3, 6, 16
Counter Contacts (VCT)	16992 (041140)	3, 6, 16
Special Relays (VSP)	17024 (041200)	4

Modbus EPICS Support

- I’ve written EPICS Modbus driver that supports almost all features, including serial-RTU, Serial-ASCII, and TCP.
- Runs on all EPICS platforms.
- Uses standard asyn device support on top and standard asyn serial or IP driver below.
  - Code is small, fewer than 2,500 lines of code.
- Modbus read functions are done using a driver poller thread so input records can have SCAN=I/O Intr.

- Note: Modbus does not support floating point values, but some vendors do it anyway. No standard on the floating point format or the order of the 16-bit words in a 32-bit or 64-bit float.
  - Eric Norum has provide database kludge that works for some vendors.

Measurement Computing Corporation

- Inexpensive I/O devices
- PCI, USB, Ethernet
- Example USB devices
  - DAQ module with 8 analog inputs, up to 12-bit resolution, 50 kS/s, two D/A outputs, and 16 digital I/O lines $189.00
  - 8-channel quadrature encoder device (differential or single-ended) $599.00
  - 8-channel electromechanical relay interface device $249.00
  - 8-channel thermocouple input module $329.00
  - 16-channel, 500 kS/s device with two analog outputs, eight DIO lines, two 32-bit counter inputs, and one timer output $799.00
  - 10-channel, 16-bit, high-performance 9513-based counter/timer device $349.00
- I've purchased the last 2 (USB-1608GX-2A0, and USB-4303) and written EPICS drivers for them

Measurement Computing Corporation

- Original motivation was need for an non-VME scaler for the x-ray lab at University of Chicago
  - Only other solution I knew of was the Ortec 974, NIM module, only 2 channels, expensive. USB-4303 seemed like a possible solution.
- Recently got the USB-1608GX-2A0, which provides analog input and output. Very nifty device!

USB-1608GX-2A0 ($799)

- 16-bit analog inputs
  - 16 single-ended channels or 8 differential channels
  - Programmable per-channel range: +-1V, +-2V, +-5V, +-10V
  - 500 kHz total maximum input rate, i.e. 1 channel at 500 kHz, 8 channels at 62.5 kHz, etc.
  - Internal or external trigger. External trigger shared with analog outputs.
  - Internal or external clock, input and output signals.
  - 4 kSample input FIFO, unlimited waveform length
- 16-bit analog outputs
  - 2 channels, fixed +-10V range
  - 500 kHz total maximum input rate, i.e. 1 channel at 500 kHz, 2 channels at 250 kHz
  - Internal or external trigger. External trigger shared with analog inputs.
  - Internal or external clock, input and output signals
  - 2 kSample output FIFO, unlimited waveform length

USB-1608GX-2A0 ($799)

- Digital inputs/outputs
  - 8 signals, individually programmable as inputs or outputs
- Pulse generator
  - 1 output
  - 64MHz clock, 32-bit registers
  - Programmable period, width, number of pulses, polarity
- Counters
  - 2 inputs
  - 20 MHz maximum rate, 32-bit registers

Measurement Computing EPICS Support

- They provide a nice Windows library for all of their devices. Very few calls to get a lot of functionality.
- Some of their older devices have Linux support from Dr. Warren J. Jasper at NCSU:
  - ftp://lx10.tx.ncsu.edu/pub/Linux/drivers
- Measurement Computing have recently released drivers for a few new devices (including USB-1608G) using a new open-source message based driver, with support for Linux, Mac and Windows.
  - However, the driver is written in C#, and so to use it on Linux requires the "mono" compiler for Linux. I don't think one can call it from gcc/g++, but I am not sure.
  - The C# driver is open-source, so it should definitely be possible to rewrite it in C++.
- For now my drivers use the Windows-only library.

USB-1608GX-2AO EPICS Support

- Based on asynPortDriver
- Standard asyn device support
- 1250 lines of code
- Digital I/O
  - 8 bi records, 8 bo records, longin, longout
- Pulse generator
  - Control of pulse period (frequency), width, count, polarity
- Analog input
  - ai records, periodically scanned. Programmable range per channel.
- Analog output
  - ao records

USB-1608GX-2AO
EPICS Waveform Generator Support

- Global control
  - Internal/external trigger
  - Internal/external clock
  - Retrigger, retrigger count
  - Continuous/one-shot (hardware)
- Predefined waveforms (defined in driver, not by device)
  - Types
    - Sin wave
    - Square wave
    - Sawtooth
    - Pulse (adjustable width)
    - Random (white noise)
  - Control
    - Number of points in waveform
    - Repeat frequency (or time per point)
    - Amplitude
    - Offset

USB-1608GX-2AO
EPICS Waveform Generator Support

- User-defined waveforms (arbitrary waveform generator)
  - Waveforms defined by external application (e.g. Matlab, IDL, Python) and downloaded to waveform record over Channel Access
  - Control
    - Number of points in waveform
    - Repeat frequency (or time per point)
- Waveforms are defined in volts, not device units
- 16-bit output, maximum 500,000 output voltages/s
- Only limit on number of points is available RAM.

USB-1608GX-2AO
EPICS Waveform Digitizer Support

- Control
  - Number of points to digitize
  - Time per point
  - First channel to digitize
  - Number of channels to digitize
  - Burst mode (all channels measured as close together in time as possible)
  - Internal/external trigger
  - Internal/external clock
  - Retrigger, retrigger count
  - Continuous/one-shot (hardware)
  - Auto-restart (software)
  - Read rate to read device into waveform records. Automatically reads when acquisition completes.
- Waveforms are read in volts, not device units
- 16-bit input, maximum 500,000 conversions/s
- Only limit on number of points is available RAM.

Measurement Computing Breakouts

- Using standard BCDA BC-020 LEMO breakout
- For both the 1608GX-2A0 and the USB-4303 the cost of the 2 BC-020 and daughter cards exceeds the cost of the USB device! (~$450 per BC-020)
- Use BC-087 daughter card (designed for IP-EP201 IPSoftGlue FPGA IP module) for digital signals, supports all 32 LEMO connectors
- Use BC-026 daughter card (designed for IP-330 ADC) for analog signals. Supports 16 LEMOs with isolated shells for differential signals.

USB-1608GX-2A0

- Demo

USB-4303 ($349)

- Architecture
  - 2 C9513 counter/timer chips
  - 8 digital input
  - 8 digital output
- C9513
  - 5 16-bit counter timers
  - Programmable on-chip interconnects between them

USB-4303 EPICS Support

- Based on asynPortDriver
- Standard asyn device support
- 750 lines of code
- Digital I/O
  - 8 bi records, 8 bo records, longin, longout
- Pulse generator
  - 10 16-bit pulse generators
- Counters
  - 10 16-bit counts. With understanding of how the C9513 chips work quite complex timing/counting is possible.
- EPICS scaler record. Provides preset timer, 4 32-bit counter channels, 1 16-bit counter channel
  - Preset timer is only 16-bits, but the input frequency is automatically changed from 5 MHz through 500 Hz to maximize precision

USB-4303 Demo

- Show binary I/O
- Pulse generator
- Individual timers
- EPICS scaler record