PPPL Calculation Form - No: 2327-CALC-007

Calculation # 000 ______NA________ Revision # 0 ____ WP #, if any 2327

(ENG-032)

Purpose of Calculation: **(Define why the calculation is being performed.)**

Data Bandwidth Usage Calculation

Codes and versions: (List all codes, if any, used)

n/a

References **(List any source of design information including computer program titles and revision levels.)**

[1] *Simple, Complete Ethernet Data Acquisition*, National Instrument Newsletter

[2] *NSTX-U System Design Description - Central Instrumentation & Control*, PPPL

[3] *Maximum Throughput on the NI cDAQ-9188 or cDAQ-9188XT*, National Instrument Support

Assumptions **(Identify all assumptions made as part of this calculation.)**

We derive the data bandwidth from the performance data provided in NI articles.

The capacity of analog input channels *N* could be predicted as below:

$$N = 10^{6} \times 4 \div 5 \div 10^{3} = 800$$

Calculation **(Calculation is either documented here or attached)**

In total ,the network theoretically support up to 14400 channels AI data acquisition at rate of 5 kS/s.

In current CAMAC systems, the maximum number *N* of channels of simultaneous analog input is counted as below

$$N = 16 \times 4 + 32 \times 12 + 32 \times 9 = 608$$

Conclusion **(Specify whether or not the purpose of the calculation was accomplished.)**

This number is smaller than predicted capacity of cDAQ system no matter using NI provided data or our own experimental data. Based our own experimental data, we would have very large spare capacity to grow in the future.

Cognizant Individual (or designee) printed name, signature, and date

Fanghao Yang (Fanghao out on leave 7/31/2018) GREGORY J TCHILINGUIRIAN Digitally signed by GREGORY J TCHILINGUIRIAN Date: 2018.07.31 11:00:37 -04'00'

Preparer's printed name, signature and date

I prepared the calculation. I can't sign it becase I was in maternity leave. Fanghao Yang 9/21/2018

Fanghao Yang GREGORY J TCHILINGUIRIAN Digitally signed by GREGORY J TCHILINGUIRIAN Date: 2018.07.31 11:04:34 -04'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

GREGORY J TCHILINGUIRIAN Digitally signed by GREGORY J TCHILINGUIRIAN Date: 2018.07.31 10:59:31 -04'00'

Final Calculation

Data Bandwidth Usage Calculation

Fanghao Yang, Paul Sichta

AI Data Bandwidth Estimate by Using NI Data

Consider the large overhead of data operation and memory access, the cDAQ system may not be able to fully utilize all data bandwidth of a Gigabit ethernet link. Without knowing the implementation details of the data streaming technology in NI cDAQ product, it is difficult to theoretically predict the upper limits of samples transferred by NI cDAQ system in fixed amount of time. However, we could derive the data bandwidth from the performance data provided in NI articles.

According to a NI article[1], it states that "*To take advantage of the 1,000 Mbits/s of bandwidth on a Gigabit Ethernet network, NI CompactDAQ chassis implement a TCP/IP version of the same patented NI Signal Streaming technology found on high-performance NI USB data acquisition (DAQ) products. With this technology,* ***new high-speed C Series modules, such as the NI 9223, can continuously acquire up to 1 MS/s of simultaneous 16-bit data on each of four channels****. Using a sophisticated software architecture, NI-DAQmx driver software maintains a double-buffered transfer mechanism between the chassis and host computer capable of sustaining* several *bidirectional continuous waveforms. At the same time, the driver monitors the state of the network to adjust for unexpected delays or temporary interruptions. All of this is abstracted from the user, so you can focus on the measurement application and not the network.*"

Based on above information, we know the acquired data could be streamed to a PC up to 1 MS/s of simultaneous 16-bit data on each of four channels. NI patented technology may provide high sampling capacity to a data acquisition system thru ethernet link which was only available thru PCI/PCI-E bus on a PC. If we use the same bit depth for cDAQ data acquisition and the current sampling rate is selected as 5 kS/s, a number of analog channels may be acquired simultaneously. The capacity of analog input channels *N* could be predicted as below:

$$N = 10^{6} \times 4 \div 5 \div 10^{3} = 800$$

AI Data Bandwidth Estimate by Using Test Data

Currently, CAMAC systems are mostly sampling data at 5 kS/s. In our experimental test, the peak throughput at 5 kS/s for 10k samples were measured. This result could be used to estimate the maximum channel capacity and how much we could expand cDAQ system in the same Ethernet if running at the same speed.

The test result indicates the data streaming only uses up to 1.1 Mbps. In current test, one NI 9401 AI module were used. Thus, for a 1 Gbps private network, we may use up to 900 AI modules. Because every 9401 module supports 16 AI channels. In total ,the network theoretically support up to 14400 channels AI data acquisition at rate of 5 kS/s.

Comparison between cDAQ and CAMAC

Then, the number of current analog input channels used by CAMAC modules need to be compared to the predicted capacity of cDAQ system. The usage of CAMAC modules is listed in CI&C SDD[2]. It shows all analog ADC modules as highlighted by yellow background in a table as below.

Module	Manufacturer	Description	# in use
OD48	Interface Standards	DUAL 24-BIT REGISTER DIGITAL OUTPUT MODULE	1
P2 debounce	PPPL	KLUGE MODULE TO DE-BOUNCE P2	1
P002	PPPL	16-CHANNEL PPPL-MADE SIGNAL CONDITIONER	2
60A	Jorway	Dual Channel Input Register	2
302	BiRa and Jorway	Relay Digital Output Module	30
304	BiRa	Opto-Isolated Digital Output Module	4

307	Standard Eng.	16 CHANNEL SCANNING ADC [0-10V]	8
313	BiRa	U-Port Module	24
320	Joerger	16-Channel Digital ADC Module	4
321	Aeon and Jorway	8-Channel Digital to Analog Module	2
322	Aeon and BiRa	16-Channel Digital Input Module	164
352	BiRa	Fiber Optic Link Repeater	3
353	PPPL	4-CHAN SERIAL COUNTER MODULE	1
359	Joerger	Multiplexing Analog Signal Conditioner Module	14
367	PPPL	Pattern Generator	1
401-2	PPPL	Facility Clock Subsystem (Clock Encoder Module)	1
404	PPPL, Interface Standards, and BiRa	Timing Module	19
408	BiRa	Serial Time Interval Counter Module	3
409	Jorway and Kinetic Systems	Timed Gate Module	11
410	PPPL	4-Channel Shot Counter Module	1
412	Jorway/I-standard	Timing and Sequencing Module	6
413	BiRa	Parallel Time Interval Counter	1
903	BiRa and Kinetic Systems	Remote Memory for 908 Digitizers- 32K	14
908	BiRa	32 Channel Transient Digitizer	12
910	BiRa	Function Generator Module	1
1903	PPPL	Remote Memory for 908 Digitizers- 1Meg	1
3232	Aeon	Transient Digitizer, Higher input impedance than 908. 10v range	9
3271	Kinetic Systems	Voice Module	1
3340	Kinetic Systems	Communication Interface	3
3421	Kinetic Systems	Digital Input (344)	2

After checking the table, there are three types of simultaneous analog input modules: 320, 908 and 3232. 307 is an ADC module but scanning type, which may operate at much lower acquisition rate and requires lower data bandwidth.

In current CAMAC systems, the maximum number *N* of channels of simultaneous analog input is counted as below

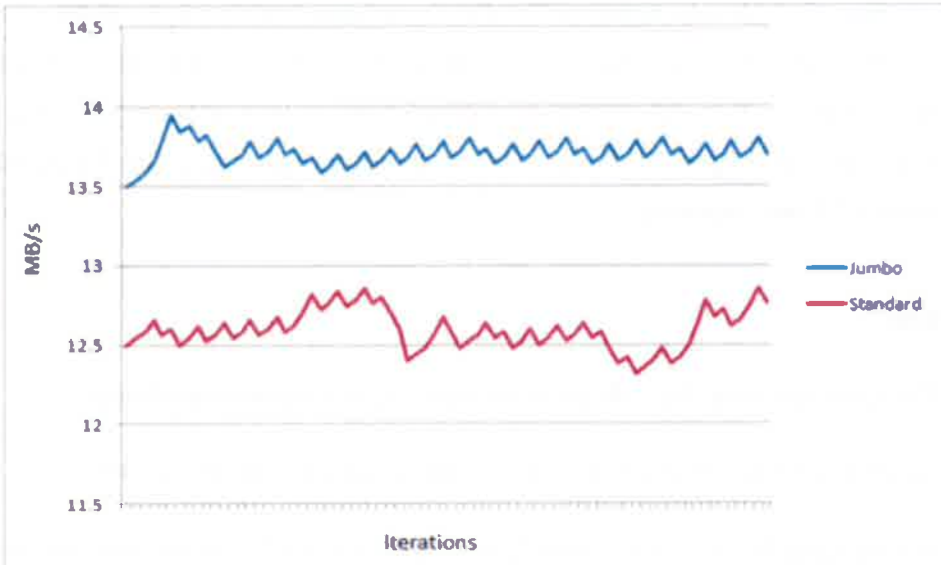
$$N = 16 \times 4 + 32 \times 12 + 32 \times 9 = 608$$

This number is smaller than predicted capacity of cDAQ system no matter using NI provided data or our own experimental data. Based our own experimental data, we would have very large spare capacity to grow in the future. Thus, in conclude, the Gigabits Ethernet network may provide enough bandwidth to replace all CAMAC simultaneous analog input modules with a single ethernet link between the controller PC and the Ethernet switch.

DIO Data Bandwidth Estimate

There might be other data acquisition tasks which takes a large portion of bandwidth. For example, there are 164 of 322 CAMAC modules as shown in the orange band in the above table, which equals 2624 digital input channels. If assume every digital channel takes 100 kbit/s bandwidth for maximum 10 μs transmission delay for each bit, it would be in total 100 x 2624 kbit/s, which is 32.8 MB/s bandwidth.

The maximum throughput of cDAQ 9184/9185 is not provided by NI. But the maximum throughput of cDAQ 9188, which may use similar data streaming technology, was provided by NI[3]. The graph below shows the typical throughput performance using digital input on the cDAQ-9188 comparing Standard and Jumbo Frames.



Maximum Data Throughput of cDAQ 9188 Chassis

As shown in the graph, 12.3 to 12.8 MB/s data throughput could be achieved on cDAQ system with a Gigabit ethernet link. Using the lower limit of the data transfer speed, the bandwidth used by all CAMAC digital input modules is 32.8 MB/s, which is 266% of 12.3 MB/s. It is significantly larger than maximum data throughput of a single cDAQ chassis. If we reduce the data transfer rate of digital input channels to 50 kbit/s, the total usage of bandwidth would be 16.4, which still exceeds the upper limit of a cDAQ chassis.

Based on above calculation, it may use most data streaming throughput and approach or beyond its upper limit to replace all current CAMAC modules with a cDAQ chassis in a single Gigabit ethernet link. In a real system, we may not push the DIO to its maximum rate and we would have multiple cDAQ chassis and controllers for all DIO ports.

In all, it suggests that the cDAQ systems should use its private network to avoid data traffic and possible data dropout because if the onboard buffer is overflown, some important data may be overwritten by following data. It is also suggested to separate important data acquisition tasks with other tasks on the same tasks. If possible, a network scheduler algorithm may manage network traffic and provide QoS (quality of service) to important data acquisition tasks. And we may provide multiple ethernet link on the controller (the PC running DAQmx service) to extend the network bandwidth and support more data acquisition channels.

It worth to mention that all calculation and estimate is based on a single cDAQ chassis on a single Gigabit ethernet link. In current systems, multiple cDAQ chassis would be distributed in a data acquisition network. It is still unknown whether more or less network resource would be used with such distributed systems. It may be included in our future test plan for cDAQ systems to replace current CAMAC systems.

Reference

[1] *Simple, Complete Ethernet Data Acquisition*, National Instrument Newsletter

[2] *NSTX-U System Design Description - Central Instrumentation & Control*, PPPL

[3] *Maximum Throughput on the NI cDAQ-9188 or cDAQ-9188XT*, National Instrument Support