ICS ELECTRONICS
division of Systems West Inc.

IEEE 488 APPLICATION BULLETIN

EXTENDING THE GPIB BUS

INTRODUCTION

IEEE-488 Bus users continue to seek creative and low cost solutions to the problems caused by the GPIB Bus limitations. Our last edition of "Extending the IEEE-488 Bus into the '90s", addressed many of these problems but since that time, much has changed. Some products have been discontinued and other new and exciting products have been introduced. The IEEE-488.2 Standard has also changed our expectations of what GPIB products should do.

Therefore it was time to update the "Extending the IEEE-488 Bus into the '90s" application note to reflect these changes and to include a current list of available Bus extension products.

All data presented here was obtained from the manufacturers' data sheets or from factory applications personnel. If our material inadvertently contains errors or omissions, they are unintentional. It is our desire to make this note as helpful as possible so that you may construct the most effective IEEE-488 Bus system possible.

BASIC LIMITATIONS

The IEEE-488 Bus has proven to be a good method of interconnecting instruments and computers, because it is simple to use and takes advantage of a large selection of programmable instruments and stimuli. Large systems, however, are hampered by the following limitations:

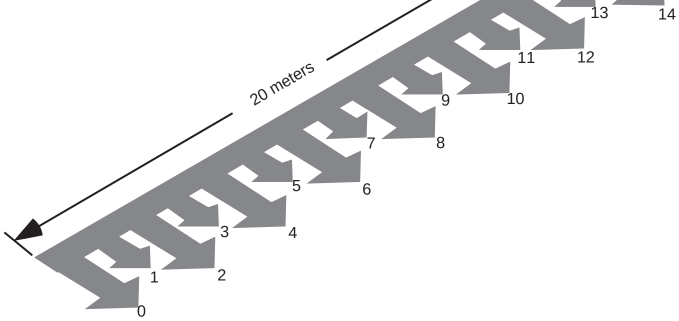

Figure 1 Basic IEEE-488 Bus

Driver fanout capacity limits the system to 14 devices. This places an unnecessary size limitation on IEEE-488 Bus systems.

Cable length limits the controller-device distance to two meters per device or 20 meters total, whichever is less. This imposes transmission problems on systems spread out in a room or on systems that require remote measurements.

Primary addresses limits the system to 30 devices with primary addresses. Todays instruments rarely use secondary addresses so this puts a 30 device limit on the size of large systems.

Therefore the systems engineer will have problems whenever he needs to:

1, Put more than 14 devices on the bus.
2. Use a bus cable length beyond the 20 meter limit.
3. Run GPIB devices at a remote location.
4. Isolate GPIB devices.
5. Expand the system beyond 30 primary addresses.
6. Share GPIB devices among several Bus Controllers.

Solutions are available for these problems.

This bulletin describes several solutions to these problems and the trade-offs and benefits of each. It also compares the available Bus Extenders, Bus Expanders and Bus Switches, to provide guidelines that will help you select the best products for your application. This booklet is arranged into the following four sections:

Section 1: Adding more than fourteen devices to the bus.

Section 2 : Expand the bus cable length beyond 20 meters.

Section 3 : Control more than 30 GPIB devices

Section 4 : Share GPIB devices with multiple Bus Controllers.

Problem 1: System needs more than 14 Devices

Solution No. 1: Expand the System by Adding an Additional Bus

The real problem with adding more devices to the bus is driver capacity. GPIB Bus drivers are only specified to drive 14 GPIB devices. Logically the system can address up to 30 devices using primary addresses or up to 961 devices using primary and secondary addresses. One way of overcoming the electronic drive capacity limit is to add a second bus to the system.

Most desktop PCs have extra expansion slots that can accommodate additional peripheral driver cards. If a spare slot is available, then an additional GPIB Controller card can be used to add up to 14 more devices to the bus system. This is a fairly inexpensive way to add bus device; $300 to $500 for a PCI GPIB Controller card. In addition to ICS Electronics, there are five other domestic manufacturers of GPIB Controller cards for the PC.

Program complexity increases slightly with this solution - the user now has to address two GPIB Controller cards. This solution is not cost-effective if it forces the user to increase the computer size or buy a “computer I/O expander chassis” to add just a Bus controller card.

Solution No. 2: Expand the System by Adding a Bus Expander

A “Bus Expander” is the ideal solution to the bus driver capacity limit. The ideal expander should transparently pass signals in both directions, replicating the bus controller’s signals to drive the added devices and providing device responses back to the Bus controller. Any delays through the expander should be minimal so that its addition to the system will not degrade the system’s performance. In the diagram below, the Bus Expander replaces device #14 on the local Bus and drives an additional 14 devices for a maximum of 27 devices on the system.

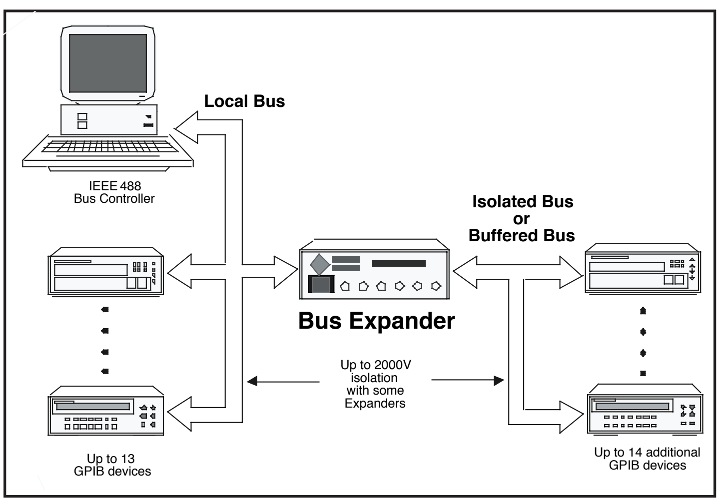

Figure 2 Adding a Bus Expander to a GPIB System

While Bus Expanders are simple and relatively easy to add to a system, there are some factors that should be considered when adding a Bus Expander to the system. Because the expander has to locate the talker, some Bus Expanders use address switches to set the addresses of the buffered devices. With these expanders, the buffered address group must not include the Bus controller’s address or the address of any of the devices on the local Bus. Second, some Bus Expanders respond to all listen addresses and thereby give false answers to the IEEE-488.2 Findlstn protocol. This causes applications such as LabVIEW™, VEE™, ICS’s GPIBkybd and other programs that use the 488.2 Findlstn protocol to return false information about the system to the user. Third, if the system uses different power sources, has noisy signals, or must work at different ground potentials, then optical isolation is a must. The added delay introduced by the optical isolators has little or no effect on the performance of most systems.

If it becomes necessary to expand the system beyond 27 devices, simply add more Bus Expanders. The previous diagram shows a single expander added in parallel to the existing devices on the Local Bus. Each added Bus Expander reduces the number of devices on the Local Bus by one but adds up to 14 more buffered or isolated devices on its own bus.

The practical limit for adding devices with Bus Expanders is typically 30 devices because of the bus address limitation. The IEEE-488 Bus address structure permits 31 primary and 961 primary and secondary addresses. Because GPIB bus controllers use an address to make themselves talkers and listeners, this leaves only 30 primary addresses for the remaining devices. Most bus devices only respond to primary addresses and those devices that do use secondary addresses normally just use the secondary address just to select an internal function or channel.

Cascading Bus Expanders to Create Large Systems

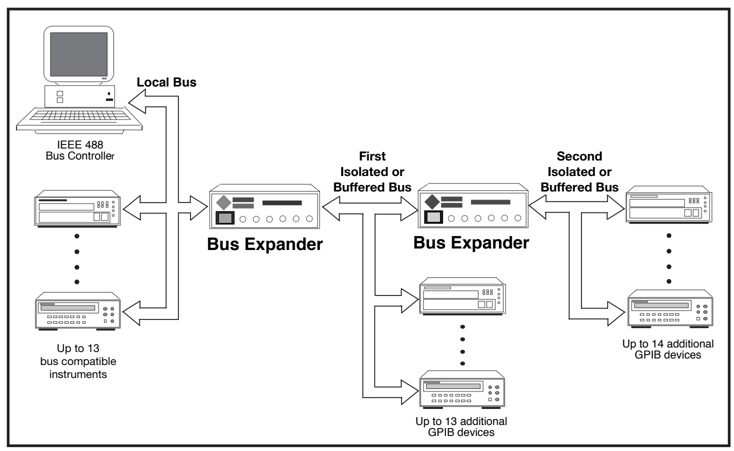

Figure 3 Cascading Bus Expanders

Figure 3 shows how Bus Expanders can be arranged serially, with expander #1 driving expander #2, etc. to expand the system. The limit to this approach is how many expanders can be added in series before the signals become so distorted that they no longer meet the bus specifications nor are recognized by the devices. Tests at ICS have shown that a practical limit is four isolator/expanders. The following precautions should be taken when cascading bus expanders:

1) Check bus handshake timing at the bus controller and at each device. Use low speed handshakes where possible to prevent data errors.

2) Check IFC pulse width. Bus specifications require a 100 μsec wide pulse at each device. Cascading bus expanders could distort the IFC signal so it no longer becomes recognizable by the last devices on the system.

3) Plan for system hang up when some devices are turned off. The bus expander can hang the GPIB bus if all buffered devices are off.

Additional Expander Functions:

Use a Bus Expander to Isolate System Grounds

In GPIB Bus systems, ground loops between the Bus controller and the unit-under-test (UUT) or noisy industrial devices can put unwanted current on the Bus data lines. The extra current creates offset voltages which reduces the system's noise immunity. Non-isolated devices also provide a path for RF noise and voltage spikes to get onto the bus signal lines. The result is the additional chance for data errors and system crashes. In other cases, an instrument making high-voltage measurements with less than perfect isolation, can leak high-voltage current onto the Bus data lines. Also noise from the GPIB Bus could interfere with an instrument's measurements.

Adding an isolating Bus Expander to the system is a good way to prevent these problems and protect the other Bus devices from damage caused by high-voltage leaking onto the GPIB Bus.

Use Bus Expanders to Drive Multi-rack Systems

Multi-rack test systems can easily have more than 14 instruments or use more than 20 meters of cable to interconnect all of the instruments in the racks. Putting a Bus Expander in each rack provides added drive capability for up to fourteen instruments in each rack. If the expander provides isolation at the same time, it will prevent circulating ground loops between the racks.

Cables in each rack can be wired either in a daisy chain fashion (instrument-to-instrument) or in a star fashion. The star configuration is better where the instruments are slide mounted since it cuts the moving cable count in half. To implement the star, connect the common end of each cable into a GPIB connector strip like ICS's 4801 BusStrip™ mounted between the rails at the rear of the rack.

Bus Expander Comparison

There are several bus expanders available on the market today, all having somewhat similar specifications. The selection of the proper bus expander for your application involves consideration of cost, performance, noise rejection and compatibility parameters shown in the following chart.

Table 1 Available GPIB Bus Expanders

MFGR	MODEL	488.2 COMPATIBLE	ISOLATION	COST US$
ICS	4860A	YES	2,000 V	$ 995
ICS	4862A	YES	none	850
IOtech	Isolator 488	NO	1,500 V	1,295
NI	GPIB-120A	NO	1,600 V	1,295

ICS offers two Bus Expanders with almost identical functions. The Model 4860A is a fifth generation Bus Expander that incorporates improved bus isolation, selectable open collector or tristate drivers and IEEE-488.2 compatibility. The 4860A provides added drive capability for 14 additional bus devices and at the same time provides 2,000 volts of isolation for voltage offsets, ground loops and some RF noise reduction. Device address location is automatic. There are no switches to set. The unit meets the FCC's EMI/RFI requirements and the EU's CE requirements. The Model 4862A is the functionally same as the 4860A but does not include optical isolation.

The IOtech Isolator 488 is an isolated Bus Expander with 1,500 volts of isolation. It has no address switches. Its data sheet does not state if it meets FCC or EU requirements.

The National Instruments GPIB-120A is an isolated Bus Expander with 1,600 volts of isolation. The GPIB-120A has no address switches, is UL listed and does meet FCC's EMI/RFI requirements and EU's CE requirements.

Solution No. 3: Expand the System with a Bus Switch

A "bus switch" provides the means to time share or switch the controller among several GPIB buses or groups of devices. Such a switch lets the controller operate n x 14 instruments where n is the number of available switch positions. ICS's Model 4842 bus switch provides up to three additional buses, each bus selected by commands from the Bus controller. ICS's Model 4842 is the only GPIB Bus controlled Bus Switch /Multiplexer on the market today.

The major features of the 4842 Bus Switch are: programmability (it accepts switching commands from the bus controller), very small signal delay, and the ability to pass all SRQs back to the bus controller. The 4842 has three selectable output ports and can drive up to 14 devices. The 4842 is transparent to all bus commands.

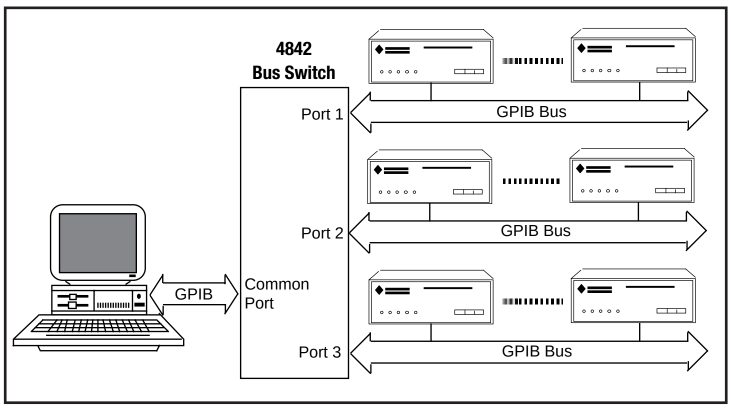

Figure 4 Using a Bus Switch to Expand the System

The 4842 can be addressed as a normal device, given bus selection commands and serial polled to determine which remote bus has an SRQ. When enabled, service requests from devices on the remote buses are passed through the 4842 to the bus controller.

The 4842 is reversible in that it can operate as a 3:1 multiplexer, letting up to three bus controllers share GPIB devices that are connected to its common bus port. This feature provides a way to share expensive instruments among two or three bus systems. Typical uses are sharing calibration systems among several test systems, sharing an expensive analyzer or granting multiple systems access to a printer or data storage device. See Problem 4 for more details.

Problem 2: System Needs Longer Cable Length

Solution No. 1: Use a Bus Expander for Short Cable Extensions

Bus expanders are the least expensive way to add an additional 20 meters of cable length to a 488 bus system. They also can isolate the remote device(s) from the Bus controller while extending the bus cable length. To extend the system cable length to 60 meters, you could simply cascade two expanders as shown in Figure 3. Beyond 40 meters, however, you would be better off using a pair of Bus Extenders as shown in Figure 5.

A drawback to using long cables with a Bus Expander is that it does not meet the IEEE-488.1 Specification for 2 meters of cable between instruments. Because this approach does not fully comply with IEEE-488 specifications, it should only be used with caution and should be thoroughly tested for each application. Our experience shows that cascading Bus Extenders works with low speed devices and instruments. It may not work with high speed devices or with GPIB controllers using the NI TNT chip and again should be thoroughly tested.

Solution No. 2: Use a pair of Bus Extenders to Extend the Bus

Devices located more than 40 meters from the bus controller will usually require a pair of Bus Extenders to extend the bus distance as shown in Figure 5. The extender pair should operate as a transparent link, the local-site extender taking the commands from the Bus controller and passing them on to the remote-site extender, which then acts as a pseudo system controller for the remote devices. When the remote devices are addressed as talkers, their responses are passed back to the Bus controller.

Several types of Bus Extenders are available, each having its unique application. The selection of the proper Bus Extender involves trade-offs among distance, bus handshake speed, transmission-medium, compatibility and finally cost. The following paragraphs discuss the major trade-offs.

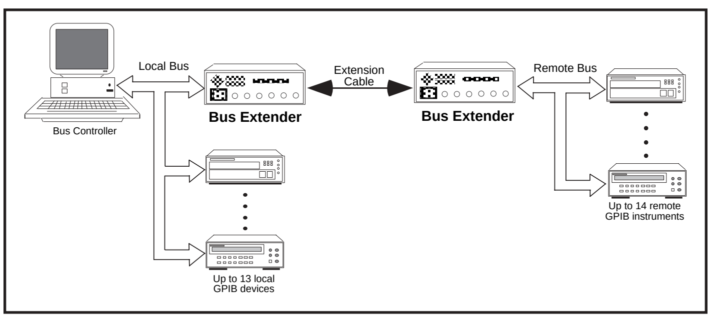

Figure 5 Using Bus extenders

Distance is the Major Selection Factor

There are four major distance categories for bus extension: short (up to 200 meters), up to 1 km, 1 km to 5 km, and beyond 5 km. Obviously all of the bus extenders will work for short distances but they might not be the optimum solution unless of course you already own the extenders. Also the choice of the extension media gets narrower as extension distance increases.

Table 2 Bus Extension Media Guide

DISTANCE	TRANSMISSION MEDIA
0 to 200 meters	Coax, fiber-optic, multi-conductor wire cable or twisted pair cable
Up to 1 km	Coax or fiber-optic cable
1 km to 15 km	Fiber-optic cable
Beyond 15 km	RF links

For short distances up to 200 meters, you can select between extenders that use coax, fiber optic, multi-conductor cable or twisted shielded pair cable to extend the bus. The twisted shielded pair cable extender only goes to 200 meters but the multi-conductor cable extenders can be used up to 300 meters or in one case, up to 1,000 meters. Coax and fiber-optic cables can be used up to 1 km.

Multi-conductor cable extenders are basically a Bus Extender that is cut in half with a multi-conductor cable connecting both halves. These extenders have fast data transfer rates for short distances. Their data rates fall off sharply as cable length increases. They are fine for short indoor bus extensions but should not be used for outdoor applications as they do not protect your equipment from lightning strikes. The cost of the multi-conductor cable is higher than that for a serial cable.

Coaxial cable extenders use two coaxial cables or a dual coaxial cable between the two extenders. Coaxial cable types vary and almost any type can be used for short distances. For long distances, be sure to use the manufacturers' recommend cable type to achieve maximum distance. Coaxial cable cost is moderate and it is easy to install. Coaxial cable is not recommended for outdoor applications because of possible lightning damage.

Twisted shielded pair cable extenders use two individually shielded twisted pairs between the two extenders. This can be CAT6, IBM Type 1, Belden 9688 or an equivalent cable. CAT5 cable should only be used for short distances because its wire pairs are unshielded and have high crosstalk between its signals. Twisted shielded pair cable cost is low to moderate and it is easy to install. Twisted shielded pair cable is not recommended for outdoor applications because of possible lightning damage to all of the equipment.

As you might expect, fiber-optic links are your best selection for bus extension distances over 200 meters or for outdoors applications. Extenders using optical fiber can provide high speed links and protection against EMI/RFI interference as well as equipment damage from lightning strikes. Cable cost is low and very comparable to twisted shielded pair cable cost. Installation is not a problem as most communication wiring companies have learned how to safely install fiber cables. Use multimode fiber for extension distances up to 5 km and single-mode fibers for distances up to 15 km.

Speed is the Second Selection Factor

The following Table shows how the different Bus Extenders compare. Because the Table is divided by the transmission media, some Bus Extenders appear multiple times.

Table 3 Bus Extender Comparison Chart

UNIT	488.2	CABLE TYPE	MAX DATA RATE (kbytes/sec)	DISTANCE (meters)	LINK COST* (US dollars)
ICS 4897	Y	dual Coax	660#	1 km	$2,120**
ICS 4897	Y	duplex FO	660#	5 km	$1,990
ICS 4897L	Y	duplex FO	660#	15 km	$2,990
I/OTech 488/F		duplex FO	0.04	1 km	$2,590
NI GPIB-140A	Y	duplex FO	1,100#	1 km	$2,590
NI GPIB-140A/2	Y	duplex FO	1,100#	2 km	$2,590
I/OTech 488/HS		Multi-Cond	840	1 km	$2,590
NI GPIB-130	Y	Mult-Cond	900#	1 km	$2,590
ICS 4897	Y	Twisted Shielded Pair	660#	0.2 km	$1,990
ICS 4897L	Y	Twisted Shielded Pair	660#	0.2 km	$2,990
I/OTech 488/F		Twisted Shielded Pair	0.04	1 km	$1,790

Notes: * Cost is for a pair of units and excludes cable and installation cost.
** Cost includes DE-9 to BNC adapters
Y Indicates IEEE-488.2 compatibility
Listed data rate is for buffered mode, NI HS mode is not listed
Maximum Data Rate is for short 10 to 20 meters distances

Table 3 shows all of the GPIB Bus Extenders on the market today arranged by cable type to facilitate comparison. The chart deals with four cable types, coaxial, fiber optic, multi-conductor and twisted shielded pair cable. Some extenders are listed more than once since they drive multiple cable types. The Max Data Rate column shows the extenders maximum data rate for short cable distances of 10 to 20 meters. The Distance column shows the maximum distance each unit will extend the bus with a given media. The Link Cost column lists only the costs of each extender pair and does not take cable cost and installation labor into account. These latter costs could vary considerably, depending upon whether the installation is an office, in cable trays or air plenums, or outdoors, the cable jacket requirements (plenum, weather proof, direct burial, etc.) and the cost of labor.

Five of the extenders are IEEE-488.2 compatible and provide the correct response to the 488.2 Findlstn protocol. The other extenders respond to all GPIB Bus addresses and prevent GPIB application programs from correctly identifying the GPIB Bus devices, Only IEEE-488.2 compatible extenders should be used in new systems.

Bus Extender speed rating are a good demonstration of specsmanship. The Maximum Data Rates shown in Table 3 are for short 10-20 meter distances and do not take into account delays for addressing the devices or for command execution delays. Data rates typically fall off as the cable length increases. Bus extension distance inversely affects the overall data transfer rate for all Bus Extenders, regardless of cable type. Figure 6 shows the affect Bus extension distance has on some of the faster extenders' data transfer rates.

The performance for both multi-conductor cable extenders is very similar. Their data transfer rate starts near 900 kbytes per second for short distances of 10 meters and quickly drops to 40

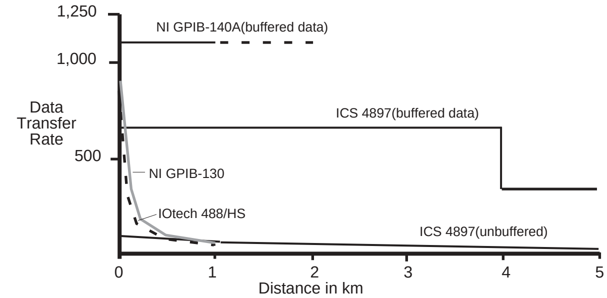

Figure 6 Data Transfer Rate vs Bus Extension Distance

kbytes per second at 1,000 meters. This is not too surprising as they simultaneously handshake every GPIB byte transfer on both buses. This requires multiple cable propagation delays for each byte transfer. As the cable length increases, propagation time increases and the GPIB byte transfer rate drops by the number of times the signals have to transverse the extension cable.

Fiber-optic, dual Coax and Twisted Shielded Pair Cable extenders use a serial protocol to transfer data over the cable. In their normal or unbuffered mode, they simultaneously handshake every GPIB byte transfer on both buses. The curve for ICS's Model 4897 on the bottom of Figure 6 is typical of the performance for the unbuffered mode. It closely matches the performance of the multi-conductor extenders at 1 km.

Extenders with a buffered data mode transfer data at the extenders maximum transfer rate to memory in the remote unit. The remote unit then handshakes the data out at the remote device's slower handshake rate. The buffered mode eliminates the back and forth cable delays for transferring data byes. GPIB command (address) bytes are simultaneously handshaked on both buses so the system pauses until the remote device has absorbed all of the buffered data bytes before issuing another command. System performance depends upon how fast the remote unit can absorb the data bytes and not on the extenders buffered data rates. Most GPIB devices handshake data between 5 to 20 kbytes per second rate. Bus controllers have surprisingly high setup delays when addressing a device that further reduces system performance.

Bus Extender Limitations

No bus extender can return a parallel poll response from the remote bus within the 200 ns response time specified in the IEEE-488.1 Standard. Cable propagation and extender delays increase the typical parallel poll response by 20-50 μsec per km. There are a couple of workarounds to get a correct response with bus extenders.

The ICS 4897/4897L and the National Instruments GPIB-140A both store the prior parallel poll response and output it on the local bus in response to the next parallel poll. The new parallel poll response updates the stored value when it is received. This approach lets the user execute either 1 or 2 parallel polls (depending upon the Bus controller's parallel poll width) to obtain the correct response. A switch lets the user inhibit updating until the end of the current parallel poll time.

Some GPIB Controllers have a configuration setting that lets the user widen the Parallel Poll time to be greater than the extenders Parallel Poll delay time. This solution works with all of the above extenders.

Problem 3: System Needs more than 30 Devices

While Bus Expanders can easily drive large numbers of GPIB Bus devices, the system quickly runs out of primary GPIB addresses. Most modern GPIB devices only recognize their primary address. The few modern devices that use secondary addresses do so to address internal functions or I/O channels. There are also GPIB devices that use two primary addresses to address different functions in the device.

There are two solutions to this problem. Both split the system into multiple buses.

Solution No. 1: Use Multiple GPIB Controller Cards

One solution is to add one or more GPIB Controller cards to the computer. Each GPIB Controller card can add another 30 primary addresses to the system. The number of GPIB Controller Cards is limited by the number of cards that your GPIB software driver can support. Older HP systems used to support four GPIB Controller cards. ICS Electronics, Measurement Computing and National Instruments cards support 2 boards.

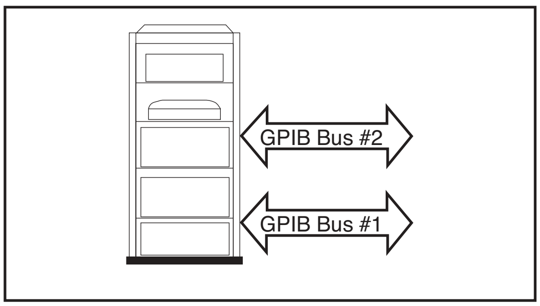

Figure 7 Computer driving Multiple GPIB Buses

Solution No. 2: Use a Bus Switch to Control Multiple Buses

A second solution is to use a GPIB Bus Switch to control multiple GPIB Buses as shown in Figure 8.

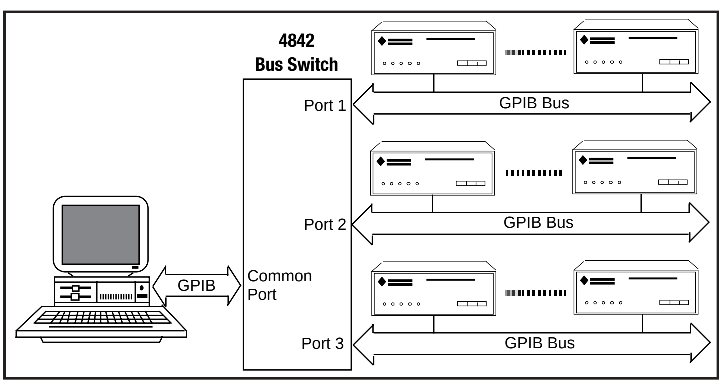

Figure 8 Bus Switch drives Multiple Buses

The Bus Switch lets the Bus Controller select which bus to control. Each Bus can have up to 30 primary addresses. Only one bus is active at time so the same addresses can be assigned on each bus. From then on it is just a matter of programming.

ICS's 4842 is the only GPIB controlled Bus Switch on the market. In the switch mode shown in Figure 8, the 4842 accepts switch commands on its common port. The 4842 uses one GPIB bus address and transparently reports SRQ signals from all three Buses to the Common port. The Bus does not have to be active for the 4842 to send the SRQ back to the Common port. This lets a GPIB device on any Bus inform the Controller when it needs service.

One caveat. The 4842 'connects' the Controller's GPIB Bus to the switched Bus. It uses one GPIB load and does not provide any drive capability. This leaves 13 loads for driving all other GPIB devices on the local and switched Buses.

Problem 4: Sharing Expensive GPIB Bus Devices

The price of the instrumentation in test systems is often many times the cost of the computer. It is not uncommon to find test systems with $25,000 to $75,000 analyzers and other expensive instruments whereas a good quality PC can be had for $1,000. System engineers can save serious money by sharing an instrument or instruments among two or three computers. Applications are sharing a calibration device among several test systems or two computers with different tasks (and programs) sharing the same measuring instrument.

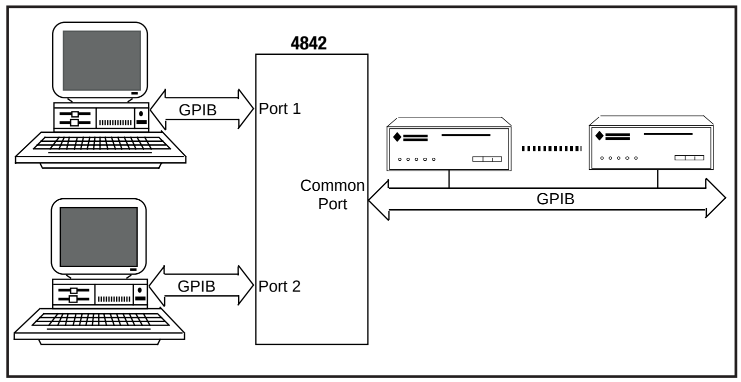

Figure 9 Sharing GPIB Devices

Figure 9 shows two GPIB Controllers using a Bus Switch in the Multiplex mode to share several GPIB devices. Control of the common Bus is shared between the two Controllers.

In the Multiplex mode, the 4842 uses the same GPIB address at each port. A Controller can Serial Poll the 4842 to determine if the common Bus being used by the other computer. If not, the 4842 can be sent a 'connect' command to give the Controller access to the common GPIB devices. Once connected to the remote devices, the path through the 4842 is totally transparent. When done, the Controller disconnects the Bus or passes it back to the other Controller. A Controller can also take control of the common Bus at any time by issuing an 'override' command. The 4842's Multiplex mode overcomes the problems encountered when trying to share bus devices by passing control between two GPIB controllers.

Summary

This application note has described several solutions to overcoming the GPIB Bus limitations and presented the reader with the latest information about the currently available GPIB Bus Extenders, Bus Expanders and Bus Switches to guide your selection. The reader should consult the manufacturer's application personnel to verify that the selected product will satisfy his or her needs.