THE IMPACT OF LOCAL AREA NETWORKS ON ANTENNA MEASUREMENT RANGE DESIGN

Marion C. Baggett
MI Technologies
1125 Satellite Boulevard, Suite 100, Suwanee, Georgia 30024-4629

ABSTRACT

The increasing numbers of microwave instruments and devices that include IEEE 802.3 interfaces are influencing range design and capabilities, as well as the ability to remotely locate GPIB instruments. The major benefits of LAN based instrumentation systems are increased flexibility in instrument location and increased capabilities over long distances compared to GPIB based ranges. This paper discusses the relative merits of LAN based microwave test instrumentation ranges. Several example range designs are included that demonstrate how LAN based instrumentation can increase range flexibility and reduce costs in range implementation.

Keywords: Antenna measurements, Commercial Products, Measurement systems, Standards, Local Area Networks

1. Introduction

Since its introduction in the late 1970's, the IEEE 488 bus (GPIB) has been the standard for computer control of laboratory instruments. As automated antenna ranges evolved during the same time, virtually all microwave test instruments have been designed with GPIB interfaces for control and data. The properties of the GPIB bus have influenced the design and architecture of antenna test ranges. Over the last ten years, the IEEE 802.3 (colloquially termed "Ethernet" from the original Xerox implementation) local area network (LAN) standard has been adapted to instrumentation and range design. More and more microwave instruments are designed with 10/100 Mbps LAN interfaces and TCP/IP protocol stacks. With the advent of the Standard Commands for Programmable Instruments (SCPI) standard, many instruments support identical programming protocols over GPIB and TCP/IP connections. In the following sections we will address the classic GPIB range architecture, LAN range architectures, and the performance factors of determinism, latency and throughput as they apply to both GPIB and LAN architectures. We will evaluate the strengths and weaknesses of the two bus approaches. The conclusion of the paper will discuss approaches on high performance range architectures.

2. GPIB Based Ranges

The original GPIB bus required direct cabling of instruments to the control computer via standardized GPIB cables, with the restriction that the total cable length could not be longer than 20 meters. This total length is reduced as more instruments are added to the bus. An automated antenna range of the basic GPIB era is shown in Figure 1.

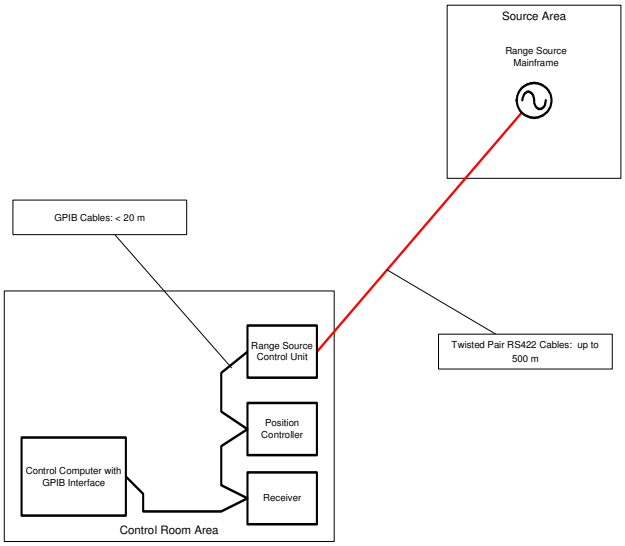

Figure 1 Basic GPIB Range Architecture

Note that all "smart" units have to be in close proximity to the control computer. However, an antenna test range is by nature a distributed instrumentation environment, with transmit and receive areas that can be at a far distance from the control location. This problem actually introduced increased complexity in microwave instrumentation. For example, the MI Technologies Model 2180 Signal Source had a control unit that could be located in the vicinity of the control computer and an RF chassis that was located at the transmit location in the range. To connect these two units, serial cabling was required and of course, both units had to provide an interface over a serial link, increasing the complexity of the total unit.

Fairly quickly, vendors came out with "extender" units, allowing the instruments to be distributed up to a considerable distance. An example is shown in Figure 2.

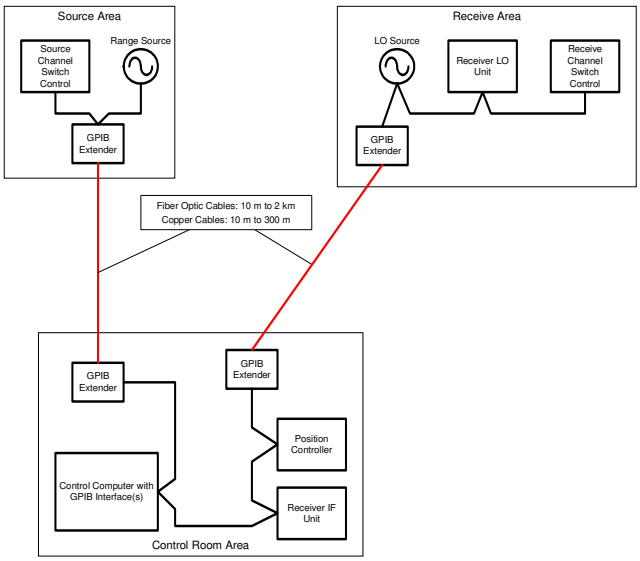

Figure 2 GPIB Range Architecture with Extenders

Note that GPIB bus throughput is often reduced by using the extenders. Ranges where running cable to a remote site is not practical or cost effective are still not covered. Examples would be a rooftop to rooftop range or a canyon range. An advantage of extenders is that they are transparent to the control software.

3. LAN Oriented Ranges

By bringing Ethernet with TCP/IP protocols into the picture for antenna range architecture, many more options are available. Figure 3 shows several options for employing LAN components. The "source area" of the range layout shows two GPIB based instruments. Several vendors make "ENET/GPIB" converters. In all cases, the vendor's GPIB software treats the converter as a bus controller. After configuration, user software sees the converters as bus controllers, making these items essentially transparent to measurement control software. An obvious advantage of the converter unit is that as opposed to a GPIB extender pair, a single unit is required. In addition, the LAN cable for connecting remote instrument locations is much less expensive on a unit length basis than the specialty GPIB extender cables or fiber optic cables. With the converters, the cable distance to the remote location has to be less than 100 m to comply with the basic 10/100 BaseT limitations. LAN bridges and dedicated routers can increase this distance to several km. A down side of the converters is that their GPIB throughput generally reduces HS488 rates to 1 MB/sec. An example of how modern instruments are supporting this trend, recall the MI-2180 Signal Source discussed in Section 2. The latest MI Technologies signal source, the MI-3111 has only a LAN interface for command and control. It also supports hardware triggering for changing frequencies, providing a high range throughput.

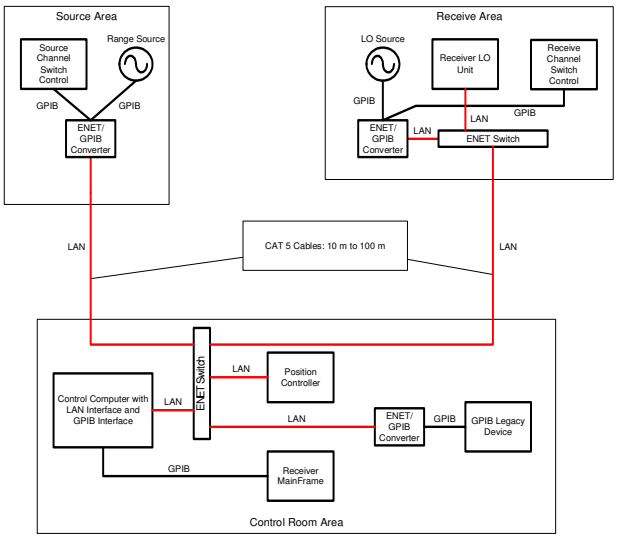

Figure 3 Range Architecture with LAN Options

The Receive area of Figure 3 shows another possible combination. A small ENET switch is placed at the location and the LAN cable from the control room area connects it to the LAN. A GPIB/ENET converter handles two GPIB instruments and an Ethernet capable instrument is attached to the switch directly. In the control room area, the control computer has both LAN and a GPIB controller. A GPIB device is connected directly to the PC's GPIB controller card. A LAN switch connects the PC to all of the nodes of the LAN. An Ethernet capable instrument is attached to this switch, as is another GPIB/ENET converter. Range architecture could be any of the combinations all the way from all GPIB instruments connected by converters to a PC that has no GPIB controller card to the combination where all instruments are LAN capable. Many instruments, such as the MI Technologies 4190 series Position Controllers, most modern vector network analyzers and even some power meters provide both a GPIB and LAN interface.

Figure 4 shows a LAN method for connecting to a remote instrument location at a distance much greater than 100 m. The devices labeled "ENET modems" are IEEE 802.11 wireless links. These items have become ubiquitous in supporting "campus" LAN's. An industrial quality system [7] uses an antenna with 6 dBi gain for ranges of up to 7 miles while maintaining data rates of up to 6 MB/sec. A disadvantage of wireless modem technology is that the

units use the 2.4 GHz band, generally precluding range use at that frequency.

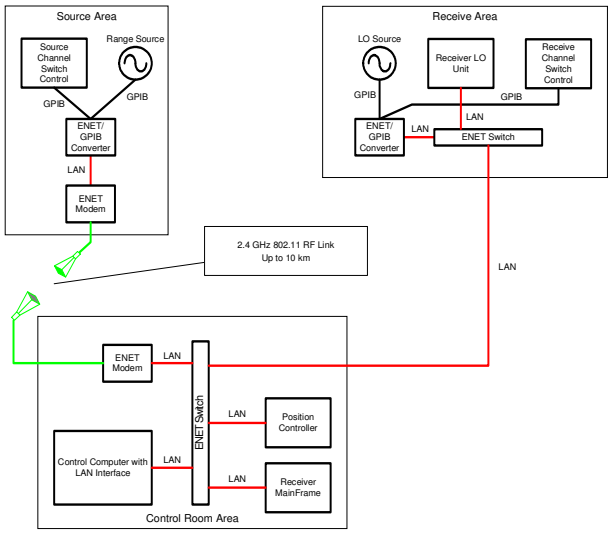

Figure 4 Range Architecture with Wireless Modems

4. Cost Comparison

The table below shows current representative prices from several vendors [3] [7] for GPIB and LAN components:

Item	Catalog Price
GPIB Controller PWB	$500
GPIB cables	$95 - $120
GPIB/ENET Converter	$1045
CAT 5 shielded LAN cable	$15 + $1/m
Fiber Optic GPIB Extenders (pair)	$2950
Fiber optic cable for FO GPIB Extender	$200 + $4/m
Copper cable GPIB extenders (pair)	$2350
Specialty copper cable for GPIB extenders	$200 + $5/m
Wireless Modem with antennas (pair)	$4500
5 Port ENET Switch	$35

While all of these costs appear relatively small, several cost differences can be significant. For example, using GPIB/ENET converters instead of GPIB extenders halves the hardware cost for each remote location needing instruments and the cables are much cheaper. In addition, the LAN cables are smaller than the copper extender cables, making their routing around a range much easier and possibly reducing the size of cable conduits. While the cost of wireless modems appears high, the occasions for their use actually makes them quite cost effective. For a 1 km outdoor range, the fiber optic cable for that length would be over $4000, not counting the cost of conduits and their installation on this length of range. Another consideration for using a pure LAN architecture or using GPIB/ENET converters exclusively is that almost any modern PC, particularly laptop/notebook machines can be antenna range control computers without the need for a GPIB controller in the PC.

5. Control Software Comparison

Conversion from GPIB architecture to LAN based architecture does impact the measurement control software. As stated previously, most recent instruments support both GPIB and LAN interfaces. With most instruments conforming to the SCPI protocol, the command and response protocols are identical. A significant difference however, is that for a LAN connection, the software developer must open TCP/IP socket connections to the instrument instead of opening a file handle through a vendor software package such as the National Instruments NI-488.2 software. Another significant difference is that with a TCP/IP socket type connection between the computer and the instrument, the GPIB functions of parallel poll and interrupts upon assertion of the GPIB bus SRQ line are no longer available. A TCP/IP solution must use unsolicited messages from the instrument or a polling scheme to achieve the same results of monitoring instrument changes or alerts. Use of the GPIB/ENET converters with GPIB instruments allows control software to operate in the traditional GPIB mode.

6. Performance Comparison

For antenna measurements, the performance characteristics of throughput, transactions per second, message latency and determinism impact the capability of the range.

The GPIB bus started with a 1.1 MB/sec throughput and evolved to the HS488 protocol, which supports a theoretical throughput of 8 MB/sec. Note that GPIB extenders can reduce this theoretical rate as can the GPIB/ENET converter solution. GPIB extenders and GPIB/ENET converters both reduce effective throughput to 1 MB/sec. Most PC's and LAN capable instruments can support 100 Mbps (bits/sec) LAN rates, which translates to 12.5 MB/sec. The LAN would appear to have a significant advantage, except for the message structure on the two buses. GPIB messages are typically only as long as the command string or response is sent, perhaps only 8 bytes or less. TCP/IP traffic is in standard length packets, usually 2kB, with payloads of up to 1500

bytes. An 8 character message requires a full packet. Therefore, the advantage for short messages goes to the GPIB. Message latency is how long the bus requires to setup a message. In GPIB, a three wire hardware handshake establishes the communication link from controller to instrument or vice versa. The literature [4] has identified GPIB latencies in the vicinity of 50 μsec, while the TCP/IP message latency is on the order of 900 μsec. This means that if a message from one instrument is required by the control computer to interact with another instrument, the TCP/IP solution will place the message at the computer on average 850 μsec later than GPIB. The measurement application and scenario may determine whether or not that delay is significant. For measurement scenarios where this may be critical, the subject of obtaining very high performance measurements is discussed in Section 7 of this paper.

One of the reasons for avoiding TCP/IP based measurement solutions has been that it is not deterministic on message delivery. In the general case, many nodes on the LAN could attempt to transmit simultaneously, leading to collisions and re-transmissions, delaying message arrivals. However, this characteristic is less important on a LAN forming a dedicated antenna range for several reasons. Firstly, traffic on this type of LAN is directed client/server communications and usually, multiple instruments are not trying to communicate simultaneously. A second reason is that the inexpensive modern Ethernet switch maintains full capacity bandwidth between two nodes that are communicating and prevents traffic destined for other nodes away from any given node. A hub based solution would incur bandwidth sharing penalties.

Every instrument mix and bus type has an impact on measurement efficiency. There is no one rule of thumb. However, several studies have been made comparing GPIB and TCP/IP based solutions [4] [5] [6]. The study in the National Instruments white paper [6] may be particularly instructive. The study compared HS488, standard GPIB and 100 Mbps LAN in interacting with digital oscilloscopes from two manufacturers, Agilent and Tektronix. The study used a recent PC of 3 GHz CPU speed for the study. The study varied the size of the data set from the instrument and measured the number of transactions per second that could be achieved. Figure 5, (located at the end of the paper) shows a graph of the results.

Note that for small messages of less than 32 bytes, the GPIB solutions could achieve several thousand transactions per second and fell off to less than 200 transactions per second as data block sizes rose to 8 kB or more. The TCP/IP solutions could only achieve several hundred transactions per second for the small messages, but their performance fell off much more shallowly, remaining at 500 transactions per second even for very large data sets. This is mainly due to the 1500 byte payload in the normal TCP/IP packet. This study is instructive for antenna measurements viewpoint since small data size messages occur in a single frequency, single channel scan taken at extremely fine increments on a fast positioner. The large data sets correspond to large frequency block data from a network analyzer configured for multiple channels.

So, what kind of antenna measurement needs thousands of transactions per second? Note that the study above was working with a single instrument performing a single task. An antenna measurement scenario requires the cooperation of several instruments and possibly some interaction by the control computer. Assume a 3 RPM positioner for a scan axis and the need for 0.1 degree resolution data. This translates to a record increment cycle of 5.5 msec or 180 transactions per second. If one assumes a minimal instrument complement of a network analyzer and a position controller, the application software must cycle transactions to two instruments, making the requirement a minimum of 540 instrument messages per second (recognize desired position, trigger receiver, read receiver). While this number seems to be within the bounds of the study above, receiver measurement time must also be factored in, so experience tells us that neither a GPIB nor TCP/IP solution is going to suffice without some sort of hardware triggering scheme, as discussed in Section 7 below. This bus comparison analysis seems to show that in a practical sense for general purpose antenna measurements, the GPIB and TCP/IP approaches are essentially equal, with the TCP/IP solution gaining an advantage as data blocks get larger.

7. High Performance Solutions

However, experience and the analysis above show that high performance in antenna measurement efficiency requires some sort of hardware triggering solution in addition to the communication bus used. External triggering of receivers by position controllers, frequency list setup in fast signal sources with external triggering for "next frequency" and dedicated trigger management units have been used in antenna measurements for many years. Figure 6 shows the triggering scheme for the MI-2097 Automated Microwave Measurement System when performing a multiple frequency, multiple channel scan of an AUT. In this architecture, the command and control bus (GPIB or LAN) is used for command and control, not data, so the choice of control architecture can be driven by other considerations, such as ease of cabling.

The DAC is the MI Data Acquisition Co-Processor, which is basically a state machine trigger management device

and buffer for receiver and position data. The position controller generates a TTL trigger on reaching the next angle of interest. This unit can produce up to several hundred position triggers a second, depending on the position sensor employed. As an option, a high speed BCD output of the position controller can make up to 4 axes of position data available for access by the DAC.

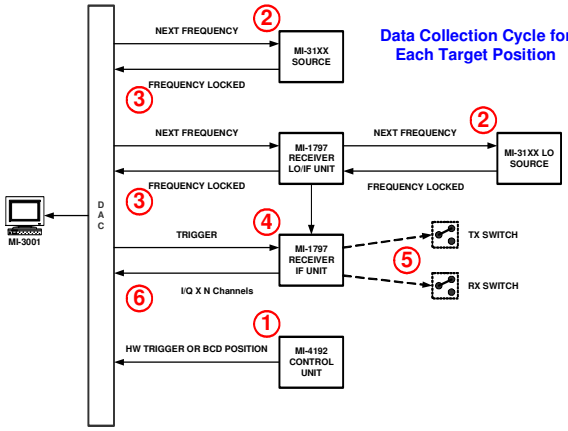

Figure 6 MI-2097 Triggering

The DAC recognizes the position trigger and triggers the range source and receiver LO units to the next frequency in their lists.

These sources can tune to the new frequency in from 200 µsec to 1msec, depending on model. The sources provide a TTL signal on settling into the next frequency. The DAC then triggers the receiver, which has control of transmit and receive multiplexers. This receiver can make a measurement in 100 µsec and can cycle channel switches at that same rate. Once the receiver completes its measurements, it triggers the DAC over a high speed parallel interface and the DAC reads the data for all channels. The DAC then proceeds to the next frequency. The DAC buffers data from the receiver and positioner and the PC reads the data buffers at a relatively easy 4 Hz rate. As an example, if the 3 RPM, 0.1 degree increment scenario of the previous section is used, this system comfortably collects a 4 frequency measurement in the allotted 5.5 msec. However, the architecture pays the penalty of parallel cables from the receiver and position controller to the DAC and parallel cables from the DAC to the PC. For performance, these cables have to be short, on the order of 10 feet or less. In this scenario, the choice of a GPIB or TCP/IP solution is purely dependent on range cabling needs since the buses are only used for instrument setup and status monitoring.

An architecture that employs a LAN structure that would provide more performance is shown in Figure 7. Here, the position controller not only generates record increment triggers, it buffers position data for block reads by the PC over the LAN. The receiver manages the frequency shift triggering for the sources and buffers multiple sets of data for buffer reads by the control computer.

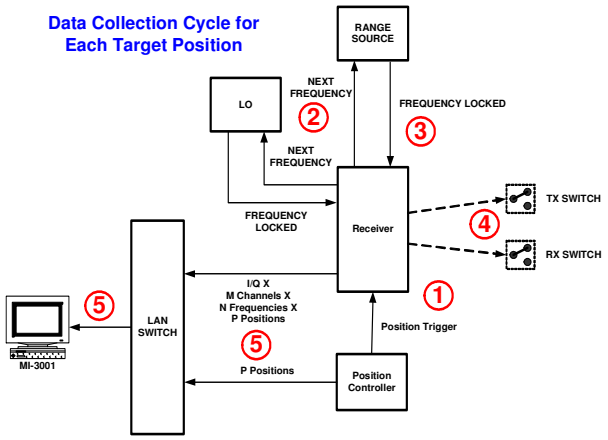

Figure 7 LAN Based Triggering

This architecture uses hardware triggers where appropriate and the TCP/IP efficiency of moving large blocks of data instead of many small blocks. This architecture was implemented in a limited way on the GPIB bus in the Agilent 8530 receiver with its FASTAD mode. In this mode, the 8530 is externally triggered and the receiver buffers many triggers worth of data for large block reads by the control computer. However, this mode was limited to single frequency measurements, making a big performance change in merely going from one frequency to two with the 8530. By using hardware triggering media that can span longer distances, such as RS-422, instruments can be widely dispersed as needed.

8. Summary

This paper has shown how the architecture of antenna measurement ranges is affected by the use of GPIB, LAN or combination bus solutions for instrument control. Analysis of bus performance has shown that for general purpose measurements, both GPIB and TCP/IP architectures are functional. In some cases of small data sets at high resolution, a GPIB bus may have an advantage in efficiency, while as data sets from the receiver get larger, the LAN solution becomes more and more attractive. Both architectures support extensions for longer ranges. For high performance systems, the bus structure is much less important in that custom interfaces funnel the data at the required speeds. As new high performance architectures are needed, receivers and position controllers that can buffer large amounts of data for TCP/IP delivery will make an impact.

9. REFERENCES

[1] (IEEE Std 488.1-2003) Higher performance protocol for the standard digital interface for programmable instrumentation – Part 1: General, 2004, available on the IEEE (www.ieee.org) or ANSI (www.ansi.org) web sites.

[2] (IEEE Std 488.2-1992) Standard digital interface for programmable instrumentation – Part 2: Codes, formats, protocols and common commands, 2004, available on the IEEE (www.ieee.org) or ANSI (www.ansi.org) web sites.

[3] National Instruments on Line Catalog, www.ni.com, July 2006.

[4] White Paper, "Techniques for Optimizing Instrument Throughput", National Instruments web site (www.ni.com) July 2006

[5] Strassburg, Dan, "IEEE 488: Not Dead Yet?" EDN Magazine, June 12, 2003.

[6] White Paper, "Is GPIB or Ethernet Better for Instrument Automation", National Instruments web site (www.ni.com) July 2006

[7] Esteem Model 195 Wireless Modem, Electronic Systems Technology, Inc web site (www.esteem.com), July 2006.

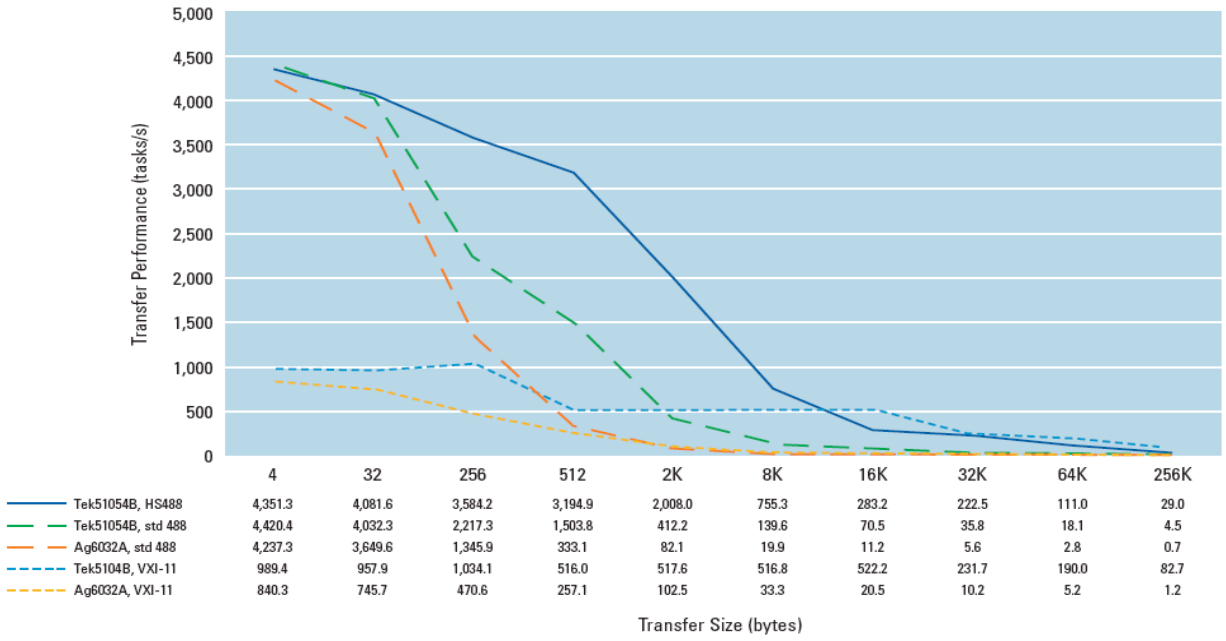

Figure 5 GPIB & TCP/IP Transactions per Second Results