INSTRUMENTING AN ETHERNET AVIONICS BUS FOR APACHE TESTING

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ABSTRACT

Last year, the U.S. Army Yuma Proving Ground (YPG) faced a short suspense requirement to instrument an Apache's Ethernet bus. YPG was able to implement an effective method to satisfy this requirement; however, more capable and effective methodologies could not be developed and utilized due to time constraints. While continuing to support ongoing Apache testing, YPG is working to implement more efficient methods to capture and utilize the Ethernet data. This paper will discuss YPG's initial implementation and the follow-on efforts being pursued.

KEYWORDS

1. Ethernet bus
2. Chapter 7
3. Streaming User Datagram Protocol (UDP)

INTRODUCTION

YPG, a subordinate command of the U.S. Army Test and Evaluation Command, is one of the largest military installations in the world. Located in southwestern Arizona, it encompasses 1,308 square miles. YPG personnel conduct tests on nearly every weapon system or piece of military equipment in the ground combat arsenal. With a mission to provide premier test services to the U.S. Government and her allies, YPG conducts, reports, and supports developmental tests, experiments, production tests, integrated developmental/operational tests, as well as provides training support. In 2016, YPG fired over 212,000 rounds of artillery, mortar, missile, and small arms munitions, flew over 2,900 aircraft sorties, drove over 68,000 test miles, and conducted over 1,500 airdrops. These numbers more than double when events conducted in support of training are counted, and for the last 7 years, YPG has been the busiest Army proving ground.

The Aviation Systems and Electronic Test Division at YPG is responsible for testing aviation ballistic weapons and missiles, unmanned aerial systems, aircraft systems, precision guided and unguided air delivered systems, personnel parachutes, sensors and surveillance systems, and electronic warfare systems. As a developmental test activity, the goal is to help the developer field their systems and provide the Soldier with the safest, most lethal equipment. Instrumentation is critical to capturing the necessary data that is generated by the item under test or capturing the "true" performance of the system. It is also important to display real-time critical information from the system under test so the test team can operate efficiently and safely.

BACKGROUND

One the systems tested at YPG that benefitted tremendously from the real-time display of critical data is the AH-64 Apache Helicopter Fire Control Radar (FCR). The FCR allows the aircrew the ability to quickly survey the battlefield by detecting and displaying both stationary and moving wheeled, tracked, and airborne vehicles. The FCR is capable of detecting and prioritizing hundreds of vehicles, allowing the aircrew to efficiently process all the provided information.

The FCR performance is based on Probability of Detection (the ratio of vehicle detections versus detection opportunities) as well as the False Alarm Rate (the number of times a false detection occurs). When testing the FCR, it is common to utilize 20 or more vehicles of various types for detection trials. During a typical 2-hour test flight, the FCR will scan a vehicle array hundreds of times, resulting in thousands of vehicle detection opportunities. Given the large number of detection opportunities and resulting detections (both real and false), trying to determine how the FCR is performing during the test flight quickly becomes impossible for the test team if the FCR/aircraft and ground truth data is not effectively presented.

After supporting FCR developmental testing for over 25 years, YPG developed an effective way to collect, merge, and display the available data in a way that allowed the test team to conduct real-time analysis of the radar's performance as well as provide enhanced situational awareness to optimize data collection. Figure 1 shows an overview of data flow.

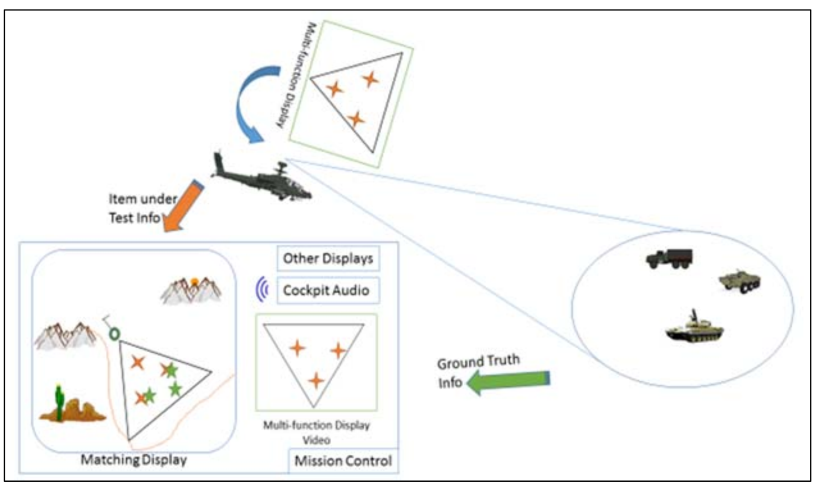

Figure 1. Data Flow Overview

To enable a real-time analysis capability for the test team, information from the Apache helicopter and ground truth information from the actual vehicles are sent to Mission Control to be displayed. The vehicle ground truth information was gathered using existing YPG infrastructure. Figure 2 shows the instrumentation scheme for the Apache.

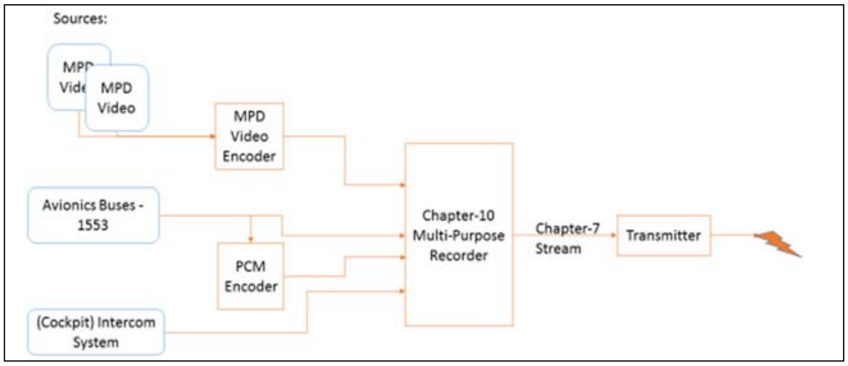

Figure 2. Apache Instrumentation Scheme

The Mission Control room was set up with large projector screens and workstations to display the key information provided to the test teams. In order to gain awareness of what the aircrew was seeing, the cockpit Multi-function display(s) (MFD) was shown with corresponding audio from the cockpit intercom system. Whenever possible, the various pages were displayed on the instrumented MFDs to allow the entire test team to witness the aircrew utilizing FCR to perform the planned test points. It also allowed the various SMEs in Mission Control access to any of the diagnostic or setup pages that could be brought up on the MFDs. This greatly increased the SMEs and aircrews ability to interactively perform different diagnostic and error isolation steps when anomalies were encountered during testing.

Although there were numerous benefits to displaying the cockpit MFDs, there were two main shortcomings for the test team with respect to analyzing FCR performance. The first shortcoming was that the MFDs were oriented with respect to aircraft heading, i.e. out the front of the aircraft. Multiple different headings were used during any particular flight test, which required the test team to reorient themselves when comparing the MFD video to other displays. The second shortcoming was the absence of any ground truth information on the MFDs as the MFDs only show the vehicles detected by the FCR. When FCR scans were performed, it was difficult to validate the detections shown on the MFD as true detections because the actual vehicle array was displayed elsewhere in a traditional map orientation, i.e. the top of the map was north. The aircraft's heading was rarely north so it was very difficult to match the FCR detections depicted on the MFD to the actual vehicle location displayed. The net result of these shortcoming was that the test team could not determine FCR performance from just the MFD video.

Based on the limitations of the displayed MFDs, an integrated display that showed both FCR detections and actual vehicle location was developed. This display became known as the "Matching Display" since both the FCR detections and actual vehicle location were superimposed on a common map. In order to validate an FCR detection, the test team only had to look at the display to see if the detection matched an actual vehicle location. The Matching Display also showed key geographical information such as terrain features and roads in a traditional map orientation (top of the display is north). All these feature combined on a single display allowed the test team to determine how well the FCR was performing. This display also helped the test team verify that the desired test point was actually executed by displaying information, such as radar field-of-view size, center of scan, terrain mode, etc.

Other displays utilized included a meteorological display that presented temperature, pressure, humidity, wind speed, and direction from various points on the test range, as well as a custom FCR Engineering Display. This Engineering used special instrumentation messages that were enabled on a MIL-STD-1553 bus to present important information to the FCR SMEs in real-time that was not usually shown on the MFDs during test.

INITIAL INSTRUMENTATION IMPLEMENTATION

The AH-64E model is the latest variant of the Apache. Currently, the U.S. Army is developing a Version 6 update to the AH-64E Apache that includes improvements to the FCR. With respect to instrumentation, many features were the same as previous models/versions; however, with the addition of a second Ethernet Routing Device (ERD) with Version 6 (ref 1), the FCR data was split with the FCR mode commands/responses being sent via a MIL-STD-1553 bus and all the vehicle detection information being sent via Ethernet bus, shown in Figure 3.

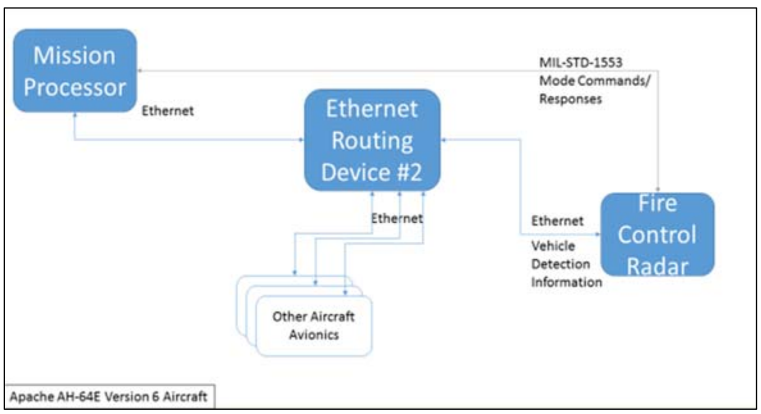

Figure 3. Apache Version 6 Overview

In the summer of 2016, YPG was requested to support a series of FCR developmental flights in support of the Version 6 improvements to the FCR. This was the first time YPG instrumented an Apache Version 6 aircraft, and due to the changes with Version 6, a significantly different instrumentation approach was required. Furthermore, the flight tests were schedule to begin in late summer 2016, which meant the new instrumentation suite would have to be designed, checked out, and installed on the aircraft in approximately 10 weeks.

Given the short time available, the initial efforts were focused on what modifications could be made to the existing instrumentation in order to capture the necessary Ethernet data. The data flow from the aircraft to mission control was broken down into six major areas and each area was examined for any necessary changes. A discussion for each of the six areas is provided below.

1. Aircraft Instrumentation: Perhaps the biggest impact to the existing instrumentation suite was to the aircraft instrumentation. Gaining access to the Apache's Ethernet bus was a primary concern. The Ethernet bus on the Apache is a hub and spoke design and the necessary data for the FCR test was passed on a single spoke to the Ethernet Routing Device (ERD) number 2 (Figure 3). Since it had not been previously instrumented, it was not clear if any new instrument components or specialized pieces such as connectors would be required. The short time necessitated that any new items be identified as soon as possible to ensure that they could be procured in the time available.

   Assuming that the necessary Ethernet access would be possible, the next question was how the Ethernet data would be sampled. Since a Chapter 10 (ref 2) multipurpose recorder was already being utilized and data was being transmitted utilizing Chapter 7 (ref 3) in the existing instrumentation suite, the Ethernet data could be sampled either on the aircraft or on the ground. Regardless of where the Ethernet data was sampled, an on-board recording—by virtue of its lack of transmission errors—was needed for any post-flight data reduction.

   Finally, the transition to Ethernet substantially increased the amount of data that could be sent at one time to or from the FCR. An entire block of FCR detections were now sent in a single Ethernet packet, where previously a block FCR detections required a series of multiple 1553 messages. Also, due to the greater throughput available with Ethernet, the amount sent with each block also increased. It was immediately apparent that these changes resulted in more data that would need to be telemetered in order to maintain the same real-time analysis capability that was provided in previous test events.

2. Downlink: It was understood that more data would be telemetered. At the time of this initial assessment, it was still unclear how much more data would need to be telemetered, but it was believed that it would be well within the capability of the transmitters currently in use. The transmitter utilized on the Apache instrumentation suite had already been used on another effort at a 20 Mbps, and the previous Apache data rate had been 5 Mbps. The only concern was that frequency diversity that was employed on Apache combat antenna masking (ref 4), and the increase in data rate would also result in a 2-fold increase of the spectrum requirements.

3. Receiving Sites: Similar to the transmitters, the impact to the tracking antennas and receivers was assessed as minimal. The components were capable of much higher data rates and had previous been utilized at a 20 Mbit per second rate in support of another test effort.

4. Ground Station: The ground station is a vital component when utilizing a Chapter 7 data stream as it breaks out the different signals that were combined when creating the Chapter 7 stream. The impact to the ground station was assessed as minimal, as the worst case anticipated data stream was well within the capabilities of the ground station, to include Ethernet data streams.

5. Decom: The impacts to the Decom were significant and on par with the impacts to aircraft instrumentation: the need to send more data to ground resulting in a larger data frame; the restructuring of the FCR data to include addition parameters; and, changes in data types meant that little of the existing set-up could be used. Furthermore, previously in support of the Matching Display additional processing had been done to FCR detection data to facilitate the display of data. Because of the significant changes to the FCR detection message, it was unclear what modifications to these processes were required but there would surely be many.

   Finally, as previous discussed, the sampling/parsing of the Ethernet data could potentially be done on the ground with the Decom rather than with the aircraft instrumentation. This brought to light an interesting concern, because although the ability existed to do the sampling/parsing, to do so would require the use of a new Decom. The new Decom had been available for a while; however, the test support workload, some integration issues, and other initiatives kept it from being incorporated into a mission support role.

6. Displays: With all the changes to the data sources, it was assumed that there would be changes needed. Both the Matching Display and the FCR Engineering Display had been developed over many years and had functioned well, so there was very little recent experience with the code behind the display. When trying to decide a path forward, a good deal of thought was put into the impact to the displays and trying to minimize the amount of changes required by doing additional changes upstream of the display. This decision was based on the fact that since other processes upstream would already have to be changed, additional changes would be less of an impact than trying to change the specific displays. Since the data for the FCR Engineering Display remained on the same MIL-STD-1553 bus for Version 6 aircraft as it had previously, efforts were made to preserve the input to the display to allow it to remain unchanged. Unfortunately with increase in data, changes in data types, and other data changes, it was likely that modifications to the matching display would be unavoidable.

IMPLEMENTATION

The resulting implementation is shown in Figure 4.

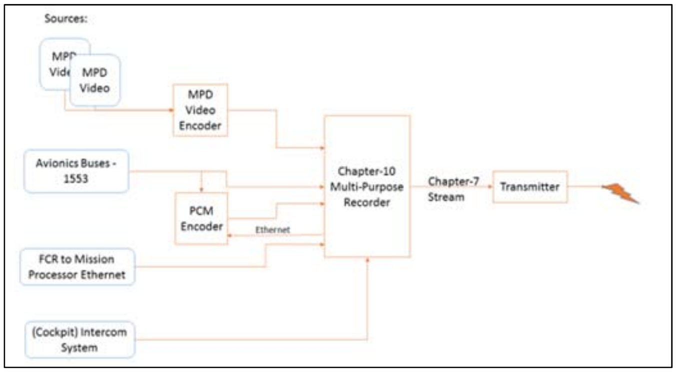

Figure 4. Resulting Aircraft Instrumentation Overview

The Apache Army Program Manager tasked Boeing Military Aircraft (BMA) to provide, among other things, instrumentation and maintenance support for the Version 6 test aircraft. After YPG completed its assessment, one of the first orders of business was to meet with BMA to discuss instrumenting the Ethernet bus. A meeting was held at BMA facility that was supported by key personnel who had extensive knowledge of instrumentation, the Version 6 aircraft, and FCR. This group decided that the best course of action to gain access to the Ethernet bus was to fabricate a custom harness to allow the installation of an Ethernet tap in the FCR to ERD-2 Ethernet path. Once installed, the Ethernet data could be sent to both ERD-2 and YPG's instrumentation with no impact to the aircraft's functionality. BMA agreed to take on the task of building the custom harness, installing the Ethernet tap, and routing the Ethernet signal to YPG's instrumentation pod.

An additional benefit from the meeting at BMA was that the FCR cognizant engineer provided YPG with some samples of the Ethernet traffic between the FCR and the Mission Processor. This combined with Interface Control Document (ICD) information was used to build up the process to sample the Ethernet data.

Armed with these data samples, some initial exploration of processing Ethernet data with the new DECOM was performed. In the end, it was decided to continue to use the legacy DECOM and sample the Ethernet data at the aircraft using the existing PCM Encoder. The primary reason for this decision was the lack of an available Ethernet parser on either DECOM. Although all the necessary tools and functions existed on the new DECOM, a custom parser would have to be written. This would put additional burden on the available resources and since the new DECOM had not yet been utilized, other integration issues would inevitably be encountered so it was decided not to use the new Decom for this effort.

As luck would have it, YPG had an Ethernet module for the PCM encoder that was already being used on Apache. This module was capable of sampling the Ethernet data down to the data word level. Although the native Ethernet structure would be lost, all of the selected Ethernet data would be in a PCM frame and manipulation of a PCM frame using the legacy DECOM was well understood. Even though YPG had the necessary Ethernet module, it had not been used for many years and only then in a much different application. The PCM encoder would now be used to capture all the 1553 and Ethernet parameters needed to drive the displays in mission control, so programing the PCM encoder was not a trivial task. YPG received outstanding customer support from the Encoder manufacture, which saved us precious time getting this critical component ready.

A strategic approach was taken when programing the encoder and building the corresponding PCM Frame. With the inclusion of the Ethernet data, the resulting frame needed to be much bigger. In the previous instrumentation scheme, the encoder output a 1-Mbps stream containing 1248 parameters, which provided a 50Hz sampling rate. With the inclusion of the Ethernet parameters, the encoder bit rate had to be increased to 2-mbits/sec stream containing 2496 parameters to maintain the 50Hz sample rate. A pragmatic approach was taken when creating the new PCM frame with a focus on the time available rather than the engineering aesthetics of design. The new PCM frame was constructed to preserve as many of the data word locations used in the previous frame as possible. Although this resulted in a slightly larger frame, it significantly minimized the number of changes the Decom or displays needed. This approach worked better than expected as the FCR Engineering display ended up needing virtually no changes.

The final consideration for the aircraft instrumentation was onboard recording of the Ethernet data, with the goal to record the Ethernet directly to the multipurpose Chapter-10 recorder being utilized. To accomplish this, the Ethernet data flow needed to take the following circuitous route. The Ethernet data was sent to YPG's instrumentation via the BMA Ethernet tap. Next, the Ethernet data was sent to the Chapter-10 recorder, which both recorded and passed the data to the PCM encoder. The PCM encoder ingested the Ethernet data, sampled the required parameters, and then sent the resulting PCM stream (with 1553 data) back to the recorder where the encoder's PCM stream was recorded. Finally, the Chapter-7 stream was created and sent to the transmitters.

Once the Ethernet data flow was finalized, it was realized that an additional multipurpose recorder module not previously identified was needed. This was a serious issue because by this time, there was not enough time to procure and receive the necessary module prior to the start of the test. YPG explained their situation to the recorder vendor and gratefully accepted an offer from the vendor to utilize one of their demo cards to support the upcoming test.

The resulting Chapter-7 stream was 7.5 Mbps and contained the PCM stream from the encoder, which now included both 1553 and Ethernet parameters, the 2 MFD encoded videos, and cockpit intercom. This was an increase from the previously implemented 5 Mbps Chapter-7 stream, but as anticipated no extraordinary efforts were needed to program the transmitters, receivers, and ground station for this higher bit rate. The spectrum requirement did increase, but fortunately any negative impacts were able to be mitigated by careful coordination of all the test programs on the range.

Even though all the necessary data was now accessible at mission control and efforts had been made to minimize the impact to the DECOM, there was more work to be done. When it came to programing the DECOM, the new PCM data frame was twice the size of the previous data frame and more than half of the parameters were completely new. Ultimately, all the data words, new and old, would have to be mapped from the PCM data frame to specific places in data blocks that would be sent to the displays. Also, any engineering unit conversions, discrete bits, multiple data word manipulations, and any additional data processing would have to be done. Once completed, the painstaking task of checkout began. The good news was that with respect to data words for the FCR Engineering Display and many of the FCR mode commands/responses, much of the previous work could be quickly modified to work in the new program since they remained on the MIL-STD-1553 bus and their data word locations from the previous data frame were preserved in the new frame; unfortunately, all the Ethernet data words were new and all had to be programed from scratch.

With respect to the displays, the careful plan to preserve has much of the previous structure paid dividends as the FCR Engineering required only minor changes to be fully functional. The Matching Display required a significant amount of reprogramming and check-out was difficult because of the lack of a contiguous data set that included both Ethernet and 1553 data. Included in the Matching Display development was the efforts for the programmers to re-familiarize themselves with the display since it had been more than 5 years since a significant update had been performed. This is not uncommon for specialized displays that are tied to an Army procurement cycle, i.e. feast or a long famine, but can be a challenge when working on a tight schedule. Standards and documentation help but even in the best cases, some re-familiarization will always be needed.

RESULTS

The preliminary build up was completed, checked out to the greatest extent possible, and 2 weeks prior to the start of flight testing the aircraft instrumentation was sent to the BMA for installation on the aircraft. Installation and a 3-day ground check-out on the aircraft was a joint effort between YPG and BMA personnel. The data flow on the aircraft was replicated fairly completely, to include the transmitting and receiving data from the aircraft. The data flow on the ground side was incomplete, because it was impractical to transport all necessary personnel and equipment to the BMA facility to simulate the ground side data flow.

The check-out included utilizing the FCR, and benefitted greatly from a built-in mode in the FCR that could simulate a complete radar scan, including target detections. A series for simulated scans was conducted and recorded so that a complete check-out of the displays could be done at YPG prior to aircraft arrival. Overall, the check-out went better than expected and all the modifications done by BMA and YPG seemed to be functioning as advertised. With the completion of a successful ground check, the YPG team packed up and headed home to continue the checkout process with the data captured.

The actual flight test went well, with only minor problems and corrections needed to provide the minimum support required by the test team. Although this seems a bit anticlimactic, given the large number of changes implemented in a short period of time, the flight test was a great success. Also, because this was a typical instrumentation effort, a series of anomalies with the existing components caused some added excitement to the test support. Similar to the Ethernet instrumentation, the effects of these anomalies were mitigated enough to allow the minimum requirements to be met. The problems encountered reminds us that no matter how many pre-flight checkouts are conducted, complex instrumentation efforts still need some flight time for check-out.

Future Goals: Based on the results of this initial implementation, several areas were identified for improvements either to provide more capability or eliminate older components. With respect to the aircraft instrumentation, the improvements focused on the multi-purpose recorder. The multi-purpose recorder can be configured to, in addition to recording, filter the incoming Ethernet and 1553 messages for transmission to the ground through the Chapter-7 data link; therefore, making the PCM encoder currently being used redundant, and removable. This PCM encoder is by the oldest component utilized on the aircraft and although very reliable it is long past its service life.

Removing the PCM encoder from the Apache would result in a lighter more compact instrumentation suite that would draw less power. It would also force us to handle the received data differently as the ground station would now output a Chapter 10 User Datagram Protocol (UDP) data stream containing the Ethernet and 1553 data of interest. The DECOM utilized for this test is not capable of receiving this UDP stream; however, the beauty of this UDP stream is the possibility to DECOM data with only software, i.e. no specialized hardware. In the near term the newer DECOM originally passed over for this test effort will be brought on line, eliminating the proven but aged DECOM.

The final improvement would be an effort to streamline connecting to the Apache's Ethernet buses. The current method of using a modified harness and an Ethernet tap works well, but is both intrusive and limited to a single Ethernet bus. A better approach would be to connect directly to the ERD-2 (see Figure 3) utilizing an available port. This would eliminate the need for any modification or custom harness. The challenge with this approach is that once connected to the ERD-2, the proper subscription/publish handshake would have to be established to gain access to the data. In this approach, the multipurpose recorder's Ethernet module would be modified to provide the appropriate handshake, and request information from any of the Ethernet buses. Initial investigation indicates the multipurpose recorder is capable of this, but much more coordination with the recorder manufacture, BMA, and the Apache PM will be needed to implement.

CONCLUSION

It would be easy, but not realistic to conclude that more time would have allowed YPG to implement a better approach than what was ultimately flown. The configuration flown met all the requirements, including schedule constraints, and improvements based on careful analysis of the results can and will be made for upcoming tests. Although the short suspense resulted in a hectic schedule and more than a little stress, it also resulted in increased instrumentation capability. Though requirements for the particular test were not completely anticipated, the capability to instrument Ethernet has been part of YPG instrumentation investment planning for years. That fact coupled with very good working relationships with several vendors plus a little luck resulted in a successful endeavor. Test support will always have the highest priority, but time for investment planning as well as interacting with industry is also needed for long term success.

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