A DISCUSSION ABOUT A DISTRIBUTED DAU STANDARD

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ABSTRACT

Modern aircraft are both bigger in some dimensions and smaller in others than previous generations of aircraft. With earlier airplanes we were able to centrally locate a data acquisition system and bring wires from all of the transducers to a central location. With more recent airplanes two factors have combined to make this impossible. First, each new program requires more transducers and thus more cables: it is no longer possible to bring that many wires to a single location. The other problem is that airplane wings and control surfaces have become thinner leaving less room for cables.

To date we have been able to get around the problem by using physically small Data Acquisition Units (DAUs) that are distributed around the aircraft. However, it is now reaching the point where the space available in the airplane to run wires is becoming so limited that we need to use DAUs that have a small number of channels as well.

What is being proposed is that the test community develop or adopt a standard that will allow systems to be built that look to the higher level elements of the system as a single DAU but in reality are composed of several small nodes that are distributed around the airplane and connected by some communications medium.

INTRODUCTION

A proposal has been made to the Range Commanders Council (RCC) - Telemetry Group (TG) Vehicular Instrumentation & Transducer (VIT) subcommittee that a standard be developed or adopted to allow Distributed Data Acquisition Units (DAUs) to be developed around a standard communications medium.

For years the concept of a distributed DAU architecture has been considered and even developed to solve the problem of limited space to route wires through structure. For various reasons, these approaches have not been moved to a standards body providing a path for general acceptance.
Some suppliers have developed distributed units but not only are they vendor-specific they also remain fairly large and their approach does not address the need to minimize volume and wiring. Additionally the vendor-specific solution forces all parts of a distributed DAU to be purchased from a single source. In most cases organizations will purchase their system from that single source anyway, so the question then may be asked “what is the point of developing a standard?”

Smart sensors have always been an intriguing desire in instrumentation where the elimination of analog wiring has the possibility of maximizing signal fidelity in an acquisition system. However, the use of smart sensors involves a compromise between a proliferation of bus connections to support individual smart-sensors and multi-channel signal conditioning BIMs and the proliferation of their associated transducer wiring. Recent demonstrations of distributed DAU systems have shown that the physical connectors of smart-sensors continue to be a challenge so their use needs to be limited to the special cases where they have a compelling advantage.

Pressure scanners in the form of smart sensors are a case where a compelling advantage can be shown. These devices could incorporate a miniature communication engine that would be practical from a network physical layer. Current scanners typically rely on data acquisition system suppliers to build interfaces to these devices and often do not keep up with the latest generation of scanners. A suitable standard would allow scanner suppliers to create units that could be directly integrated into a distributed DAU architecture. Additionally later model scanners could be incorporated into an instrumentation system without requiring changes to the core data acquisition system.

The distributed DAU standard should encourage extensibility. While most systems support high-channel count stacks or chassis forms, the proposed standard would allow suppliers to keep their current product line but add the capability of “separating the assembly” into distributed modules. With a compliant distributed DAU, “overhead module” single existing modules could be supported.

Another advantage with a standard is that if the original supplier is no longer able or willing to support the system that was purchased, support may be available somewhere else.

WHAT IS THE PROBLEM?

The wiring problem can be described by considering Figure 1. A conventional DAU is a set of control logic and power supplies combined with a number of signal conditioners. Typically they are assembled as a chassis into which the signal conditioners can be installed or by using a “loaf of bread” architecture where all elements of the conventional DAU are configured as small slices that are fastened together to form the DAU. Current conventional DAUs often interface to PCM, CAIS/PCM or Ethernet networks to form a data acquisition system.

In either case, the wiring to connect the transducers to the conventional DAU must come to the location where the DAU is installed. From a cost point of view this is the least expensive way to install a system. Only one set of installation drawings are required to install the DAU. However, bringing the transducer cables from where the transducers are installed to the DAU is becoming more and more of a problem on new aircraft designs, especially emerging small unmanned
aircraft and even on large transport aircraft. The wing and control surfaces are becoming thinner and the available holes for cable routing are becoming smaller. This also results in a “rats nest” of cables at the DAU which creates problems of its own when changes need to be made.

![Figure 1 Conventional DAU Wiring](image)

### The “DISTRIBUTED DAU” Solution

The concept of a distributed system with single channel “smart sensors” has been around for many years. It has become apparent that single channel devices, whether they be integrated smart sensors or single channel signal conditioners connected to a single sensor led to practical limitations.

In the single channel smart sensor approach, as shown in Figure 2, consider the number of cables and connectors required. There is one cable for the transducer and an upstream and a downstream cable to connect to the adjacent Bus Interface Modules (BIMs) each with a set of connectors and a physical interface to the bus. Three times more cables are used for this approach than for a conventional DAU. Many organizations also require a drawing to install each BIM. Some installations may require this kind of distribution but this is definitely a more expensive way to build a system.

![Figure 2 Single Channel Smart Sensor Approach](image)

Cost and complexity can be reduced by using multichannel BIMs as shown in Figure 3. The cost of installing the system is lower with this approach. The number of cables is also reduced but it
is still more costly to install than a conventional DAU. This is clearly an improvement over the single channel smart sensor and it points to the conclusion that the more channels we have in a device the lower the overall cost.

Figure 3 Multiple Channel Smart Sensor Approach

The distributed DAU is an approach that allows the user to configure the data acquisition hardware in a given zone on an airplane. The idea is that a number of small conventional DAUs can be configured by the user to perform the measurements in a zone on the aircraft. This idea is shown in Figure 4.

Figure 4 The distributed DAU Approach

A distributed DAU would consist of a number of nodes that are connected to the System Interface Logic over some communications medium. In most situations such an interface would connect to a higher level of the system, such as a Chapter 10 recorder, an Ethernet network, or an iNET-like network. The system Interface logic plays a very similar role to the overhead unit in conventional DAUs. The nodes can consist of small DAUs or individual BIMs except that the collection of nodes would appear to be a single DAU. However internally and to the end-user it is a collection of nodes, much like a conventional DAU is a collection of signal conditioning modules.

This approach allows the user to locate nodes that have the needed signal conditioning required for the zone on the aircraft where it is to be installed. It is more expensive to install than the
conventional DAU because more installation drawings are required and more cables are needed. The advantage of this approach is that it distributes the nodes into areas where cables can be routed. If you have a case where a conventional DAU can be used, then that is what should be used. But for those other cases this is an answer.

WHAT SHOULD NOT BE REQUIRED TO DEVELOP A DISTRIBUTED DAU STANDARD?

The first thing that is needed is a set of requirements. Without a set of requirements going in there will be no way to determine when the standard is complete. So what should be in the requirements? First let’s describe what should not be in the requirements.

The characteristics of the individual signal conditioners would not be appropriate in this level of a standard. How that signal conditioner communicates with the rest of the distributed DAU is appropriate but not things like accuracy, transducer excitation, number of channels, etc.

Environmental conditions are the domain of the system specifications used to buy the system and not the standard. However harsh environments required for some systems may limit what is practical with hardware implementations, specifically electronics, and should be considered. This will have to be balanced with the need to provide a practical price point for other applications.

Connectors are a gray area in these considerations. If the characteristics of the communications medium are such that a particular family of connectors need to be specified then they should be included. It may be necessary to call out standard connector “families” such that performance compliance can be maintained.

So what should be included? To determine the answer to this question it is appropriate to consider the capabilities that are needed within a conventional DAU and from there proceed to things that would be appropriate to include.

DATA SAMPLING

One of the first things that comes to mind is the ability of the control logic in a conventional DAU to control the sampling of all of the signal conditioners within the DAU. In a conventional DAU, this is usually accomplished over some type of backplane signaling or with a bus structure that run through the signal conditioners. In the case of a distributed DAU, it is desirable to minimize the number or wires that are used for the node-to-node communications; therefore, the types of communications that are used inside a conventional DAU will not be appropriate.

It is important to achieve this sampling control as part of the distributed DAU standard. Requirements for correlation of data signals from different devices exist currently for real-time flutter analysis and for post-processing data mining and trend analysis. To minimize the number of wires, a mechanism for simultaneous sampling of various sample rates needs to be considered. The higher level of the data acquisition system may also need to handle simultaneous sampling across multiple distributed DAUs since correlation is often required between devices in different
locations that could be supported with a different bus. How this is achieved may need to be determined by the higher level system and may or may not be appropriate in the distributed DAU standard.

Something that will need to be defined is how close to “simultaneous” is acceptable. With conventional DAUs, nanoseconds variation in the sample times is achievable and should also be achievable in distributed DAUs. So just what is required in “simultaneous” sampling? Distributed architectures may introduce “time of flight” errors that result in delays between the sample time of one node and another. Often such delays are not deemed significant since in a 200 foot bus the total delay end to end is less than 300 nS. Regardless such attributes will need to be included in the requirements.

The actual time that a sample is taken is not explicitly necessary in the standard. If the System Interface Logic controls the sampling mechanism, this same unit could also be responsible for attaching a time stamp when the data is returned back through the interface.

The method for triggering individual devices on a distributed bus could take many forms. One simple method uses a trigger command with the logic in place to take an edge from the command and pass it through to the Analog to Digital Converter (ADC). For digital filter applications this signal would feed a Phase Lock Loop clock multiplier necessary to operate the oversample ADC and digital filters. Other methods are possible and are generally more complex but should be considered if they add significant capabilities.

**SAMPLE RATES AND DATA BANDWIDTH**

The sample rates that can be achieved with a conventional DAU should also be achievable with a distributed DAU. However, some careful thought needs to go into the data bandwidth requirements. The user is concerned about the data bandwidth that can be achieved coming out of the System Interface Logic and that is what the requirements should specify. However, when developing the standard, some thought will need to be given to the bandwidth of any practical communications medium. A half-duplex command response system that transmits a trigger and a read of a single value to each channel can have efficiency as low as around 25% even if the overhead is minimal. This can be increased to nearly 75% by buffering and reading multiple samples. If a full-duplex approach can be implemented a nearly 100% efficient system can be achieved, however this can result in additional wires in the data cable or communication complexity.

So, in setting the requirements for the data bandwidth, some consideration needs to be given to avoid making it so high that it cannot be achieved in a reasonable manner. Consideration should include close examination of the most beneficial needs that can be practically supported by such an architecture and what measurements are better supported using more traditional methods. Regardless, the data bandwidth needs to be included in the requirements and it is up to the standards developers to determine how to meet that requirement.
DIGITAL FILTERING AND COMMON CLOCK

Digital filtering is commonly used in most systems today and this needs to be thought out in setting the requirements for a distributed DAU. This does not mean that the characteristics of the digital filters need to be defined in the requirements document for a distributed DAU standard, but the ability to implement them within the system is needed.

When a digital filter is used, the ADC runs at a higher sample rate than the output sample rate for the data. The digital filter then decimates the number of samples to provide the output sample rate. However, the time that the sample is output needs to be controlled by the System Interface Logic.

For this to happen, a common clock needs to exist between the System Interface Logic and the ADC in the signal conditioner. As stated earlier, a probable implementation of this is a clock multiplier implementations using Phase Lock Loop multipliers that operate from some signal coming from the system Interface logic, but the requirements just need to specify the existence of the capability.

TIMING OF A DATA SAMPLE

Within a conventional IRIG 106 Chapter 4 PCM system, the time that can be associated with a sample of data can be derived based upon the time that the sample was received at the data processing or recording element in the system. Knowing the time that the sample is received, the processing system can account for delays associated with data transmission and filtering. The same capability will be needed in a distributed DAU as well.

Many systems are moving to network-centric solutions and away from a purely Chapter 4 type PCM system where it is necessary to time stamp a sample prior to the data entering the network to allow for a variable transmission delay within the network. Most likely this could happen within the System Interface Logic that “connects” the distributed DAU to the network.

In some cases it is also essential that the latency be small in order to meet system requirements. The percentage of measurements within a given system that have a low latency requirement is typically small. This makes for some interesting trade-offs. Some techniques can improve the overall system bandwidth at the expense of latency, but it may be worthwhile to be able to set up a system so that some measurements within a distributed DAU have a higher latency but a lower overall bandwidth, while others have a low latency requirement but consume a higher percentage of the system bandwidth.

The requirements will need to spell out the allowable system latency for the low latency measurements. The standard may well need to add some of the methods that can be used to improve the overall system bandwidth even if they do increase the data latency on some measurements. If the standard allows for multiple latencies, it will also be necessary to define the maximum latency for measurements that can have a higher latency. However, this may be a requirement imposed by the higher level system and not part of the standard.
UNIQUE IDENTIFIERS

Addresses will need to be assigned to each device on the communication medium. Two possible ways to do this come to mind. One is to have a system where each node can be identified by its position on the bus and each element within the node can be identified by the same or another capability. Another requires each element in a distributed DAU to have a unique identifier. Either approach should allow the higher levels of the system to identify the elements of the distributed DAU. It will also allow the system to assign logical addresses to the individual elements of the system. What elements in the system need to be identified should be limited to what is needed by the higher levels of the system.

There are a number of ways to achieve a unique identifier. One is to have an outside agency assign them as is done with the Ethernet MAC address. Another option is to use an algorithm that does not require an outside agency that uses attributes that could guarantee uniqueness such as year, month, day, time and GPS coordinates with perhaps other simple manufacturer attributes. Such methods have been successfully demonstrated. Still another option would be to combine text artifacts that will normally be in the system. These could include such things as the supplier’s model number and serial number with something that the supplier can claim as unique like a trademarked word or set of words.

Whether or not the requirements document should include anything beyond the existence of a method of identifying each element of the distributed DAU is an open question that will need to be addressed.

ADDRESS SPACE

Defining the address space within a distributed DAU can be a little bit tricky. It was noted earlier, as the number of nodes in a distributed DAU decrease, the installation costs also decrease. From that it can be implied that it is desirable to get all measurements, and thus be able to consume all of the address space, within a single node. But it will be necessary to use more than one node in many systems. This leaves questions about how to distribute the address space from one to many nodes within a system.

It will also be possible to have more measurements within a distributed DAU than with a conventional DAU. In a conventional DAU it is usually mechanical restrictions that limit the number of signal conditioners and thus the number of measurements. The card slot capacities within a chassis or stack length are typical limiting factors. With a distributed DAU the same mechanical limitations will exist but the ability to add more nodes will expand the number of measurements in the DAU.

A system could use the unique identifier as a method of managing the address space. Such implementations allow devices to be “initialized” without any addresses or allow the addresses to be changed after the device is installed in the system by accessing the device by its unique identifier.

The requirements will need to address the number of measurements (addresses) within a node and the number of nodes that are allowed within a distributed DAU.
MEASUREMENT SIZE

A measurement should be able to be defined from a single bit to many bits. The lower limit is easy to define but the maximum number of bits will take more thought.

ADCs are common today with up to 24 bits, so a limit on measurement size that is less than 24 bits would probably not make sense. However, a far more common word size is sixteen bits. In addition, sixteen-bit resolution exceeds the accuracy needed for most measurements. It should be possible to have a word size on the communications medium and to allow a measurement to occupy more than one word.

While flight test systems now typically use 16-bit data words, lab test systems often have data that is 24-bits in length. Thus any system should be able to handle both scenarios. However, the number of bits could affect the bandwidth consumed on the bus communication medium. Typically systems are partitioned to operate on 8-bit (byte) boundaries. Most modern data in PCM systems use 16-bit transmissions. Whatever the system, the standard should be able to easily accept higher byte counts without loss in efficiency other than the additional required bytes in the data transfer.

Systems, especially for military applications, will require the support of PCM telemetry. The word size on the communications medium and the word size on a PCM telemetry output do not have to be the same. The System Interface Logic or even devices on the data system network can make a translation between what is received over the communications medium and the PCM telemetry output.

This means that the standard does not need to specify the bits per word on the PCM output; that could be left to the purchase specification. The number of bits per word could also be left to the standards working group to specify.

TRANSDUCER ELECTRONIC DATA SHEETS

Transducer Electronic Data Sheets or TEDS are an artifact that has come out of the smart sensor standardization effort.

The IEEE 1451.4 standard has been emerging as a standard that is being used in lab test. There is interest in flight test applications but adoption has not been very high to date. For transducers the IEEE 1451.4 standard defines a binary TEDS that can provide the information that we would be to needed to describe a transducer but does not cover the signal conditioner. The ground based laboratories within Boeing have asked that the future systems be able to read and pass through to the processors in the system the contents of an IEEE 1451.4 TEDS. They expect the calibration lab to put the calibration information and other information about the transducer into the TEDS. This will allow the information to be passed from the calibration lab to the data acquisition system without human intervention. This can allow the data required to process the data to be derived from the system, rather than from a database. Some labs are already using this capability.
to be able to identify the sensor. It is particularly useful when an airplane part is instrumented at
the manufacturer and closed up with wires hanging out before being sent to the lab.

In systems that include large amounts of information from avionics buses this has appeared to be
less of an advantage. Basically, the system will still require that a database be provided to supply
the processing information. However, there are other advantages to being able to read a TEDS.
In the iNET standard there is the concept of a ‘Management Server.’ That management server
can determine all of the connections that exist within a system out to the DAU. The ability to be
able to read a TEDS through the DAU extends that capability out to the sensor itself. With this
capability a computer would be able to tell you that the system was in the same condition that
you left it in or that something had changed.

**ELECTRONIC DATA SHEETS FOR SIGNAL CONDITIONERS**

Using Electronic Data Sheets or EDS for signal conditioners implies a similar ability to be able
to identify all of the signal conditioners in a DAU. Some engineers have postulated this
capability would allow systems to automate parts of the airplane pre-flight testing. So, if the need
has been identified, what information should be included?

The system should be able to identify the signal conditioners and other interfaces that make up a
node. This should include at least the following:

- Function
- Serial Number
- Model Number
- Revision level
- The user’s property number or other user-supplied information. The requirements should
define how many characters to include.

Different suppliers and previous efforts to define EDS should be considered to meet this
requirement for the signal conditioner.

**CONCLUSIONS**

This paper has intended to outline what needs to go into a standard for a distributed DAU. It does
not include the requirements themselves. However, requirements will help a working group
establish what approach could be considered. The Range Commander’s Council Vehicular
Instrumentation & Transducers (VIT) committee has been asked to look into distributed DAU
requirements. Any architecture to be considered needs to be an industry-wide standard, so, if you
have any requirements please contact one of the authors or someone on the VIT.