Firewire in Modern Integrated Military Avionics

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ABSTRACT

High performance communications, navigation, and identification (CNI) functions on modern military aircraft are increasingly required for mission readiness. The operation of simultaneous waveforms through an integrated avionics rack of shared resources becomes a test in moving data rapidly from one signal processing stage to the next. The IEEE 1394, or Firewire, is a commercial high bandwidth bus whose 64-bit addressing and maximum 400Mbits/second throughput satisfies this demanding military avionics interconnect need. The challenge in applying this commercial product to integrated avionics is the requirement to seamlessly add message priority encoding. By having message priorities, the slower strategic communications links will not impair the performance of higher data rate tactical communications, thereby avoiding potentially life-threatening bottlenecks. The flight environment imposes additional challenges to ruggedize the cabling between integrated avionics racks and to utilize the full capabilities of the Firewire bus. A discussion of the physical, data link, network, and transport layers, as used in avionics applications will be done. Additionally, the versatility of 1394 in military avionics with its variable channel sizes, bandwidth on demand, hierarchical addressing, and upgrade to 800 and 1600 Mbps with a 64-bit wide data path, is emphasized. Finally, system maintenance advantages of 1394's hot pluggable features are discussed, with an eye toward cost reduction on the flight line and total operational time of the aircraft avionics systems.

INTRODUCTION

Providing a sustainable architecture that will meet the requirements of today, but to be expandable to satisfy the roadmaps for tomorrow's avionics is a challenging problem. Current platforms are forced to operate with legacy hardware and software that struggles to satisfy the data rates and bandwidth requirements necessary for current and future military waveforms and functions in a cost-effective matter. This discussion will focus on the waveforms and functions contained in Communications, Navigation, and Identification (CNI) and the advantages offered by IEEE 1394-1995.

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THE IEEE 1394 FIREWIRE BUS

In general, IEEE 1394-1995, hereafter referred to simply as 1394, is a serial bus interface consisting of a tree topology with the root at the center. 1394 has 64-bit fixed addressing, where the highest order 16-bits make up the Node ID. Within those 16-bits, the highest order 10-bits contain the Bus ID, which provide for 1023 buses, and the lower 6-bits contains the Physical ID, which provide address space for up to 63 nodes. 48-bits are left for memory addresses. 1394 consists of two mediums; the cable version and back plane versions. In this discussion we will focus on a cable version, since PCI to 1394 Link Layer chips and boards are readily available. 1394 provides for multiple data rates to coexist on the same bus, providing all nodes contain a base data rate of 98.304 Mbit/s or S100. The data rates currently supported by the standard for a given speed grade and maximum payload size are shown in Table 1, on next page.

There are two data transfer services offered under 1394, Asynchronous and isosynchronous. An asynchronous transfer provides a variable length packet transaction to a specific address on the bus with a returned acknowledge. An acknowledge packet will immediately be sent by the receiving node, assuming it was a non-broadcast asynchronous transfer.

The acknowledge feature makes asynchronous packet transfers more robust, in that it guarantees that the packets arrive at their destination or else the link layer may retry. A retry may be issued if the acknowledge is not valid or if the "time out period" on the link layer has expired. An example of an asynchronous packet follows in Figure 1, on next page.

The isosynchronous transfer service provides a broadcast packet protocol for variable length packets that are transferred on regular intervals and is application-driven instead of needing a transaction layer. The isosynchronous transfer protocol consists of multiple channels each having a 125 microsecond cycle period and are variable size limited only by available bandwidth. This form of packet transfer supports bandwidth on demand (BOD), which is ideal when an

Table 1. 1394 data rates

Speed Grade	Rate (Mbit/s)	Max Payload (Bytes)
S100	98.304	512
S200	196.608	1024
S400	343.216	2048

application's bandwidth is not fixed but variable within the scope of available bandwidth. The isosynchronous transfer protocol is ideal for real-time or video streaming, especially if the bandwidth requirements are not fixed. The one drawback with isosynchronous transfer is that there is no acknowledgment that the intended node received the packet. An example of an isosynchronous packet follows in Figure 2.

The 1394 protocol consists of 3 distinct layers. First, the Transaction Layer, provides the request–response protocol (read, write and lock) from the bus manager to the 1394 link layer. Second, the 1394 Link Layer, which provides the acknowledge datagram to the transaction layer confirming a request. The Link Layer provides addressing, data checking, data framing for transmission or reception from the physical layer (PHY), and direct isosynchronous data transfer service including the generation of a "cycle" signal used for timing and synchronization. The final layer is the Physical Layer, which contains the physical medium and transmits the electrical signal over the serial bus. The Physical Layer converts the *information from the link layer* into an electrical signal (TTL) that will be transmitted over the differential twisted pairs. It also provides arbitration services so only one node will be transmitting data at one time, and includes a fairness protocol which allows all nodes to initiate an asynchronous packet only once during the fairness interval. Specifically for the cable version, the Physical Layer will provide data resynchronization capabilities, repeat services, and automatic bus initialization. The automatic bus initialization is used whenever a new node is added to the topology provided it is still within the 63 node maximum limitation. If a new node is added to the bus, a reset will be generated and all the nodes re-identify themselves as parent or child, which is referred to as the tree-ID process. Once the tree-ID process has concluded and a root is designated, the nodes begin the self-ID process. This process begins when "the root relinquishes control of the bus to the node attached to its lowest numbered connected port" and waits for that node to send an "ident_done" signal. By a node sending an "ident_done" signal the node is informing the root that it and all of the nodes beneath it have properly identified themselves, selected a physical-ID, and exchanged speed capabilities. This process continues from there until the root itself will do a self-identify. After self-ID has concluded, normal arbitration will begin where the root has the highest priority. During the normal arbitration process, a node will send a request to its parent, which will get forwarded up the tree with a "data_prefix" issued by the parent denying access to all

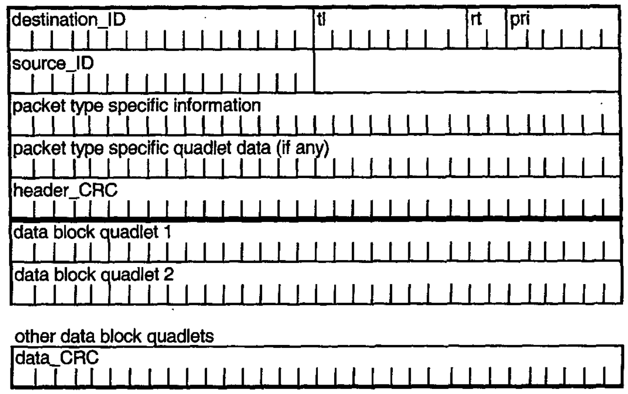

Fig. 1. Asychronous packet

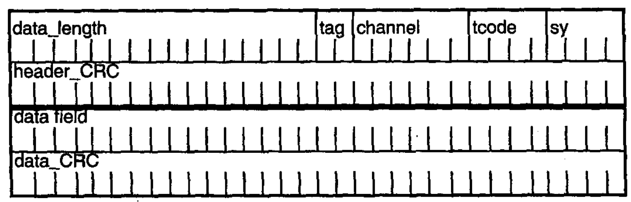

Fig. 2. isosynchronous packet

of its other children. If multiple nodes are vying for the bus, the root will issue a grant to the nearest requesting node and a "data_prefix" will be issued to all the other children serving as a deny. The strategy behind the normal arbitration scheme is that the nodes you think would naturally need higher priority need to be closer to the root then those with little priority; thereby insuring a higher probability of winning the arbitration. The root will issue only one grant and that will conclude the normal arbitration process. The resynch and repeat capability is necessary for allowing packet transfers from the root down to all the nodes, since data is re-clocked at each node. There is a maximum of 16 hops between any two points where 4.5 meters is the maximum distance between nodes, which gives you a total distance of 72 meters between two points. Another important feature of the cable version is that there is a power ground pair embedded in the cable. This power ground pair is used to keep the physical layer chip or PHY powered, even though the device it is on may be powered down. What this accomplishes is that the bus will not lose connectivity to the other branches or leaves further down if a node gets powered down. Since the cable medium is a differential twisted pair, one of which carries the data and the other carries the strobe, along with a power and a ground conductor making up the 6-conductor 1394 cable.

AVIONICS WAVEFORMS

CNI avionics consists of a multitude of complex waveforms. The communication functions comprise computer

Table 2. CNI waveforms and rates

WAVEFORM	BIT RATES (bits/second)	CNI OPERATION	ACTIVITY
Flight Range Training	2 K	Communication	Periodic
Data Communication	1572 K	Communication	Bursty/Periodic
Voice Communication	1116 K	Communication	Bursty
Navigation & Landing Systems	476 K	Navigation	Periodic
Identification	321 K	Identification	Bursty
Integrated Control	11 K	-	Periodic
Total	3498 K		

and sampled voice, with aperiodic activity cycles. The navigation functions are generally periodic and are used throughout different phases of flight, from take-off, ingress and engagement, to egress and landing. However, identification functions are usually triggered by an interrogation from other aircraft or ground stations and have a bursty-type of activity to them. All of these waveforms must operate simultaneously on modern military aircraft, be it fixed- or rotary-wing.

Table 2 outlines some typical binary data rates that would be encountered in an integrated CNI system. The data rates include commands that control receivers, transmitters, and processors, and monitor waveform and resource health. The rates listed for the waveforms are for single channels, and if additional channels are needed, then the commensurate rate would increase. Additionally, Table 2 lists integrated control, while, not strictly speaking, a CNI function, is needed to verify and control the proper operation of the integrated waveforms. The total data rate for all of the combined waveforms of Table 2 is slightly over 3 Mbits/second. Some of these waveforms, while bursty, must be processed immediately due to safety-of-flight. In particular, the identification functions are used for air traffic control and friendly force recognition. A slow response or dropped message, puts an aircraft in extreme jeopardy. Navigational messages, while very periodic, must not experience excessive latency delay prior to processing, since a high-speed aircraft would travel a significant distance before a navigational solution is obtained.

The total data in bits-per-second of the combined waveforms in Table 2 account for less than 5% utilization of the basic 1394 (S100) bandwidth available. The waveforms, as a percentage of the used bus bandwidth are graphed in Figure 3, shown on next page. Here it is clear that the waveforms using the largest amount of bus bandwidth are data and voice communications. Voice communication is inherently a bursty traffic, as pilots have random talk times. Data communication, likewise, can either be periodic status/tactical messages, or high bandwidth data transfers. Computer and network type of data traffic will have period status messages along with bursty data transmits or receives.

The data rates listed in Table 2 also only show average loading for these combinations of waveforms. Depending upon the phase of flight, there may be instantaneous bandwidth needs that are up to 10 times this average. This large instantaneous bandwidth is needed because, over a short time period, a large amount of data may be received or transmitted, but over a longer duration the average data rate is lower. However, the low bus usage (on average) shown in Table 2 for the CNI waveforms, still leaves plenty of room available for instantaneous peaks. Adding newer, more advanced waveforms to current or next generation aircraft with 1394 firewire is easily accomplished because of the low usage. Even when larger instantaneous bandwidth waveforms are introduced in the near future, the 1394 higher data rates of S200 and S400 are already built into the specification and will accommodate these upgrades.

The mix of bursty and periodic traffic for CNI can be accommodated within 1394 by taking advantage of the asynchronous and isosynchronous protocol mix. The periodic functions can use an asynchronous protocol that uses a fixed amount of the bus. Depending upon the number and periodicity of the message, bandwidth can be allocated in a fixed way through the asynchronous protocol. The only design criterion is that the asynchronous allocations do not use all of the available bandwidth if isosynchronous messages are employed. The bursty traffic will use the isosynchronous protocol to access bandwidth on demand. The bandwidth can be significant if the instantaneous bandwidth is large for the bursty traffic. This makes the 1394 bus an excellent economical choice, while having system growth capability.

CNI can take full advantage of the 1394 architecture and bandwidth on demand, which is ideal for periodic traffic that is not mission critical. An example of this would be diagnostic and maintenance information or real-time audio. As discussed before certain waveforms may need to have higher priority than others, which can be easily achieved by the location in which the node is placed on the bus. The closer the higher priority node is to the root, the more likely it will win arbitration for the bus. The acknowledge format of the asynchronous transfers is ideal for mission critical functions and waveforms, where it is necessary to have some form of confirmation that the packet was received by its destination. The 1394 bus balances these competing requirements of mixed

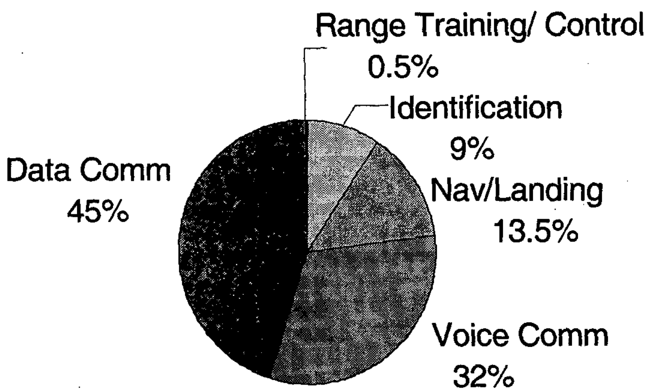

Fig. 3. CNI waveform bus usage

bursty and periodic, rapid and low-latency, low and high bandwidth waveform processing.

Low latency for some CNI waveforms is of prime importance and the 1394 bus can deal with this easily. An isosynchronous transfer provides low latency of less than 1 microsecond, with a precise time reference of 125 microseconds ± 12.5 nanoseconds. This low latency is sufficient for all of the current military avionics, CNI waveforms, and should provide enough capability for future designs.

Migration to the higher S200 and S400 data rates will accommodate higher bandwidth features such as real-time video, digital battlefield, and internet data exchange. The capabilities of firewire greatly extend the possibilities of operational waveforms and functions available within the cockpit.

BENEFITS OF 1394 TO AVIONICS

The 1394 architecture provides many advantages needed in future avionics development and testing. For systems under development, the standard provides a means to lower the cost, since that is now a driving factor in the military industry. The standard is a COTS implementation, which makes it affordable and readily available. The cost of a 1394 system runs less than $6 per chipset in quantity and there are drivers available for most applications that interface with the 1394 chips available today. Due to the selection of a COTS standard, much of the expensive software development necessary to build a system has been done by the industry and supports features such as Plug and Play. The benefit of the 1394 cable implementation is a lower susceptibility and emission of EMI, a primary concern for CNI avionics. The low EMI is achieved via the standard differential twisted pair and shielded cable.

As for a cost reduction on the flight line or at the depot level testing, 1394 offers significant advantages. The cable configuration offers a semi-rugged cable that is much easier to use then standard media, providing a firm secure connection between two devices. Another feature of 1394 is the "hot plug" or "live insertion" capability that does not require one to power down the network when inserting or removing a node. This can save large amounts of time since one can add or remove devices on the bus without having to power them down and then bringing them all back up.

The standard is growing and there are upgrade paths. Recently, 1394a was approved by the IEEE, which will provide more clarification and some improvements to the standard. Currently under development is 1394.1, which is a 1394-to-1394 bridge standard that will overcome the 4.5 meter maximum length between two points, along with providing true 1023 bus support. Another more dramatic upgrade to the standard will be 1394b, is currently under development in the P1394b working group. 1394b will increase the data rate and bandwidth even more, providing for rates of 800 Mbits/sec, 1.6 Gb/sec and 3.2 Gb/sec. With these extremely large bus bandwidths available, real-time video conferencing, or newer operational and maintenance waveforms not yet dreamed up can be made available.

CONCLUSION

Some avionics waveforms have strict latency, priority, or data rate requirements that drive system performance. There are burst transfers that come at an unpredictable time and will benefit from the guaranteed bandwidth provided by the isosynchronous protocol along with low latency. The burst transfers are mixed together with periodic types of traffic that must not interfere, such as increasing latency.

The 1394 firewire bus provides not only a clear capability to support current avionics data rates, but has an inherent growth path built-in to handle the unforseen and hard to predict additional capabilities needed in the next century for military aircraft. The commercial base provides an extensive array of companies and vendors, along with the associated cost savings. As the new generations of military aircraft exit the assembly lines, their ability to have defined performance growth and upgrade paths provide a measure of flexibility in an uncertain world. Clearly, the 1394 firewire bus is a good choice to handle the variety of CNI waveforms present in modern military avionics along with the unforseen capabilities that will become future requirements of military avionics.

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