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A Novel Scheme of an Optimal Data Rate Transmission for Airborne Telemetry of Long Range Aerospace Vehicle

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ABSTRACT

Airborne telemetry data is inevitable during the development phase of an aerospace vehicle. With the availability of telemetry data the vehicle characteristics are evaluated and the vehicle objectives are achieved subsequently. During the trajectory path, the airborne telemetry system transmits vehicle data continuously and ground receiving station receives it. The availability of data at ground station is solely dependent on various parameters; primarily data rate, modulation, RF power, etc. In this paper, typical data rate of telemetry for long range aerospace vehicle is analysed and an innovative scheme is proposed for optimal data rate transmission with multi-resolution of high speed image data for distributed telemetry system. The scheme is implemented on 25 nm ZYNQ CSOC of telemetry hardware and synthesised netlist is simulated, performance is evaluated and results verified on telemetry hardware.

Keywords: Hardware design; ZYNQ CSOC; Data acquisition unit; Airborne telemetry; Aerospace vehicle; Telemetry format

1. INTRODUCTION

Long range aerospace vehicle has to travel very long distances to reach its destination. It carries multiple stages[1] of propellant along with payload to meet the desired performance. Each propellant stage gets separated at a defined time of a predefined trajectory path[2-3]. Some stages are dropped in mid-course after their intended application is fulfilled and finally the vehicle carries payload (Ex. Satellite, warhead etc) to destination. These vehicles have huge instrumentation plan distributed throughout the vehicle to measure physical parameters, auto sequencing events and bus data. The autopilot sub systems communicate over a multiplexed data bus[4-5]. Data from physical parameters and data bus are acquired by a telemetry system and transmitted to the ground receiving system for post flight analysis.

Autopilot is the control system of the vehicle. It mainly consists of navigation computer, guidance computer and actuation system. Current position of the vehicle is measured by navigation system. Guidance system computes the mismatch between the required trajectory and actual trajectory. It issues necessary input to actuation system to correct the trajectory. Typically, an Inertial Navigation System (INS) is used in aerospace vehicles. To increase the accuracy of trajectory, INS data is corrected with satellite navigation (Ex. GPS, GLONASS etc). In some cases, pre-defined trajectory is stored in the guidance computer and in other cases, the guidance computer is aided by other information sources (Ex. RADAR, RF seeker, IIR seeker etc) during their course of travel. Guidance computer uses the information to compute corrections in the trajectory. The autopilot data (i.e navigation and guidance data) is posted to telemetry at regular intervals for post flight analysis. The performance of autopilot is evaluated in post flight analysis.

1.1 Distributed Telemetry System (DTS)

The long range aerospace vehicle has multiple stages to meet the vehicle objectives. The vehicle typical measurement plan of a stage is depicted in Table 1 for multi stage vehicle, in particular, dense measurement is used. Each stage measurement plan is also well defined. Hence, the measurement in the vehicle is distributed 6 stage wise and measured stage wise (locally) and provided this local data is provided to master acquisition system to transmit via antenna to ground station.

The DTS[6] has local data acquisition unit (DAU) at each stage to master DAU at the final stage of the vehicle and they communicate over a digital bus. The configuration of

Table 1. Typical Measurement plan of DAU at each stage

Parameter	Band width	Samples Per sec	Quantity	Data rate
Vibration	2 KHz	8 KHz	10	640 Kbps
Pressure	1 KHz	4 KHz	10	320 Kbps
Electrical	100 Hz	400 Hz	10	32 Kbps
Temperature	10 Hz	40 Hz	10	4 Kbps
Strain	10 Hz	40 Hz	10	4 Kbps
Bus Data	1 Mbps	-	1	1 Mbps

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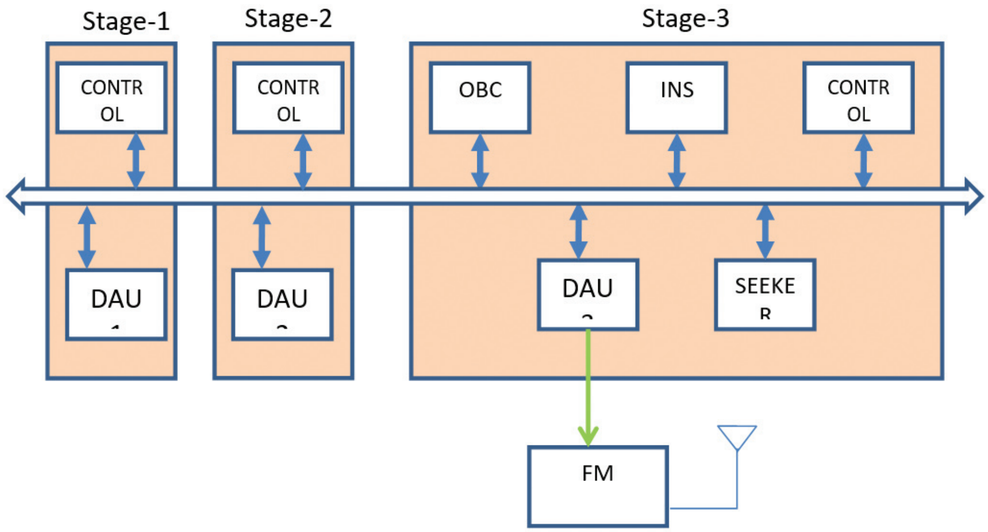


Figure 1. Distributed Telemetry System (DTS) configuration.

DTS is depicted in Fig.1. Here, each DAU is an integrated instrumentation system with both signal conditioning circuit[3] and data acquisition module. One Master DAU fetches data from local DAUs and merges data for telemetry purpose. A high speed communication bus[7-9] is used between local DAUs and Master DAU.

The DTS configuration with the above said measurement plan of data rate of each stage DAU is shown in Table 2. These systems handle high data rates (i.e 2 Mbps w.r.t Table 1) and post the data to master DAU system for down streaming to ground stations, which is located in the final stage of vehicle. The final data rate of the master DAU is typically 14 Mbps as per measurement plan which is depicted in Table 2. In traditional way DAU has to transmit 14 Mbps data to ground stations continuously. At present, the ground receiving stations, data handling capability for PCM/FM telemetry system[10-11] is up to 10 Mbps only. Hence, a scheme is proposed to meet 10 Mbps data without compromising mission requirements.

Table 2. Data rate requirement of DAU in DTS configuration

System	Data rate
DAU1 -stage1	2 Mbps
DAU2 -stage2	2 Mbps
DAU3 -stage3	2 Mbps
High speed image data- Stage3	8 Mbps

1.2 Seeker Image Data Acquisition

The onboard IIR seeker[12] is primarily used to capture thermal images in real time which will be sent to OBC for data fusion for guiding and controlling the vehicle. The images captured by the seeker are typically with an updation rate[13] of 25 to 50 Hz. Each image size[14] is typically 400 x 400 in size and each pixel information is represented by 10 bits to 12 bits. The images captured by IIR camera are compressed and enhanced[14] by seeker electronics for further processing. The processed seeker data are then transmitted to OBC to estimate vehicle characteristics and executing vehicle events accordingly.

The captured IR image data rate of the seeker is 48 Mbps. The final compressed image provided by the seeker is 8 Mbps for monitoring in the telemetry system as shown in Fig. 2. These images are used for post flight analysis and also to estimate seeker performance. The output image data rate is adjustable in the seeker with different compression factors. The compressed image data is transmitted to onboard DAU3 through AFDX bus as shown in Fig. 1. Here, a typical image captured by visual camera of 30 frames per second and with compressed images of 4 Mbps, 6 Mbps, 8 Mbps and original image as shown in Fig. 2.

In this paper, the requirement of each stage measurement plan is analysed and compressed images are considered and then optimal data rate transmission of telemetry is proposed to meet the final objectives of long range aerospace vehicle.

2. PROPOSED SCHEME

The Aerospace vehicle on-board systems complexity increases as throughput increases. Hence it is recommended to limit the throughput. It is also not required to transmit 8 Mbps of high speed image data throughout the vehicle trajectory. Mainly, high speed data is used for computation of trajectory parameters of the vehicle. As an integrated vehicle, the requirement of resolution of high speed image data is minimum at the initial stage of vehicle and at the end phase of vehicle it needs high resolution of image data. At the initial stage of vehicle, there are multiple sources of data (Ex. RADAR, RF seeker etc) available to guidance computer for computation of trajectory. Hence, during initial phase and midcourse of the vehicle, low resolution of image data is sufficient for computations. As the vehicle moves away, it solely depends on high speed image data for its trajectory computation to reach the destination. Hence, Multi resolution image data is used by auto pilot at various phases of vehicle trajectory.

Since auto pilot posts data to telemetry, the throughput of the telemetry system has to be optimised based on resolution requirement of high speed data at various phases or stages of vehicle. This is also a primary requirement with respect to telemetry data transmission to ground station.

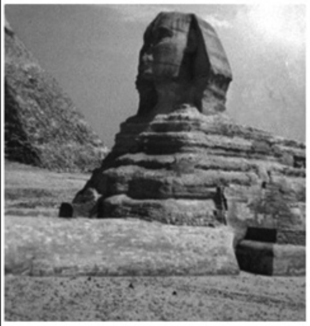
Original Image	Compression Ratio	Transmission Rate	Decompressed Image
 • Image type : Grey • Image size : 400x 400 pixels. • Pixel Depth : 10 bits • Image capture rate : 30 images/sec. • Transmission rate: 48 Mbps Note: Captured by visual camera and processed by seeker electronics.	1:6 (by DWT technique)	8 Mbps	
	1:8 (by DWT technique)	6Mbps	
	1:12 (by DWT technique)	4 Mbps	

Figure 2. Captured with visual camera of 48 Mbps and then decompressed images.

Table 3. Resolution image enhancement depends on vehicle requirements

Vehicle configuration	Local DAU1 bandwidth	Local DAU2 bandwidth	Local DAU3 bandwidth	High speed data	Remarks
Integrated	2Mbps	2Mbps	2Mbps	4 Mbps	Throughput: 10 Mbps Resolution of high speed data: 50%
Stage 1: Separated	As stage1 is discarded, DAU1 BW is allotted to high speed data.	2Mbps	2Mbps	6 Mbps	Throughput: 10 Mbps Resolution of high speed data: 75%
Stage 2: Separated	-	As stage2 is discarded, DAU2 BW is allotted to high speed data.	2Mbps	8 Mbps	Throughput: 10 Mbps Resolution of high speed data: 100%

Hence, a novel scheme is proposed to optimise data rate of telemetry transmission based on the resolution requirement of high speed data. The proposed scheme not only reduces complexity of transmitting and receiving systems but also meets mission requirements.

In this scheme, the throughput is always maintained at 10 Mbps. The bandwidth allocation is shown in Table 3. The hardware architecture for this scheme is also depicted in Fig. 3. In the vehicle, master DAU has to collect the information based on event occurring at various phases of a vehicle.

The master DAU transmits data based on stage 1 and stage 2 events. The events are processed by autopilot software and that information is posted to master DAU. The master DAU initially transmits DAU1, DAU2, DAU3 and Imagepacket 3

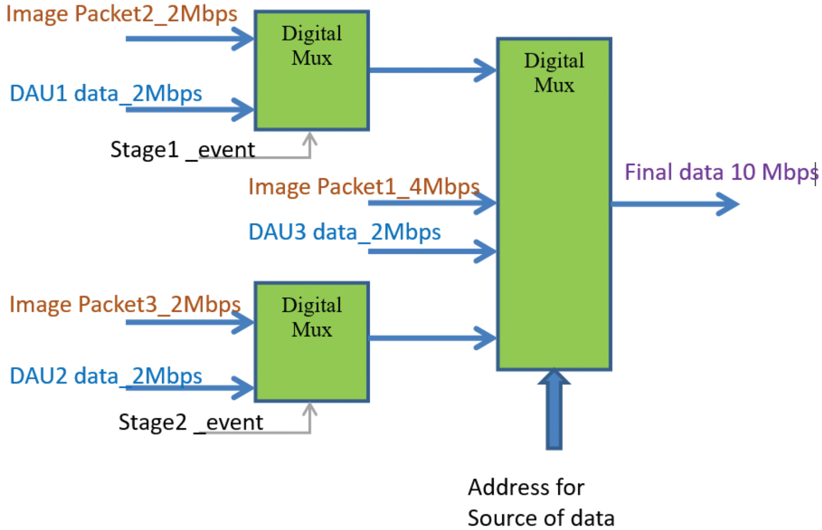


Figure 3. Proposed hardware architecture for optimal data rate.

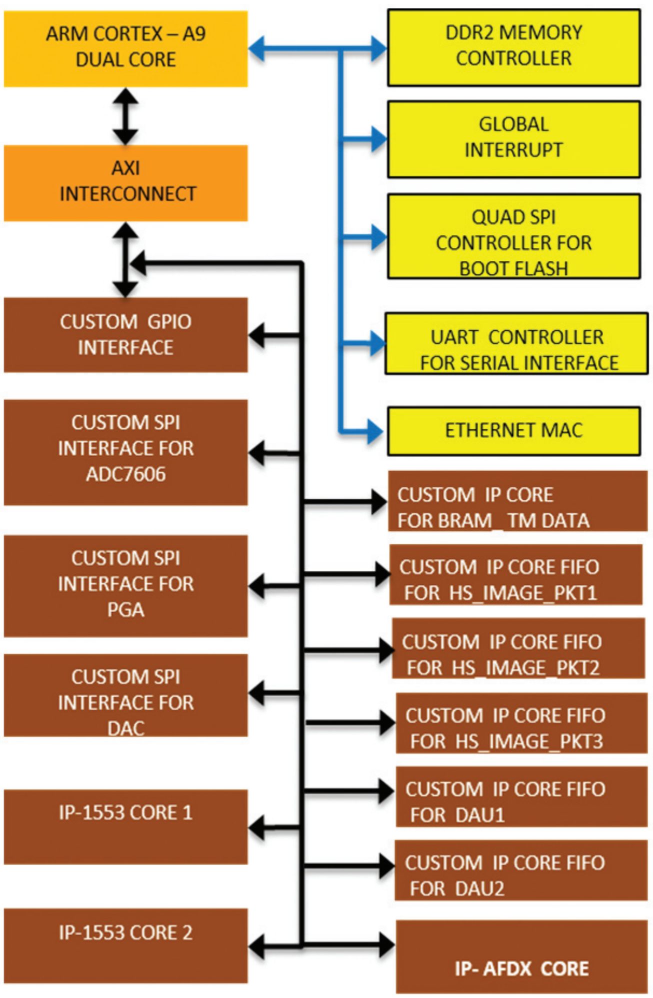


Figure 4. DAU Hardware and top level architecture of this scheme using ZYNQ.

data of 10 Mbps. As events progress, it multiplexes high speed image data of packet 1 and packet 2 and continuously transmits 10 Mbps data effectively based on mission requirements.

3. HARDWARE IMPLEMENTATION

In the design process of DAU, ZYNQ CSOC[15] has been selected for hardware realisation. The DAU[5] with CSOC is further realised with the proposed scheme using programmable logic and processing system of CSOC. In the programmable logic of CSOC, multi-resolution of image data related FIFO interfaces are realised and interfaced to the processing system. Here, the switching from low to high resolution depends on stage separations and events respectively. The hardware realisation with the proposed innovative scheme is captured from Vivado tool of Xilinx platform and top level scheme as shown in Fig. 4.

In the Hardware, common FIFO resource for high speed image data is divided into three parts of memory which is accessible by processing Logic of ZYNQ as shown in Fig. 4. Based on the event it accesses FIFO for sending data to programmable logic system which sends final serial data of telemetry to transmitter as part of ZYNQ.

The events of stage separations are processed from onboard computational data and accordingly the bandwidth is allocated for high speed image data. The DAU resource utilisation and AFDX core along with data acquisition of other sources occupied 32.66 % of LUTs and FIFO resources used 69.28 %. The resource utilisation of DAU hardware on ZYNQ FPGA is mentioned in Table 4. The proposed scheme is incorporated on DAU hardware with modifications of single source of image data into packets in the hardware. It means that the hardware common to FIFO is divided into three sub parts of data as shown in Fig. 4. These FIFO memories are connected to ZYNQ FPGA via AXI interface.

This scheme occupies 0.22% of logic resources and 1.6% of FIFO blocks in addition to DAU functionality. The proposed scheme with DAU hardware resources are listed in Table 5. With this scheme, real time telemetry data is transmitted and verified on telemetry ground system. It is also observed that the signal quality improves when telemetry data transmission rate reduces for a defined RF power[16-17]. The signal quality from 14 to 10 Mbps data rate is improved by 1.5 dB. This enhances

Table 4. DAU Hardware ZYNQ CSOC utilization with traditional methodology

Logic resources	Used	Available	Utilisation %
Slice LUTs	17328	53200	32.66
LUT as logic	17282	53200	32.48
Slice Registers	11304	106400	10.62
Register as Flip Flop	11292	106400	10.61
Block RAM Tile	97	140	69.28
RAMB3 6/FIFO	92	140	65.71
RAMB18	10	280	3.57

Table 5. DAU Hardware ZYNQ CSOC utilisation with proposed scheme

Logic resources	Used	Available	Utilisation (%)
Slice LUTs	17496	53200	32.88
LUT as logic	17344	53200	32.60
Slice Registers	11324	106400	10.64
Register as Flip Flop	11352	106400	10.67
Block RAM Tile	97	140	69.28
RAMB3 6/FIFO	94	140	67.14
RAMB18	10	280	3.57

the link margin of a telemetry system. Hence this scheme is suitable for DTS system of a long range vehicle.

4. CONCLUSIONS

The data rate requirement of telemetry for a long range aerospace vehicle with the typical mentioned measurement is 14 Mbps. The existing ground receiving stations, receiving capability of telemetry data is 10 Mbps for Bi-phase signal for PCM/FM modulation. Hence, the proposed innovative scheme optimises data rate from 14 Mbps to 10 Mbps and telemetry transmits 10 Mbps data continuously throughout the journey time of vehicle. This reduces complexity of onboard systems throughput and improves signal quality at ground stations. With the proposed scheme, the link margin is improved by 1.5 dB. This is achieved by multi resolution of high speed image data at various stages to meet the final objectives of the vehicle. This scheme is implemented on existing DAU hardware of telemetry system and the functionality verified experimentally. The same scheme is suitable for other sources of data to master DAU of DTS to optimise data rate by allocating bandwidth effectively.

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