DSP BASED SIGNAL PROCESSING UNIT FOR REAL TIME PROCESSING OF VIBRATION AND ACOUSTIC SIGNALS OF SATELLITE LAUNCH VEHICLES

Santhosh Kumar T.N., Abdul Samad A.K., Sarojini K.M.
Electronics Group,Vikram Sarabhai Space Centre,
Indian Space Research Organisation,Trivandrum 695022,India.

ABSTRACT

Measurement of vibration and acoustic signals at various locations in the launch vehicle is important to establish the vibration and acoustic environment encountered by the launch vehicle during flight. The vibration and acoustic signals are wideband and require very large telemetry bandwidth if directly transmitted to ground. The DSP based Signal Processing Unit is designed to measure and analyse acoustic and vibration signals onboard the launch vehicle and transmit the computed spectrum to ground through centralised baseband telemetry system. The analysis techniques employed are power spectral density (PSD) computations using Fast Fourier Transform (FFT) and $1/3^{rd}$ octave analysis using digital Infinite Impulse Response (IIR) filters. The programmability of all analysis parameters is achieved using EEPROM. This paper discusses the details of measurement and analysis techniques, design philosophy, tools used and implementation schemes. The paper also presents the performance results of flight models.

KEY WORDS

Acoustic Data Processing, Vibration Data Processing, Real time Processing, Digital Signal Processor

INTRODUCTION

Measurement of vibration and acoustic environment of launch vehicles is very essential for structural design verifications, design margin calculations, failure analysis in case of flight failures and deciding vibration test levels of subsystems for future vehicles. These high bandwidth signals occupy considerable telemetry bandwidth if directly transmitted to ground. Hence an onboard processing system was designed and developed to find the average spectral energy of the signals in real time. DSP techniques were used to find the energy on different frequency bands with adequate resolution. For the spectral estimation of vibration signals, Fast Fourier Transform followed by onboard averaging was adopted [2]. For acoustic signals, constant percentage bandwidth digital bandpass filters implemented using IIR techniques were employed [3]. These computation techniques assume gaussian stationary random signals as input [1].

SYSTEM DESCRIPTION

The system developed caters to 8 vibration channels and 2 acoustics channels (refer figure 1). Vibration signals are analysed over a bandwidth of 2KHz with 20Hz resolution. Power spectral density is estimated by 256 point Decimation In Time Radix-2 FFT technique followed by spectral averaging. For each channel, 100 bytes of spectral information is transmitted. This corresponds to a spectral estimate of 100 frequency bins averaged over 1 sec.

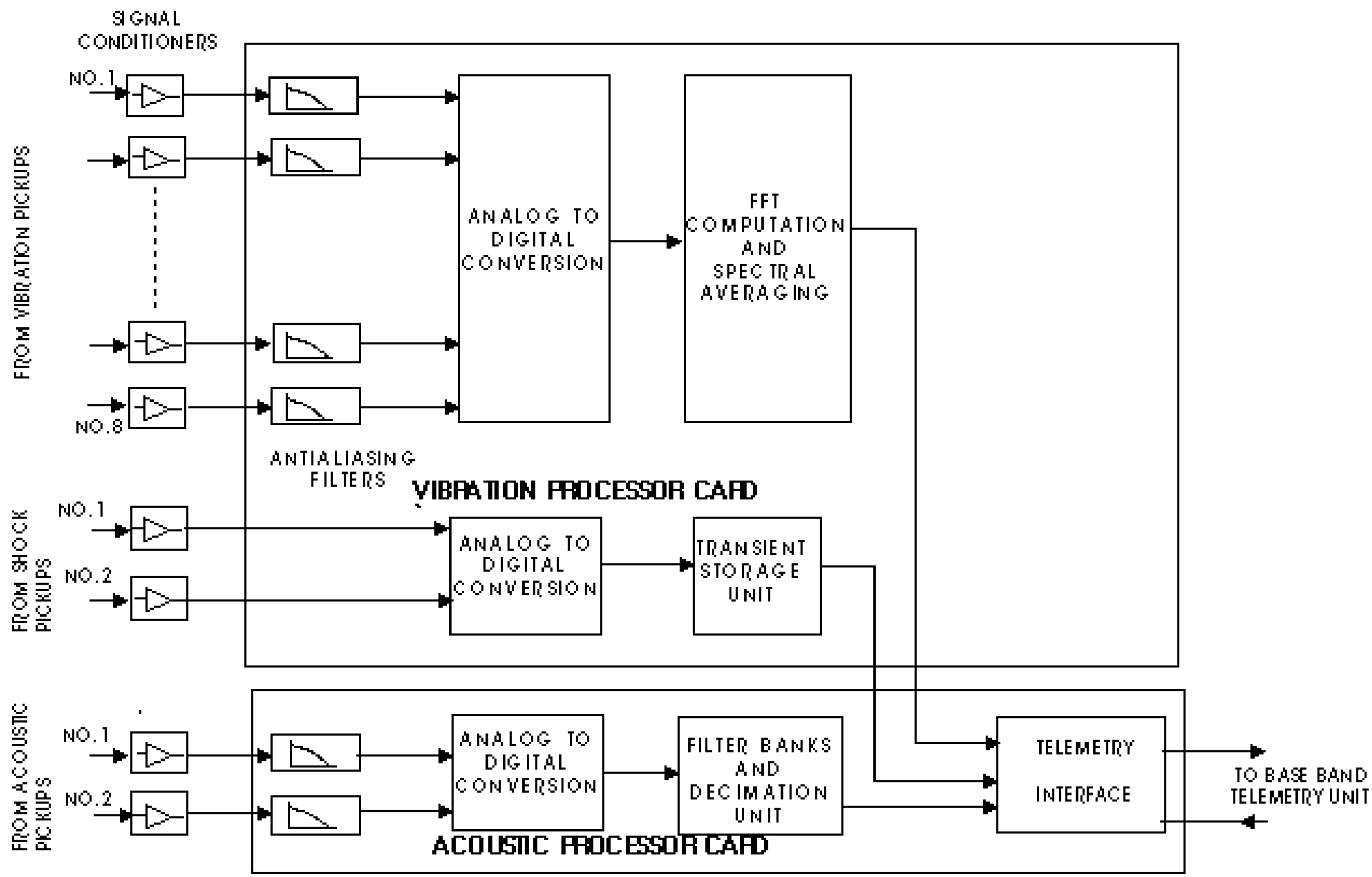
Acoustic signal bandlimited to 7.5 KHz is estimated in 27 frequency bands by 1/3rd octave analysis as per ANSI class III standards. The bandpass filters are realised using 6th order elliptic digital IIR filters.

HARDWARE DESCRIPTION

The hardware is realised in three printed circuit cards, one for vibration processing, another for acoustic processing and the third containing front end analog amplifiers, antialiasing filters and built in DC/DC converters. The system has a standard serial MIL-1553 interface.

The hardware is built around ADSP2100A, a 16 bit fixed point DSP processor from Analog Devices. The analog to digital conversion has a resolution of 12 bits. The glue logic and control signal generation circuitry are implemented using EPM5128, a 2000 gate EPLD from Altera Corporation. Antialiasing filters are implemented using 8th order switched capacitor filters. The cut-off frequency of the filters are programmable through the EPLD. To increase the system reliability, hardware watch dog timers are incorporated. An EEPROM is provided in the board for storing the programmable parameters and special circuitry has been designed to avoid inadvertent writes.

The acoustic processor card is a dual DSP card with each chip running at the rated speed (12.5MIPS). Real time processing of signal demands 99% of the processor time . The processors are running in master-slave mode and resources like ADC and EEPROM are available to master processor only.



VIBRATION/SHOCK/ACOUSTIC DATA PROCESSING CHAIN

FIG NO. I

SOFTWARE DESCRIPTION

It was necessary to code the software in assembly language to achieve the speed required in real time processing. Memory bank switching scheme which fills ADC data in a separate memory bank while the previously acquired data block is being processed, was adopted in data acquisition routine to avoid any loss of input samples. For increased dynamic range of the system, block floating point was used in FFT computations and two word simulated floating point in power computation and averaging[5].

Acoustic processing involves computation of average acoustic energy in 27 bandpass filters, with centre frequencies spaced $1/3^{rd}$ octave apart, ranging from 16Hz to 6.3KHz. As lower octaves are processed, multirate signal processing techniques like decimation (preceeded by lowpass filtering) are employed [4]. This effectively optimises the processing time. It also enables the usage of the same set of filter coefficients for all octaves as sampling frequencies are correspondingly reduced.

Parameters like the maximum PSD to be measured in a frequency band (given an overall vibration level), gains of filter banks in acoustic filters, averaging time etc. are programmable through EEPROM. These can be changed through serial interface even after closing the package.

To analyse transient vibrations like shock signals which may occur in launch vehicles, a provision has been provided in the package to capture such signals for a short duration. These signals bandlimited to 2.5KHz are sampled and stored. This is transmitted to ground at a slower rate, thus reducing telemetry bandwidth requirements.

The coefficients for digital filters were generated using 'Filter design and analysis software' from Momentum Data Systems Inc.. Extensive simulations were done to analyse pole-zero plots and study the stability problems of IIR filters. Software simulator was used as a tool for developing the assembly language code. EPLD circuits were designed and developed using Maxplus II software from Altera Corporation.

TEST RESULTS

Being proposed to use onboard, realisation of the system with low weight, volume and power was essential. The package has a weight of 2.0 Kg, consumes 16W power and occupies 1800 cc. The system has a dynamic range of 42dB with an accuracy >98%. Telemetry bit rate reduction of 50:1 for vibration data and 70:1 for acoustic data was achieved. As a part of field trial, in one of the launch vehicle flights, an input channel to the system was monitored through direct telemetry also, ie without processing. The frequency spectrum was computed for that channel at ground. The onboard processed data matched very well with the direct channel computed results. Sample plots of the Acoustics and Vibration data of one of the launch vehicle flights as measured through the package are given in figure 2.

CONCLUSION

This paper discussed the design and development aspects of an onboard system with real time signal processing capabilities for high bandwith acoustic and vibration signals. The system is used in the current satellite launch vehicles of ISRO.

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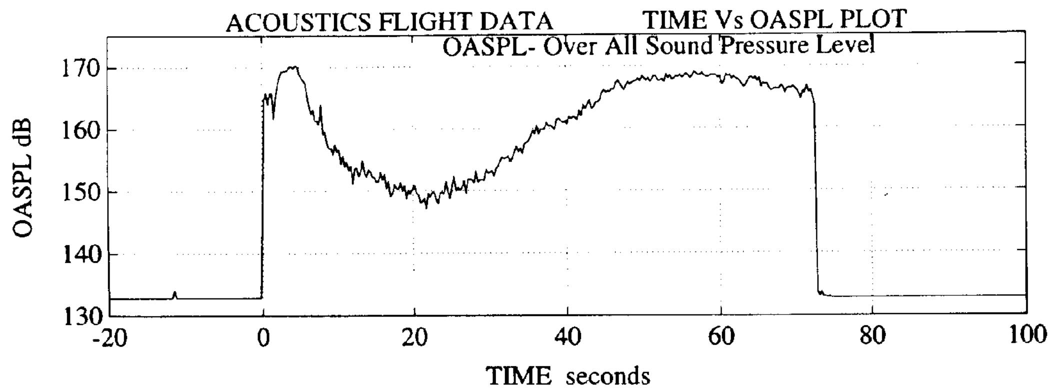
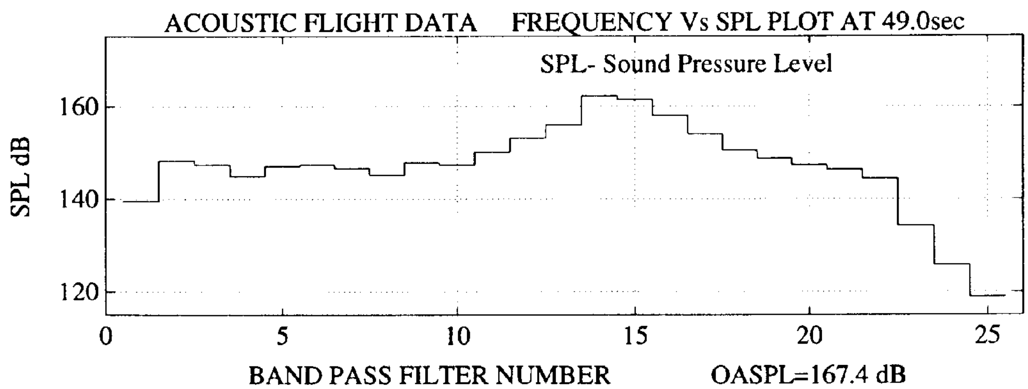
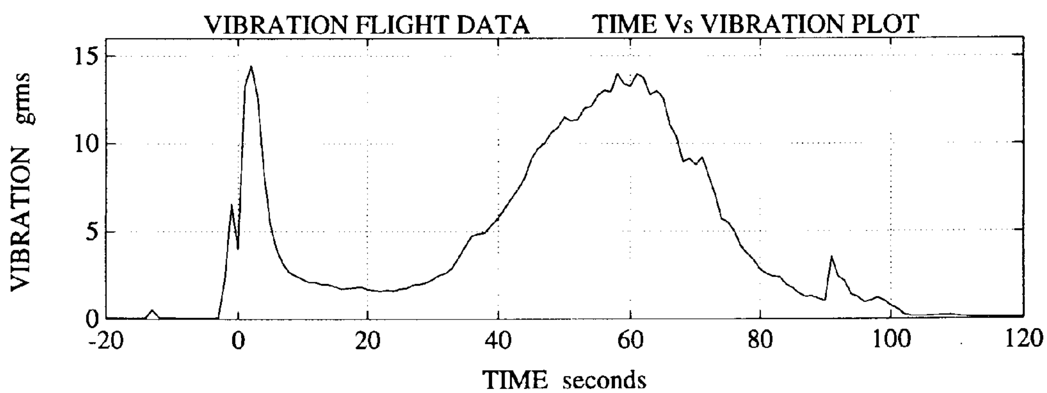
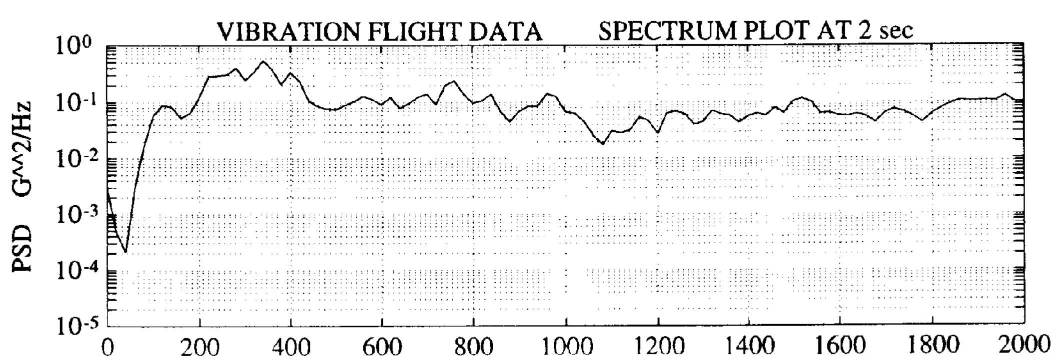

ACOUSTICS FLIGHT DATA
TIME Vs OASPL PLOT
OASPL- Over All Sound Pressure Level
OASPL dB
TIME seconds


ACOUSTIC FLIGHT DATA
FREQUENCY Vs SPL PLOT AT 49.0sec
SPL- Sound Pressure Level
SPL dB
BAND PASS FILTER NUMBER
OASPL=167.4 dB


VIBRATION FLIGHT DATA
TIME Vs VIBRATION PLOT
VIBRATION grms
TIME seconds


VIBRATION FLIGHT DATA
SPECTRUM PLOT AT 2 sec
PSD G^^2/Hz