COVER SHEET

Title: **On-Board Spectral Analysis System (OBSAS)**

Authors: Kostas Makris
Dimosthenis Fragopoulos
Stelios Kaloutsakis
Nikolaos Agianniotis
Mario Marchitti
Constantin Papadas
Kostas Fotiadis

ABSTRACT

The On-Board Spectral Analysis System (OBSAS) is a complete electronic unit capable of acquiring and digital processing analog signals by incorporating an embedded DSP. The system is mainly intended as a pre-processing stage for a broader health monitoring system on-board an aircraft. The unit receives analog input signals from various remote sensors mounted on different parts of the aircraft's fuselage. The analog signals are then conditioned, digitized at a sampling rate of 16 kHz, and then undergo Fast Fourier Transform (FFT) to obtain their full frequency spectral densities. The computed spectra are further manipulated to produce spectrograms in fractions of octave band and finally transmitted over a serial RS-422 data link for logging and/or further processing.

INTRODUCTION

The system was designed and developed with the intention to be part of a broader flight test instrumentation system, aiming at the efficient and qualitative analysis of several vibro-acoustic phenomena in the aircraft's structure. The ultimate objective of this activity is the development of smart sensors, with weight and dimension compatible with the triaxial accelerometers currently in use. These smart sensors shall include the sensor element along with the corresponding hardware and software components necessary to perform the signal conditioning and processing functions.

Kostas Makris / Dimosthenis Fragopoulos / Stelios Kaloutsakis / Nikolaos Agianniotis / Constantin Papadas Integrated Systems Development ISD S.A., 32 Kifisias Avenue, Atrina Center, Building B, 15125, Maroussi, Greece.
Mario Marchitti, Alenia Aeronautica Flight Test, Strada Malanghero, 10072, Caselle, Torino, Italy.
Kostas Fotiadis, on leave from ISD S.A. since April 2008.

OBSAS was designed and implemented in the framework of an intermediate development evaluation phase, which foresees the separate implementation of the sensor element and its associated signal conditioning and processing circuitry. In respect to the analysis software it was decided also to limit the analysis function to the sole calculation of spectrograms in fractions of octave. OBSAS was designed and developed to fulfill stringent real-time performance requirements and adhere to demanding specifications for maximum reliability, mechanical endurance (vibration, acceleration) and compatibility with the rest of the instrumentation equipment installed on-board an aircraft.

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SYSTEM FUNCTIONAL DESCRIPTION

The system follows mixed-signal (analog/digital) architecture and is implemented on separate PCB modules for signal isolation and expandability. The base unit features four analog input channels, but thanks to the modular and scalable board architecture, it can be expanded to accommodate up to twelve analog inputs. The electrical signals are generated by transducers such as accelerometers, strain gauges, microphones, pressure transducers, etc.

The analog input signals are buffered and pre-filtered by a second order, continuous time low-pass filter in series with a first order high pass filter. The pass-band of the combined pre-filter is from 2.8 Hz to 8.2 kHz to -0.05 dB amplitude and 0.3 Hz to 82 kHz to -3 dB amplitude. The high-pass filter component is there to remove near dc components while the high pass filter rejects signals at frequencies over 4 MHz, thus providing adequate suppression for any frequencies that may cause aliasing phenomena during the sampling process. The pre-conditioned signals are then driven into a multi-channel 24-bit ΔΣ ADC with an output sampling frequency of 16.384 kHz and oversampling frequency of 4.194 MHz. The digitized data from the analog input channels are multiplexed using TDM and transmitted via a serial data interface to the DSP stage.

The first DSP block performs a 16K point FFT over data of duration of 1 second for sampling and after its square magnitude is calculated, the first 8K points (frequencies 4 Hz to 8K Hz) are kept for further processing. The spectrum is reformulated in a fraction of octave form using an octave band algorithm and the results are transmitted via an RS-422/485 serial link to the data recorder usually employed for the flight test. The described signal flow is depicted in Figure 1. Each acquisition period is adjacent to the next one with no data lost in between the two acquisition periods.

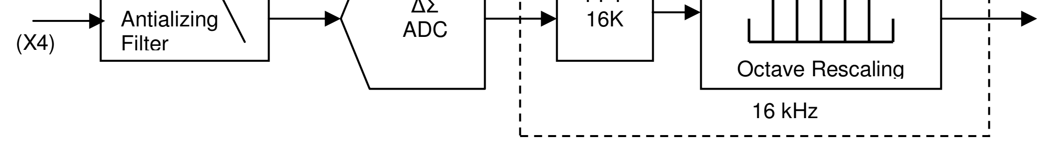

Figure 1. OBSAS signal flow diagram.

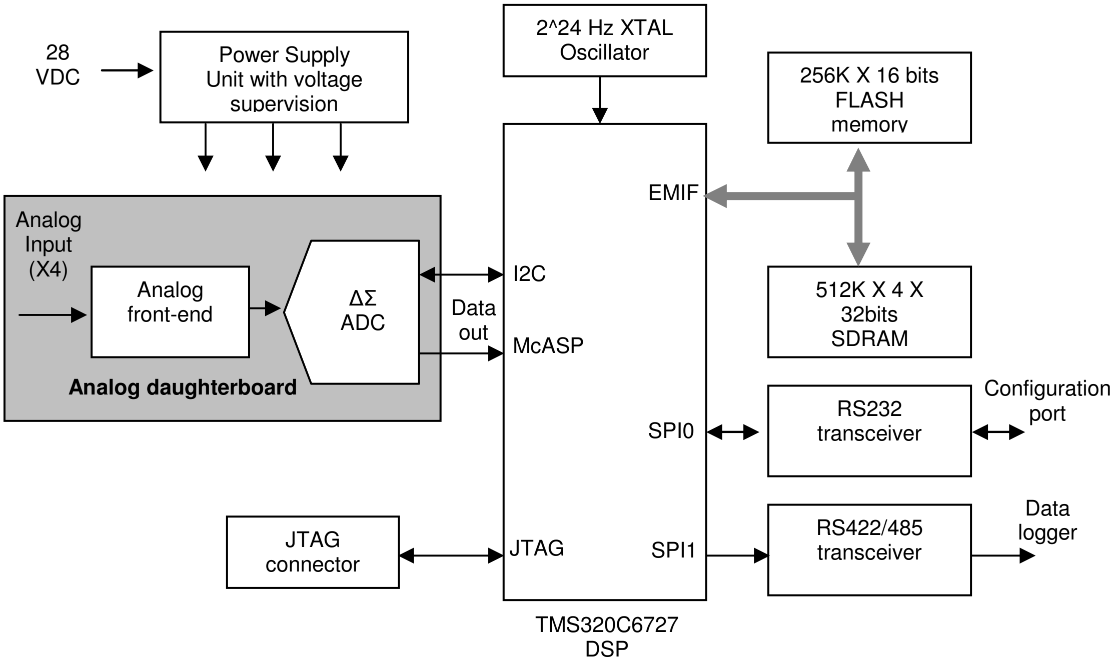

Figure 2. OBSAS hardware architecture.

HARDWARE ARCHITECTURE

The system hardware architecture is illustrated in Figure 2. The analog front-end is realized on a separate board and includes a signal conditioning stage performing the functions of low-pass filtering, buffering, and level-shifting, as well as a four-channel 24-bit ΔΣ ADC for the digitization and TDM multiplexing of the pre-conditioned signals. Each analog input signal is a single-ended, voltage signal in the range of +/-2.5V with respect to the ground potential.

A separate main board hosts a TMS320C6727™ DSP from TI®, RAM and Flash memory devices, a power supply section including voltage supervision circuitry and RS232, RS422 transceivers (UART). The latter is exclusively used for transmitting the data into the recording equipment, while the RS232 is used for the configuration/parameterization of the unit via a host-computer running a specially developed, GUI based software application. The DSP firmware is downloaded to the processor via a JTAG interface, while an I^2C bus is reserved for configuring the ADC. The system requires a single 28VDC supply for its operation.

The electronic circuits are placed inside a robust, custom made and weatherproof box, which isolates the system from the environment. The overall box dimensions are (LxWxH) 145 x 96 x 47mm, it is manufactured using 7075 wrought aluminum alloy and it is specially designed to withstand mechanical shocks and harsh environmental conditions. The connectivity is accomplished via three high-grade D-sub connectors placed on the front panel. The box is mechanically secured inside the aircraft via a set of holes located in flanges on either side of the box.

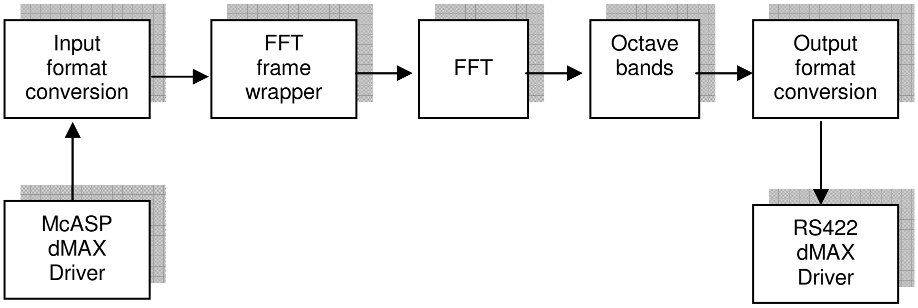

Figure 3. OBSAS digital signal processing block sequence.

SOFTWARE ORGANIZATION

The digital signal processing is accomplished by software embedded in the DSP processor. The software module stack consists of three layers. The bottom layer is the device mini driver, which interfaces directly with the hardware interface and outputs the digital data. The device driver interfaces with the device mini drivers and exposes a multichannel interface to the firmware layer. Establishment of context to the extracted channel data is done at the firmware layer. The firmware layer implements the application specific functionalities like data processing and the communication protocol with a host computer. This separation of data acquisition tasks across three layers in the OBSAS interfaces helps to support functionalities like on-the-fly update of parameters and plug-n-play of sensors.

The OBSAS DSP sequence is illustrated in Figure 3. The multiplexed four channel serial input coming from the ADC is demultiplexed and transferred to the input buffer with the help of the DSP embedded DMA engine (DSP dMAX^{TM} peripheral) in a block of 4N samples, where N is the number of samples stored in the input buffer per channel. The receiving mechanism works in a FIFO circular buffering fashion and is implemented by an appropriate input driver. The main process starts with a block of 4N samples received by the driver and stored in the input frame buffer. Then the samples are converted from fixed to floating point format and fill the FFT buffer with 16364 points to implement the FFT. The octave bands block which follows, outputs its data to the output frame buffer. Finally, the samples are converted back to fixed point format and a dMAX^{TM} driver is used to output the data in an appropriate packet format through the SPI software UART to the RS-422 port.

Octave Bands Algorithm

The power spectrum of the input signals obtained through the FFT block is further analyzed and processed by the octave bands algorithm. The algorithm calculates the power spectra over a specified fraction of octave band (partial octave band) and a single value for that particular band is obtained. The relationship between the center frequencies of simple (1/1) octave bands is given by (1).

$$f_{c,i+1} = 2 \cdot f_{c,i} \tag{1}$$

where f_c is the centre frequency of the octave band and $i = 1,2,3\ldots$

Partial octave bands (1/3, 1/12, 1/24) represent frequency bands according to (2):

$$f_{c,i+1} = 2^{\frac{1}{x}} \cdot f_{c,i} \tag{2}$$

where x = 1, 3, 12, 24…

The lower, $f_{low,i}$, and upper band limits, $f_{up,i}$, of the i-th band in a 1/x octave arrangement are given by (3) and (4) respectively.

$$f_{low,i} = f_{c,i} \cdot 2^{-\frac{1}{2x}} \tag{3}$$

$$f_{up,i} = f_{c,i} \cdot 2^{\frac{1}{2x}} \tag{4}$$

The octave section represents the power of the i-th band as the summation of squares of magnitude values over frequencies corresponding to the i-th band. The bands defined by (1) - (4) are termed as "natural" bands. Normalized centre frequencies for octave bands are defined in [1] and these are adopted in the implementation of the present algorithm. The starting centre frequency is 4Hz and x=1 and x=3 cases are implemented.

VALIDATION AND MEASUREMENTS

The tests aimed at the functional and performance verification of the system hardware and software components under real environmental conditions, by taking into account the physical stress the equipment is subjected during a flight.

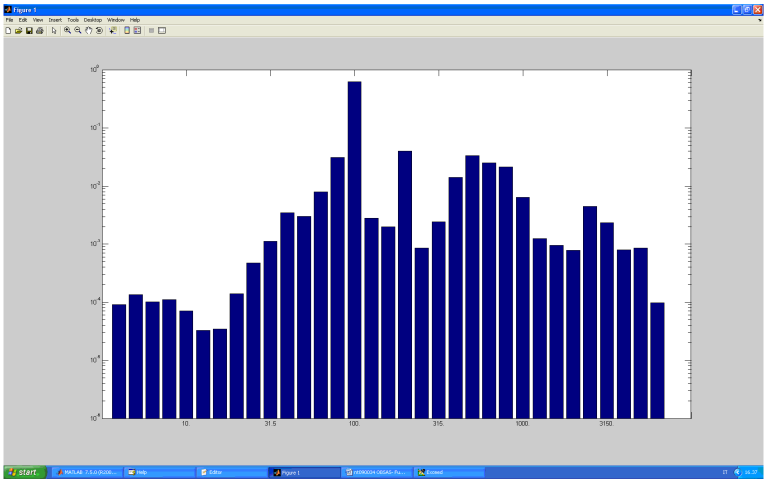

Figure 4. 1/3 octave spectrum from OBSAS data.

TABLE I. SUMMARY OF ELECTRICAL PERFORMANCE

Parameter	Condition	Value	Unit
Frequency range	-0.05dB	8.2	kHz
THD+N		96	dB
Dynamic range (DR)		102	dB
Channel separation		102	dB
Maximum power consumption	4-channel operation	2.16	W

The test procedure relied on the simultaneous recording of primary senor data in PCM form and the recording of the spectrogram obtained from OBSAS. The two sets of data were compared after the PCM data are processed off-line. The procedure and the software that have been implemented to interface the OBSAS to the recording system utilized by the Alenia Flight Test Center is described in [2], [3] and [4] .

Laboratory tests with generated signals have been performed to test the OBSAS and the procedure and software implemented. Sinusoid with known amplitudes and transitions with known time have been selected and recorded, either with the traditional procedure for recording the time signal or through the OBSAS for recording the spectrogram. The electrical performance of OBSAS is summarized in Table I. Subsequently the OBSAS was installed in the aircraft cabin to perform similar tasks, but with real signals in a real environment. A spectrum representation at 1/3 of octave acquired in flight is presented in Figure 4.

CONCLUSIONS

A compact spectral analysis system for the analysis and processing of analog electrical signals generated by transducers, aiming at the health monitoring on-board an aircraft was presented. Laboratory tests and in flight tests were successfully performed. This method for acquiring and processing flight data and their real time spectral analysis during flight dramatically reduces the post flight analysis time. The hardware and software equipment dispenses with the post flight data analysis, and the memory mass that are presently required to record vibration and acoustic noise data. The system can be further developed in order to expand the input signals channel number. Also it can be further developed to read aircraft bus containing flight conditions, in order to perform an intelligent selection of the data to analyze, and to produce synthesized functions, as the averaged spectra and peak hold spectra.

REFERENCES

1. ISO 266:1975. “Acoustics–Preferred frequencies for measurements.”
2. Alenia Doc. 99/NT/1840/T833a/080014 Issue2. “OBSAS Equipment – Laboratory Test.”
3. Alenia Doc. 99/NT/1820/T833a/080068. “OBSAS – On Board Spectral Analysis System Description and Laboratory Tests.”
4. Alenia Doc. 04/NT/1810/T833a/090034. “OBSAS – Functionality Test Verification in Flight.”