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A New Portable, PC Based, USB Powered Dynamic Signal Analyzer

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ABSTRACT

A new USB powered portable 4-channel real time Dynamic Signal Analyzer and its automotive applications are described. The design and architecture lend themselves to realtime NVH measurements and analysis in the field, in-vehicle or on production lines. Built-in signal conditioning provides for direct sensor power while the embedded DSP provides for signal processing on-board. Performance and implementation of FFT, digital filters and order analyses are presented.

INTRODUCTION

Lower cost, higher performance dedicated digital signal processing (DSP) with a more accessible programming environment has helped to change the nature of dynamic signal analyzers (DSAs) and bring portable solutions to the market. First generation DSAs used analog circuitry, were bulky, required significant power and had limited displays. Circa 1975, a dual channel Fast Fourier Transform (FFT) DSA[1] or single channel real time digital filter DSA[1] weighed nearly 75 pounds, had dimensions of 30 x 27 x 19 inches, and consumed as much as 600 Watts. The onset of DSP technology allowed DSAs in the 1970's to become more powerful, although portability could be best described as "transportable" as displays became larger, size and weight remained unchanged. In the 1980's portable systems[2] with LCD and CRT displays reached the market although battery life was limited and batteries were a major contributor to the system weight. With the advent of the PC and later the laptop PC, the display and some or all post-processing could be moved to the PC dividing the system into a front end and PC. This allowed the front end to be smaller, faster, and use less power while displays, documentation devices, post-processing and application support could steadily evolve with PC technology.

Circa 1988, PC based digital DSAs were introduced[3]. A front end box contained the DSP and analog to digital and digital to analog (AD/DA) circuitry. The front end box weighed 20 pounds, had dimensions 6 x 19 x 18 inches, and consumed 100 Watts.

Figure 1. Photon, USB cable and laptop PC

As internal connections and PC busses became standardized, hardware was soon designed for the PC's internal connections, making desktop systems more compact, but requiring expansion chassis for laptop installations. While size was reduced, external power was still required and portability suffered from a laptop-expansion chassis package. Heat, PC power supply electrical noise and PC component compatibility became new design issues

Now, using the new DSP technology the DSA size has been reduced in size while performance has been increased. The PC based portable DSA, presented in this paper weighs 0.5 pounds, has dimensions 3.75 x 4.75 x 1 inches, and consumes a maximum of 2.5 watts.

This paper presents the design of the Photon: a portable, PC based, Universal Serial Bus (USB) powered DSA that was developed by taking advantage of the new DSP and PC communication technologies.

Figure 2. Photograph of DSA showing small form factor, 1 output/tachometer and 4 input SMA connectors.

DESIGN CHALLENGES

Packaging design and power requirements are two features that limit the application of portable DSAs in the field. The device must communicate with the PC via a rugged, flexible and stable connection. A small form factor, rugged mechanical design, and easy access connections are important features. Also, a portable DSA requires a battery for power, therefore the use time is proportional to power consumption. For longer operation a larger battery must be used thus compromising the portability of the system. Power management can also impact thermal design and reliability as well capability of handling in-situ measurements without introducing noise due to ventilation systems.

Functional performance criteria such as dynamic range and real time sampling rate determine the usefulness of a DSA. Dynamic range, the ratio in dB between the largest and smallest signal that can be accurately measured, is critical for high quality measurements. Real time sampling rate, the number of samples per second that a DSA can compute multiple time and spectra without dropping samples is often the feature that is used to judge the usefulness of a device.

SYSTEM DESIGN

PACKAGING DESIGN - A significant challenge with designing the DSA was minimizing the form factor. Every effort was made to keep the footprint and height as small as possible during the hardware design. The hardware architecture consists of 2 main printed circuit boards (PCBs): one digital and one analog. The digital PCB includes the DSP, USB and communication chipsets. The analog PCB includes the AD/DA converters, oscillators, and a programmable gain amplifier. The two PCBs were designed to stack one on top of the other to minimize the packaging footprint. A low power consuming DSP results in no cooling or ventilation needs further reducing the packaging design.

The DSA includes 4 input and 1 output/tachometer channels. The small form factor presented a challenge to mount 5 connectors on the enclosure. For example there was not sufficient space for standard BNC connectors. Alternatively, microdot connectors were considered, but eventually rejected due to the high cost per connector. Finally a compromise was selected between minimizing the size and low cost. The final design uses ¼ inch, threaded, SMA connectors. Since most measurement transducers use BNC connectors, the DSA includes 5 4 inch SMA to BNC adaptors. There is also a start/stop button flush mounted on the top surface of the enclosure. This can be used to start a measurement without using the PC keyboard or mouse. Two LEDs indicate when there is power to the DSA and when the device is acquiring data.

SWITCHING SOURCE/TACHOMETER INPUT- Another feature included in the hardware design to minimize the form factor is a switchable source output and tachometer input. The signal analysis software includes a basic signal analysis package and several specific modules for specialized measurements. The signal analysis module has a signal source to generate a variety of output signals. One of the specialized modules is a rotating machinery analysis module for order tracking. This requires a tachometer signal input. Instead of adding an additional SMA connector for the tachometer input, the first SMA connector can be switched from an output to a tachometer input channel. Rotating machinery analysis consists of measuring vibrations from rotating machinery, so a drive signal is not needed in this application. The result of this design is that there are only 5 instead of 6 connectors and the form factor is therefore reduced.

USB INTERFACE – The power source and communication design are important considerations that effect the portability of the device. The more cables required to operate the system, the more cumbersome the system setup and design with more equipment to carry in the field. The connection from the DSA to the PC must be rugged and flexible so that the system can be used in a variety of conditions in the field and the connection must be stable so that communication between the PC and DSA is not lost resulting in lost data and wasted time. To meet the cabling issues the DSA was designed to USB communication between the DSA and the PC.

Figure 3. Photograph showing USB connection to the DSA.

USB devices can get their power from the USB power supply on the PC. According the USB Spec.1.1, any USB power supply must provide a minimum voltage of 4.01V, and a maximum power output of 2.5W(500ma@5V). The DSA was designed to meet this specification and gets all of its power from the USB cable only. There is no other power cable required. Consequently this reduces the number of cables required to operate the device. Because power is limited, the DSA was designed to use minimum power. The TI TMS320VC3x DSP used in the DSA dissipates only 200 mW power which is considerably less than its predecessor, the TI TMS320C4x, used in many DSP applications, which consumes as much as 4.25W (850 mA@5V). The USB power constraints also drive the choice of the maximum number of input channels and the number of bits in the AD/DA. The DSA has 4 input channels. More input channels would require more power than is supplied by compliant USB ports. The input AD channels were also limited to 18 bit due to power constraints.

Another innovative feature associated with the USB connection is the use of compression technology that enables data transfer rates higher than USB specification. This enables features such as raw data throughput to disk in parallel with processed data from the DSP. Analyses, realtime display calculations, and data quality monitoring can occur using a data streaming rate that would exceed USB specifications.

DSP TECHNOLOGY - The heart of the DSA is the TI TMS320VC3x DSP. This new DSP operates at 120 MHz allowing faster, more advanced operations than were previously possible. The DSP software was designed to have 48,000 samples per second real time sampling rate meaning that time signals can be captured and autospectra for 4 channels can be computed without dropping data. In addition to computing realtime spectral information the system can stream data to the PC at the same time. The maximum sampling rate depends on many factors including hard drive speed, channel number, available Windows resource, etc. Also with the powerful DSP FFT zoom and an arbitrary waveform source were added.

Table 1. Key Performance Specifications

110 dB_{fs} input dynamic range
>95 dB input signal to noise ratio
0.08 dB input amplitude accuracy
1.0 degree input phase error
<-95 dB_{fs} source output THD plus noise
dimensions: 0.9 x 4.1 x 4.9 in
2.5 x 10.5 x 12.5 cm
weight: 7 ounces, 0.2 kg
power supplied by USB connection only

APPLICATIONS

The DSA, software, and laptop PC (or desktop PC) form the measurement and analysis system. The system is capable of performing most four channel measurements such as acoustic octave analysis, modal tests using hammer excitation and triaxial accelerometer response or BSR testing using a portable shaker driven by the waveform source with a combination of microphone and vibration inputs.

The software developed specifically for the DSA performs real-time spectral, octave, order, coherence, histogram and frequency response functions. A user friendly Windows based interface makes viewing and managing data easy, as well as provides straightforward Plug & Play installation. Figure 4 shows a typical display from the software with 2 channel octave analysis showing 1/3 octaves, narrow band auto spectra, and a time trace of each channel.

AUTOMOTIVE NVH TESTING - The DSA size, portability and functionality make it ideal for use in automotive NVH testing. It is fully powered by the USB connection and therefore can be used with a portable laptop PC for field and vehicle testing. The integrated IECE signal conditioning eliminates the need for sensor conditioners. The 4 channel inputs and fast DSP based computation speed enable multiple channel spectral analysis and cross channel frequency response functions, real time digital filtering and online order processing, in most cases with background raw data capture and throughput to disk. Time domain, amplitude domain and frequency domain analyses can be computed during the same measurement. User-defined calculations are supported. Data export formats compatible with MATLAB, MS-Excel and industry standard analysis programs allow the user to expand on the built-in functions provided by the software.

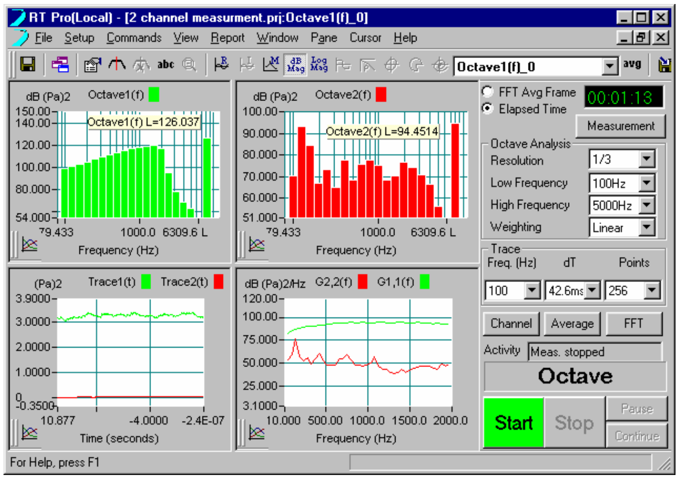

Figure 4. Software application screen showing 2 simultaneous channel 1/3 octave analysis bar graph displays, narrow band auto spectra and time traces.

ORDER ANALYSIS - The software includes a specialized module for rotating machinery analysis. With this module the source output is converted to a tachometer input for RPM order tracking. The software uses digital, real time tracking filters to compute online order analysis based on a digital resampling technique. Figure 5 shows a display from the software with real time order tracks, RPM trace, spectragraph and waterfall plots.

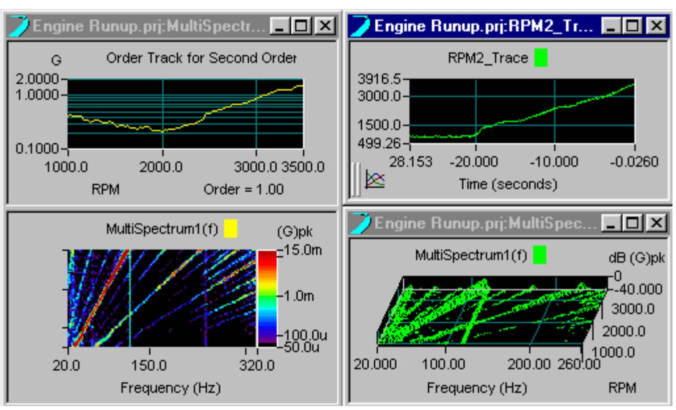

Figure 5. Rotating machinery analysis module with real time order tracks, 4 cylinder engine run-up with RPM trace, spectragraph and waterfall plots.

PRODUCTION TEST - For production testing a specialized module was designed that optionally performs sine sweep or random tests and then performs pass/fail analysis based on predefined limits. Various consequences can be programmed to occur based on a pass or fail such as display warning, sound alarm, stop the test, etc. Figure 6 shows a typical display.

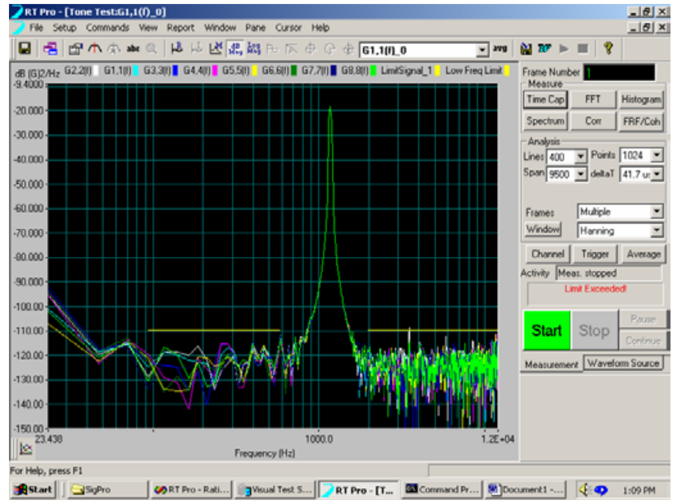

Figure 6. Production test software module example showing limits and data exceeding limits.

BUZZ, SQUEAK & RATTLE REPRODUCTION – An automotive manufacturer posed the challenge of combining closed-loop shaker control with buzz, squeak & rattle (BSR) measurement and diagnosis. The goal is to reproduce a BSR event in the lab to verify the lab is experiencing the same problem as the field and/or the production facility. The portable DSA is linked to a Shaker controller performing a low frequency sine sweep. The DSA measures wideband noise and vibration, acquiring raw data from the component under test while capturing waterfall data and displaying frequency analyses. The DSA and controller are synchronized via software control. When the test is completed, the results are automatically exported to an MSWORD file, including the raw time signals converted to WAV format. The report can be emailed, the receiver can open the file without special software, click on a plot and listen to the signal and optionally hear voice commentary describing the event and how it was simulated. Direct network communication of results and viewing of tests in progress are also supported.

The portable DSA can also acquire field vibration data for road replication and/or noise and vibration from BSR events for comparison with those reproduced in the lab.

CONCLUSION

This paper presents the design of a 4 channel, portable PC based DSA. The design goals were to develop a USB powered, PC based device with rugged cabling and PC connections in a small form factor having powerful performance specifications. The design takes advantage of new 120 MHz DSP technology, 18 bit A/D and 24 bit D/A converters and IECE (IE) transducer powering and direct connection. The powerful DSP made it possible to add new computational intensive features such as throughput to disk, FFT Zoom, simultaneous digital filtering in parallel with FFT narrowband processing, real time order analysis and arbitrary waveform generation. The system uses customized software to perform spectral, octave, order, coherence, histogram and frequency response functions.

Applications such as octave analysis, order tracking, production testing with pass/fail and buzz squeak and rattle capture are supported by the unique hardware/software feature set resulting in a portable DSA that supports a wide range of automotive NVH, quality and dynamic measurements.

REFERENCES

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