DIGITAL SIGNAL PROCESSING IMPROVES ACOUSTIC NOISE MEASUREMENTS

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ABSTRACT

Recent advances in Digital Signal Processing hardware and algorithms have expanded acoustic noise measurement capability while reducing costs. The authors give an example of a complex measurement implemented in a new two channel frequency analyzer. The noise standard for aircraft, FAR-36, is based on a measurement of Effective Perceived Noise Level, EPNL. The process of computing EPNL on-line within the instrument after capturing a flyover of a commercial jet aircraft is described. Initially uncorrected for atmospheric sound absorption, aircraft weight and flight path variations, the EPNL estimate is used to quickly determine first order compliance to the regulation, and as an early indicator of faulty test conditions. Additional analysis using FFT processing can detect and account for the presence of pseudo-tones.

INTRODUCTION

Realtime Frequency Analyzers have been used for over twenty years to measure 1/3-octave Band acoustic noise. The performance and usefulness of these analyzers has improved recently due to advances in digital signal processing technology. These improvements are having a direct impact on the cost and ease with which complex acoustic measurements can be made today.

THE ADVANTAGE OF DIGITAL SIGNAL PROCESSING

Off-the-shelf digital signal processing (DSP) hardware such as a Motorola 56001 or a Texas Instruments TMS 320C25 are relatively inexpensive, approximately $55 in 1991 dollars, yet are capable of impressive performance when programmed with the appropriate measurement algorithms. For example, in the past only dedicated analyzers with custom, single-purpose digital hardware were capable of providing realtime 1/3-Octave acoustic analysis. Now with modern high performance algorithms implemented on standard DSP hardware, a standard FFT-type analyzer can provide better acoustic measurement performance at lower cost.

It is possible to digitally implement 1/3-octave analysis in a standard FFT-type analyzer because the analog circuit requirements are the same. Both FFT and 1/3-Octave measurements require AC/DC coupling, input ranging, analog anti-alias filtering, and excellent analog-to-digital conversion. Once the signal is digitized, then DSP hardware can be loaded with the appropriate 1/3-Octave filtering algorithm to produce measurement results that compare with the best dedicated 1/3-Octave analyzers. When these algorithms are combined with the proper acoustic user interface, the FFT analyzer can meet the needs of an acoustic test specialist.

Likewise it is also possible to load DSP algorithms that are specifically tailored for Order Tracking Analysis and Swept-Sine Analysis to address a broad range of measurement applications.

REALTIME 1/3-OCTAVE VS. FFT-SYNTHESIZED 1/3-OCTAVE

For 1/3-Octave analysis, FFT analyzers have typically used a synthesis technique where the 1/3-octave bands are formed by a weighted summation of narrowband FFT bins. The FFT-synthesized method is acceptable for crude approximations of actual 1/3-Octave levels, but cannot be used to accurately measure transients or other non-stationary signals. In fact it is not possible to meet the current ANSI specification for 1/3-Octave filters (S1.11-1986) using the FFT-Synthesized 1/3-Octave technique.

The previous version of ANSI S1.11, released in 1966, had broad limits of filter shape and no transient measurement requirements. It was therefore possible to meet ANSI S1.11-1966 requirements with an FFT-synthesized 1/3-Octave filter. The current version of the ANSI filter specification released in 1986, however, is modeled after a true Butterworth filter, with fairly narrow limits on the shape of each 1/3-octave band filter. Transient measurements are also specified in S1.11-1986 that effectively prohibits the use FFT-synthesized 1/3-Octave analysis.

1/3-OCTAVE MEASUREMENTS IN THE HP35665A

The HP35665A architecture highlights two DSP components. The first is a gate array which implements all the low pass (anti-alias) filter and decimation sections. A Motorola 56001 collects the output of the gate array and performs all subsequent 1/3-Octave filtering, detection, and averaging. This same hardware is used for all of the measurement algorithms implemented by the HP35665A, including Digital Swept Sine, narrowband FFT, and Computed Order Tracking. For the case of FFT measurements, one band limited sample rate is selected from the gate array, and the 56001 performs the window operation, FFT, and power spectrum calculation.

REALTIME 1/3-OCTAVE BLOCK DIAGRAM

Implementation of realtime 1/3-Octave measurements in a standard FFT-based analyzer is especially powerful because potentially higher dynamic range and sample rates are available.

The cascaded design of the filter gate array has 88 dB stop band rejection, in which each stage consists of a 12th order low pass filter, band limited at 0.2 of the sample rate. After decimation (discarding every other sample point), the cutoff frequency of the low pass filter must be significantly higher than the centerband frequency of each 1/3-Octave filter implemented at that sample rate. This is specified by the filter shape requirements for digital filters in ANSI S1.11-1986. For third order Butterworth filters, the highest 1/3-Octave which can be implemented at the 131072 Hz sample rate is 32 KHz. If the sample rate is lower, as with many dedicated 1/3-Octave Realtime analyzers, the anti-alias filter will over-attenuate the 1/3-Octave filter at higher frequencies will fail to meet ANSI S1.11. This over-attenuation would repeat for every lower octave due to the symmetric nature of the decimation filtering process. Each set of three 1/3-Octave filters sees one-half the sample rate of the previous section, while the center band frequencies are also less by one-half. Thus if the problem is noted to occur at 20 KHz, it will also occur at 10 KHz, 5 KHz, 2500 Hz, 1250 Hz and so on. None of these bands would meet the filter shape requirements of ANSI S1.11-1986.

SYSTEM PROCESSOR ENHANCES CAPABILITIES

In addition to the 1/3-octave filtering algorithms, the HP 35665A has an on-board system processor that handles measurement results. With this processor, up to 49,500 1/3-Octave spectra can be routed to waterfall memory, displayed at 32 traces per second, or sent to an external device over the IEEE-488 bus. The on-board processor is also capable of being programmed with HP Instrument BASIC to provide extensive post-processing of 1/3-octave data and control of external IEEE-488 devices, such as programmable switches and noise sources.

AN EXAMPLE OF COMPLEX ACOUSTIC ANALYSIS: PRATT & WHITNEY NOISE MEASUREMENTS

Commercial aircraft have stringent noise requirements that are specified in Federal Aviation Requirement 36 (FAR 36). The community noise level of an aircraft flyover is characterized by one value in this requirement: an Effective Perceived Noise Level (EPNL). The EPNL calculation accounts for several annoyance factors, including frequency and amplitude of the acoustic energy received on the ground, as well as penalities for discrete tones and flyover duration.

Computation of an EPNL starts with the acoustic calibration of the input channel eg a 1/3-Octave measurement of a pistonphone with a calibrated

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amplitude of 124 dB is measured. An automatic routine in the HP 35665A allows this measurement to define the engineering unit conversion for that channel.

PISTONPHONE CALIBRATION

The next step toward an EPNL is the acquisition of 1/3-Octave sound pressure levels (SPLs) during the aircraft flyover. An exponential time constant of 1 second is applied each 1/3-Octave band to conform to FAR36, and a trace is stored into waterfall memory every 0.5 seconds.

COMPUTING PERCEIVED NOISE LEVEL

After the flyover is complete, a special overall noise level for each. o.5 second interval is calculated, called Perceived Noise Level, or PNL. With the post-processing capability provided by the HP35665A's system processor, each 1/30Octave sound pressure level (SPL) is converted into an equivalent noisiness, called noy, where frequencies of maximum annoyance, from 2000 to 5000 Hz, similar to acoustic A-weighting. The PNL is then calculated from a formula that heavily weights the maximum noy value.

TONE CORRECTIONS

After PNL is calculated for each time interval, a penalty for the presence of tones is computed. This correction was implemented by federal regulators to account for the extra annoyance generated by jet engine turbine or fan whine. The computation takes a spectrum of 1/3-Octave band level is more prominent than the bands surrounding it. If the band's SPL stands out from the spectrum, then a tone penalty is levied. The maximum tone penalty that can be applied is 6 2/3 dB.

The resulting noise criteria, Tone-Corrected Perceived Noise Level, or PNLT, is then computed for each of the 0.5 second intervals during the flyover and plotted.

DURATION

By definition, an Effective Perceived Noise Level (EPNL) is equal to the maximum PNLT (PNLTM) during a flyover plus a duration correction. The flyover duration is defined as that part of the flyover where the PNLT is within 10 dB of the PNLTM. The duration correction is then calculated from the difference between the total PNLT energy during the "10 dB-down interval" and PNLTM. If the difference is greater than 13, then a duration correction is applied. If it is less than 13 dB, then the Effective Perceived Noise

Level (EPNL) is reduced.

PSEUDO-TONE CORRECTIONS

One of the most critical components of EPNL for aircraft flyover noise levels is the tone correction penalty that is assessed in the spectrum associated with the maximum PNLT. This tone correction has a direct impact on the EPNL level. Because a tone penalty can sometimes be assessed due to amplification from ground plane reflection and not due to a loud engine, FAR36 has a clause that allows the tone penalty at PNLTM to be investigated.

In order to prove that a tone correction was due to ground-plane reflection and not the aircraft engine noise, the characteristics of the Doppler-shifted tone must be demonstrated. This requires narrowband FFT analysis at the same interval of time as the 1/3-Octave tone correction. To accomplish this using the HP35665A, a flyover time history is first digitally sampled and stored into time capture memory.

FLYOVER COMPRESSED BUFFER

The sampled data is then analyzed using the 1/3-Octave measurement mode using the FAR36 measurement parameters of exponential averaging, 1 second time constant, and 0.5 second time interval between spectra. A flyover time history for the data acquired in the capture buffer is in Figure 7. EPNL is calculated, and the time interval of the maximum PNLT is determined. The data is then analyzed again using the FFT mode.

FFT WATERFALL HELPS IDENTIFY PSEUDOTONES

From the waterfall display it is possible to identify the frequency of the first reinforcement due to the ground plane, as well as the first null frequency due to the ground lane reflection. Examining the FFT trace at the time of maximum PNLT, the frequency of amplification can be compared to the 1/3-Octave band frequency of the tone correction at maximum PNLT. If the two frequencies are aligned, and the resulting path difference between the direct incidence acoustic wave and the reflected incidence wave are close to 1/2 of a wavelength for the offending tone, then a pseudo-tone contributed to the EPNL and the noise level can be reduced.

CONCLUSIONS

The recent application of advanced DSP algorithms within traditional FFT-based analyzers coupled with on-board system processors for data management and post-processing has opened new doors to complex measurements that previously required dedicated, expensive analyzers and external post-processing computers. Measurement quality has improved at the same time that system cost has been reduced dramatically.

A potential outcome of new, lower-cost instrumentation with built-in post-processing is that noise regulations will change. Since complex noise criteria such as EPNL provide more accurate assessment of actual annoyance, it will now be possible to measure every takeoff, sideline, and approach noise level at an airport to assess the true impact on the community.