The MIL-STD-810G, Change 1, Solution to the Aliasing Problem

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Seven years ago, I started putting my course, *Mechanical Shock Testing and Data Analysis* that I teach with Howie Gaberson, together, and as I pondered what topics to include, I rejected including the aliasing topic. After all, as Strether Smith pointed out in his S&V February '13 editorial "Begone Cursed Alias!," this problem was solved in the 1980s. However, as I talked to students in my courses and at my tutorials, I found that the aliasing problem is rampant. My first encounter was with a student who told me that his data acquisition system (DAS) has a light that comes on when his DAS is not protected from aliasing and wanted to know what I thought of this. At first, I was puzzled, but then I slowly realized that his DAS deliberately allowed aliasing to occur! Next, a severe case of aliasing occurred in a large commercial testing business for which, I was told that criminal charges were still on the table. I soon ran into another large commercial testing business that gave their DoD customer data sampled at 25,000 Hz with a DAS having a four-pole, analog, anti-aliasing filter cutoff of 20,000 Hz. The operator who took this data announced: "I have been taking pyroshock data for 30 years, and it always looks the same, no matter how you measure it!" I now shifted from disbelief to alarm because the people involved in these instances are my age, and we were all working in shock, pyroshock, and/or ballistic shock in the 1980s.

One can speculate about what has caused this severe memory loss for people my age or the severe loss of industry knowledge passed down to younger folks, but at this point, I decided that something had to be done. Not only is corrupted, aliased data widespread, but it is also part of the qualification of equipment operated by people.

MIL-STD-810G was issued in 2008 (available for free download on the internet), but as I started to publicize what I have learned as per above, a consensus developed in the MIL-STD-810G committee, specifically the subject matter experts (SMEs) for shock methods – Method 516 for Shock (SME, Mike Hale, Redstone Test Center), Method 517 for Pyroshock (SME myself), Method 519 for Gunfire Shock (SME, Ron Merritt, formerly of Naval Air Warfare Center, China Lake) and Method 522 for Ballistic Shock (SME Scott Walton, Aberdeen Test Center). I held a Pyroshock Working Group meeting at the 81st Shock and Vibration Symposium (October 2010) at which there was a spirited discussion about aliasing based on Tim Edward's work that recommends high sample rates to prevent aliasing.[1] I also did a literature search, and the only requirement I found to prevent shock aliasing is

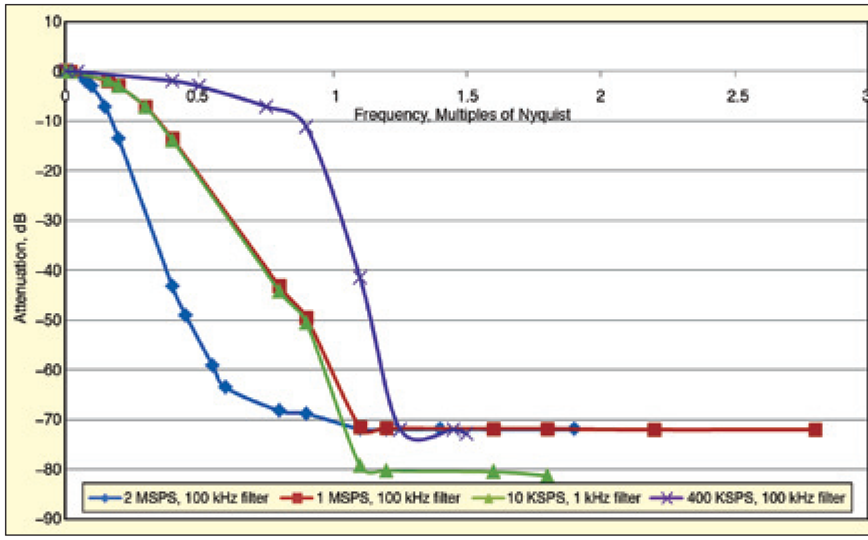

Figure 1. Characteristics of ATC's custom VHSD (very high speed digitizer) showing attenuation vs. frequemcy content using several digitizing and filter frequencies.

Allan Piersol's that specifies 60 dB/octave.[2] This requirement has severe time domain consequences, but I proposed Piersol's criteria and that got the discussion going. About that time, I also started using the term "Out of Band Energy" to describe any type of noise (explosive detonation spikes, accelerometer resonance, etc.) beyond a DAS bandwidth and to justify a shock DAS with a wider bandwidth than 20,000 Hz (also may prevent slew rate problems[3]). In February 2011, Scott Walton briefed the ATC Technical director on "Out of Band Energy" and anti-aliasing issues and the ATC responses to those issues. By the end of 2011, the MIL-STD-810G committee, under the leadership of Ken Thompson, HQ US Army Test & Evaluation Command, was actively creating MIL-STD-810G, Change 1. At the 82nd Shock and Vibration Symposium, ATC presented material on "Out of Band Energy" as both a formal session and at the Pyroshock Working Group meeting hosted by myself. Also during 2011, Scott Walton and Lee Francis of ATC, as well as others, tested six different DASs, involving three different Army installations, for susceptibility to aliasing. The IEEE Standard 1057 sine wave test and noise tests provide tools for evaluation. The results for ATC's custom, sigma delta DAS are shown in Figure 1 for various sample rates and analog, low-pass filter cutoff frequencies.

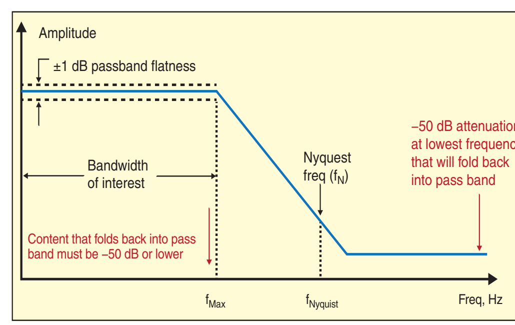

Figure 2. Proposed aliasing requirement for MIL-STD-810G, Change 1.

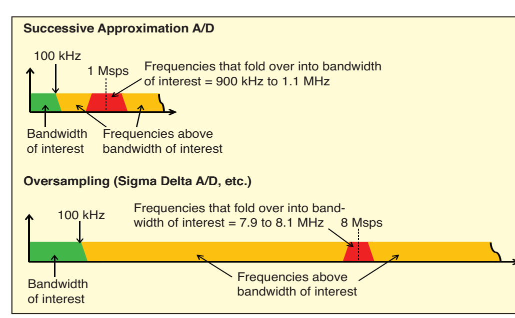

Figure 3. Illustration of sampling rates and out of band "fold over" frequencies (created by Brandon Hepner, ATC).

Testing continued for commercial sigma-delta DASs as well with contributions from Mike Hale, RTC. After another spirited Pyroshock Working Group discussion at the 83rd Shock and Vibration Symposium (also held at ESTECH conferences) the criteria in Figure 2 was proposed for MIL-STD-810G, Change 1. This requirement with 50 dB analog, anti-aliasing filter attenuation resulted from Brad Allen's, Moog CSA Engineering, comments and critique of the proposal that required 80 dB attenuation. The intent of these requirements is to allow the flexibility of both low sample rates with a sharp rolloff slope and high sample rates with a shallow rolloff slope and everything in between. After many MIL-STD-810 telecons, the committee has agreed upon the final wording, shown below, as added to Method 522. Minor changes may appear in the specific shock methods. For example, Method 516 for Shock requires a bandwidth of 10,000 Hz instead of 100,000 Hz. These changes require DAS testing, not manufacturers' specifications. Believe it or not, the requirement for an analog filter is necessary since some manufacturers are making (very cheap) digital DASs without any analog front end. Highlights are mine. These changes (and much more) will also be documented in an upcoming revision of "The History and Rationale of MIL-STD-810."[4]

METHOD 522.2

4.4.2 Data Acquisition Instrumentation.

4.4.2.1 Filtering and Frequency Response.

The data recording instrumentation shall have flat frequency response to at least 100 kHz for at least one channel at each measurement location. Attenuation of 3 dB at 100 kHz is acceptable. The digitizing rate must be at least 2.5 times the filtering frequency. Note that when measurements of peak amplitude are used to qualify the shock level, a sample rate of at least 10 times the filtering frequency (1 million samples per second) is required. Additional, lower frequency measurement channels, at the same location may be used for lower frequency response measurements.

It is imperative that a responsibly designed system to reject aliasing is employed. Analog anti-alias filters must be in place before the digitizer. The selected anti-alias filtering must have an attenuation of 50 dB or greater, and a pass band flatness within one dB across the frequency bandwidth of interest for the measurement as in Figure 2. Subsequent resampling e.g., for purposes of decimation, must be in accordance with standard practices and consistent with the analog anti-alias configuration (e.g. digital anti-alias filters must be in place before subsequent decimations).

The end to end alias rejection of the final discretized output must be shown to meet the requirements in Figure 2. The anti-alias characteristics must provide a minimum attenuation 50 dB or greater for frequencies that will fold back into the passband. Spectral data including SRS plots may only be presented for frequencies within the passband (between 0 and f_{max}). However, this restriction is not to constrain digital data validation procedures that require assessment of digitally acquired data to the Nyquist frequency [either for the initial ADC (analog to digital converter) or subsequent resampled sequences].

Verification of alias rejection should start by establishing the dynamic range within the pass band in terms of the signal to noise ratio (SNR). The SNR = 20 $\log_{10}(V_{FullScale}/V_{NoiseFloor})$ must be ≥60 dB. Once sufficient SNR is verified, establishing the alias rejection characteristics may be determined using an input sine wave with a magnitude of 0.5 × full scale range and at the lowest frequency range that can impinge i.e., be aliased into f_{max}, and then confirming (using the IEEE 1057 sine wave test procedure or through inspection of the time domain data) that the alias rejection is sufficient at this frequency. If the 1 million sample/second digitizing rate is used, for example, then $f_{Nyquist}$ = 500 kHz. Theory says that if a signal above the Nyquist ratio is present, it will "fold over" into a frequency below the Nyquist ratio. The equation is:

$$F_a = \text{absolute value } [(F_s \times n) - F]$$

where:

F_a = frequency of "alias"
F = frequency of input signal
F_s = sample rate
n = integer number of sample rate (F_s) closest to input signal frequency (F)

Hence the lowest frequency range that can fold back into the 100 kHz passband is from 900 kHz to 1,100 kHz = 0.9 to 1.1 MHz.

It should be noted that sigma delta (SD) digitizers "oversample" internally at a rate several times faster than the output data rate. Analog anti-alias filtering for SD digitizers may be used at the Nyquist rate for the internal sample rate. For example, if a 1 million sample/second SD digitizer samples internally at 8 million samples/second, then the internal Nyquist frequency is 4 MHz, hence the analog anti-alias filter should remove content above 4 MHz that can fold back into the 100 kHz pass band (7.9 MHz to 8.1 MHz and similar bands that are higher in frequency). Figure 3 illustrates sampling frequencies, Nyquist frequencies, and frequency bands that can fold back into the bandwidth of interest for both conventional ("Successive Approximation") digitizers and over sampling digitizers, such as the sigma delta digitizer.

References

1. Edwards, T., "Effects of Aliasing on Numerical Integration," *Mechanical System and Signal Processing*, Vol. 21, pp. 165-176, Elsevier, 2007.
2. *Handbook for Dynamic Data Acquisition and Analysis*, IEST-RD-DTE012.2, Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 620, Arlington Heights, IL 60005.
3. V. I. Bateman, H. Himelblau, and R. G. Merritt, "Validation of Pyroshock Data," *Journal of the IEST*, October 2012 (available on the website) and winner of the 2013 Maurice Simpson Technical Editors Award.
4. Egbert, Herbert W., "The History and Rationale of MIL-STD-810 (Edition 2)," January 2010; Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 620, Arlington Heights, IL 60005.

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