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Response Limited Shaker Shock Testing

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ABSTRACT

When conducting dynamic testing on shakers it is often prudent to limit the response of the test article to protect the unit from over test and to more closely represent the environment. This is an accepted practice with random vibration testing. A methodology will be presented for response limiting shaker shock testing. The method allows multiple response limit channels with independent shock response spectra limit profiles. The notches to the input shock response spectra are determined with iterative solutions of the inputs with the system transfer functions to the responses with limits.

INTRODUCTION

Transient vibration testing on shakers has been common practice for many years (Smallwood, 1975). Several commercial packages are now available to perform transient testing on shakers. Typically the response is measured in terms of the shock response spectra (SRS). In some respects these packages are limited by liability issues. As a result Sandia has maintained and improved internal software for transient testing. The internal software is used primarily for system level testing where the limits imposed by the commercial software are most apparent. Small packages and components are typically tested using the commercial software. The single point response of a large structure to a shock is often not a very good representation of the response of the overall structure. In random vibration testing this limitation is addressed by averaging responses and/or adding limit channels. This paper discusses how averaging and limits are addressed for shock testing where the measure of success is the SRS.

The software package used at Sandia is called TSHAKER. It is used to control transient testing on both electrodynamic and electrohydraulic shakers. The system works with transients synthesized to match the SRS using sums of decayed sinusoids, wavesyn, and other user defined time histories.

THE CONTROL PROCESS

The algorithm is derived from the SRS correction algorithm in TSHAKER. The FRF needed to derive the drive waveform necessary to reproduce the control waveform is estimated in the usual manner for transient testing. The system is excited with a low level broad band waveform and the FRF is estimated. The drive waveform needed to reproduce the required response is estimated. A low level test is then preformed and the SRS at the control location (or locations) and the limit locations are computed.

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Modification of the drive to correct the SRS error is a non-linear process both at the current level and as the level is increased to the desired final level. The SRS is not a linear transformation and the test item may not be linear. For a particular test the FRF is a characteristic of the system under test and normally does not change. The drive waveform is modified by updating the magnitude of the estimated FRF and not changing the phase.

The test operator selects the parameters used for the error correction. The operator can pick the: Frequency range, the correction factor, and the option to amplify only, attenuate only, or both amplify and attenuate. Obviously an experienced operator is required to rationally pick these parameters.

TEST and CONTROL SETUP

The control location or locations (if averaging is used) and response limit locations are defined. The required SRS is defined for each location. The required SRS's can be the same or different for each location. The required SRS's are interpolated to the same frequency spacing as the frequency response function (FRF) from the control system. The limit options include: Amplify only, Attenuate only, and Attenuate and amplify.

CONTROL SCHEME

A low level broad band input is run. The error calculation is performed at the control and limit locations.

$$Error = achieved\ SRS / reference\ SRS \qquad \text{Equation 1}$$

The error for limit locations is only considered if greater than one.

Based on the largest error source for each frequency line the magnitude of the FRF is modified with a weighting. The weighting for the correction is always less the 100% because of the non-linarites. The weighting is an operator picked parameter based on the current results.

The level is increased (typically in 3dB increments) with the new computed input using the modified FRF. And the process is repeated until full level is reached.

ERROR UPDATE WEIGHTING

The weighting updating helps with several issues.

Structural nonlinearities- Damping often increases with level. The weighting helps to make sure the control does not overshoot.

Nonlinearities in the SRS- Low frequency response will change the SRS at higher frequencies. The weighting helps to help assure the control does not overshoot at frequencies above the limiting band.

The update weighting factor is manually selected. The same weighting factor is used for all frequencies. It may be necessary to iterate the weighting without increasing the level. The weighing historically never reaches 100%.

Table 1. Typical weighting

Test Level (dB)	Weight (%)
-12	50
-9	70-75
-6	80-85
-3	80-90
0	80-90

EXAMPLES

Close Loop Example

The first examples were generated with the system in closed loop (the FRF are unity). A control spectrum and two limits were defined (Figure 1).

Sums of exponentially decaying sinusoids were used for this example. Other waveforms should work but have not been tested.

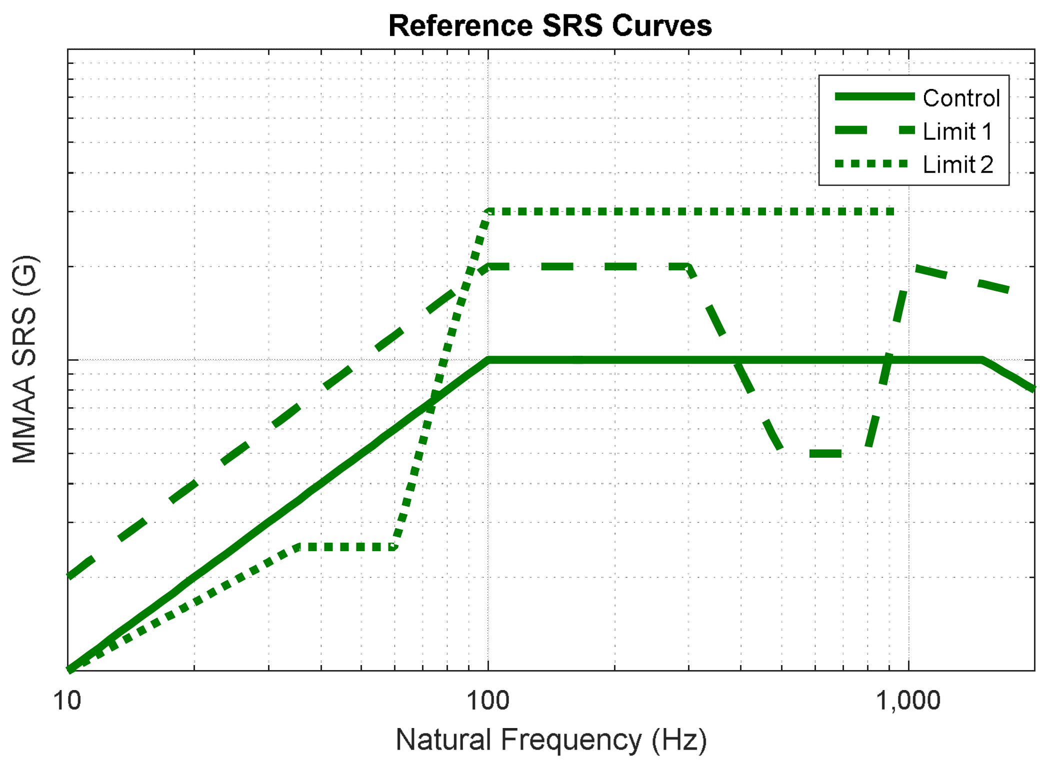

Figure 1. Example with 2 Limit channels, the reference control and two limit spectra

The control spectrum at -12dB without the limits is shown in Figure 2. Since the system was closed loop the SRS of the limit channels are the same as the control spectrum. The initial SRS's of the limits together with the desired limit spectrum are shown as Figure 3 and Figure 4.

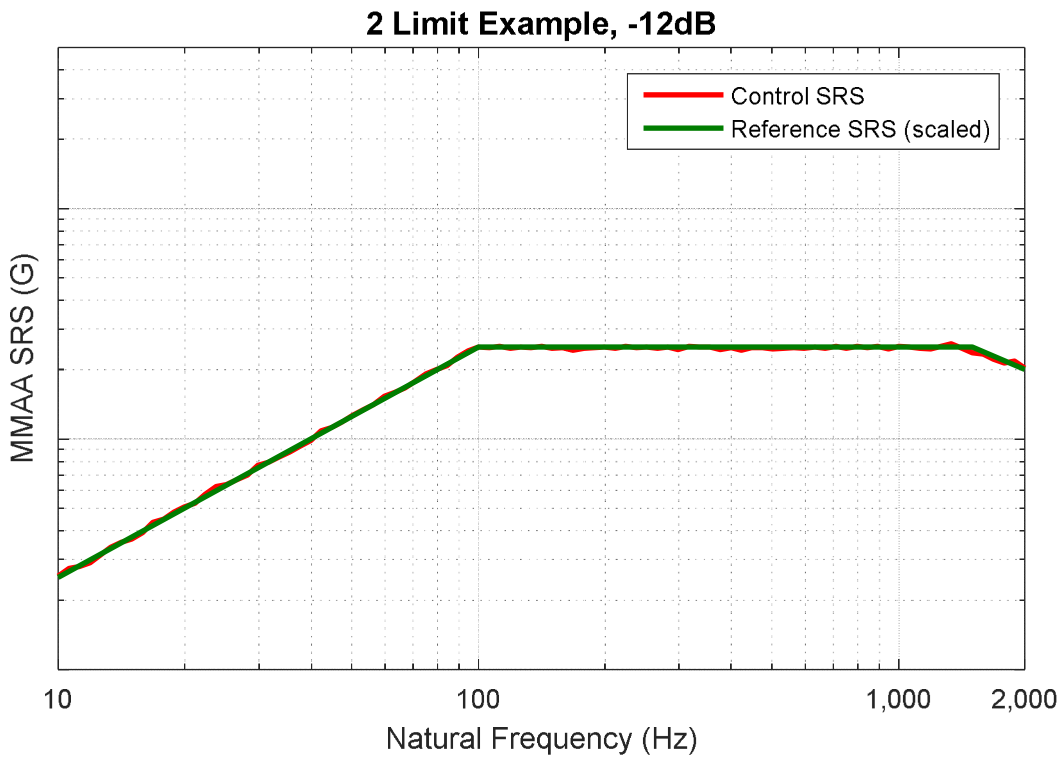

Figure 2. Control SRS without the limits

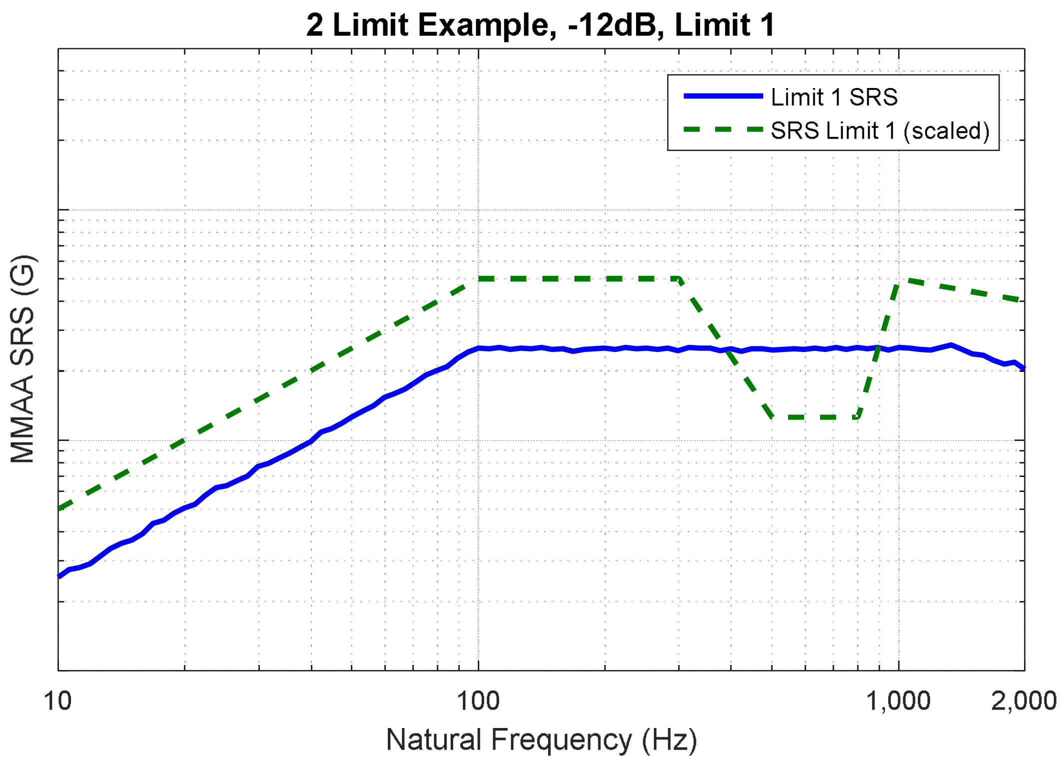

Figure 3. Two limit example, -12dB, Limit 1

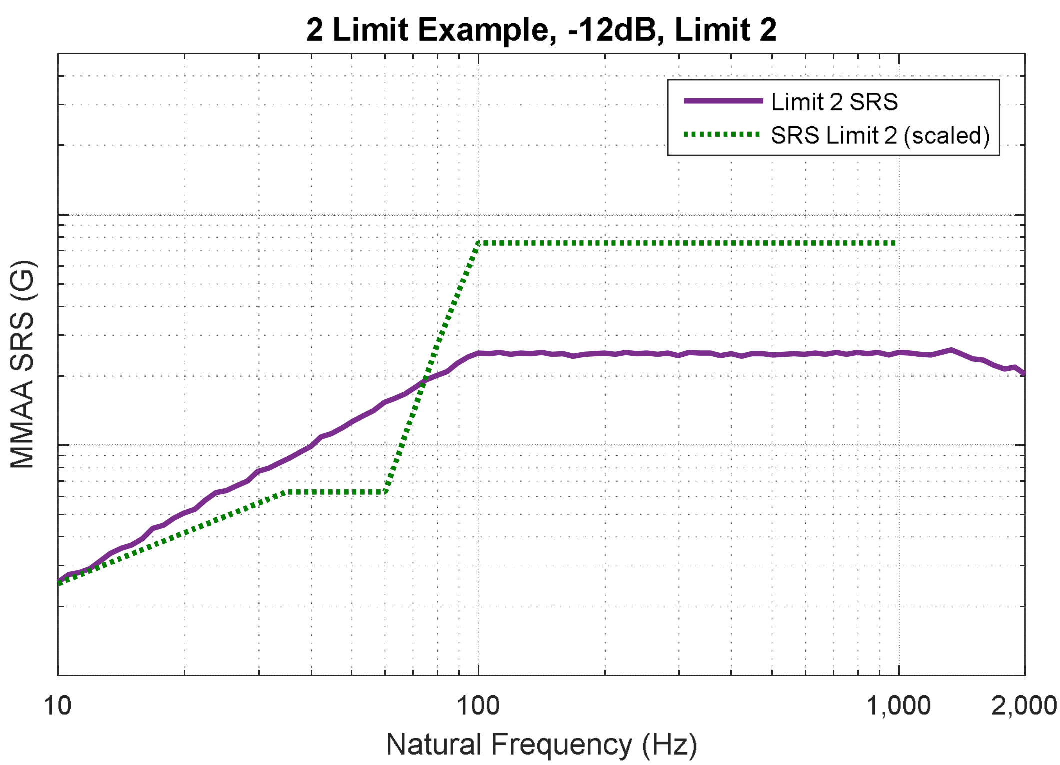

Figure 4. Two limit example, -12dB, Limit 2

As can be seen, the limit is exceeded for Limit 1 in a band near 800Hz. The limit is exceeded for Limit 2 below about 80Hz. The error for each channel is shown in Figure 5.

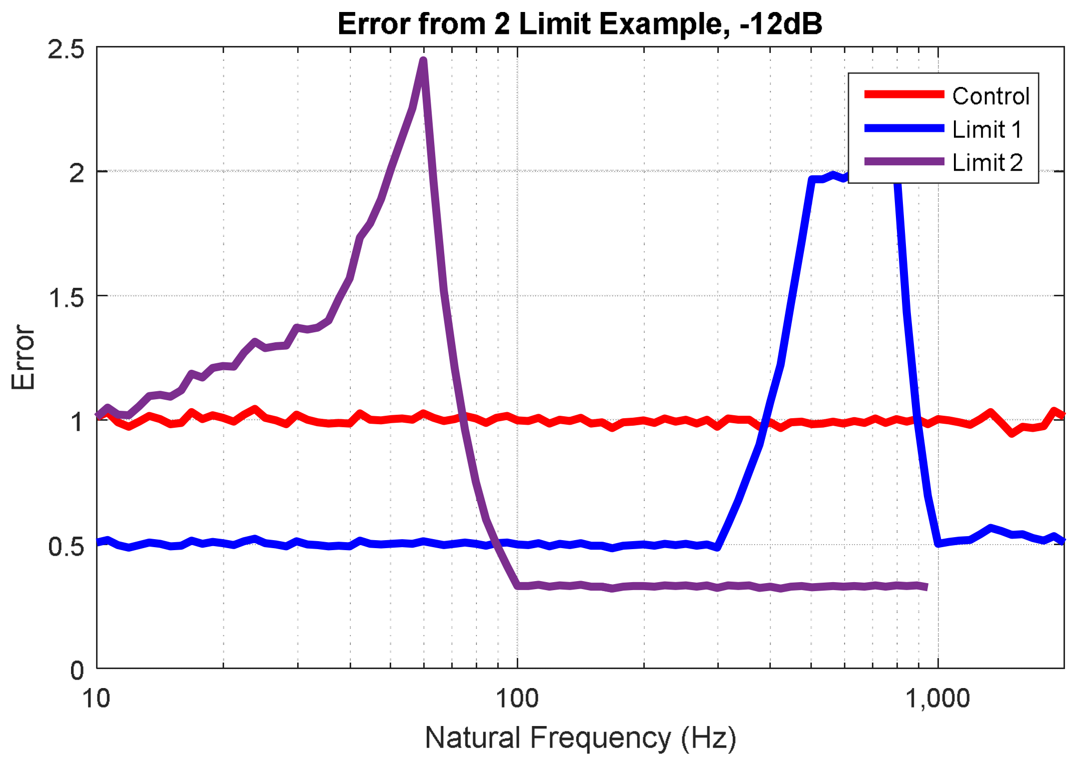

Figure 5. Two Limit Error, -12dB

The corrected control SRS at -9dB is shown in Figure 6.

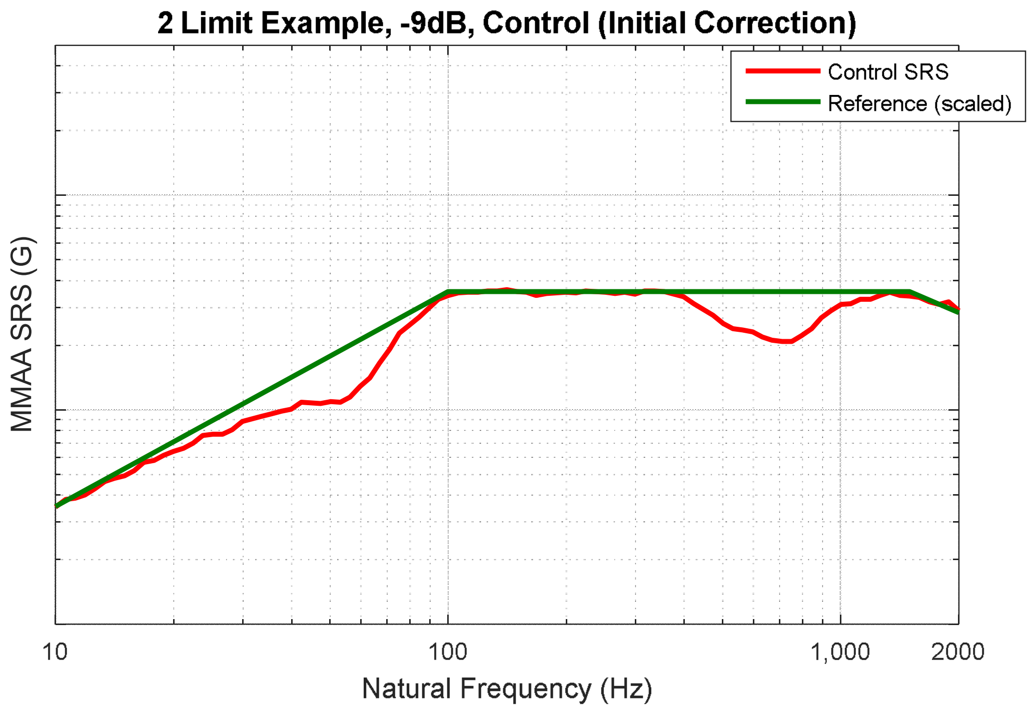

Figure 6. Two Limit Example, -9dB Control

The SRS's of the two limit channels after the correction at -9dB are shown in Figure 7 and Figure 8. As can be seen from the SRS the limit SRS's are improved but not completely corrected. This is because the correction factor was not set to one. Also note that because the SRS is a nonlinear function, when a correction is made at a frequency the change affects other frequencies. The error correction method accounts for these effects. This is evident in Figure 7 and Figure 8. The error at -9dB is shown as Figure 9.

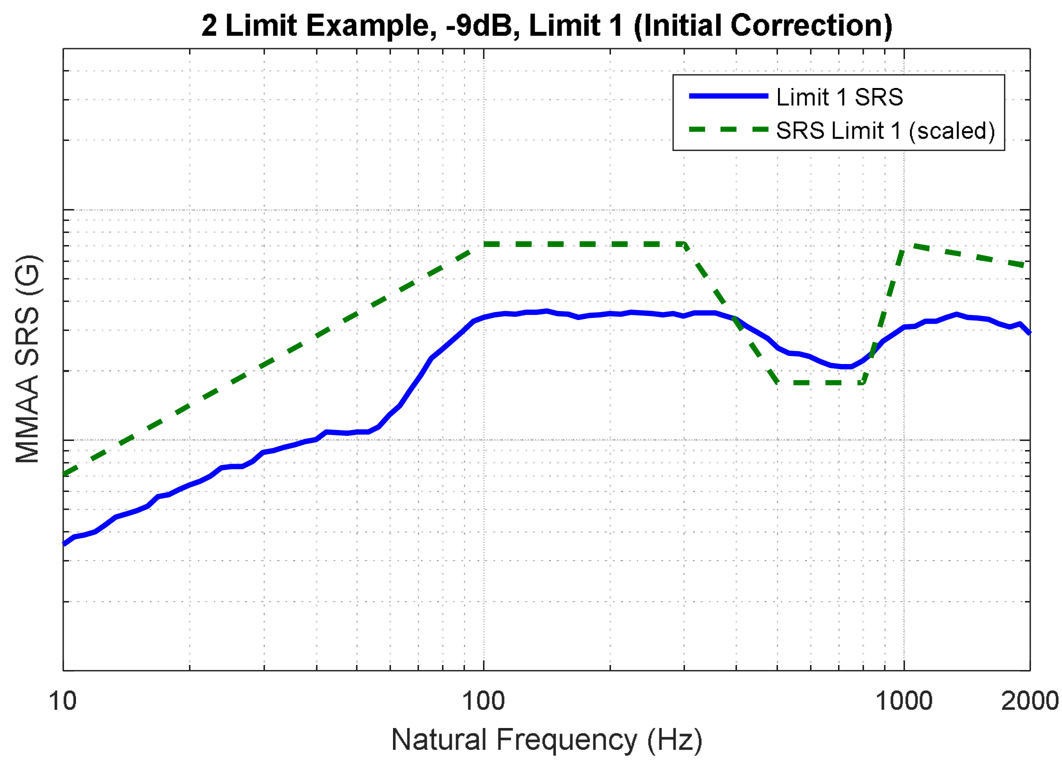

Figure 7. Two limit example, -9dB error

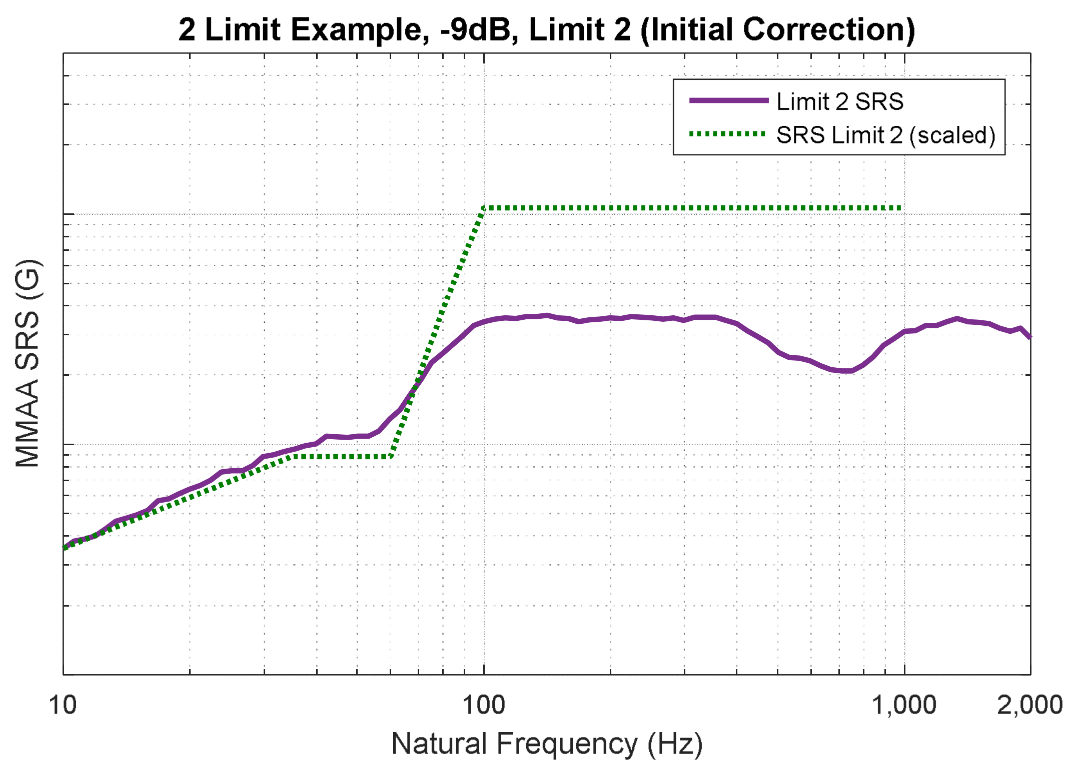

Figure 8. Two Limit Example, -9dB, Limit 2

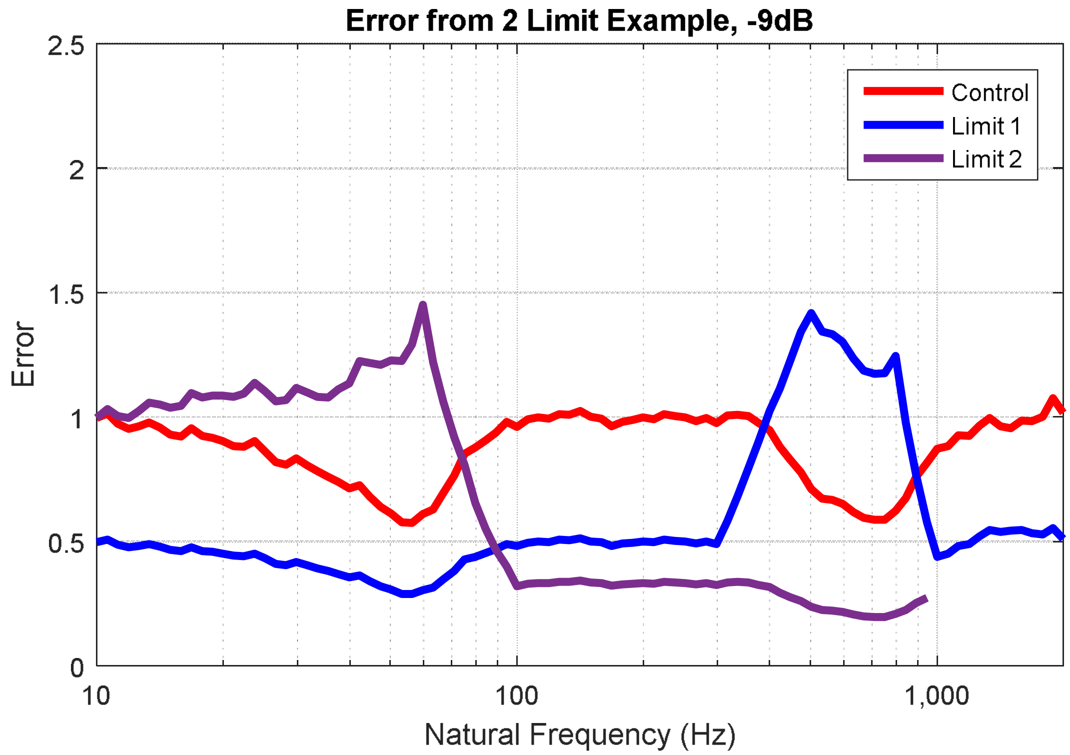

Figure 9. Two Limit Example, -9dB, Error

As can be seen the error has been considerably reduced.

Finally the level is increased to 0dB. The Reference SRS (Figure 10), the SRS of the Limit 1 (Figure 11), and the SRS of the Limit 2 (Figure 12) are shown. Figure 13 shows the Error at 0dB. As can be seen the error does not significantly exceed 1 at any frequency. Since the system is closed loop, the FRF is a constant. Figure 14 shows the modification to the magnitude of the estimated FRF.

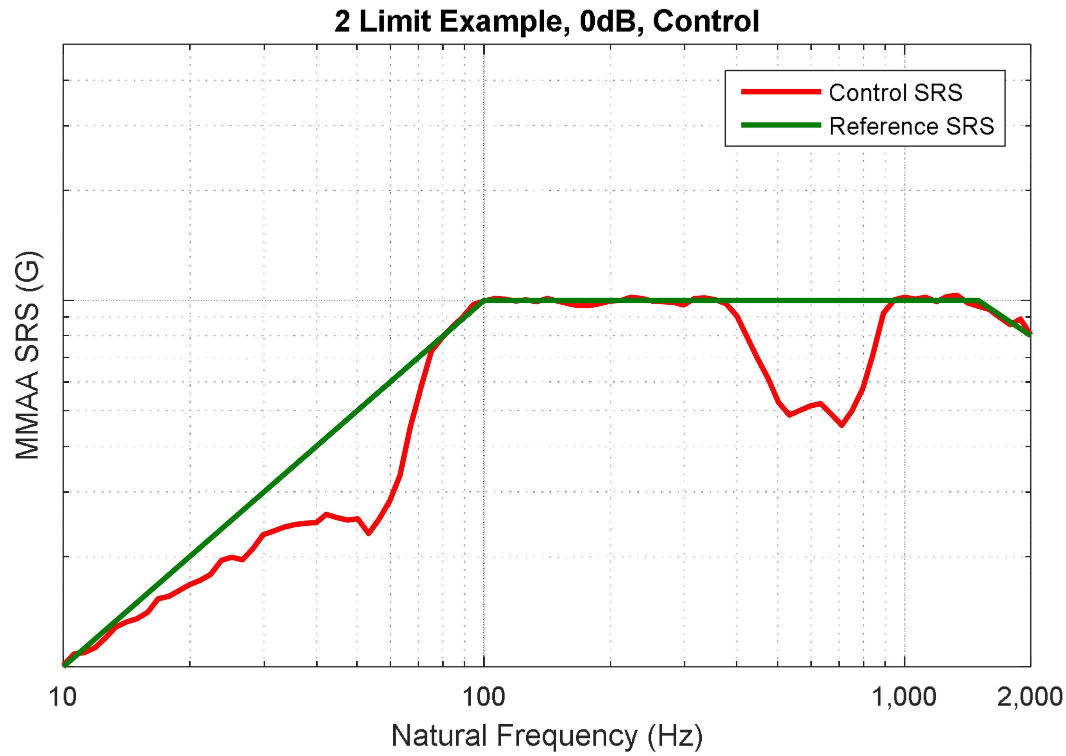

Figure 10. Two Limit Example, 0dB, Control

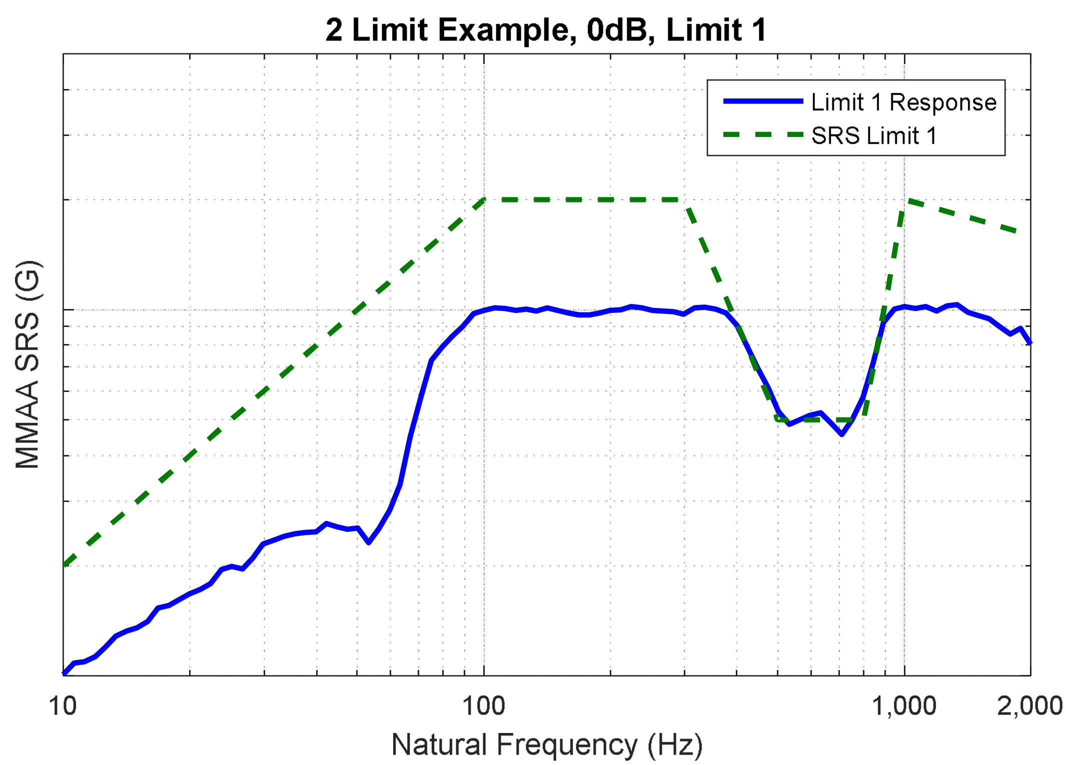

Figure 11. Two Limit Example, 0dB, Limit 1

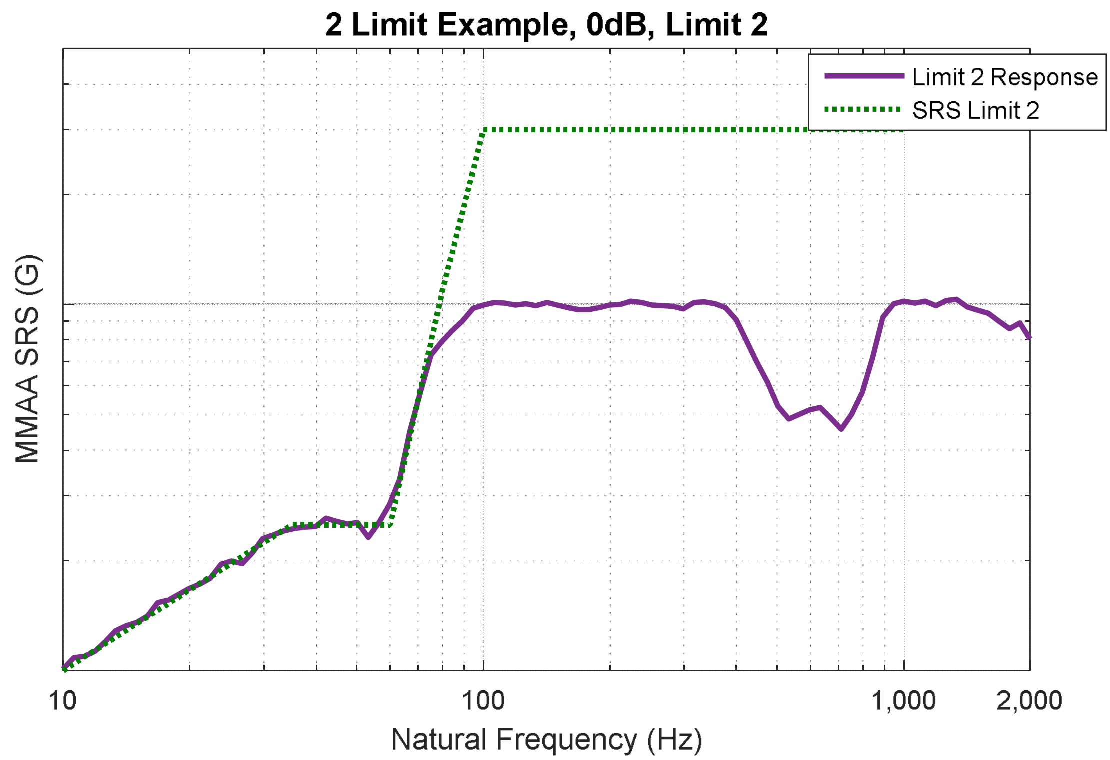

Figure 12. Two Limit Example, 0dB, Limit 2

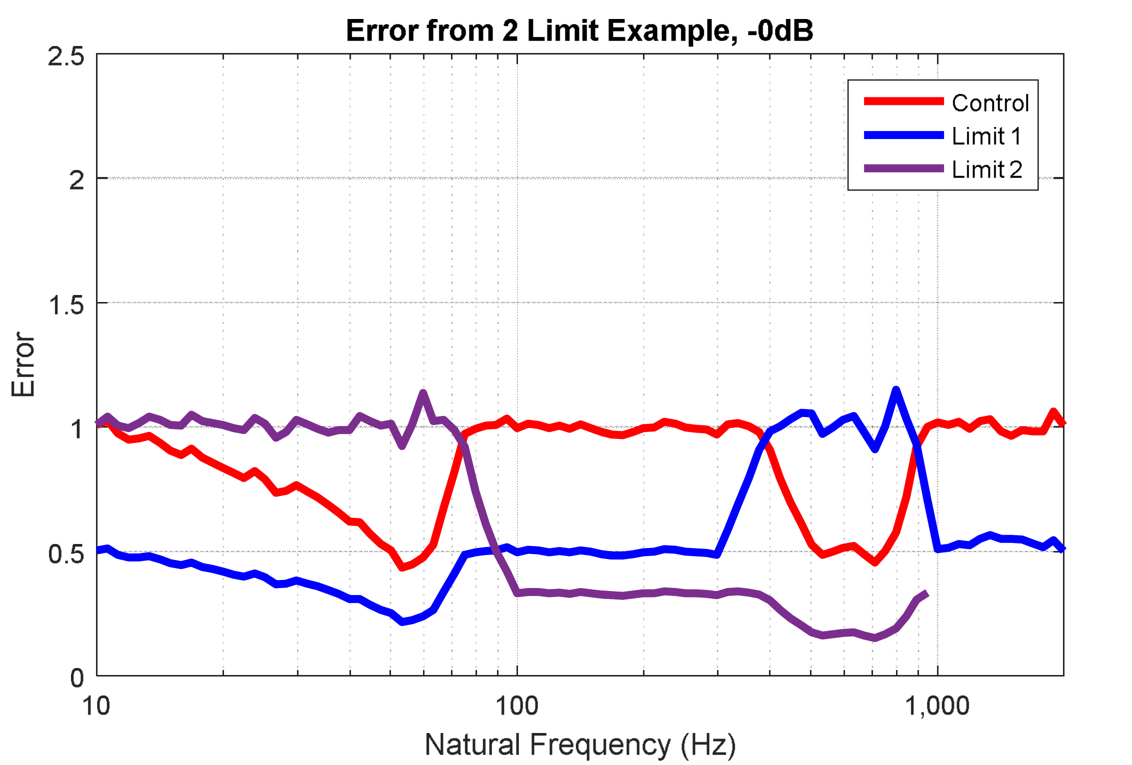

Figure 13. Two Limit Example, 0dB error

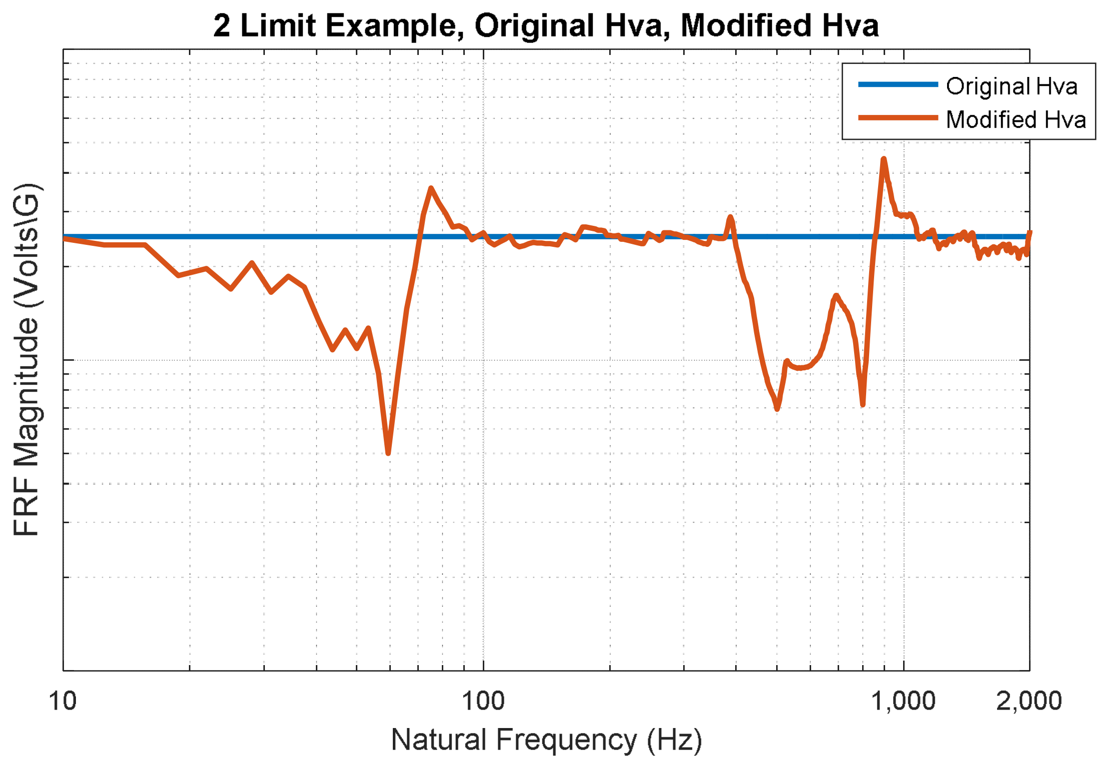

Figure 14. Two Limit example, FRF Magnitude, No Limit/With Limit Comparison

Example with a Test Article

The test item was a simulated external store (Figure 15). The control was at the aft lug. A single limit channel was on the top of the store. The full level control SRS without the limit is shown in Figure 16. The limit SRS is 6dB above the control SRS. The limit SRS with no limiting is shown as Figure 17. As can be seen the limit is exceeded in several frequency bands. Figure 18 and Figure 19 show the final result for the control and the limit SRS. Notice that the limit SRS does not exceed the limit at any frequency. Figure 20 shows the modification of the estimated FRF.

Exponentially decaying sinusoids were used for this example.

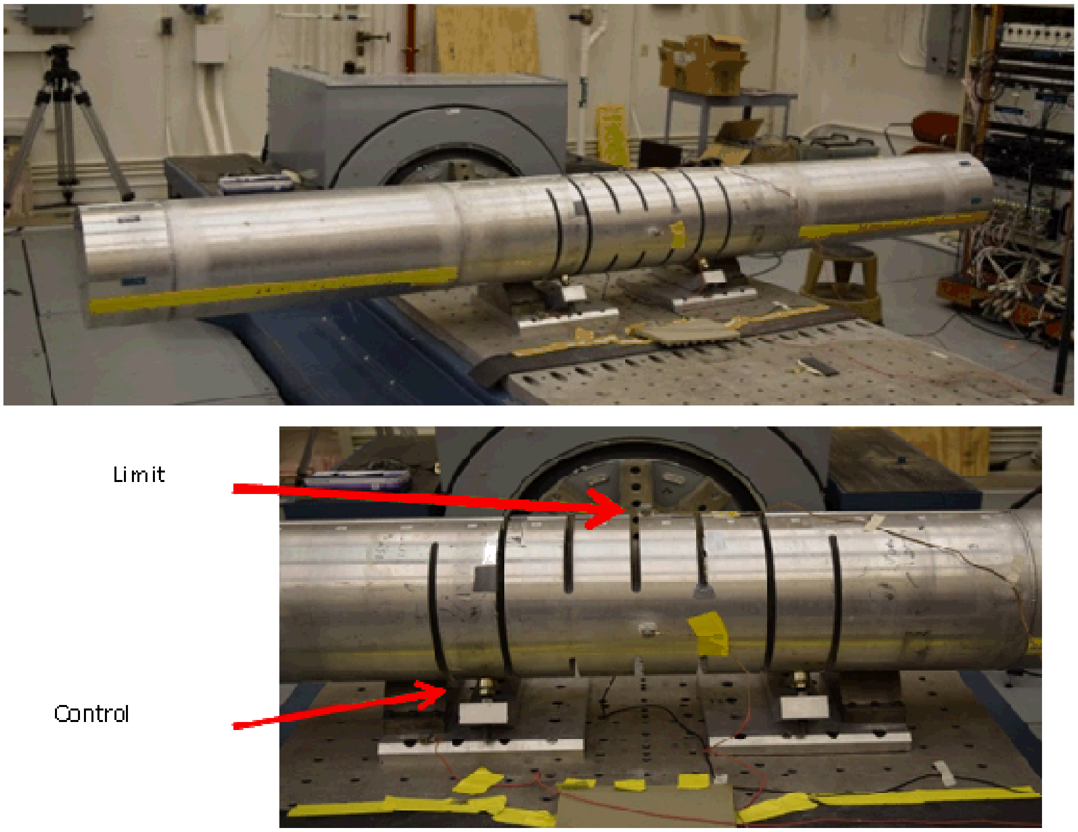

Figure 15. A Simulated External Store

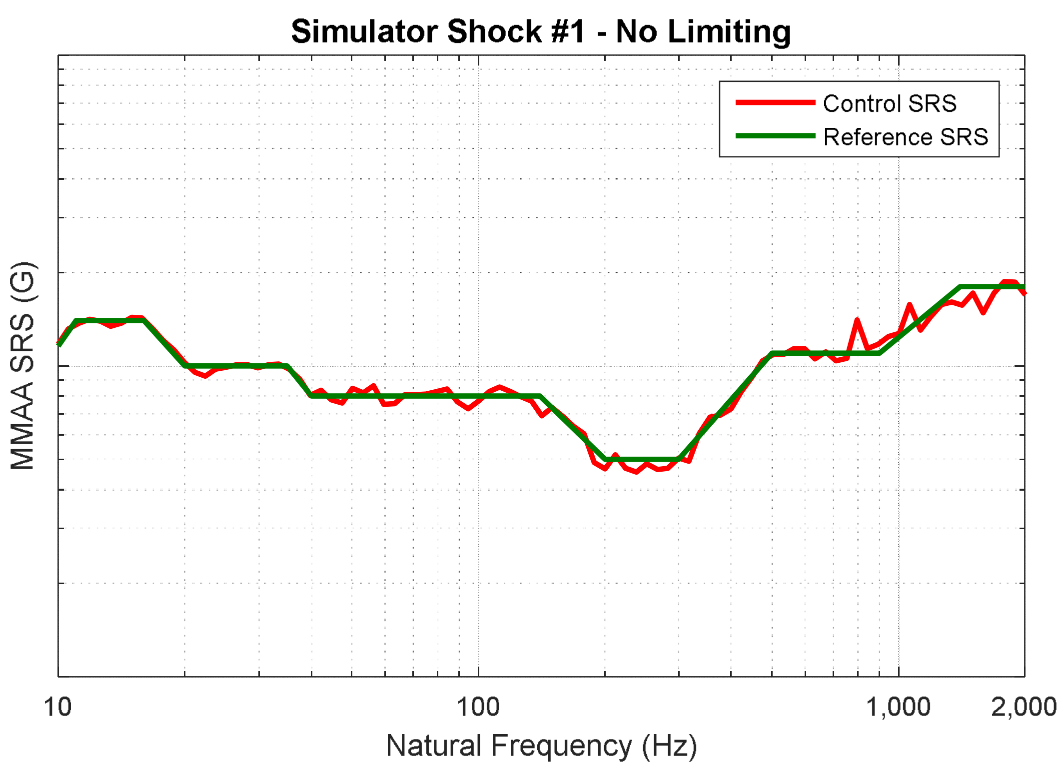

Figure 16. The control SRS and the Reference SRS with no limiting

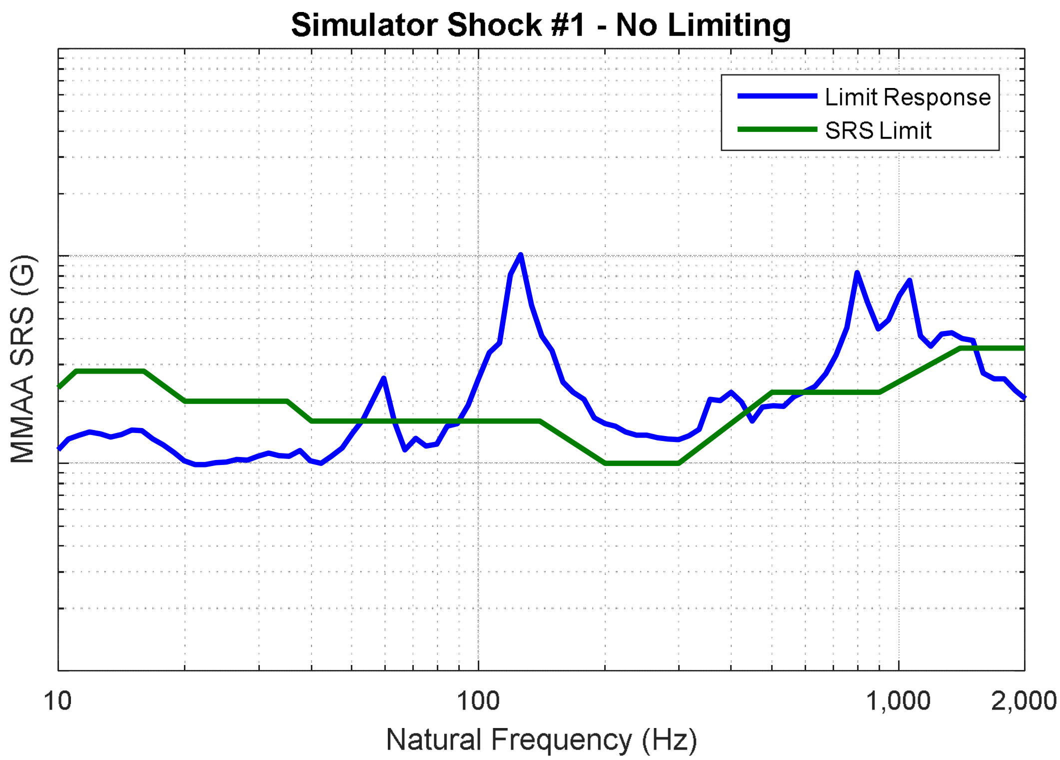

Figure 17. Limit SRS Response with no limiting

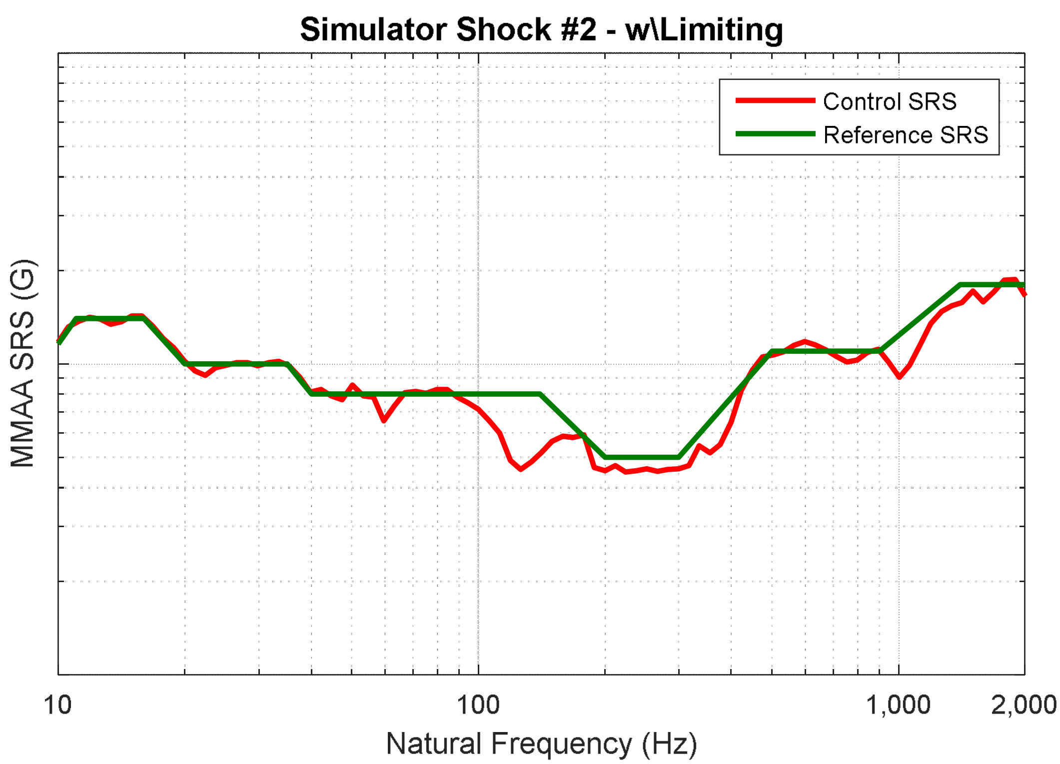

Figure 18. Simulator SRS with limiting

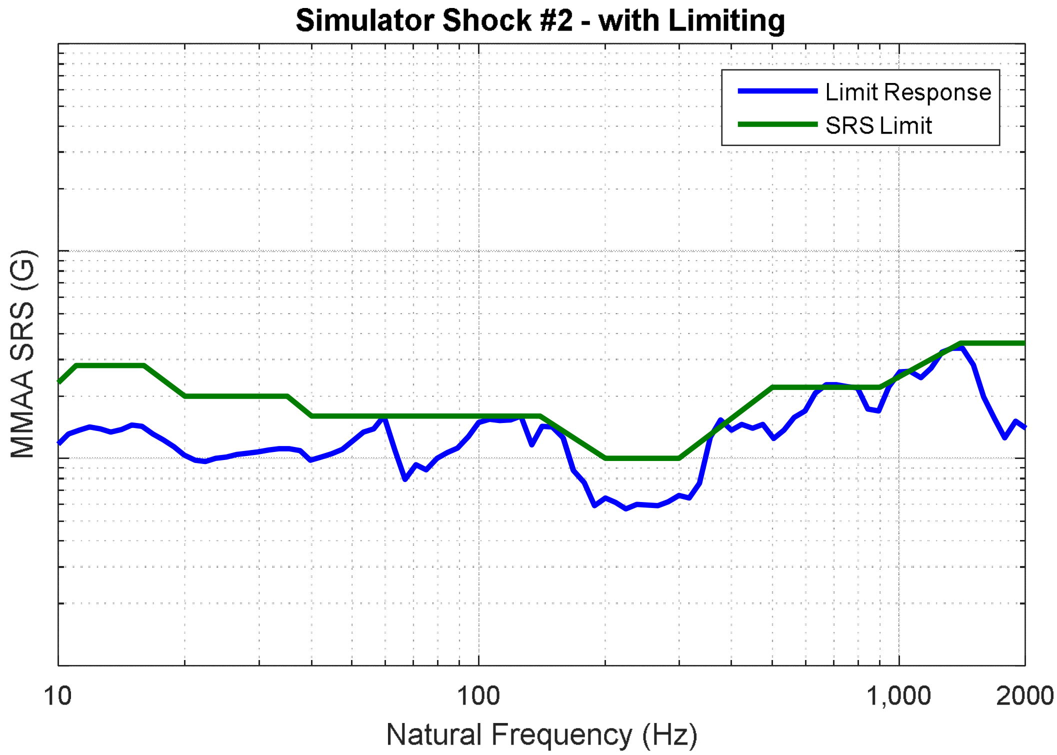

Figure 19. Simulator Limit SRS with Limiting

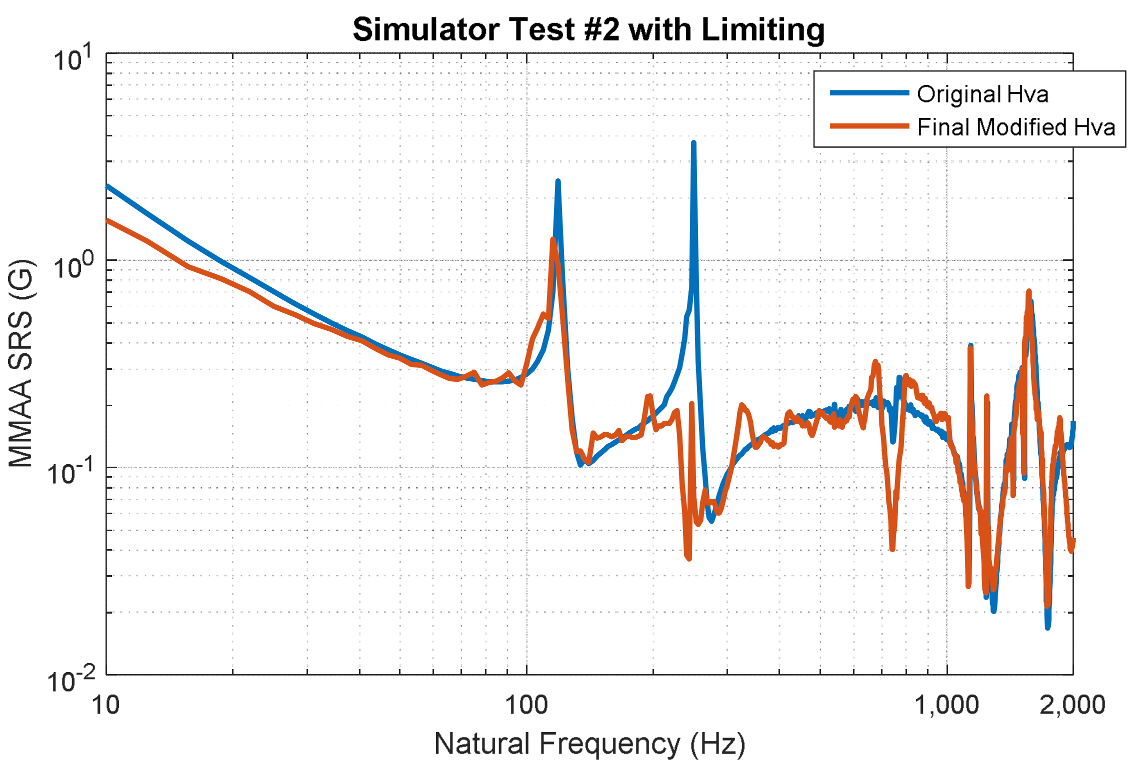

Figure 20. Modifications of the Magnitude of the Estimated FRF

Acknowledgments

Ron Coleman was largely responsible for modifying TSHAKER to accomplish this task. TSHAKER was developed using a combination of LabVIEW and Matlab software. LabVIEW provides the user interface and hardware control. Matlab operates in the background providing data processing and signal analysis. Troy Skousen generated the presentation for the symposium and presented the paper. David Smallwood wrote the original Matlab SRS code and worked with others on the original TSHAKER. David also wrote most of the text in this paper.

References

Smallwood, D. O., "Time History Synthesis for Shock Testing on Shakers," Seminar on Understanding Digital Control and Analysis in Vibration Test Systems, Part II, pp 23-42, A Publication of the S&V Information Center, NRL, Washington DC, May 1975.