OPTIMIZING A CIRCUIT BOARD NATURAL FREQUENCY WITH RESPECT TO RANDOM VIBRATION

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Introduction

Consider a circuit board as a single-degree-of-freedom system. The natural frequency is a function of the board dimensions, boundary conditions, and the mass properties.

Further consider that the board and its piece parts must withstand the random vibration qualification test specified in Table 1 and in Figure 1. Note that the test duration is left undefined for this example.

Next, consider that the board design parameters can be varied so that the natural frequency is greater than 50 Hz but less than 600 Hz.

Assume that the circuit board is mounted in an enclosure, or chassis, that must be hardmounted to a structure.

What is the optimum natural frequency to minimize the response of the board and its components to the test level? The purpose of this report is to provide guidelines for answering this question.

Failure Modes

A circuit board may have numerous potential failure modes, including: yielding, buckling, and fatigue. Each failure mode depends in part on the board's natural frequency. Each mode may be provoked by excessive displacement, velocity, or acceleration

This paper focuses on relative displacement and absolute acceleration. An excess of either parameter may lead to a fatigue failure.

In particular, the fatigue of electrical parts is typically modeled in terms of relative displacement, as discussed in References 1 and 2. The concern is that the lead wires or solder joints may break. Minimizing relative displacement mitigates this concern.

On the other hand, minimizing absolute acceleration is also a goal. Excessive absolute acceleration could cause a crystal in an oscillator to shatter, for example.

The proper choice of natural frequency often involves a trade-off between minimizing each of the two response parameters.

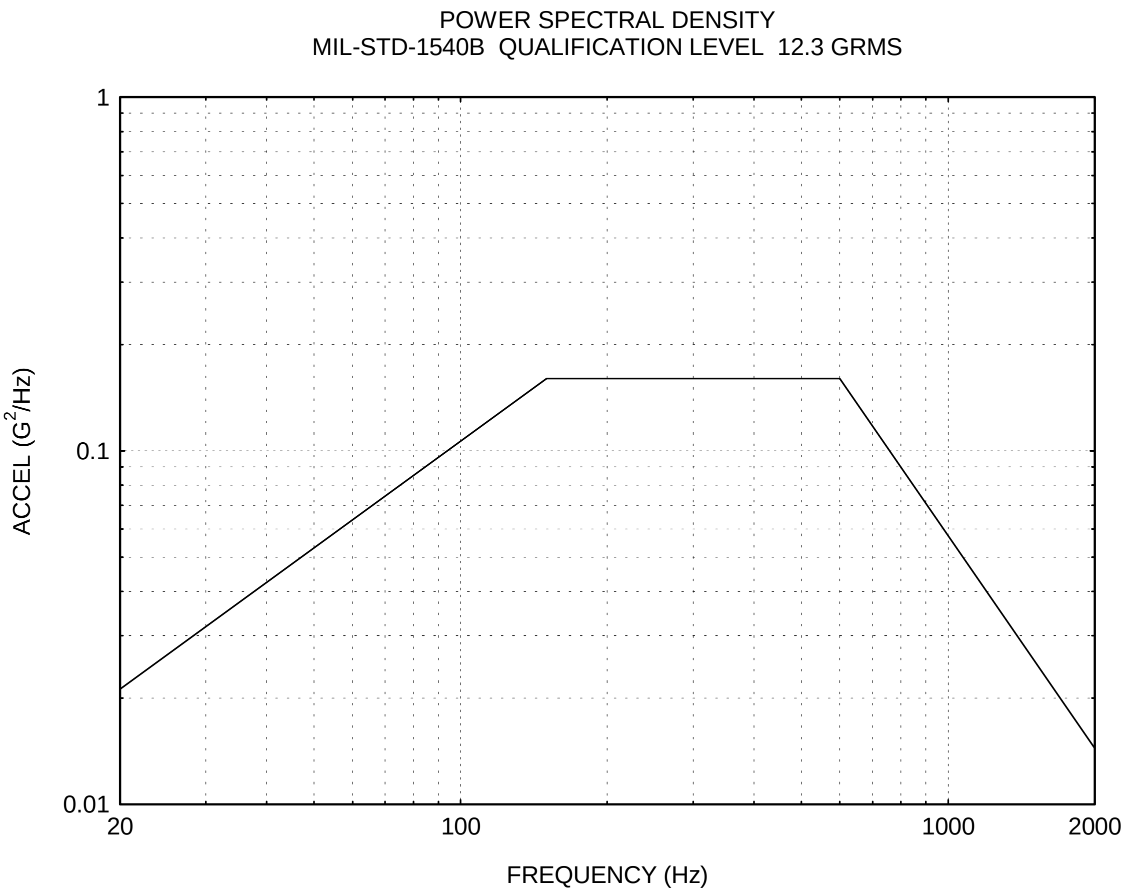

Figure 1.

Table 1. PSD, Qualification, 12.3 GRMS	
Frequency (Hz)	Accel (G^2/Hz)
20	0.0212
150	0.16
600	0.16
2000	0.0144

Analysis of the Sample Problem

Again, the base input is the power spectral density shown in Figure 1. The board design parameters can be varied so that the natural frequency is greater than 50 Hz but less than 600 Hz.

The board is modeled as a single-degree-of-freedom system with an amplification factor of Q=10. The natural frequency is an independent variable.

The board's response is calculated via a vibration response spectrum, as derived in Reference 3. The vibration response spectrum is calculated using the single degree-of-freedom model shown in Figure 2.

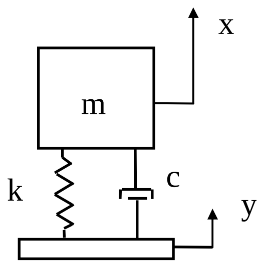

Figure 2.

where

m	is mass
c	is the viscous damping coefficient
k	is the stiffness
x	is the absolute displacement of the mass
y	is the base input displacement

The natural frequency is

$$fn = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad (1)$$

Again, further details of the vibration response equation are given in Reference 3.

The resulting vibration response spectra for the sample problem are shown in Figure 3, with key values summarized in Table 2. The relative displacement and absolute acceleration responses are represented by separate Y-axes in the plot. Furthermore, the respective Y-axis limits are chosen so the peak responses of each curve have nearly the same height.

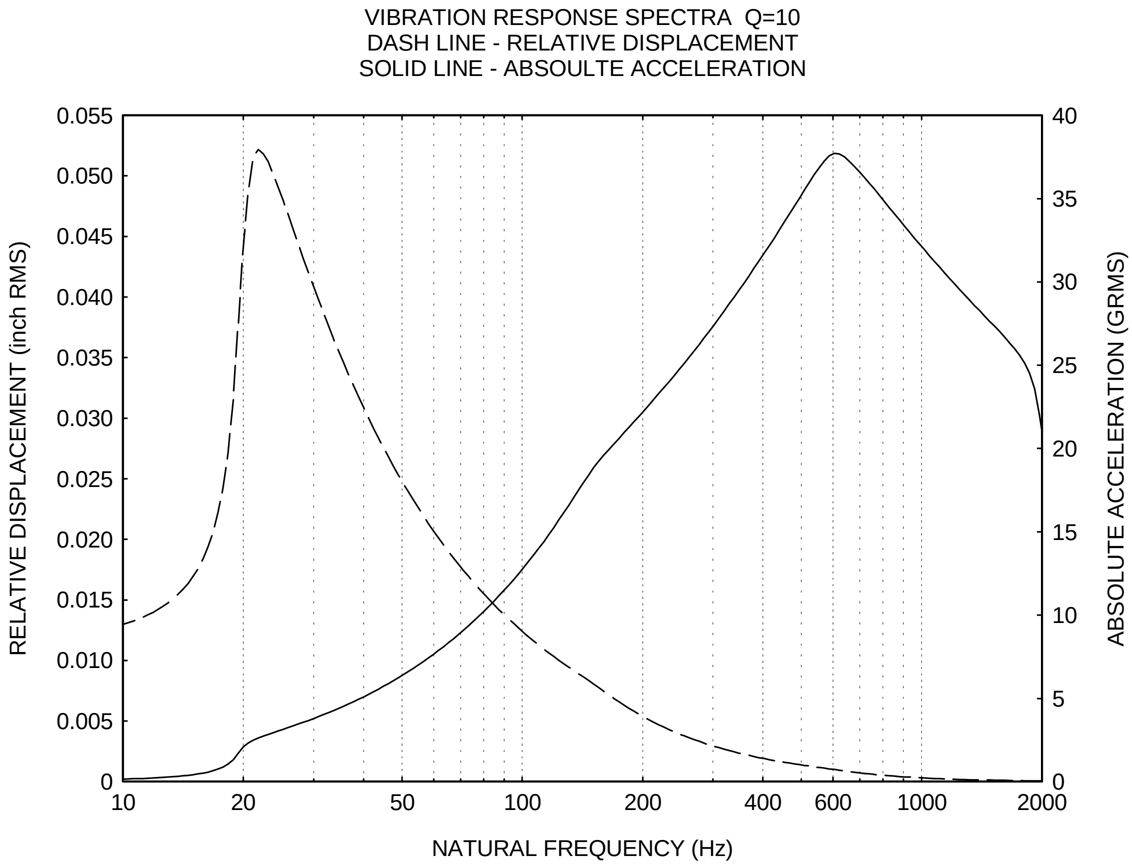

Figure 3.

Table 2. Vibration Response Spectrum Results, Q = 10		
Natural Frequency (Hz)	Relative Displacement (inch RMS)	Absolute Acceleration (GRMS)
50	0.025	6.4
85	0.015	10.9
100	0.012	12.8
200	0.005	22.2
300	0.003	27.3
400	0.002	31.6

Optimum Frequency for the Sample Problem

In some sense, the optimum natural frequency would be nearly zero. This is impractical for most design problems, however. Furthermore, an arbitrarily low natural frequency can lead to dynamic instability problems.

On the other hand, an arbitrarily high natural frequency may be desirable, at least in terms of minimizing relative displacement. Note that the response acceleration converges to the base input level as the frequency approaches higher values beyond those shown in Figure 3. Circuit boards cannot be designed as infinitely stiff, however.

Thus, the problem statement gives the rather realistic requirement that the circuit board natural frequency must be greater than 50 Hz but less than 600 Hz.

For the sample problem, the optimum natural frequency would be 85 Hz if relative displacement and absolute acceleration are of equal concern.

Another approach would be to apply a weighting factor to each parameter. Perhaps the relative displacement is twice as critical as the absolute acceleration. In this case, the optimum natural frequency would be 300 Hz.[1]

Postscript

An assumption was made that the circuit board is mounted in an enclosure where the enclosure is hardmounted to a structure, such as a vehicle.

A hardmounted enclosure is a realistic design requirement.

On the other hand, mounting the enclosure with external isolator bushings might be permissible. In this case, the optimum solution might be to choose compliant isolators and a stiff board design. The isolation frequency should be at least one octave less than the circuit board natural frequency to avoid dynamic coupling. Ideally, the isolators would render the enclosure as a single-degree-of-freedom system.

This design approach would minimize the circuit board's relative displacement as well as its absolute acceleration. The isolators might be required to undergo a high relative displacement, however. This approach is somewhat analogous to mounting a car body to its suspension system via shock absorbers.

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[1] Note that the calculation is made by first normalizing each parameter so that its peak value is one. The relative displacement is then multiplied by two. The sum of the absolute acceleration and weighted relative displacement is then taken in order to determine the natural frequency at which the minimum sum occurs. This is only one example of an optimization approach.

References

1. Dave Steinberg, Vibration Analysis for Electronic Equipment, Second Edition, Wiley, New York, 1988.
2. T. Irvine, Vibration Fatigue Criteria for Electrical Components, Vibrationdata Publications, 2002.
3. T. Irvine, An Introduction to the Vibration Response Spectrum, Vibrationdata Publications, 2000.