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1. Background

In 1998, Real Time Devices USA, Inc. introduced a novel packaging concept for embedded PC/104 modules to build Intelligent Data Acquisition Nodes. This system, called IDAN for short, has been very successful due to its rugged design that maintains PC/104's inherent modularity. The system is designed to withstand harsh environments, shock and vibration. To assure that the design standards were met, the RTD USA BME Laboratory was tasked with evaluating the vibration resistance of the shock mount isolation plate. Here are the results of the study.

2. Introduction

The IDAN shock and vibration isolation base plate is ideal for mounting IDAN systems in aircraft, shipboard or vehicular applications. The system can be installed in any attitude yielding superior high frequency vibration isolation along with low resonant amplification which increases equipment reliability and extends component life. The IDAN-Base-SM includes a flanged base plate for mounting, 4 shock mount isolators, and an IDAN bottom plate which can be assembled onto any standard IDAN system.

We measured the efficiency of the insulator vs. frequency and the mass of the IDAN and performed an extended vibration test using sweep sine wave and random noise excitation. The IDAN system was in continuous operation throughout the tests without failure.

3. The operation of shock and vibration isolation base plate

The simplified construction of a shock mounted IDAN is shown in Figure 1.

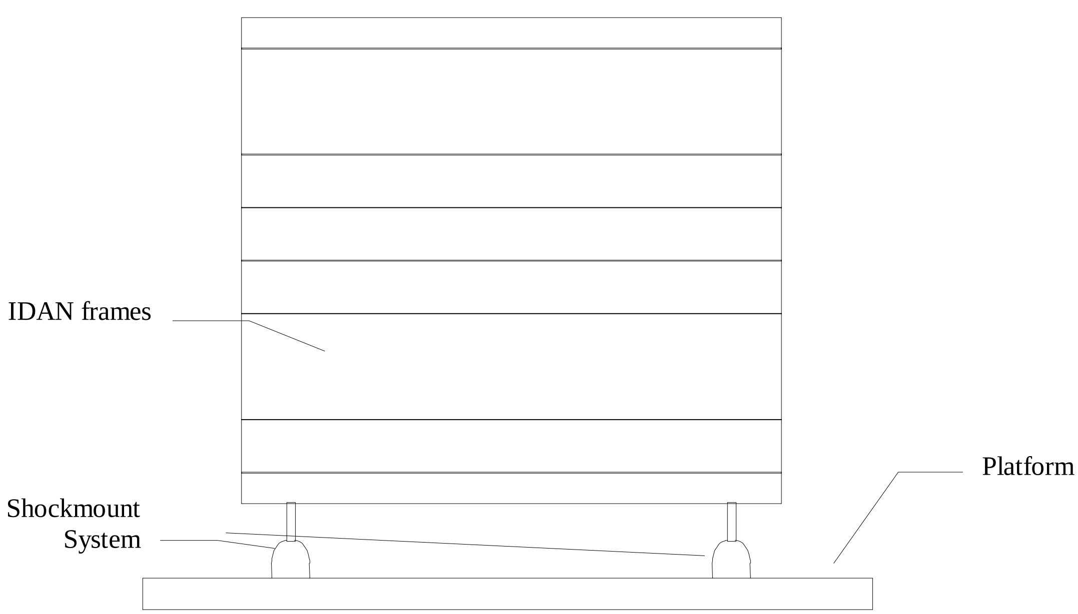

Figure 1. Simplified shock mounted IDAN

The shockmount system is actually a spring with loss. Therefore, the concentrated parameter mechanical model of the system is according to Figure 2.

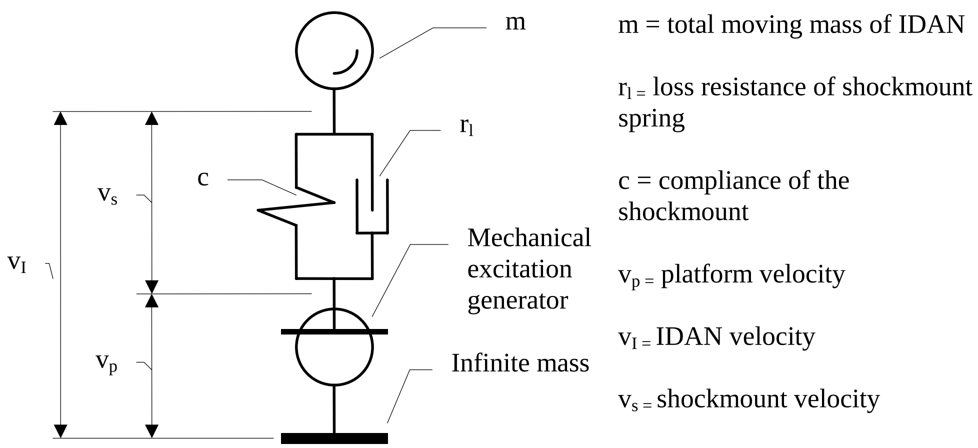

Figure 2. Concentrated parameter mechanical model of the system

The mechanical impedance is the force divided by velocity on a mechanical element. The following analogy between the mechanical and electronic systems can be used:

Mechanical parameter [unit]	Electrical Parameter
Force [N]	Voltage
Velocity [m/s]	Current
Mass [kg]	Inductance
Compliance [m/N]	Capacitance
Mechanical Resistance [Ns/m]	Resistance

Based on this, the electrical equivalent of the mechanical setup is:

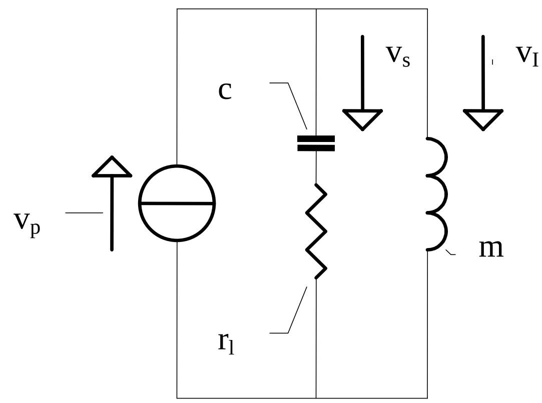

Figure 3. Electrical equivalent of the mechanical setup.

Therefore, we can write the velocity of the IDAN using the current dividing rule:

$$v_I = v_p \frac{\frac{1}{sc} + r_l}{\frac{1}{sc} + r_l + sm}$$

We can then define the transfer function between the IDAN velocity and the platform velocity:

$$F(\omega) = \frac{v_I}{v_p} = \frac{1 + \frac{s}{\omega_1}}{1 + D\frac{s}{\omega_0} + \frac{s^2}{\omega_0^2}}$$

where

$$\omega_1 = \frac{1}{r_l c}, \quad \omega_0 = \frac{1}{\sqrt{mc}}, \quad D = r_l\sqrt{\frac{c}{m}}$$

The absolute value of $F(\omega)$ can be seen in Figure 4.

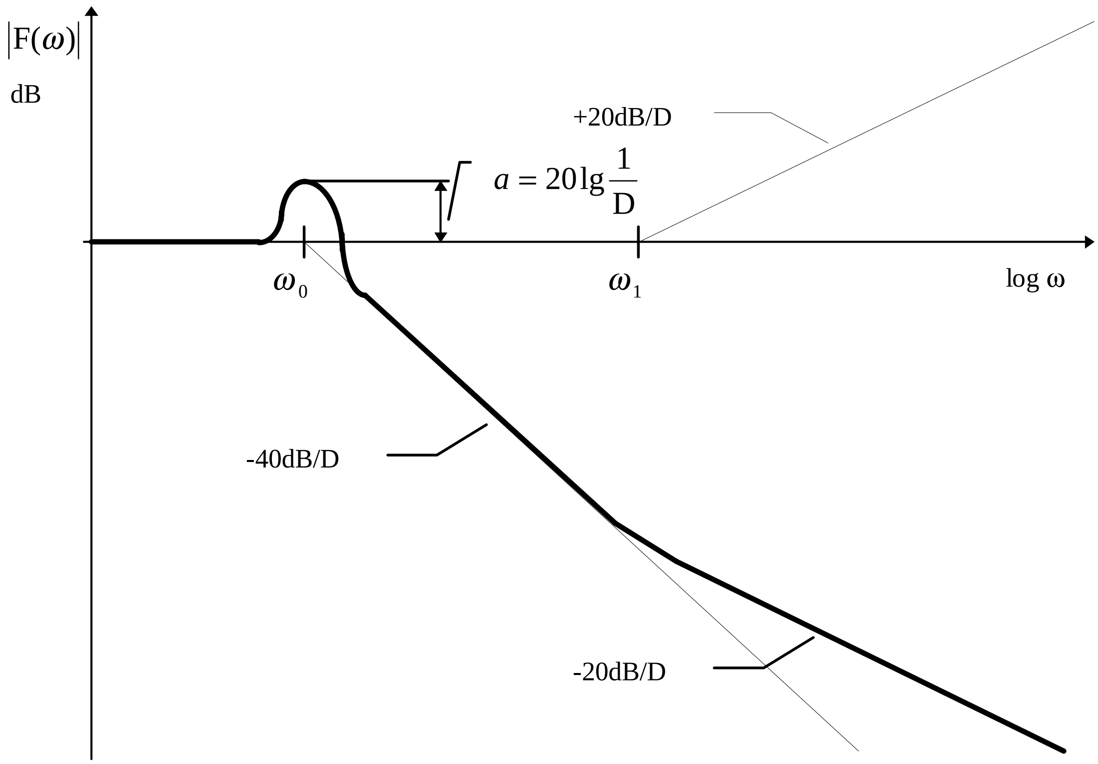

Figure 4. The absolute value of the transfer function $F(\omega)$.

The transfer function in Figure 4 corresponds to the measured transfer function.

4. Measuring the transfer function of the shock and vibration isolation base plate

Figure 5 shows the measurement setup of the isolation base plate transfer function.

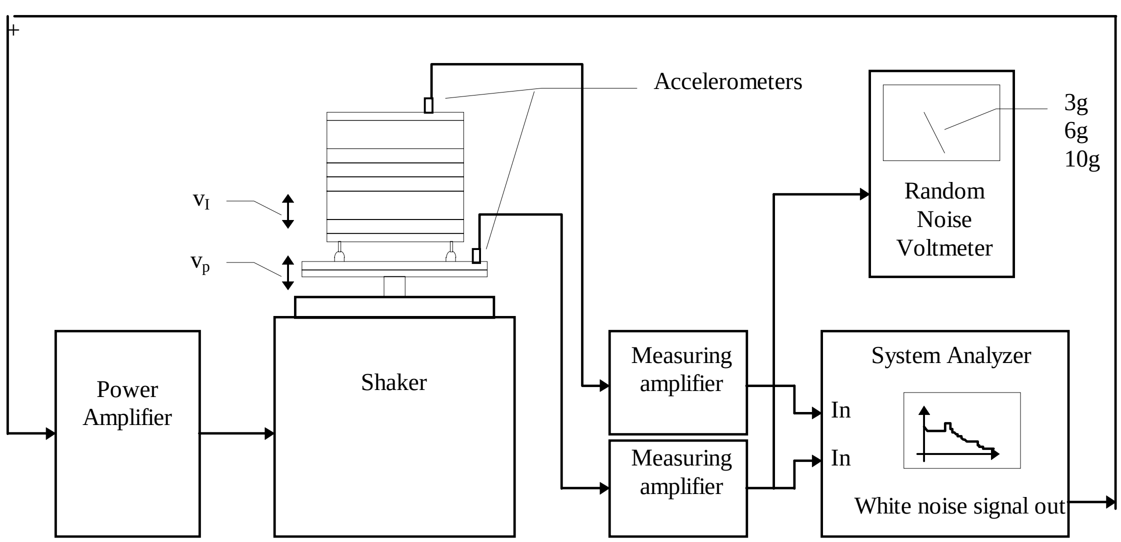

Figure 5. The measurement setup of the isolation base plate transfer function

We have measured the isolation transfer function in two IDANs. IDAN System 1 is a typical, relatively complex IDAN and IDAN System 2 is a minimum system.

IDAN System 1	**IDAN System 2**
CMM686GX233 cpuModule™	CMM686GX233 cpuModule™
CMT103 HDD utilityModule™ (with Sandisk drive)	EPWR104 Power Supply utilityModule™
DM6420 Data Acquisition dataModule®	
ECAN527 CAN bus utilityModule™	
CM202 Ethernet utilityModule™	
EPWR104 Power Supply utilityModule™	

As discussed previously, the transfer function is:

$$F(\omega) = \frac{v_I}{v_p}$$

The transfer function expresses the ratio between IDAN and the platform velocity. We can measure the acceleration:

$$F^{'}(\omega) = \frac{a_I}{a_p}$$

and since

$$a(t) = \frac{d\mathrm{v}(t)}{dt}$$

and

$$a(\omega) = v(\omega) * s$$

where *s* is the complex frequency, so

$$F(\omega) = \frac{v_I * s}{v_p * s} = \frac{a_I}{a_p} = F^{'}(\omega)$$

We used Maximum Length Sequences (MLS) sequences to excite the system. The MLS series are pseudo random periodic series with periodic dirac autocorrelation function. Because of this feature, MLS series generate uniform distribution random numbers approximating white noise. It can be shown that the impulse response of a system is the cross-correlation function of the system response and the excitation MLS sequence. We used this method to measure the transfer functions. The bandwidth of excitation was approximately 2 kHz. The excitation voltage of the shaker in this bandwidth was white. This means that the excitation was a constant voltage excitation vs. frequency. The shaker excited the system in constant velocity mode, because of the constant voltage excitation, up to 50 Hz and in constant acceleration mode from 50 Hz up to 2 kHz (see Figure 9). We measured the transfer function at 3 g, 6 g, and 10 g platform RMS accelerations. There were no significant differences between the measured transfer functions at various excitation levels.

Figures 6 and 7 show the measured transfer function of the isolation base plate of IDAN System 1 and IDAN System 2 respectively.

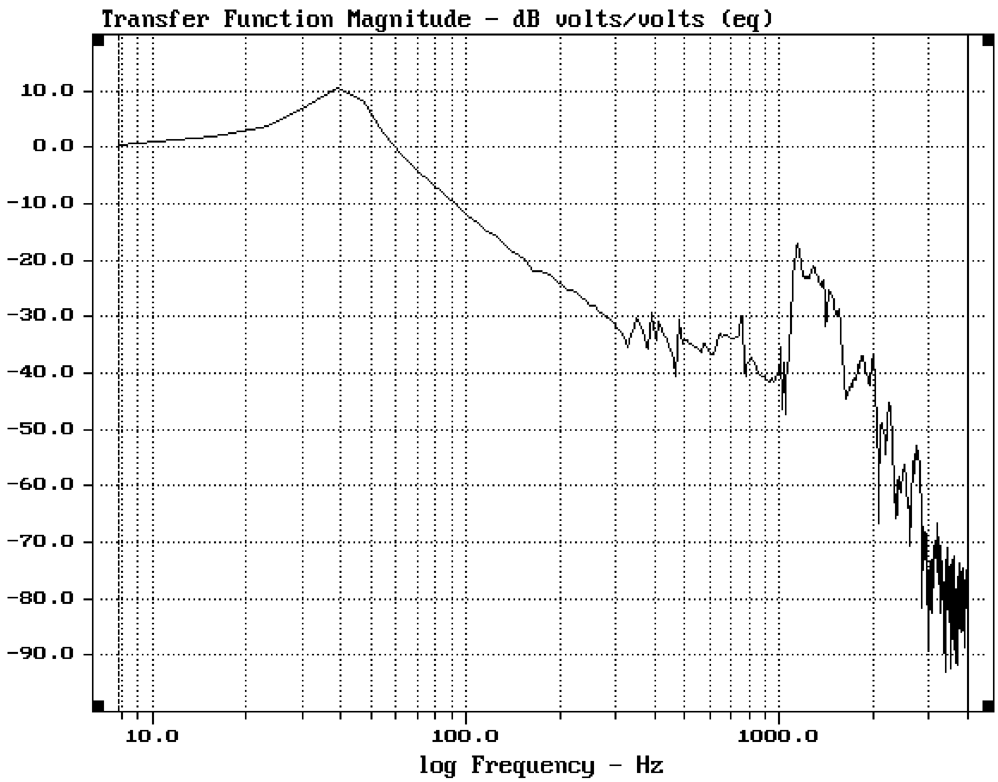

Figure 6. Measured transfer function of the isolation base plate with IDAN System 1

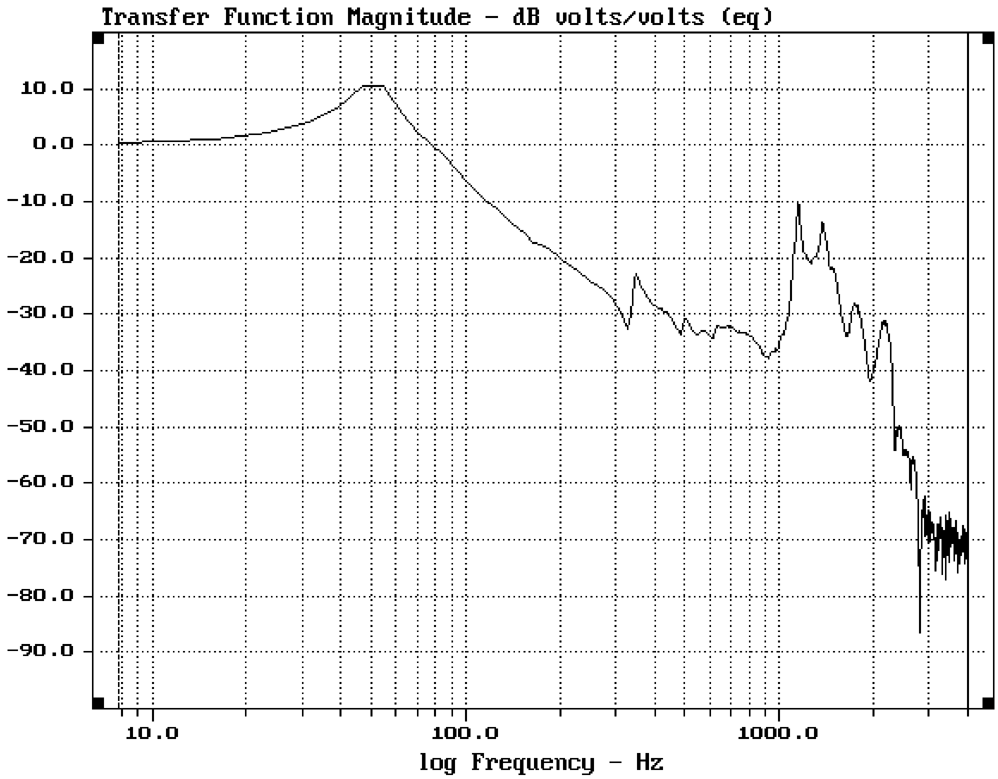

Figure 7. Measured transfer function of the isolation base plate with IDAN System 2

The figures show that above the resonance frequency the isolation suppresses vibration efficiently. The resonance frequency depends on the mass of IDAN, which can be seen comparing the higher mass IDAN in Figure 6 with the lower mass IDAN in Figure 7.

The transfer function was measured several times before and after the large amplitude, extended time vibration test. There were no significant changes in the transfer function.

Using these diagrams, we can calculate the parameters of the concentrated mechanical equivalent network of the isolation. First let's see consider IDAN System 1.

The mass of the moving part is:

$$m = 2.66 \text{ kg}$$

because

$$\omega_0 = \frac{1}{\sqrt{\text{mc}}}$$

The resonant frequency from the transfer function is:

$$\omega_0 \approx 40Hz$$

Therefore, the compliance of the shock mount is:

$$c = \frac{1}{m\omega_0^2} = \frac{1}{2.66\text{kg}\left(40\frac{1}{s}2\pi\right)^2} = 5.96*10^{-6}\frac{s^2}{kg} = 5.9\frac{\mu m}{N}$$

Because the attenuation at the resonance frequency is:

$$a = 20\lg\frac{1}{D}$$

and from Figure 6:

$$a = 10\text{dB}$$

The loss factor (D) can be derived from the attenuation at resonance frequency:

$$D = 10^{-\frac{a}{20}} = 10^{-\frac{10}{20}} = 0.3$$

Because the loss factor:

$$D = r_l\sqrt{\frac{c}{m}}$$

The mechanical resistance of the insulator:

$$r_l = D\sqrt{\frac{m}{c}} = 0.3\sqrt{\frac{2.66kg}{5.9*10^{-6}\ \frac{m}{N}}} = 201.4\frac{Ns}{m}$$

The second cutoff frequency:

$$\omega_1 = \frac{1}{r_l c} = \frac{1}{201.4\frac{Ns}{m}5.9*10^{-6}\ \frac{m}{N}} = 134Hz$$

This fits the transfer function in Figure 6.

In the same manner, we can calculate these equations in the case of minimal IDAN System 2.

The mass of IDAN System 2 is:

$$m = 1.65\text{ kg}$$

The resonant frequency from the transfer function is:

$$\omega_0 = 51Hz$$

Therefore, the compliance of the shock mount is:

$$c = \frac{1}{m\omega_0^2} = \frac{1}{1.65\text{kg}\ \left(51\frac{1}{s}2\pi\right)^2} = 5.9*10^{-6}\frac{s^2}{kg} = 5.9\frac{\mu m}{N}$$

Because the attenuation at the resonance frequency is:

$$a = 20\lg\frac{1}{D}$$

and from Figure 7:

$$a = 10dB$$

The loss factor (D) can be derived from the attenuation at resonance frequency:

$$D = 10^{-\frac{a}{20}} = 10^{-\frac{10}{20}} = 03$$

Because the loss factor is:

$$D = r_l\sqrt{\frac{c}{m}}$$

The mechanical resistance of the insulator is:

$$r_l = D\sqrt{\frac{m}{c}} = 0.3\sqrt{\frac{1.65kg}{5.9*10^{-6}\ \frac{m}{N}}} = 132.2\frac{Ns}{m}$$

The second cutoff frequency is:

$$\omega_1 = \frac{1}{r_l c} = \frac{1}{132.2\frac{Ns}{m}5.9*10^{-6}\frac{m}{N}} = 204Hz$$

This fits the transfer function in Figure 7.

Based on the simple model in Figure 2 we were able to explain the measured transfer function.

5. The vibration test of IDAN with shock and vibration isolation base plate

The measurement setup can be seen in Figure 8.

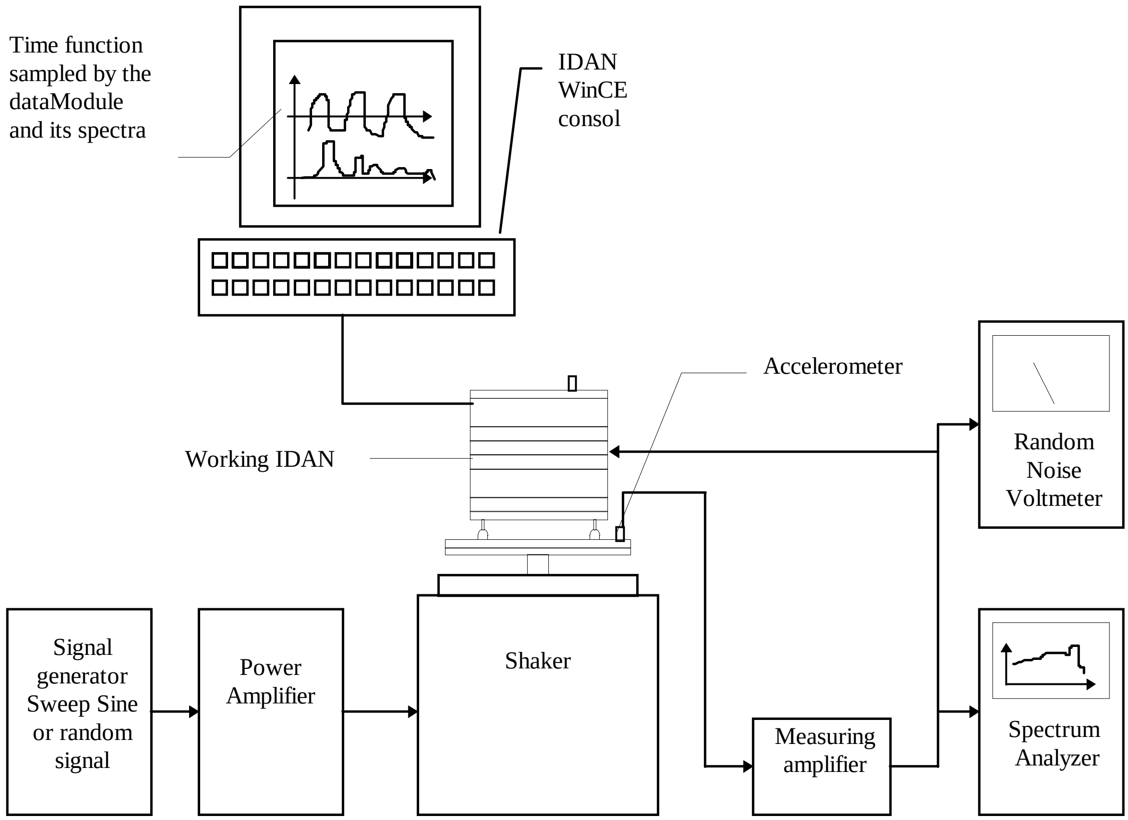

Figure 8. IDAN vibration test setup

The acceleration of the IDAN platform in the case of constant voltage excitation vs. frequency can be seen in Figure 9. We can divide the function into two parts. One part is the constant velocity and the second one is the constant acceleration.

The constant velocity part can be characterized by a +20 dB/D line because:

$$a(\omega) = v(\omega) * s$$

The constant acceleration part ends at 2kHz, which was assured by a low-pass filter in series with the random noise generator.

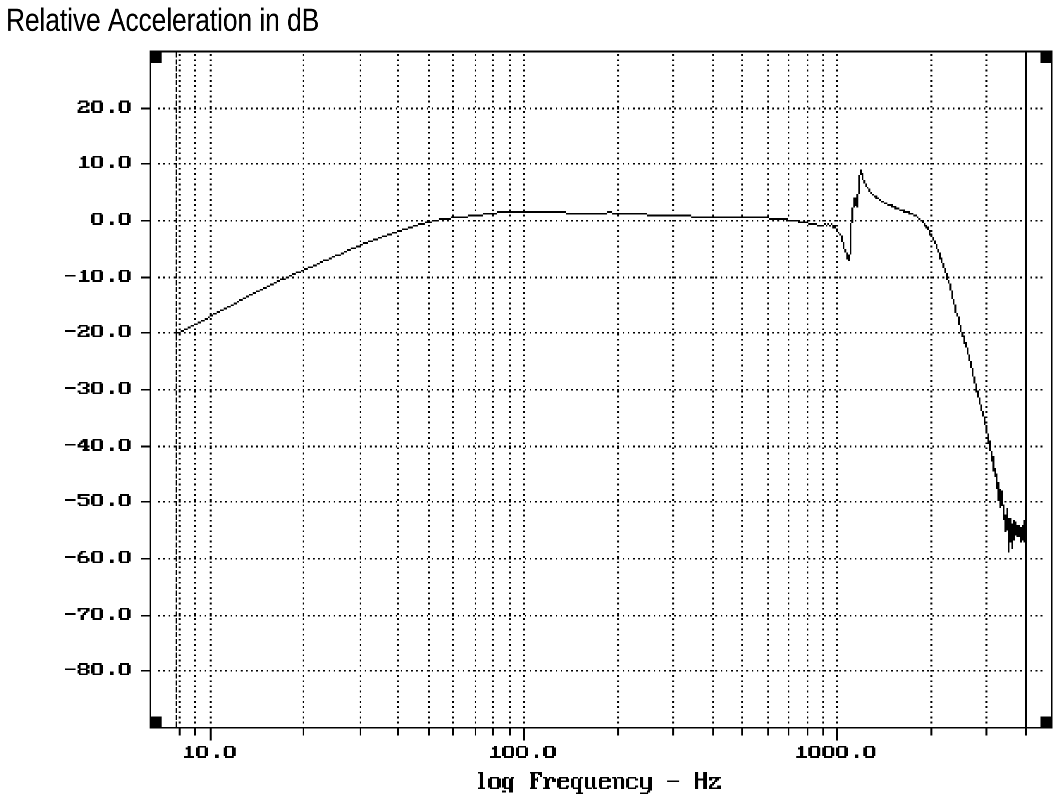

Figure 9. The IDAN platform acceleration with constant voltage excitation vs. frequency

5.1. The vibration test of IDAN with random noise

We used MLS sequences to excite the system which means, that the platform acceleration spectra is according to Figure 9 because the MLS voltage spectra is constant vs. frequency. The RMS value of the platform acceleration was increased in three test cycles from 3 g to 6 g and finally to 10 g. All tests lasted one half an hour. During random excitation, the IDAN systems were continuously operating without failure.

5.2. The vibration test of IDAN with sweep sine

This test cycle used a constant amplitude sweep sine wave to excite the system which means, that the platform acceleration amplitude was according to Figure 9. The constant amplitude acceleration part was 6 g. The constant velocity part was 0.2 m/s. Figure 10 shows the acceleration, velocity and amplitude of the IDAN platform. The sweep start frequency was 5 Hz and the stop frequencies were 200 Hz and 2 kHz in two test cycles. The sweep speed was 30 seconds in both cases. After a sweep cycle, the next cycle started automatically. The total test time was 30 minutes. During the test, the IDAN systems were continuously operating without failure.

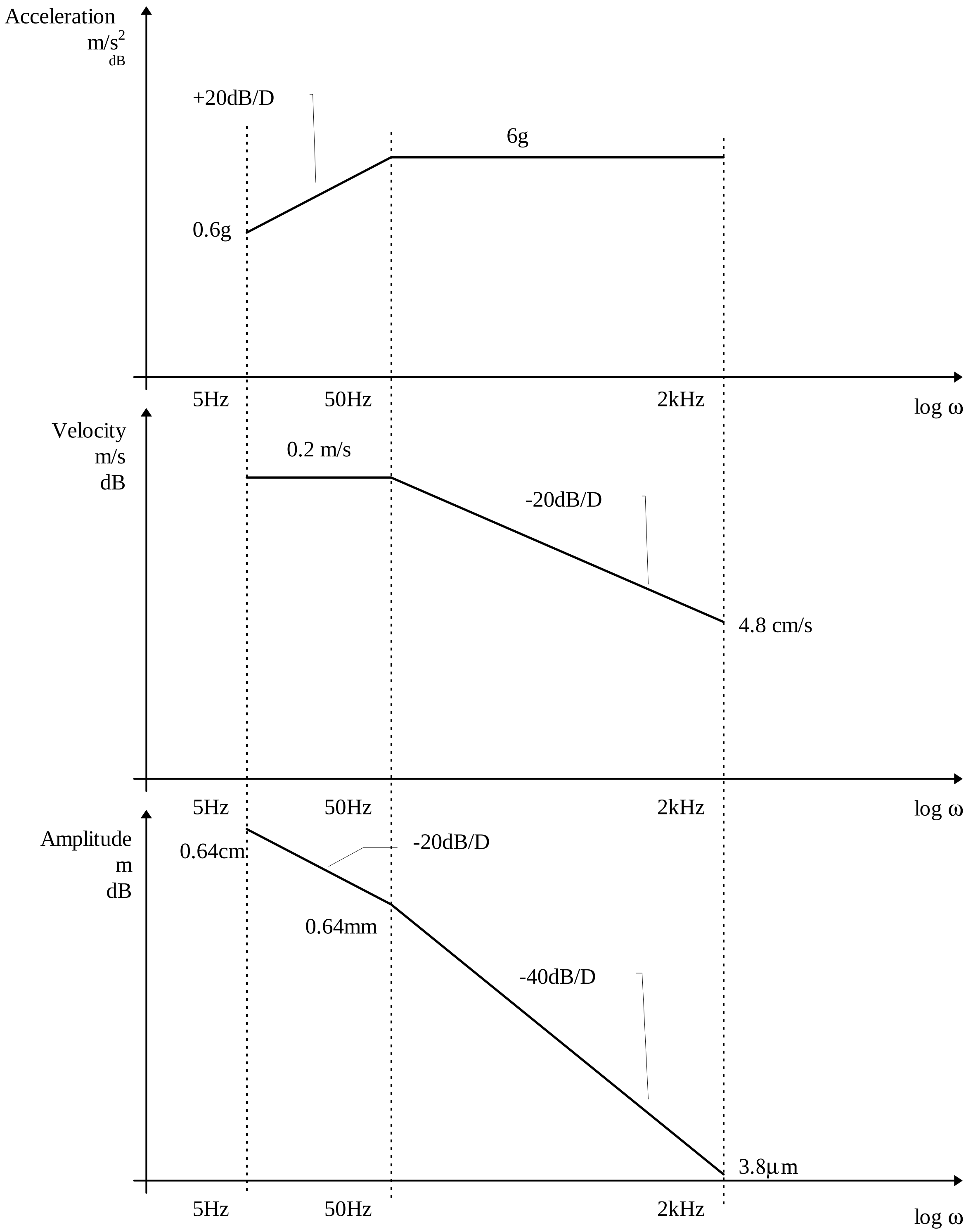

Figure 10. Acceleration, velocity and amplitude of the IDAN platform under test.

6. Summarization of the IDAN vibration test results

6.1. The shock mount

- Resonance frequency: *40 - 50 Hz depending on the number of IDAN frames*
- Amplifying at resonance frequency: *less than 10 dB*
- Vibration suppression above resonance frequency: *-40 dB/D up to 200 Hz and -20 dB/D above 200 Hz*

6.2. Sweep sine vibration test

The IDANs under test were continuously operating without failure before, during and after the test.

- Frequency range: *5 Hz - 2000 Hz*
- Constant platform velocity excitation frequency range: *5 Hz - 50 Hz*
- Constant velocity value: 0.2 m/s
- Constant platform acceleration excitation frequency range: *50 Hz - 2 kHz*
- Constant acceleration RMS value: *6 g*
- Sweep time: *30 seconds*
- Total sweep cycles: *60*
- Total measurement time: *30 minutes*

6.3.Random noise vibration test

The IDANs under test were continuously operating without failure before, during and after the test.

- Frequency range: *5 Hz - 2000 Hz*
- Spectra of platform acceleration: *+20 dB/D up to 50Hz, constant from 50 Hz to 2 kHz*
- RMS vale of platform acceleration: *10 g*
- Time of test: *30 minutes*