IEC TR 62343-6-5

Edition 2.0 2014-06

TECHNICAL REPORT

colour inside

Dynamic modules –
Part 6-5: Design guide – Investigation of operating mechanical shock and vibration tests for dynamic modules

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FOREWORD

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IEC 62343-6-5, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2011. It constitutes technical revision.

The main change with respect to the previous edition is the addition of "Results of a questionnaire on dynamic module operating shock and vibration test conditions" in Annex A.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86C/1206/DTR	86C/1246/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of IEC 62343 series, published under the general title *Dynamic modules,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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DYNAMIC MODULES –

Part 6-5: Design guide – Investigation of operating mechanical shock and vibration tests for dynamic modules

1 Scope

This part of IEC 62343, which is a technical report, describes an investigation into operating mechanical shock and vibration for dynamic modules. It also presents the results of a survey on the evaluation and mechanical simulation of mechanical shock and vibration testing. Also included is a study of standardization for operating mechanical shock and vibration test methods.

2 Background

The recent deployment of advanced, highly flexible optical communication networks using ROADM (*reconfigurable optical add drop multiplexing*) systems has been accompanied by the practical utilization of dynamic wavelength dispersion compensators, wavelength blockers and wavelength selective switches as “dynamic modules.” Since these dynamic modules incorporate such new technology as MEMS (*micro electromechanical systems*), there are concerns about the vulnerability to operating shock and vibration conditions, which urgently require establishing evaluation methods and conditions. Standards for shock and vibration test conditions pertaining to storage and transport are already established, but methods and conditions for evaluating operating shock and vibration are not yet established.

The JIS (*Japanese Industrial Standards*) committee consequently conducted a questionnaire survey on the shock and vibration testing of passive optical components and dynamic modules in commercial use. The survey revealed that many respondents confirmed a need to standardize evaluation conditions for operating shock and vibration; some suggested earthquake, hammer impact testing and inserting an adjacent board as cases of shock and vibration during dynamic module operation. Based on the survey results, the JIS committee evaluated operating shock and vibration by conducting hammer impact tests using several dynamic modules, compared the results through simulation, and then recommended specific evaluation conditions.

This technical report is based on OITDA (Optoelectronic Industry and Technology Development Association) – TP (Technical Paper), TP05/SP_DM-2008, "Investigation on operating vibration and mechanical impact test conditions for optical modules for telecom use."

3 Questionnaire results in Japan

The JIS committee conducted a questionnaire on operating shock and vibration testing. The questionnaire allowed the respondents to specify the optical components to be tested. This questionnaire included optical switches, VOAs (*variable optical attenuators*) and tuneable filters among the mechanical components used in all possible situations. The survey covered 18 organizations: eight Japanese manufacturers of mechanical optical components, eight device makers as users of such components, and two research institutes. Reponses were received from 14 of these organizations for a response rate of 78 %, among which 12 respondents specified optical switches, seven specified VOAs and three chose tuneable filters. In tabulating the data, the survey asked questions regarding these three types of components and described occurrences not dependent on the type of component, the manufacturer and the user, and evaluation conditions.

The results revealed a strong need for the standardization of operating shock and vibration evaluation methods and conditions for such dynamic modules as optical switches and VOAs. A majority of respondents also requested that the hammer impact testing and the insertion of an adjacent PC board be included as cases of operating shock and vibration.

4 Evaluation plan

Based on the survey results described in Clause 3, the appropriate conditions for shock and vibration testing were determined based on an evaluation. The evaluation method consisted of the following three steps:

Step 1: Measure the shock and vibration characteristics of a board with a shock sensor inserted into a standard rack by striking the front face of the board with a hammer or by inserting an adjacent PC board.

Step 2: Test an optical module installed in a standard rack by repeating the procedure in Step 1. Measure any changes in the optical characteristics of the optical module.

Step 3: Use standard shock and vibration test equipment to reproduce the shock and vibration characteristics obtained in Step 1 and the optical characteristics of the optical module obtained in Step 2.

5 Evaluation results

5.1 Step 1

5.1.1 Evaluation of hammer impact

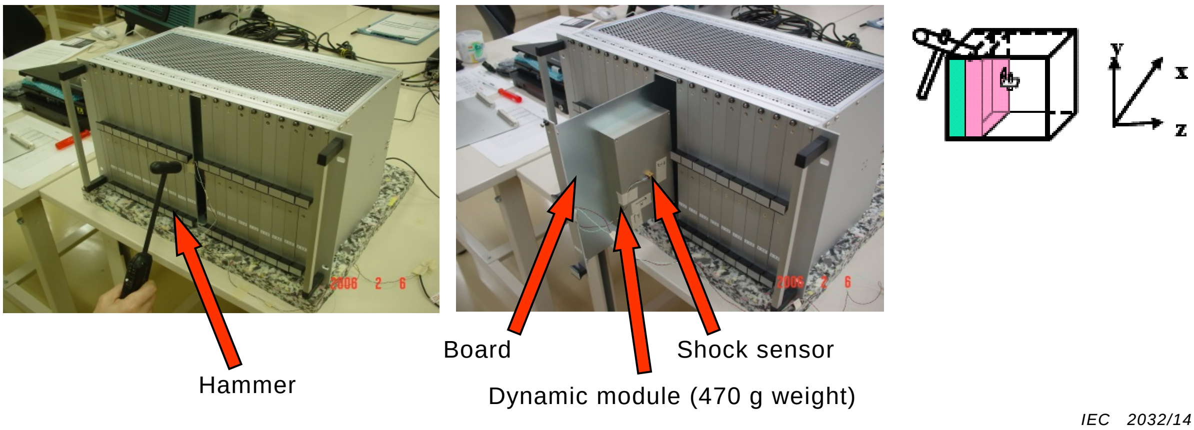

Figure 1 – Photos of evaluating hammer impact, rack and boards

A PC board with a shock sensor attached is inserted into the rack. The front of the board is then struck repeatedly by a hammer, along with an adjacent board being forcibly inserted in order to measure the impact and frequency detected by the shock sensor. The handles attached to the front edge of the rack are also forcibly struck by hand, with the impact being measured as well. Figure 1 shows photos of the hammer impact as well as the rack and PC boards. Table 1 below summarizes the specifications of the rack and PC boards, and the conditions of evaluating hammer impact and the acquisition of data.

Table 1 – Rack and board specifications, conditions of evaluating hammer impact and acquiring data

Item	Specification/Conditions
Rack size	432 mm (W) × 240 mm (D) × 262 mm (H)
Back connectors	2 pins – 96 pins
Number of PC boards	20
Striking force (acceleration intensity)	H (1 800 m/s^2 – 2 400 m/s^2) ~ 210 G M (1 200 m/s^2 – 1 600 m/s^2) ~ 140 G L (300 m/s^2 – 400 m/s^2) ~ 35 G
Places to strike	Top, middle of front panel of board
Board thickness	1,6 mm, 1,5 mm, 1,2 mm
Location of board	Centre, side
Number of boards	One, full size
Directions	x, y, z
Data acquisition	40 µs × 5 000 points (200 ms)
Sensing frequency band	10 Hz – 10 kHz

Figure 2a shows the measurement results. Here, H denotes a high level of hammer impact (at 210 G). The location of impact is at the centre of the front face of a PC board 1,6 mm thick, located at the centre of the 20 installed PC boards, with data being acquired on tests repeated 11 times. Figure 2b shows the Fourier transform results of data based on the frequency component.

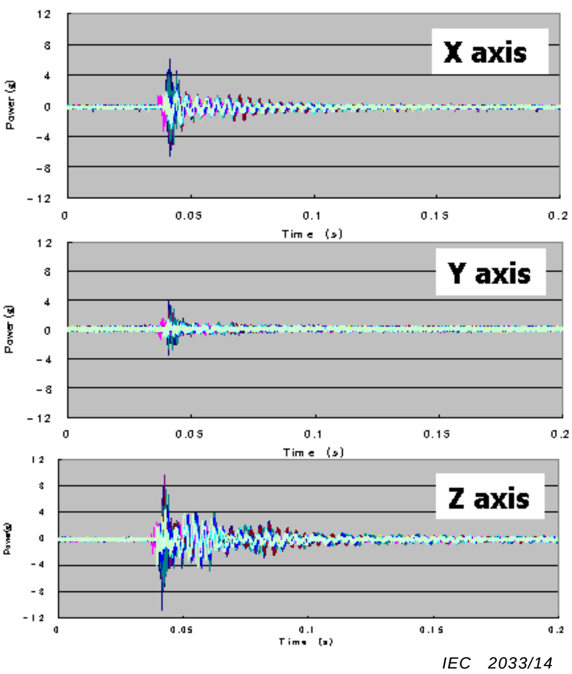

Figure 2a – Measurement results

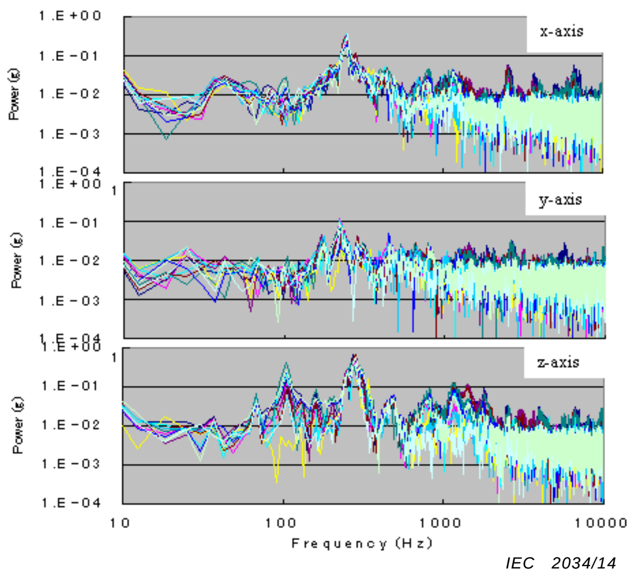

Figure 2b – Fourier transformation data

Figure 2 – Evaluation results of hammer impact H

The results show vibration time in the range of 100 ms to 200 ms, with vibration amplitude descending in order of z-axis > x-axis > y-axis. The peak shock (initial pulse) was 5 G to 10 G (in 2 ms to 5 ms). In contrast, Fourier transform results show a number of vibration peaks (at 100 Hz, 250 Hz and more than 1 kHz). The largest peak was at 220 Hz to 280 Hz. For the z-axis, the peak pulse intensity was roughly 0,5 G. Here, the strongest impact was in the z-axis, despite the fact that shock had been applied to the x-axis. This is believed to be the result of drum vibrations on the PC board. The results of hammer impacts M and L (at 2,6 G to 4 G and 0,9 G to 1,5 G, respectively) show the almost same frequency spectra and peak amplitude for the z-axis.

Next, the dependence on each evaluation condition (e.g., board thickness, board installation location, number of boards installed) was examined. The evaluation showed no significant difference in any of the evaluation conditions. Regarding the dependence on hammer impact strength, the peak shock roughly correlated to impact strength. A small peak of 70 Hz was seen in the y-axis for hammer impact L. For the dependence on board thickness, there were two peaks in the x-axis at thickness of 1,2 mm. The peak also moved slightly to the lower frequency in the z-axis. No difference could be detected in terms of location of PC board installation and board impact.

5.1.2 Evaluation of adjacent board insertion and rack handle impact

In addition to evaluating hammer impact, tests were also conducted to evaluate the insertion of an adjacent PC board and impact on the handle on the front side of the rack. Figure 3 shows photos of the evaluation tests.

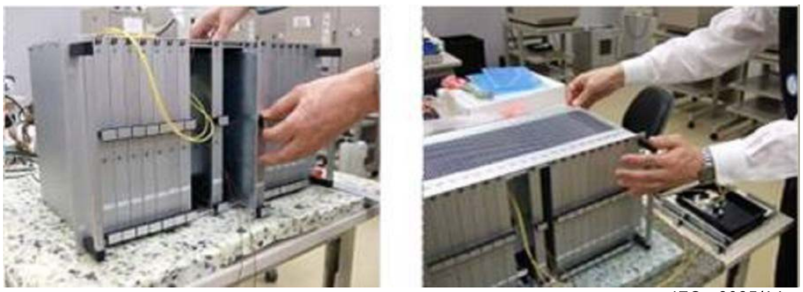

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Figure 3 – Photos of evaluating adjacent board insertion and rack handle impact

An analysis of data compared the peak amplitudes in the z-axis on the graph showing vibration attenuation before Fourier transformation. This analysis revealed that peak shock for the z-axis was 5,2 G to 6 G for the adjacent board insertion test (similar to the result for hammer impact H) and 1 G to 1,4 G for the rack handle impact test (similar to the result for hammer impact L).

An examination of data on the frequency characteristics after Fourier transformation did not reveal significant differences from the evaluation of hammer impact.

5.2 Step 2

In Step 2, a dynamic module is attached to a PC board for which the shock sensor monitors shock and vibration, identical to the approach in Step 1. At the same time, any changes in optical characteristics (loss) were monitored. Figure 4 shows photos of the PC board with the VOA and the rack with WSS (wavelength-selective switch) attached on the PC boards.

IEC 2036/14

Figure 4a – PC board with VOA

IEC 2037/14

Figure 4b – Rack with WSS attached to PC boards

Figure 4 – DUT (VOA and WSS) installed on PC boards and rack for second step of the evaluation

In addition to VOA and WSS, the dynamic modules listed in Table 2 were used as DUT.

Table 2 – Dynamic modules used in evaluation and evaluation conditions

DUT	Mechanism	Evaluation conditions
VOA-1	MEMS	Monitoring: changes in attenuation Attenuation: 20 dB
VOA-2	MEMS	
WSS	MEMS	
Switch-1	Mechanical (with movable mirror)	Monitoring: changes in insertion loss
Switch-2	Mechanical (with movable fibre)	
TODC	Stepping motor	Monitoring: changes in insertion loss Dispersion: +1 800 ps/nm

Figure 5 shows an example of observation results (on the oscilloscope screen).

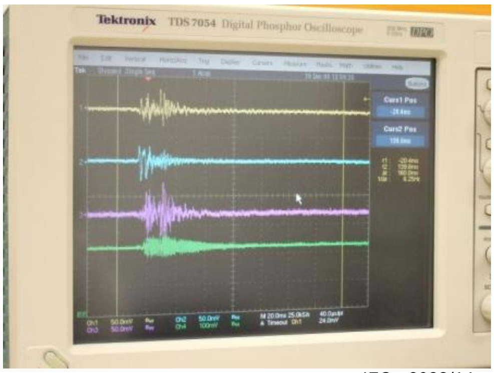

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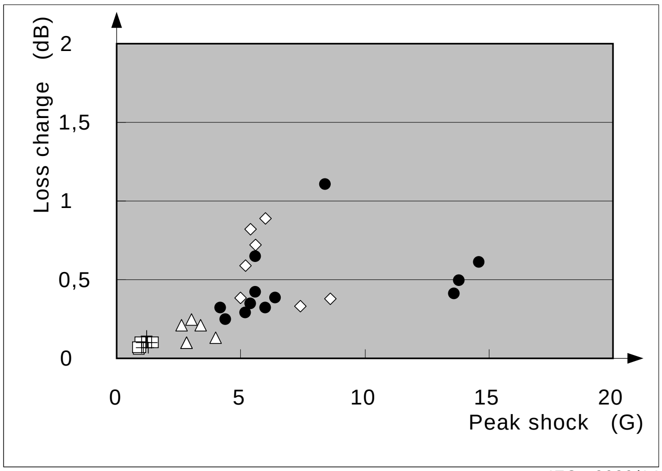
Figure 5 – Oscilloscope display of waveform changes in vibration and optical output

The four lines in Figure 5 appear to be vibration waveforms but actually show (from the top down) the x-, y- and z-axes, and the optical waveform. The optical waveform (loss change) shows rapid vibration identical to that shown in the shock waveforms.

The evaluation results did not show changes in optical loss characteristics for the optical switch and dynamic dispersion compensator, even under hammer impact H.

Each evaluation condition – shock, vibration peak and optical loss change – have been organized as described below, with VOA-1 employed as a reference. The VOA was set to an attenuation of 20 dB. Figure 6 shows the results for the z-axis.

The graph in Figure 6 shows the shock peaks on the horizontal axis (readings from the graph on time versus shock (data similar to the oscilloscope waveforms)), and changes in VOA attenuation on the vertical axis. A positive correlation was seen between shock and changes in attenuation (optical power) for the x-, y- and z-axes, despite significant variations in data. The degree of variation ranged from 50 % to 200 %. This variation was considered dependent on the state of board insertion (such as electrical connector connections on the back), dispersion of hammer impact level, location of impact, method of VOA installation, and other factors.



Key

●	hammer impact H	◇	adjacent board insertion
△	hammer impact M	+	rack handle impact
□	hammer impact L		

Figure 6 – Evaluation results when employing MEMS-VOA for Z-axis

5.3 Step 3

5.3.1 MEMS-VOA

The principal object of the third step is to apply the shock and vibration conditions to an optical module determined in the first and second steps of the evaluation by using standard shock and vibration test equipment, and then reproduce the shock and vibration characteristics.

Figure 7 shows the MEMS-VOA shock and vibration test equipment; Table 3 lists the evaluation conditions.

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Figure 7a – Shock/vibration equipment

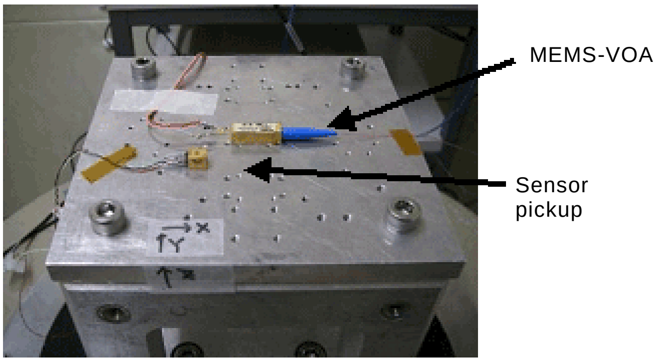

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Figure 7b – MEMS-VOA on the shock/vibration test equipment

Figure 7 – Photos of the MEMS-VOA shock/vibration test equipment

Table 3 – Conditions for MEMS-VOA vibration/shock evaluation

Test item	Test conditions	Remarks
Shock	Pulse width: 2 ms (half sine) Intensity: 10 G, 20 G, 40 G Direction: ±(x), ±(y), ±(z)	Dependent on intensity
	Intensity: 10 G Pulse width: 1 ms, 2 ms, 5 ms (half sine) Direction: ±(x), ±(y), ±(z)	Dependent on pulse width
Vibration	Frequency: 50 Hz – 500 Hz, 1 oct/min Intensity: 1 G, 2 G, 5 G Direction: x, y, z Data acquisition: 50 Hz, 100 Hz, 200 Hz, 400 Hz, 500 Hz	

The shock evaluation results showed a directional dependence on the operating shock characteristics of MEMS-VOA. Figure 8a shows the shock characteristics for the z-axis at 10 G and 2 ms (with the horizontal axis showing time, and vertical axis showing optical output level) that accompany the change in optical output shown above and the shock pulse below. There was a 0,38 dB change found in optical loss.

Figure 8b shows the dependence on shock intensity as pertaining to a change in optical loss. There are increased variations in attenuation in line with increased shock intensity.

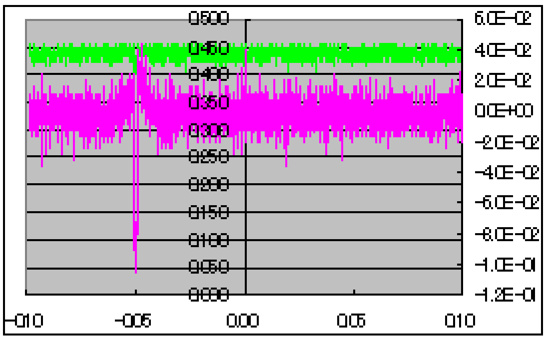

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Figure 8a – Z axis, 10 G and 2 ms

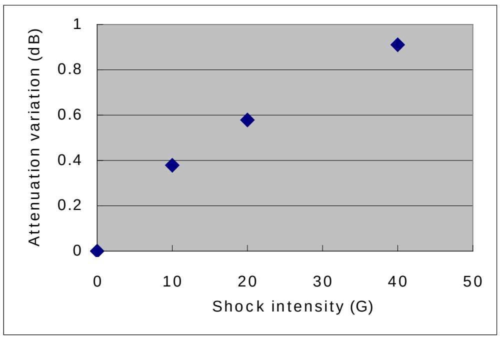

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Figure 8b – Dependence on shock intensity value dependence in z axis, 2 ms

Figure 8 – Operating shock characteristics of MEMS-VOA

With regard to the dependence on shock pulse duration, however, the changes in optical loss had been 0,34 dB, 0,38 dB and 0,38 dB for pulse widths of 1 ms, 2 ms and 5 ms, respectively, thereby showing roughly identical values (in the z-axis and at 10 G).

Figure 9 shows an example of the vibration evaluation results. A relatively large variation in loss is observed at around 470 Hz.

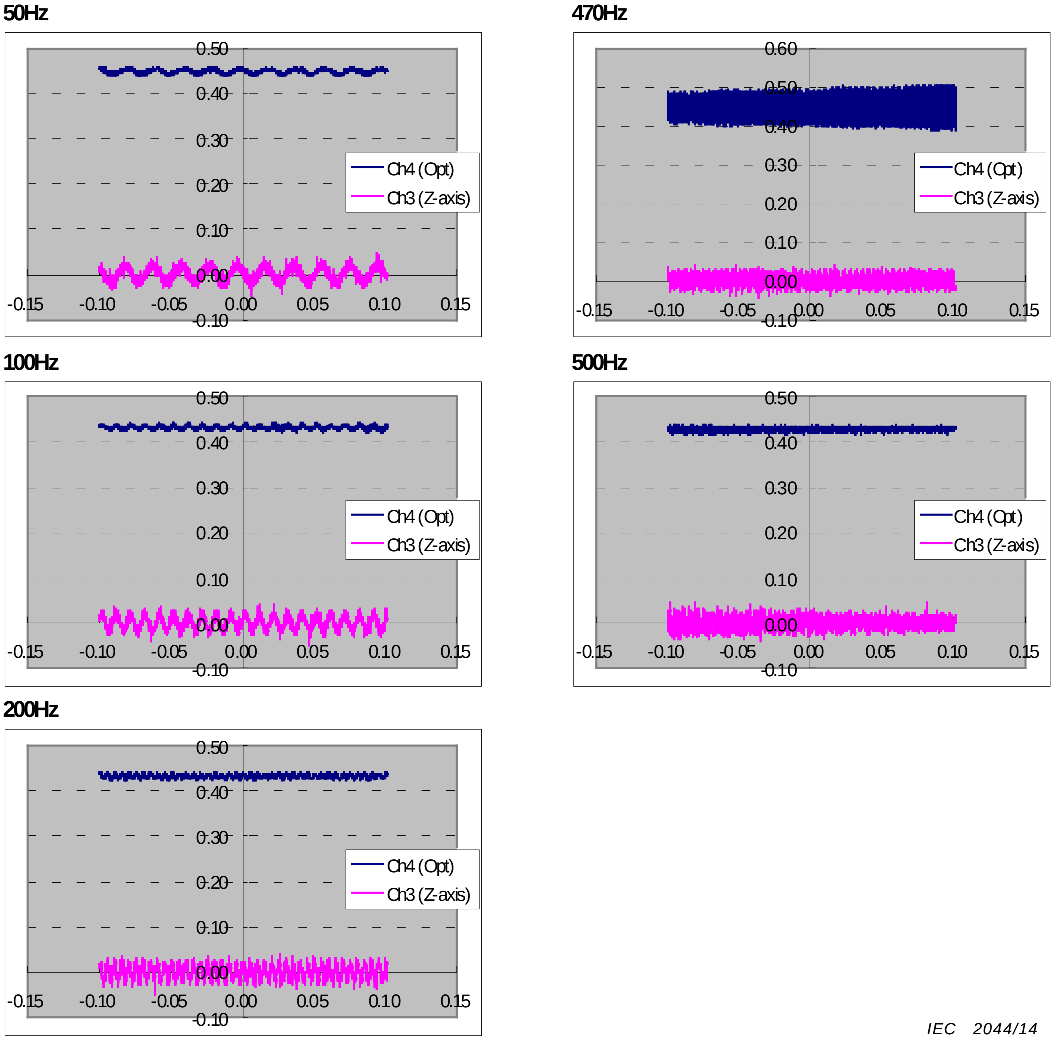

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Figure 9 – Vibration evaluation results for MEMS-VOA (Z-axis; 2 G)

In the evaluation, changes were made to acceleration in addition to frequency. Table 4 lists the test results. In the test, the change in optical loss rose significantly at 410 Hz to 470 Hz, independently of acceleration level. This is believed due to the resonance occurring in MEMS inside the optical module at a certain frequency, resulting in a drastic rise in loss change.

Table 4 – Results of MEMS-VOA vibration evaluation

Intensity	**Frequency**	
	50, 100, 200, 500 Hz	**400-470** Hz
1 G	0,1 dB	0,7 dB (465 Hz)
2 G	0,2 dB	1,1 dB (470 Hz)
5 G	0,38 dB	2,7 dB (410 Hz)

5.3.2 WSS and tuneable laser

A wavelength selective switch (WSS) and a tuneable LD were also evaluated in the same manner as was MEMS-VOA. Figure 10 shows photos of the system.

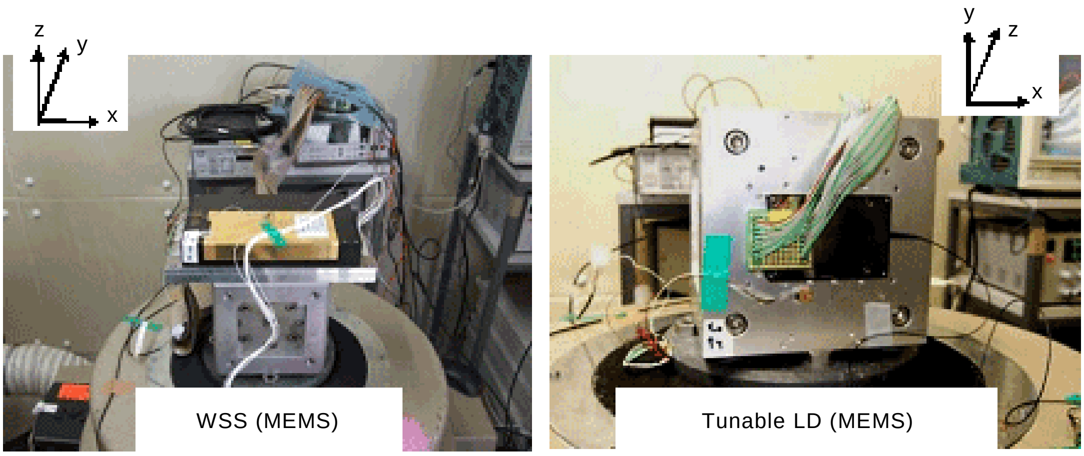

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Figure 10 – Shock and vibration evaluation system for WSS and tuneable laser

Figure 11 shows an example of the WSS shock evaluation results (dependence on shock direction), which are weakest on the z-axis. Vibration evaluation results showed a rising change in optical attenuation at around 250 Hz. Figure 12 shows the shock dependence of optical attenuation on the z-axis. Evaluation was conducted with the attenuation set at 20 dB, the upper limit for optical attenuation commonly seen in device specifications. As measured against shock in the z-axis direction, attenuation fluctuated widely from 16,5 dB to 40 dB at 10 G. At shock of 2 G, a change in attenuation of about 2 dB was noted as well. No dependence on shock pulse duration was seen in shock evaluation, yielding the same results as for MEMS-VOA). In the evaluation of shock, a significant change in optical attenuation was noted at around 250 Hz. This is believed to be due to the resonance occurring in MEMS inside the optical module at a certain frequency, resulting in a drastic rise in loss change.

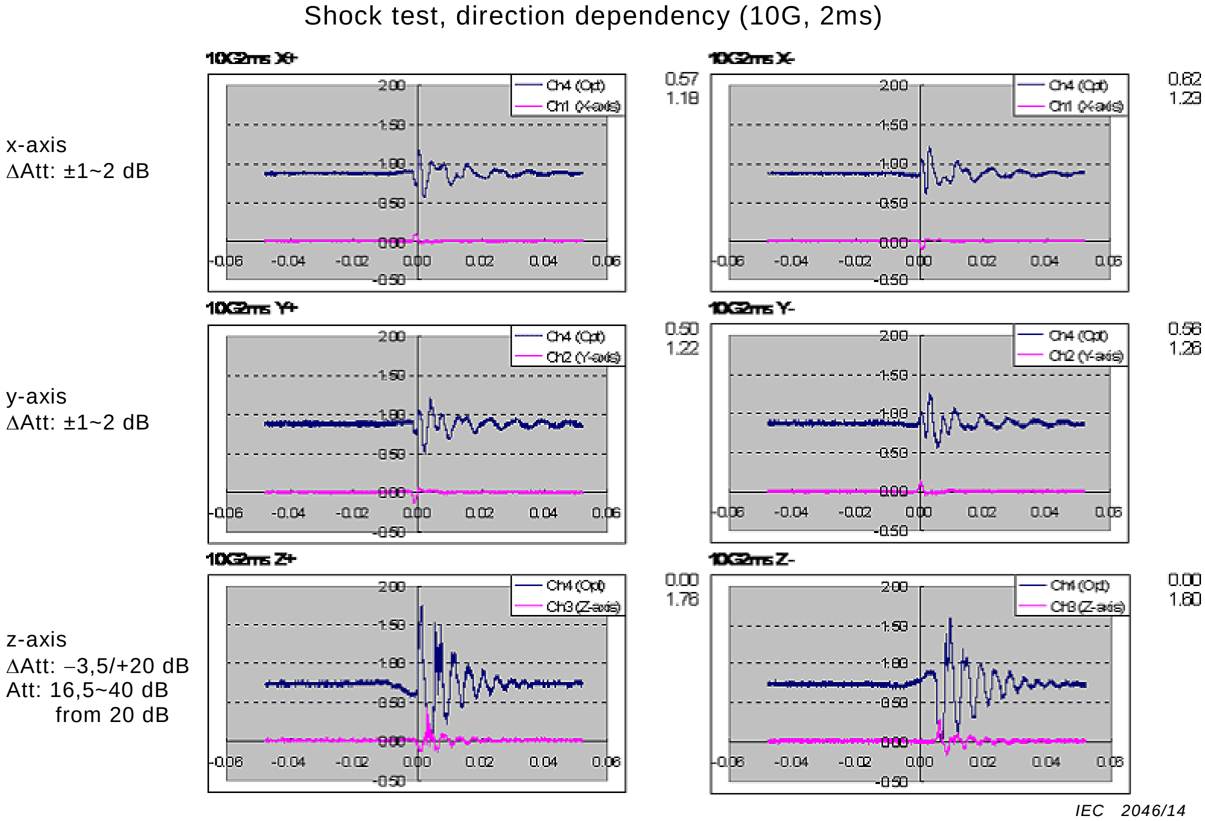

Figure 11 – Shock evaluation results for WSS (directional dependence)

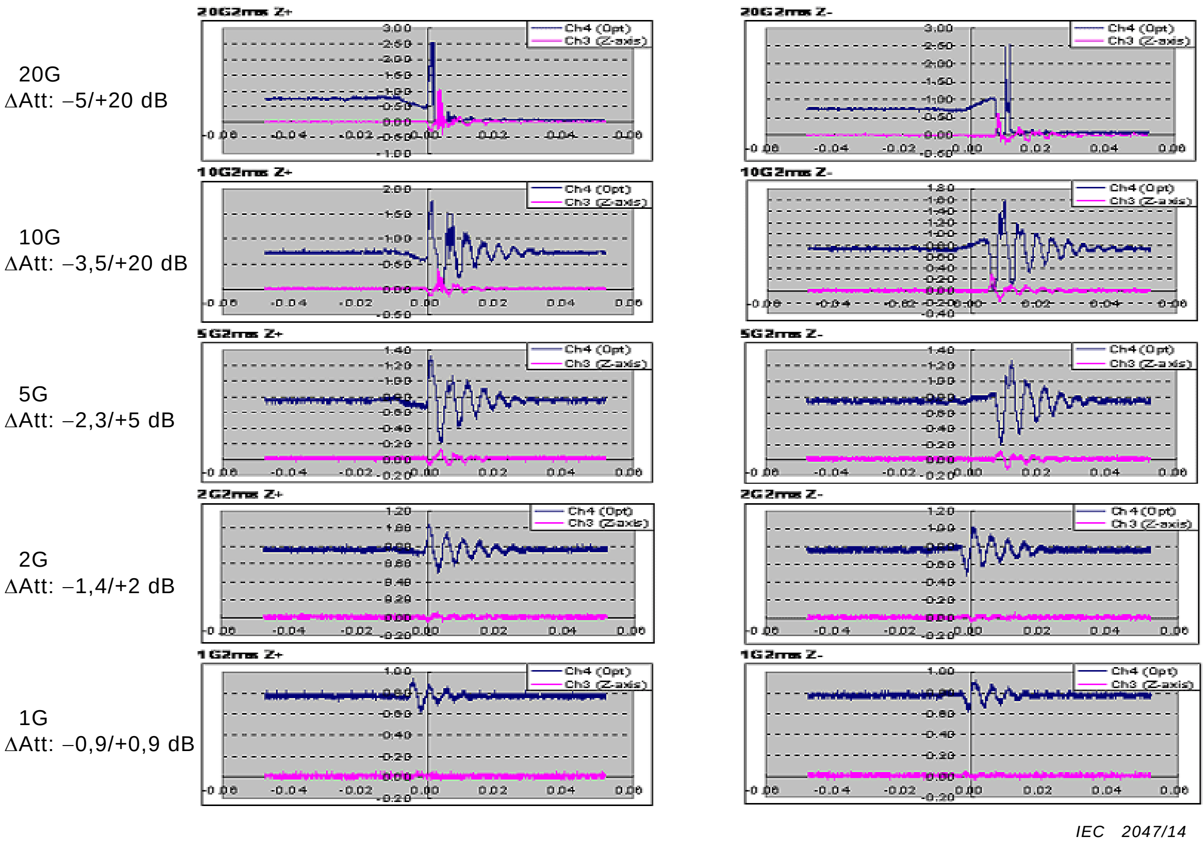

Figure 12 – Shock evaluation results for WSS (z-axis direction and shock dependence)

The tuneable laser also showed a directional weakness against shock, the weakest being in the y-axis direction. On the y-axis, optical output changed by 0,6 dB at shock conditions of 40 G and 2 ms. In the evaluation of vibration, a significant change in optical output was noted at around 300 Hz.

6 Simulation

6.1 Simulation model

Shock and vibration were simulated to confirm the dependence on peak vibration at around 250 Hz relative to PC board thickness and measurements, and dependence on shock strength on the x-, y- and z-axes, as well as respective strength ratios. Simulation was only conducted for the PC board. Table 5 lists the simulation conditions. Figure 13 illustrates the simulation model.

Table 5 – Conditions for simulating board shock and vibration

Board thickness (weight, material) Board size	1,2 mm (250 g, aluminium) H:240 mm, D:220 mm (standard) H:480 mm, D:440 mm D:150 mm (70 % of standard)
	1,5 mm (290 g, aluminium) 1,6 mm (710g, SUS) H:240 mm, D:220 mm
Dynamic module	Tunable dispersion compensator (470 g)
Direction of applied shock	X-axis (from the front of the board)
Output data of simulation	Frequency characteristics (x, y, z) Distribution of vibration (dependence on location) Maximum vibration (x, y, z)
Remarks	Decreasing characteristics (decreasing time): Fit by test results

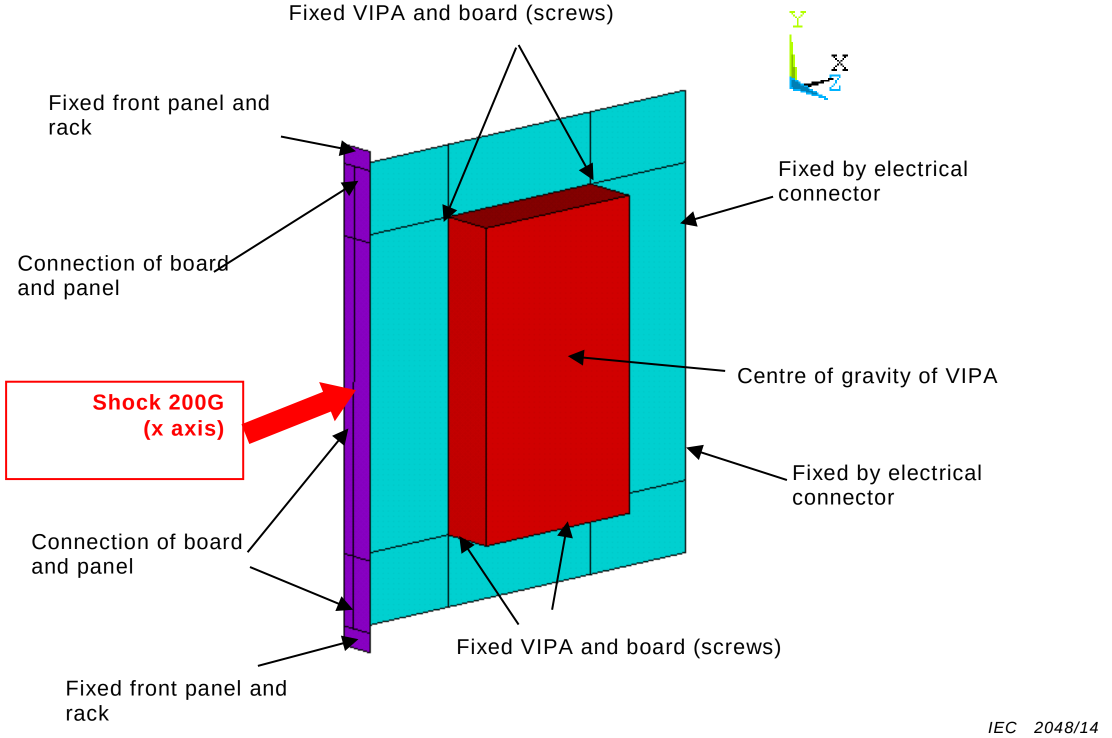

Figure 13 – Simulation model

6.2 Frequency characteristics

Figure 14 shows an example of the simulation results. The board conditions are a thickness of 1,6 mm, height of 240 mm and depth of 220 mm. Shock values of 4 G on the x-axis, 1 G on the y-axis and 10 G on the z-axis were obtained. In the frequency characteristics after Fourier transformation, peaks were noted at 100 Hz and 200 Hz.

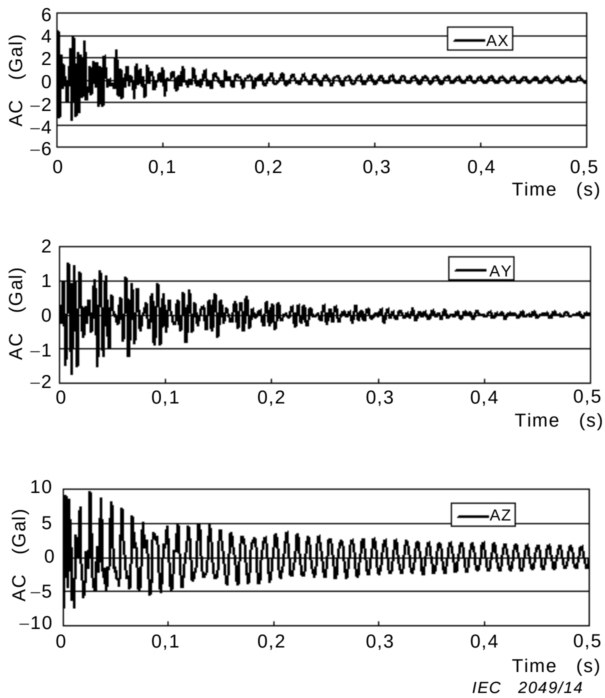

Figure 14a – Vibration characteristics

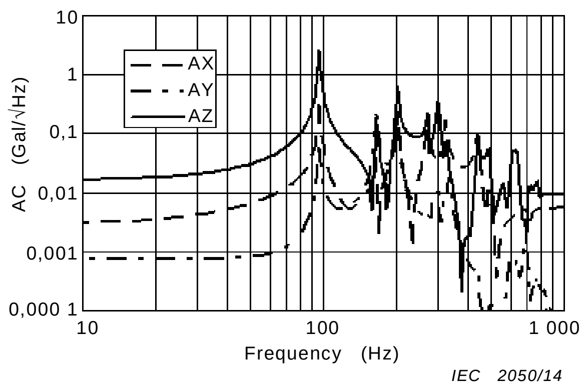

Figure 14b – Frequency characteristics

Figure 14 – Vibration simulation results

6.3 Dependence on PC board design

Since the evaluation results roughly matched the simulation results, the validity of the simulated vibration was verified. However, the size of boards and racks actually used vary. For this reason, simulation was conducted with varying conditions (parameters) set on board measurement, thickness, weight, centre of gravity (i.e. optical module location on the PC board) and duration of hammer impact, in order to provide guidelines on actual board installation, as well as to estimate the level of tolerance to shock and vibration conditions applied to the optical module. The results show that frequency is in reverse proportion to PC board measurement and weight, but proportionate to board thickness. Figure 15 shows graphs of the simulation results. Furthermore, no dependence was found regarding optical module location on the board or the duration of hammer impact.

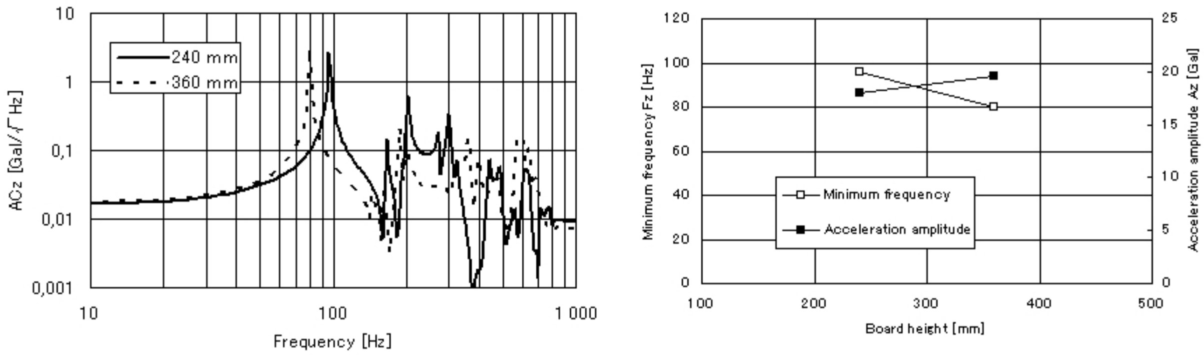

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Figure 15a – Dependence on PC board size

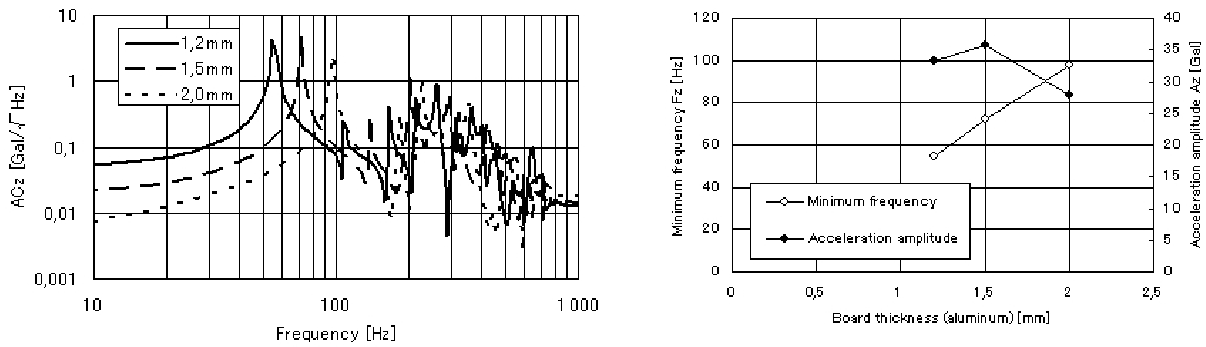

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Figure 15b – Dependence on board thickness

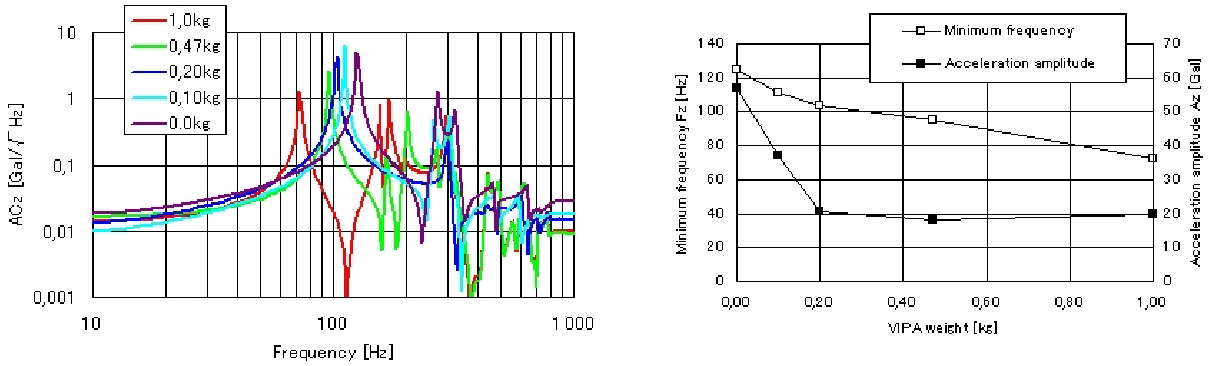

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Figure 15c – Dependence on board weight

Figure 15 – Vibration simulation results (dependence on board conditions)

6.4 Consistency of evaluation and simulation results

The results of evaluation in the first and second steps, and the vibration simulation results were examined for consistency. For impact of 200 G at the front of the board, the evaluation showed impact of 10 G for 2 ms on the z-axis. Shock of 10 G on the z-axis was also seen in the simulation results. The dependence on shock direction also matched as well, declining in order of z > x > y. In terms of frequency characteristics, a peak was seen at 250 Hz in the evaluation; while peaks in the simulation were noted at 100 Hz and 200 Hz. Table 6 lists the comparative changes.

Table 6 – Comparison of hammer impact shock evaluation results and vibration simulation (conditions: 1,6 mm × 240 mm × 220 mm, t × H × D)

Item	Evaluation results	Simulation results	Comparative results
Direction dependence and vibration intensity	Z (10 G) > X (6 G) > Y (4 G)	Z (10 G) > X (4 G) > Y (1 G)	Intensity: good match Direction: simulation shows a stronger dependence than that of evaluation (The evaluation of hammer impact may include other directional impact.)
Frequency	250 Hz peak 100 Hz Other: small	100 Hz 200 Hz Others	The board may have a basic resonance frequency of 100 Hz

The fact that the evaluation results matched the results of single-board simulation suggests that shock and vibration applied to an optical module are dependent of the structure of each PC board. This result corroborates with the lack of dependence on board installation location and the number of boards installed, as shown in the first step evaluation results.

7 Summary

The following is a summary of the investigation:

- A questionnaire survey on shock and vibration testing revealed that both suppliers and users confirmed the need for standardizing evaluation methods and conditions as pertaining to operating shock and vibration.
- The conditions for operating shock and vibration were assumed to be an earthquake, a hammer impact, and the insertion of an adjacent PC board.
- A hammer impact test at 210 G resulted in shock of 10 G lasting 2 ms to 5 ms perpendicular to the PC board (z-axis), and showed that shock has a directional dependence with z > x > y.
- The shock value of inserting an adjacent board is similar to that revealed in hammer impact tests.
- There was a change of about 1 dB in optical loss in MEMS-VOA under these conditions (at a setting of 20 dB in optical loss).
- A number of vibration peaks around 100 Hz, 250 Hz and more than 1 kHz were observed by Fourier transformation.
- A computer simulation supported the same tendency a shown by the evaluation results.
- There was a 38 dB change in optical loss at 10 G and 2 ms on MEMS-VOA in testing using standard shock and vibration test equipment, as conducted in the third step of evaluation, thus corresponding to about half the value obtained in hammer impact tests.

- Optical loss changes in vibration tests using standard shock and vibration test equipment showed relatively large values at 470 Hz for MEMS-VOA, around 250 Hz for WSS and around 350 Hz for a tuneable laser.

8 Conclusions

The conclusions of this investigation are as follows:

a) According to the results reported in this technical report, the test conditions of operating shock and vibration must be defined depending on the direction in which dynamic modules are installed on a PC board and inserted into a rack.

b) Furthermore, dynamic module suppliers and users are recommended to define the direction in which to install dynamic modules on a PC board and rack.

c) Recommended operating conditions are summarized below.

   - Shock testing conditions:
     - Z-axis: 40 G, 5 ms
     - X-axis: 20 G, 5 ms
     - Y-axis: 10 G, 5 ms
   - Vibration conditions:
     - Z-axis: 50 Hz - 500 Hz, 2 G sweep
     - X-axis: 50 Hz – 500 Hz, 1 G sweep
     - Y-axis: 50 Hz – 500 Hz, 0,5 G sweep

Annex A
(informative)

Results of a questionnaire on dynamic module operating shock and vibration test conditions

A.1 Background

This technical report provides recommendations for operating shock and vibration test conditions for dynamic modules. An informal survey of the prevalent test conditions in the industry was carried out in 2012 and 2013 by using an informal questionnaire. The information regarding the operating shock and vibration test conditions was gathered from the module suppliers and network equipment manufacturers. The survey results are summarized in this annex.

A.2 Questionnaire methodology

Nine (9) optical network equipment manufacturers/module suppliers in EU, JP and US were surveyed.

The questionnaire gathered information about the operating shock and vibration test conditions for commercially available dynamic modules.

A.3 Survey result

Out of nine manufacturers surveyed, seven (7) responses were obtained, and the results are summarized in Table A.1.

Table A.1 – Summary of survey results on operating shock and vibration test conditions

	Company A	Company B	Company C	Company D	Company E	Company F	Company G
Vibration test conditions	Condition 1 Swept sine wave 5 Hz – 100 Hz 1,0 g, 3 mm max. 0,1 oct./min. 3 axes Condition 2 Swept sine wave 100 Hz – 200 Hz 2,0 g 8 oct./min. 3 axes	Swept sine wave 5 Hz – 100 Hz 1,0 g, 3 mm max. 0,1 oct./min. 3 axes	Swept sine wave 5 Hz – 100 Hz 1,0 g, 3 mm max. 0,1 oct./min. 3 axes	Condition 1 Swept sine wave 5 Hz – 100 Hz 1,0 g, 3 mm max. 0,1 oct./min. 3 axes Condition 2 Swept sine wave 100 Hz – 200 Hz 2,0 g 8 oct./min. 3 axes	5 Hz – 50 Hz 1,5 g 0,1 oct./min.	No requirement	Swept sine wave 5 – 100 Hz 1,0 g 0.1 oct/min. 3 axes
Shock test conditions	500 m/s2 (50 g) 10 ms 3 axes, 2 directions	No requirement	No requirement	Half sine shock pulse 10 g 0,3 ms 3 axes	No requirement	50 g 3 axes	200 G for 1.33 ms 2 directions 3 axes

The survey results in Table A.1 show that the required conditions of operating shock and vibration test in the actual market are looser than the recommended conditions mentioned under Clause 8: Conclusions. It is recommended that the hammer impact test is not carried out so often, and that the adjacent PC board be inserted so that an excessive shock may not be added. Therefore, the required conditions may be loose.

Bibliography

[1] OITDA (Optoelectronic Industry and Technology Development Association) – TP (Technical Paper), TP05/SP_DM-2008, *"Investigation on operating vibration and mechanical impact test conditions for optical modules for telecom use"*

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