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TECHNICAL REPORT

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

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DYNAMIC MODULES –

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

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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.

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

Enquiry draft	Report on voting
86C/943/DTR	86C/958/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- withdrawn,
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DYNAMIC MODULES –

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

1 Scope

This part of IEC 62343, which is a technical report, explains an investigation of operating mechanical shock and a vibration test for dynamic modules. It also describes the results of a survey, evaluation and mechanical simulation of mechanical shock and vibration testing. This report covers 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 putting dynamic wavelength dispersion compensators, wavelength blockers and wavelength selective switches to practical use as “dynamic modules.” Since these dynamic modules incorporate such brand-new technology as MEMS (micro electromechanical systems), there are concerns about the vulnerability of MEMS to operational shock and vibration conditions, which urgently require establishing evaluation methods and conditions for operational shock and vibration. Standards for shock and vibration test conditions as pertaining to storage and transport are already established, but methods and conditions for evaluating operational 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 operational shock and vibration, and some suggested earthquakes, hammers 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 such operational 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 operational vibration and mechanical impact test conditions for optical modules for telecom use."

3 Questionnaire results in Japan

The JIS committee conducted a questionnaire on operational 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 tunable 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 tunable 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 operational shock and vibration evaluation methods and conditions for such dynamic modules as optical switches and VOAs. A majority of respondents also requested that hammer impact testing and the insertion of an adjacent board be included as cases of operational 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 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

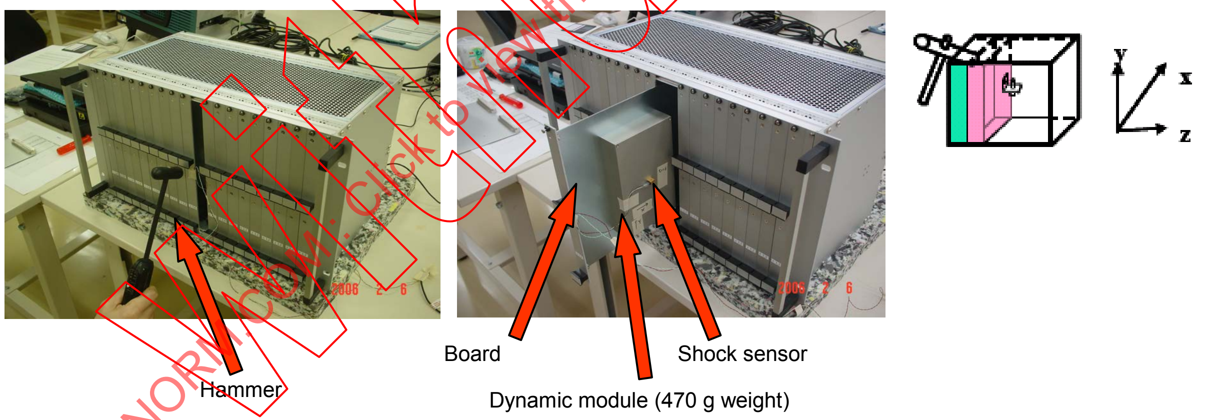

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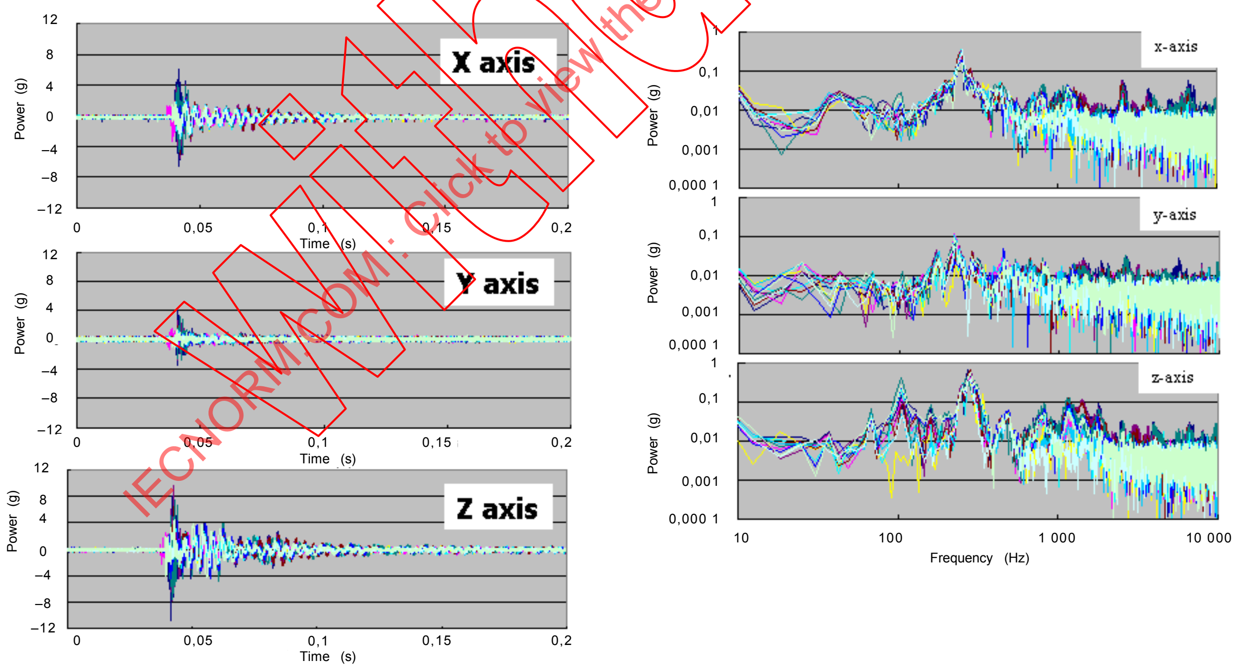
Figure 1 – Photos of evaluating hammer impact, rack and boards

A 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 evaluating hammer impact, as well as the rack and boards. Table 1 summarizes the specifications of the rack and boards and the conditions of evaluating hammer impact and acquiring data.

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

Item	Specifications / Conditions
Rack size	432 mm (W) × 240 mm (D) × 262 mm (H)
Back connectors	2 pins - 96 pins
Number of boards	20
Striking force (acceleration intensity)	H (1 800 m/s^2 to 2 400 m/s^2) ~ 210 G M (1 200 m/s^2 to 1 600 m/s^2) ~ 140 G L (300 m/s^2 to 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 board	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 on the front face of a board 1,6 mm thick, located at the centre of the 20 boards installed, with data being acquired on tests repeated 11 times. Figure 2b) shows the Fourier transform results of data based on the frequency component.



2a) Measurement results

2b) Fourier transformation data

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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 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 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 board and impact on the handle on the front side of the rack. Figure 3 shows photos of the evaluation tests.

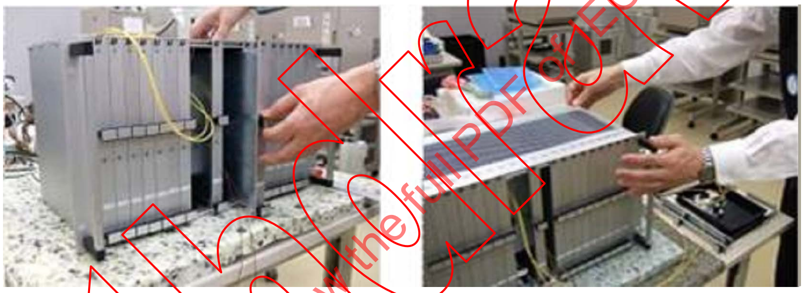

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Figure 3 – Photos of evaluating adjacent board insertion and rack handle impact

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 some 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 was attached to a 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 board with the VOA and the rack with WSS (wavelength-selective switch) attached on the boards.

4a) Board with VOA

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4b) Rack with WSS attached on boards

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Figure 4 – DUT (VOA and WSS) installed on 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 DUTs.

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 fiber)	
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).

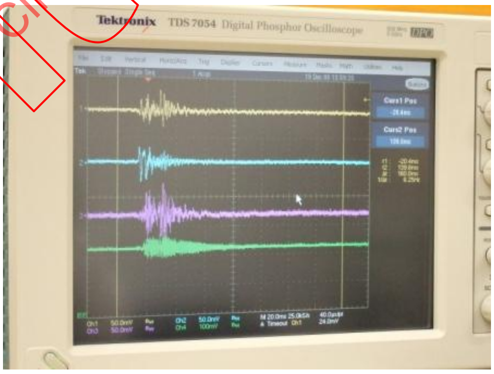

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Figure 5 – Oscilloscope display of waveform changes in vibration and optical output

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 and vibration peaks, and optical loss change have been organized as described below, with VOA-1 employed as reference. The VOA was set to 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.

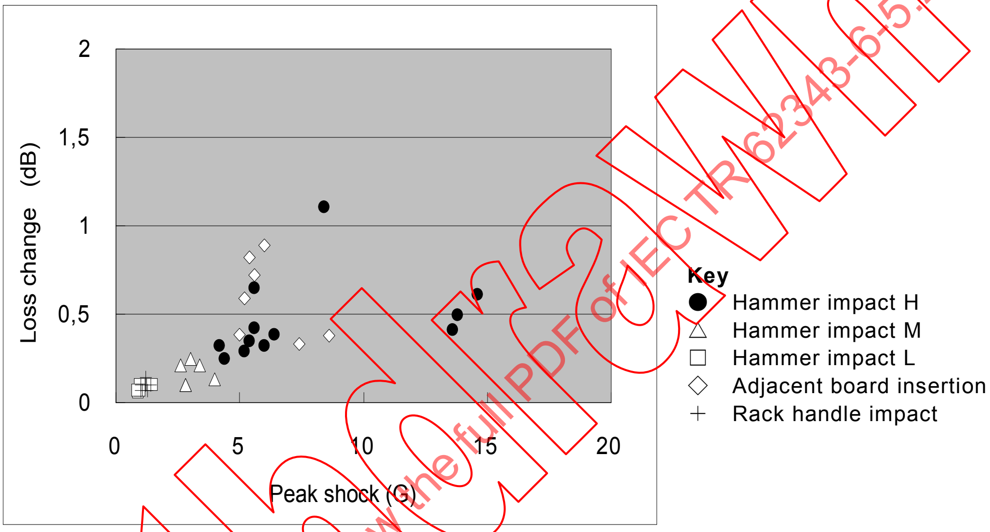

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Figure 6 – Evaluation results when employing MEMS-VOA for Z axis

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.

7a) Shock/vibration equipment

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

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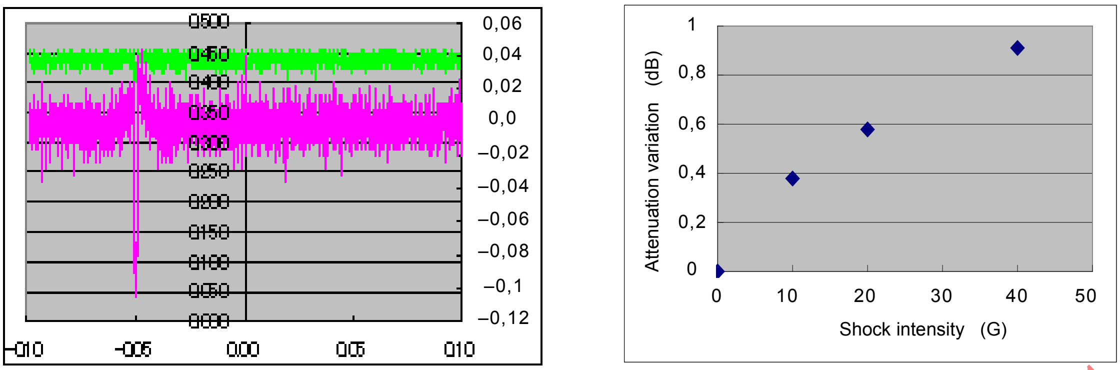
Figure 7 – Photos of the MEMS-VOA shock/vibration test equipment

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 operational 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.



8a) Z axis, 10 G & 2 ms

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

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Figure 8 – Operational 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.

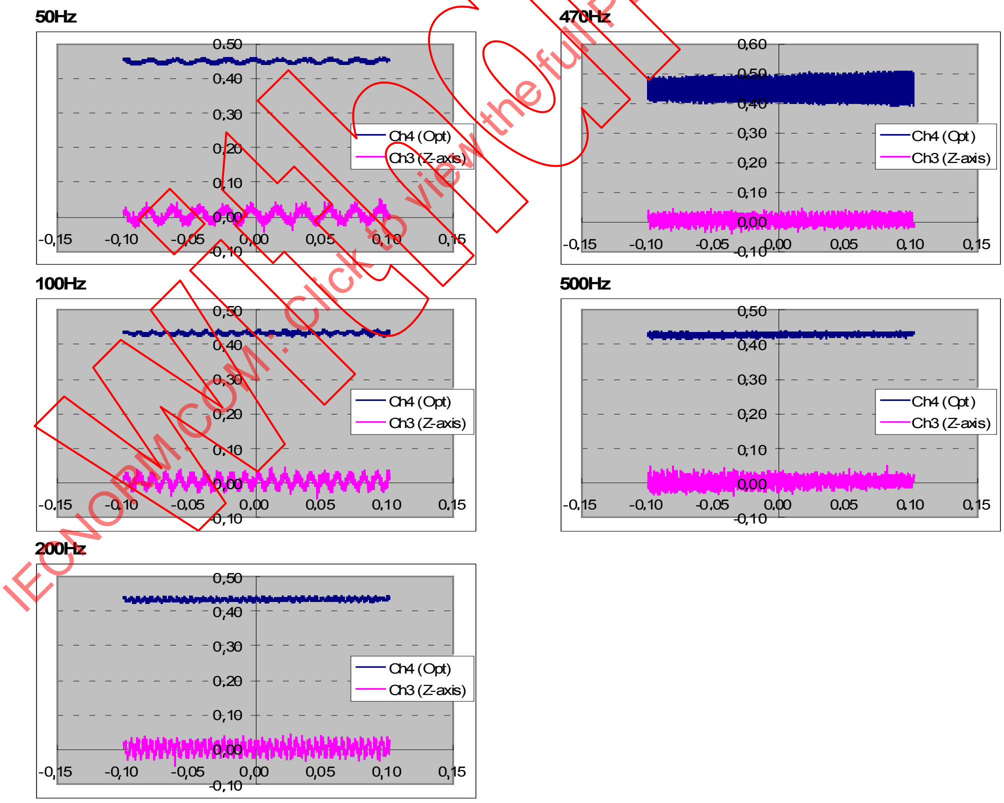

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Figure 9 – Vibration evaluation results for MEMS-VOA (Z axis; 2 G)

In the evaluation, changes were made in acceleration in addition to frequency. Table 4 lists the test results. In the text, 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 Hz to 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 tunable laser

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

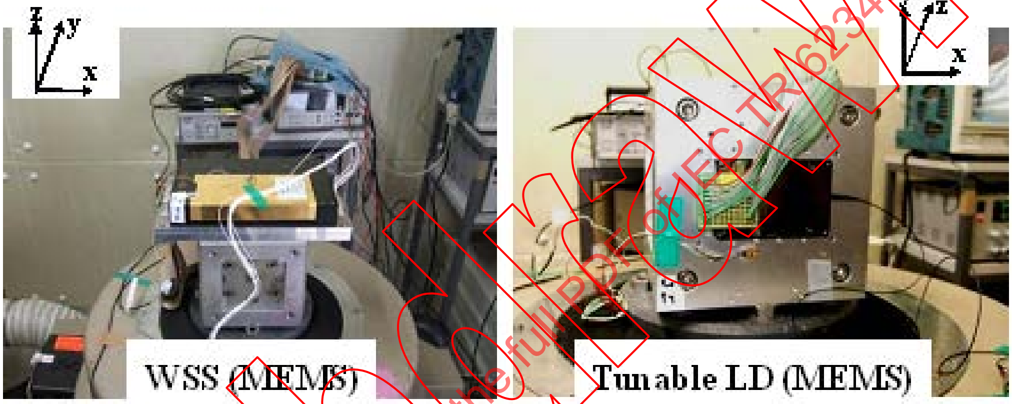

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Figure 10 – Shock and vibration evaluation system for WSS and tunable laser

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 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 due to the resonance occurring in MEMS inside the optical module at a certain frequency, resulting in a drastic rise in loss change.

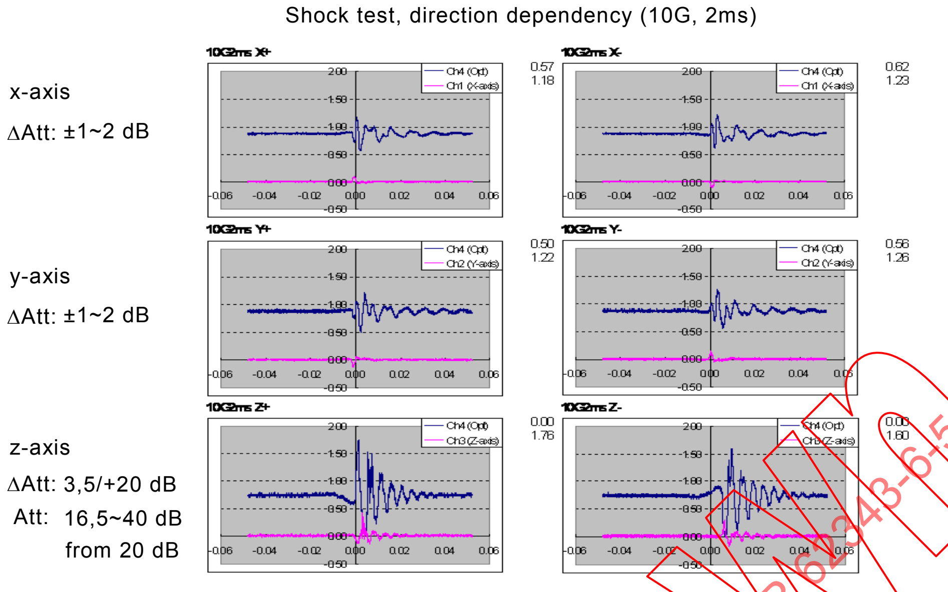

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Figure 11 – Shock evaluation results for WSS (directional dependence)

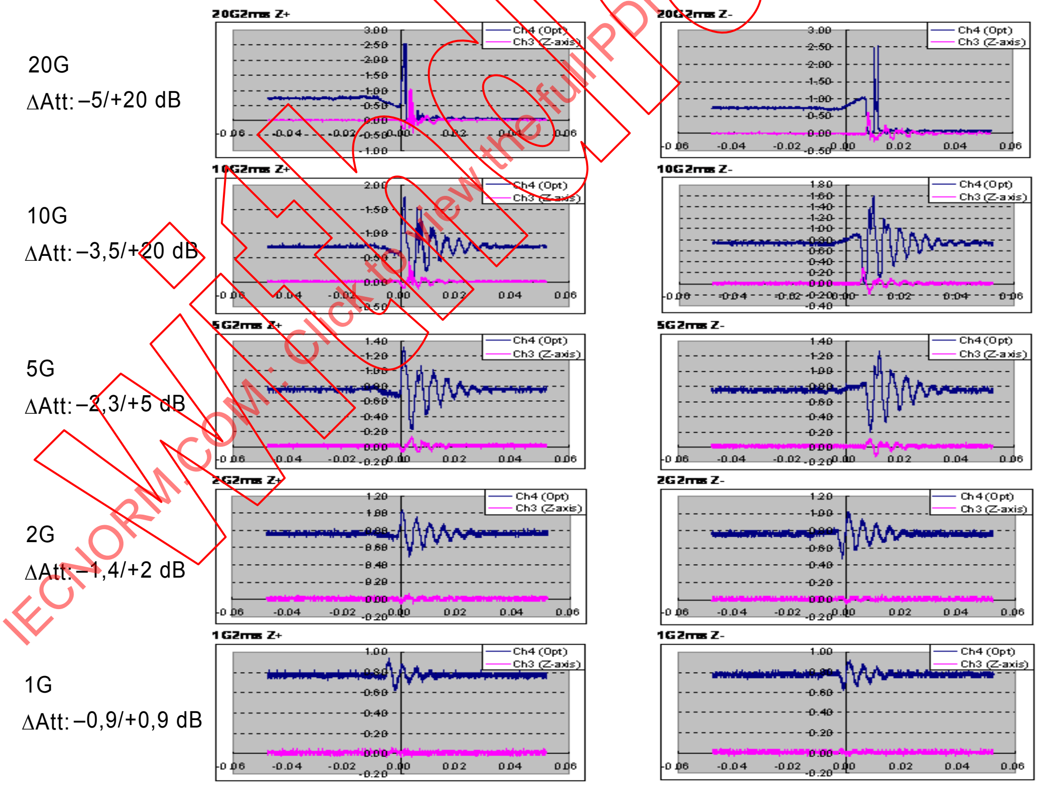

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Figure 12 – Shock evaluation results for WSS (z-axis direction and shock dependence)

The tunable 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 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 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 (710 g, 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

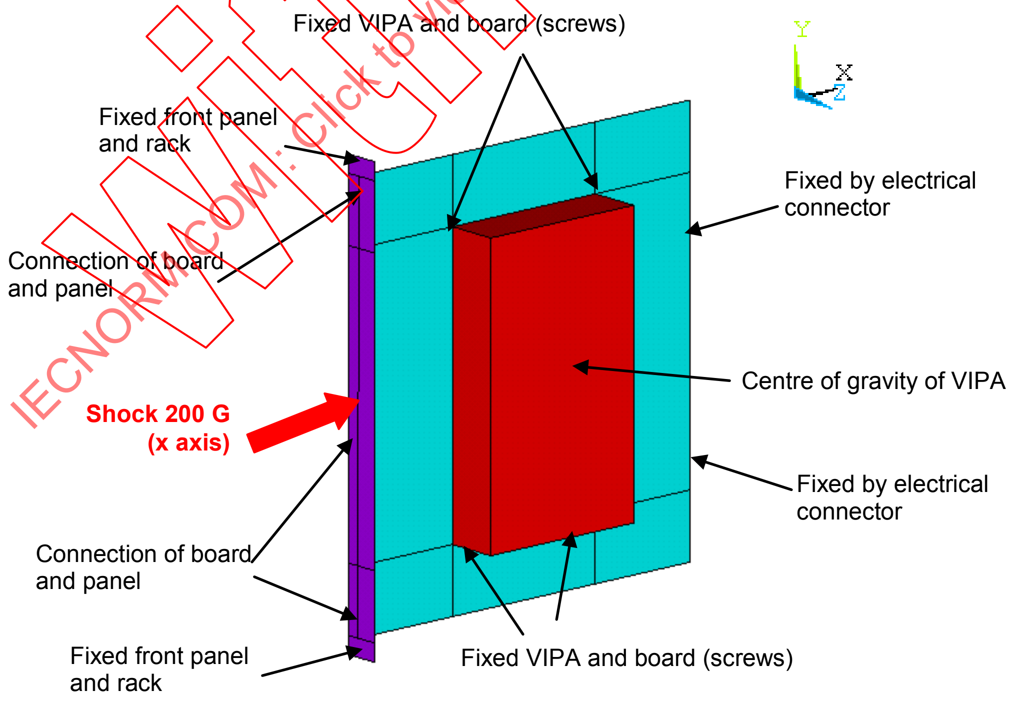

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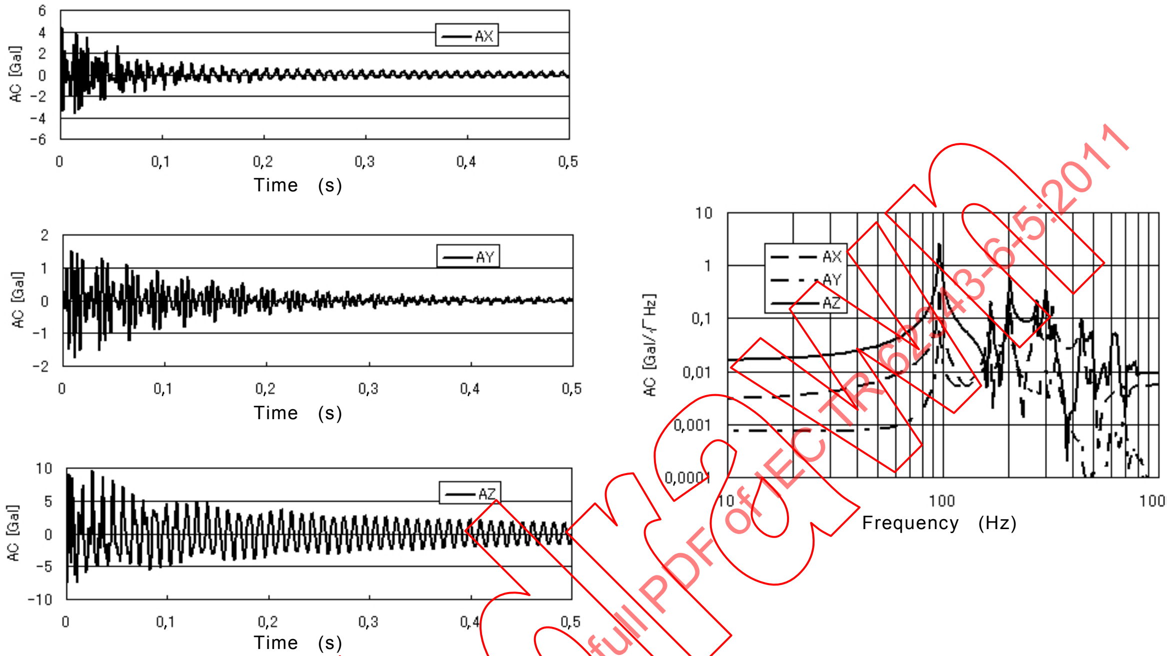
Figure 13 – Simulation model

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.



14a) Vibration characteristics

14b) Frequency characteristics

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Figure 14 – Vibration simulation results
(Conditions: 1,6 mm × 240 mm × 220 mm, *t* × H × D)

6.3 Dependence on board design

Since the evaluation results roughly matched the simulation results, the validity of the simulated vibration was verified. However, varying sizes of boards and racks are actually used. 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 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 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.