Simulation Method for Connector Packaging

● Makoto Sakairi ● Tadashi Tateno ● Akira Tamura

(Manuscript received December 28, 2009)

There is a growing demand for technology that can analyze and test contact reliability with high accuracy in high-pin-count flat packaging such as sockets for central processing units (CPUs) and application specific integrated circuits (ASICs) and in card edge connectors for modular products. We have developed simulation technology for visualizing the behavior of individual contacts, which cannot be obtained empirically. This technology lets engineers test connections in connector packaging and clarify their behavior, enabling the mechanism behind stable contacts to be determined from the desktop without the need to perform numerous experiments. This paper introduces two key examples of applying this technology. First, for land grid array (LGA) connections having a high mating pressure, we clarified the behavior of individual contacts and tested long-term connection reliability while taking into account the package and system (board) displacement over time. Next, for connector packaging for module boards that must secure a mechanical board while also achieving electrical stability in the same contacts, we tested connection safety by clarifying the mechanism of module-board slippage due to vibration during equipment transport.

1. Introduction

Connectors are used to divide or join circuits and functions in certain system units. As such, they are important components that determine the system or rack mounting scheme (structure) in equipment development. Since they are mechanically connected and disconnected, they are susceptible to disturbances such as external forces or deformation. This makes it difficult to guarantee the reliability of a connector solely on the basis of the connector itself. As a result, combined tests on the equipment manufacturer's side and technology for mastering the connector characteristics are becoming increasingly important.

This is particularly true in two cases: (1) a connector configured and mounted in combination with other components, such as a land grid array (LGA) socket in which the mating pressure that determines contact reliability is determined by the mounting structure and (2) a mounting system, such as in some card edge connectors for module boards, that serves to secure the module by mating pressure in addition to performing its primary function of providing electrical connections. A detailed understanding of the behavior of individual contacts in such a mutually dependent relationship can assist one in selecting a high-reliability contact system and deciding on a packaging system.

In this paper, we introduce technology that we have developed for visualizing the behavior of individual contacts and testing their reliability, especially for LGA sockets and module boards whose characteristics are difficult to master.

2. Behavior of LGA contacts over time

An LGA socket is used to make connections between a printed circuit board (PCB) and a central processing unit (CPU) or application specific integrated circuit (ASIC) package (PKG). It is sandwiched under high pressure by screws (springs) between a heat sink used to cool the PKG and a reinforcing component on the underside of the PCB. It must provide stable connections over the long term.

In addition to elastic material such as metallic (e.g., copper) springs, connector material in LGA sockets may be an elastoplastic material like gold bumps or a viscoelastic material like conductive rubber. In conductive rubber, the amount of deformation changes over time (creep) under a fixed load. Moreover, the resin materials used for the packaging and PCB will likewise undergo changes over time. Thus, a key requirement for establishing long-term reliability is to predict changes in aging behavior of the PKG, socket, and PCB in a composite manner.

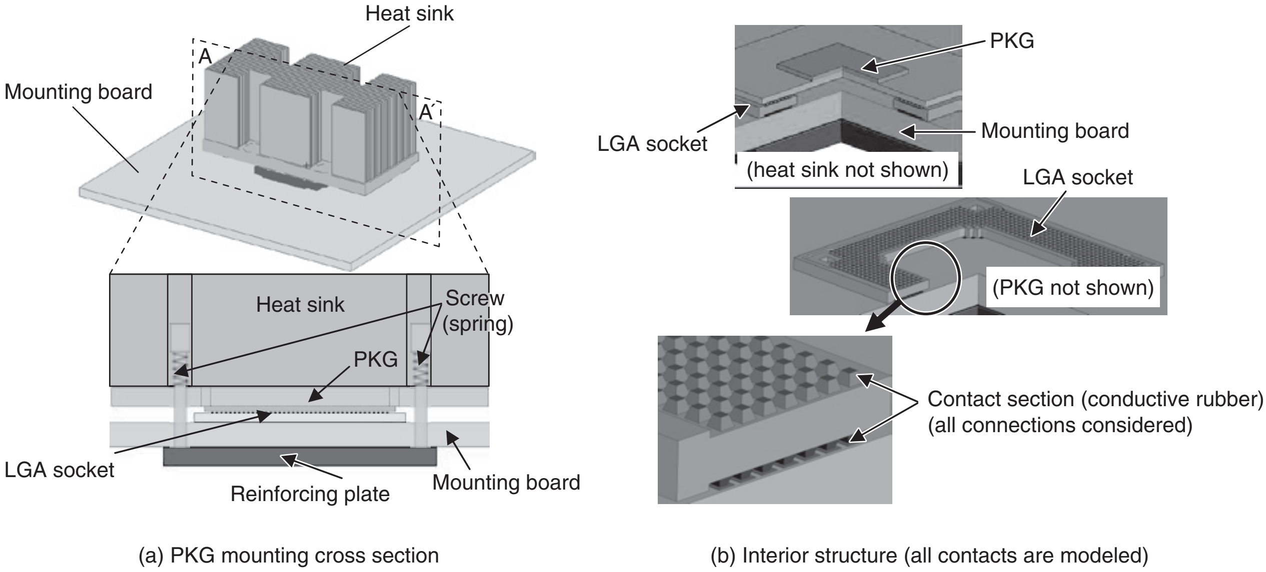
Up to now, such predictions have usually been made using a statistical method like the Monte Carlo method, but it cannot accurately treat phenomena (behaviors) that occur during an evaluation process. To overcome this problem, we have developed technology for visualizing the behavior of individual mounting elements by using a composite simulation based on a total system model of the LGA socket and peripheral components.

2.1 Existing evaluation methods and problems

Considering that equipment is subjected to various temperatures during actual operation, the reliability of an LGA socket has usually been evaluated by performing an accelerated test that applies a temperature-variation load to the socket in an isothermal oven. The connection states are electrically monitored (through resistance measurements) during the test, and the results are use to predict the long-term reliability of those connections. However, this test has some problems. The evaluation period is long (two weeks to several months) and there are many evaluation-data combinations. Moreover, it cannot determine connection behavior while the test is in progress, which means that the effects of peripheral components like the PCB and pressure structure cannot be accurately understood, so there is uncertainty about the accuracy of feedback in packaging design.

2.2 Simulation technology

In response to one of the abovementioned problems, we developed technology for simulating the behavior of an LGA socket during evaluation (during use) and investigated the visualization of that behavior. The structure used to simulate LGA socket behavior is shown in **Figure 1**. In Figure 1 (a), the lower part is a cross section through the LGA socket along A-A'. The LGA socket that we used for our study has a contact section consisting of about 900 pins. It is sandwiched between a heat sink on the PKG upper surface and a reinforcing component on the underside of the PCB. Here, the load on individual contacts is not uniform due to the positions of the screws (springs) and the component deformation produced by fastening. As a result, the contact deformations may differ, which makes it necessary to model all contacts to obtain the correct effect on the entire socket. It is also necessary to take into account the initial warping of each component to obtain the correct effect on contact displacement. Finally, it is important that values for properties (creep characteristics) of the contact section, PCB, etc. be obtained and applied to the simulation. Taking all this into account, we created a model (Figure 1), reproduced the actual usage environment, and simulated the change in behavior of contacts across the entire LGA socket over time. The main points considered in creating the model for simulation use are summarized below:



(a) PKG mounting cross section

(b) Interior structure (all contacts are modeled)

Figure 1
Structure for LGA socket behavior simulation.

- Model peripheral components such as the pressure structure and PCB.
- Model all contacts on the LGA socket (about 900 pins).
- Define connections at about 900 × 2 = 1800 locations between the contact section and PKG and between the contact section and PCB.
- Model the initial warping and deformation of each component (PKG, PCB, etc.).
- Consider the creep characteristics of the contact section, PCB, and bonding layer.

2.3 Simulation results

We investigated deformation behavior for up to ten years into the future by duplicating an actual usage environment and performing simulations. Center cross sections of system deformation and examples of LGA socket deformation at different times are shown in **Figure 2**.

As can be seen from the figure, visualizing the way in which deformation progresses over time enabled us to understand the behavior of individual components. These simulation results

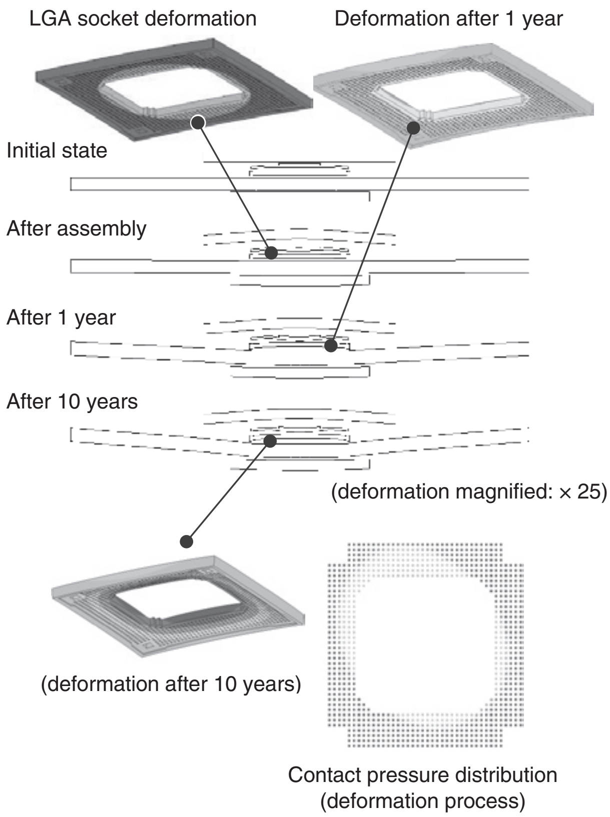


Figure 2
Deformation of socket and mounting system over time (for cross section A-A´ in Figure 1).

also revealed that the change in mating pressure over time differed between the inner and outer regions of the socket. For a viscoelastic contact made of conductive rubber, mating pressure is maintained during creep under a constant load and mating pressure (stress) eases under constant displacement. Furthermore, for the mating pressure under a constant load and/or constant displacement in combination with the pressure structure and/or resin PCB, correct visualization of the behavior of these components over time enabled us to examine connection functionality (reliability). These simulation results agree well with deformation values obtained by experiment.

2.4 Effects of new simulation technology

This simulation technology will provide three major benefits in connector testing.

1) Visualization of the detailed behavior of each component and element making up the mounting system and examination of changes over time.
2) Clarification of the mechanism behind stable connections and the ability to perform reliability testing as a result of the benefits in 1).
3) Simulation of even sockets with metallic elastic contacts (**Figure 3**), enabling contact-pressure variation and temporal changes to be visualized and the mechanism behind long-term reliability to be tested.

3. Slippage behavior in module boards

Many types of electronic equipment such as servers have a simple mounting format in which module boards can be mounted by simply inserting them into card edge connectors (**Figure 4**). Such components usually experience no problems while the equipment in question is installed and stationary, but when it is being transported, e.g., in a cardboard box, module boards have been known to fly out of their connectors or simply slip out. Therefore, connectors are generally equipped with a locking mechanism to keep module boards in place or metal fittings or similar mechanisms on the rack side to prevent the module boards from falling out. However, there are also cases in which, owing to space limitations, module boards are secured simply by mating pressure without a special retention mechanism being used.

In this section, we clarify the mechanism of vibration-induced slippage of module boards installed in connectors through simulation results and introduce a technique that we developed for analyzing ease-of-slippage even when mounting specifications for connectors and module boards change.

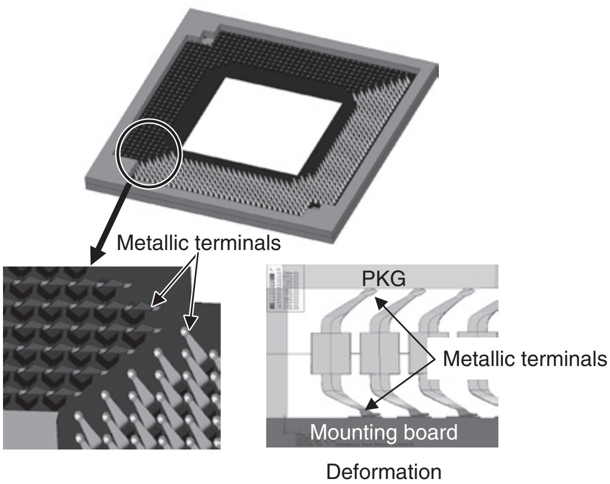


Figure 3
Finite element model of metal terminals.

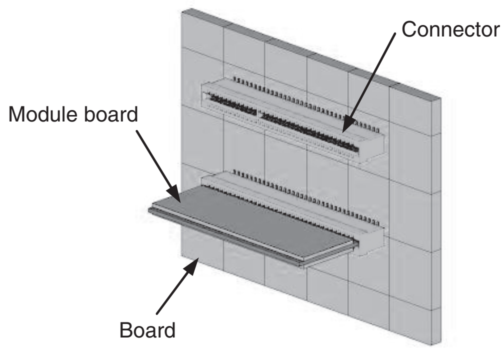


Figure 4
Connector module-mounting configuration.

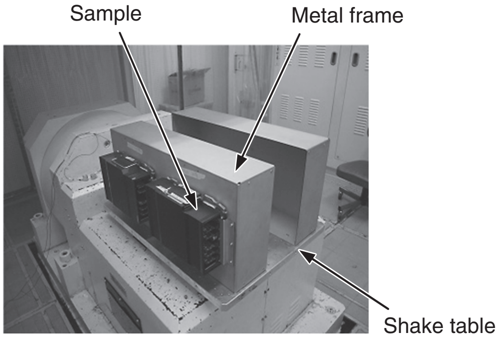


Figure 5
Vibration testing system.

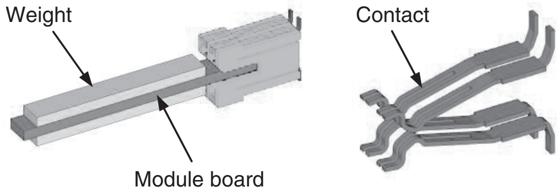


Figure 6
Analysis model for connector module.

3.1 Existing evaluation methods and problems

Module board slippage is heavily dependent on the rack's mounting structure and environmental conditions, so evaluations have usually been performed using actual equipment made to vibrate by a random waveform. It is also desirable to test connector safety in an actual-equipment situation from the viewpoint of an evaluation of the connector itself independent of the rack mounting. These two approaches have the following problems:

1) Experiments must be performed under many conditions (vibration conditions, board weight/dimensions, etc.)
2) Module-board and component specifications are subject to change, but repeating tests with actual equipment when such changes occur is uneconomical.
3) The vibration factor that must be reflected in individual-connector evaluation must be determined from the rack-mounting configuration, and extensive pre-evaluations are needed to determine actual-equipment safety from individual-connector evaluations.

In response to these problems, we worked to visualize slippage phenomena while comparing the results of shock analysis and vibration tests. On the basis of the features revealed, we developed a simulation technique for testing slippage.

3.2 Vibrations tests and results

The vibration testing system is shown in **Figure 5**. In these tests, a sample was attached to a shake table, and vibration was applied to the base of the connector mated to a module board. Tests were performed for module-board masses of 36, 52, and 95 g. We found that the module-board amplitude became larger and slippage accelerated as the module-board mass increased, indicating that mass plays a bigger role than vibration frequency in the ease of slippage.

3.3 Simulation model

The above vibration tests provided a simple evaluation in terms of whether the board stayed in place or came out. However, they could not reveal the cause of module board slippage or the mechanism involved. Therefore, we used simulation to reproduce the behavior of the module board and contacts and analyzed the cause of the slippage. In the analysis model used for simulation, we extracted a 4-pin section from a connector (**Figure 6**) and applied the following parameters that we considered to be slippage factors:

1) Connector geometric shape

Positions of contacts, mating format, dimensions tolerance

2) Terminal mechanical characteristics

Stiffness, contact force, coefficient of friction

3) Module board specifications

Mass, center of gravity, geometrical shape

4) Mounting structure (rack)

Direction of vibration, vibration factor (acceleration)

5) Disturbances
Vibration time, waveforms, deformation

3.4 Simulation results

3.4.1 Analysis for different module-board masses

The locations of the vibration source and input waveform are shown in **Figure 7**. We obtained the movement of the end of the partial module board as output when a certain waveform was applied as input to the connector mounting section. As the waveform, we used a 60-Hz sine wave expressed by $\mathrm{Dx}\,(t) = 0.5 \times \sin(2\pi \times 60\,t)$ mm with amplitude of 0.5 mm. Three module-board masses were used (3.10, 1.55, and 6.20 g, each for a 2-pin width), the contact coefficient of friction was 0.1, and the coefficient of static friction was 0.15. The force of gravity (for acceleration: 9.8 m/s^2) was assumed to act in the vibration direction.

The analysis results for different module-board masses are listed in **Table 1**. They show that higher masses produced larger swings at the module board end as well as more slippage.

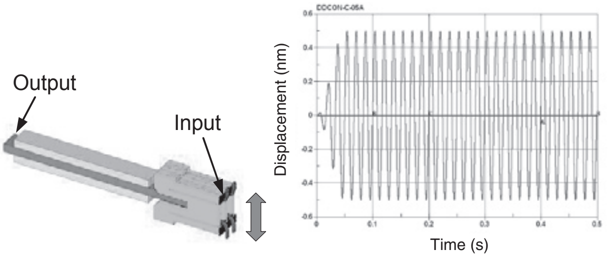


Figure 7
Input/output locations and input waveform.

Table 1
Analysis results for different module-board masses.

Mass (g)	Output amplitude (mm)	Slippage (mm) in 2.0 s
1.55	0.55	0.71
3.10	0.60	1.00
6.20	0.68	1.29

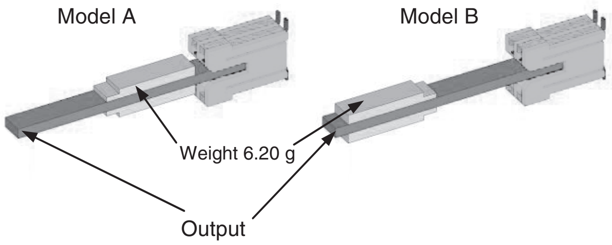


Figure 8
Models with different mass distributions.

3.4.2 Analysis for different module-board centers of gravity

Most module-boards do not have a uniform mass distribution. Therefore, we created two models in which the weight was positioned near the connector (model A) and near the module board end (model B) and compared the effects of their different centers of gravity (**Figure 8**). The input waveform was the same as in Figure 7.

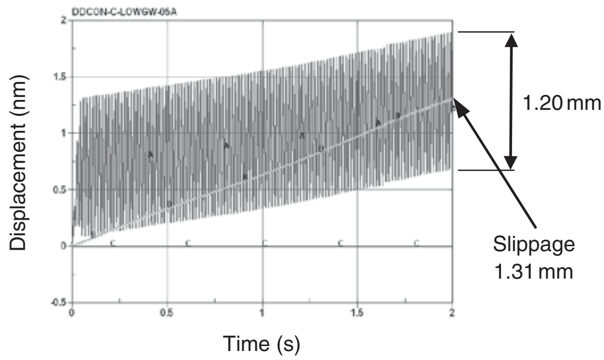


Figure 9
Output waveform (model A).

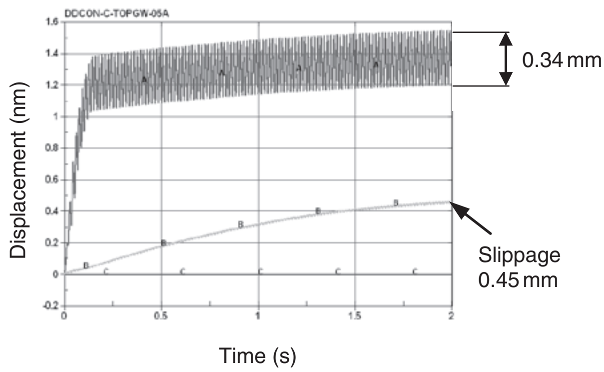


Figure 10
Output waveform (model B).

Output waveforms at the module board end are shown in **Figures 9** and **10**. The output amplitude of model A was large, about 1.20 mm, for slippage of 1.31 mm. In contrast, the output amplitude of model B was small, 0.34 mm, when the slippage was also small (0.45 mm). These results show that the amplitude at the module board end decreased as the center of gravity retreated from the vibration source owing to inertial forces and that the amplitude at the module board end increased as the center of gravity approached the vibration source and inertial forces weakened, making it easier for slippage to occur.

3.4.3 Module board movement caused by contact pins

On determining the behavior of contact pins, we found that the overall force acting on them was in the outward direction in accordance with module board vibration. The forces acting on a set of contact pins holding a module board and the differences among those forces are shown in **Figure 11**. When the module board began to vibrate, slippage started to occur, although only slightly in the section of the board in contact with the contact pins. At this time, forces due to friction and contact pressure acted in the module board's removal and insertion directions alternately. If these alternating forces were equal, the module board would theoretically not slip out off the connector. However, due to the effects of contact-pin shape and gravity, there is an imbalance between these forces, which results in module board slippage due to the pushing pressure from the contact pins.

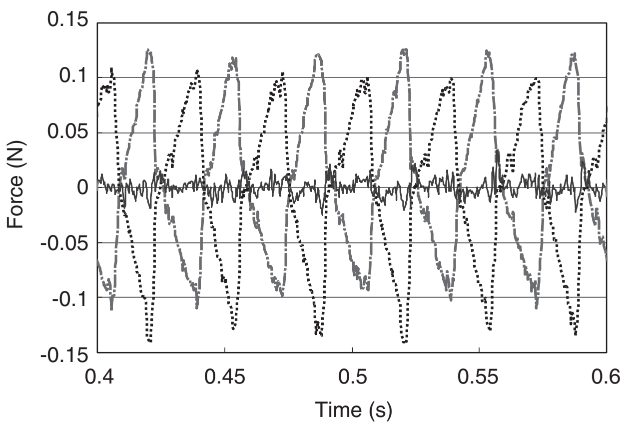


Figure 11
Force acting on contact pins.

3.5 Effects of new simulation technology

The development of technology for simulating the slippage behavior of module boards will provide the following benefits:

1) Slippage comparison tests can be performed when module board or connector specifications change or when rack mounting changes.
2) The slippage mechanism can be visualized, enabling risk tests to be performed when specifications change and early countermeasures to be taken.
3) Connector and mounting design can be performed from the viewpoints of slippage (force and amount) and secure board mounting.

4. Conclusion

In this paper, we introduced technology for visualizing phenomena in the aging behavior of LGA contacts and the slippage behavior of module boards.

In our LGA contact behavior analysis, we created a total model that incorporates creep characteristics in all the materials and enables information necessary for achieving long-term stable connections to be fed back to packaging design. From here on, as packages become larger and mounting by a flat, pressurized system advances, we intend to apply our model know-how and analysis techniques to the testing and optimization of mounting structures.

In our module-board slippage behavior analysis, we clarified the slippage mechanism and showed that slippage characteristics can be analyzed without having to perform reevaluations with actual equipment when equipment structure or module board specifications change. Looking forward, we plan to develop total analysis technology that extends to the rack structure and try to shorten the evaluation time and increase the analysis accuracy.

We showed that, to grasp the behavior of contacts that have a mutually dependent relationship with the mounting structure, rather than using statistical methods it is more effective to visualize the detailed behavior of constituent elements using a composite model that seamlessly reproduces the relationship with peripheral components. This approach is important not only because it aids in understanding the connection mechanism and reliability, but also because it can help optimize mounting design.

Our research and development efforts in this context do not stop at the two application examples introduced in this paper. With the aim of achieving packaging evaluation and packaging design with high added value, we aim to make further advancements in composite-model analysis technology together with Fujitsu's high performance computing (HPC) environment and to make this technology useful for product development.

Makoto Sakairi
Fujitsu Advanced Technologies Ltd.
Mr. Sakairi received B.S. and M.S. degrees in Mechanical Engineering from Yokohama National University, Yokohama, Japan in 1999 and 2001, respectively. He joined Fujitsu Ltd., Kawasaki, Japan in 2001 and moved to Fujitsu Advanced Technologies Ltd. in 2007. He has been engaged in research and development of mechanical simulation technology for electronic equipment and packaging.

Akira Tamura
Fujitsu Advanced Technologies Ltd.
Mr. Tamura received a B.S. degree in Mechanical Engineering from the University of Electro-Communications, Tokyo, Japan in 1986. Since joining Fujitsu in 1986, he has been engaged in research and development of packaging technology and simulation techniques. He moved to Fujitsu Advanced Technologies Ltd. in 2007. He is currently Director for interconnections in the packaging technology center.

Tadashi Tateno
Fujitsu Advanced Technologies Ltd.
Mr. Tateno graduated from the Mechanical Engineering Section of the Department of Engineering at Utsunomiya University, Utsunomiya, Japan in 1986. He joined Fujitsu Communication Systems Ltd. and engaged in design related to production facilities. Since 2000, he has been performing structural analysis based on the simulation technology. He moved to Fujitsu Advanced Technologies Ltd. in 2007.