Reducing TTM Development of Mobile Phones through Practical Simulation

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Today's ubiquitous network society in which communication is possible anytime, anywhere, and with anyone is now witnessing wide-ranging technological development in the fields of PCs, mobile phone terminals, wireless LANs, IC cards, and security. Conversely, these markets have matured in Europe, the US, and Japan, and future growth is expected to be marginal at best and coupled with intensified competition among makers. To secure a dominant competitive position in such a market environment, Fujitsu must satisfy customer demands and must therefore discriminate the design and functions of products, while shortening product development cycles through quality, cost, and delivery (QCD) activities. Fujitsu has introduced a simulation-based approach to development and taken efforts to reduce the Time To Market (TTM) through upstream development that targets quality construction. This paper introduces a practical example of simulation in the development of mobile phones.

1. Introduction

Today's ubiquitous network society, in which information can be freely obtained from networks and communication is possible anytime, anywhere, and with anyone, is now witnessing wide-ranging technological development in the fields of PCs, mobile phone terminals, wireless LANs, IC cards, and security.

Conversely, the markets for PCs and mobile phones have already matured in Europe, the US, and Japan, and we are now seeing a shift toward a market structure centered on replacement demand. In Japan, for example, the number of mobile phone subscribers was 87 million in 2004 and is expected to increase to 97.1 million in 2007. This is an increase of 10.1 million subscribers over the three-year period; but conversely, the replacement demand is expected to be in the range of 44 to 47 million units per year.[1)]

The Japanese market will see accelerated entry by overseas manufacturers in the near future, and with the introduction of the number portability system, competition among manufacturers of mobile phones is expected to further intensify.

To secure a dominant competitive position in such a market environment, Fujitsu must provide products with a discriminating design and functions and meet customer expectations with regard to cost and quality while shortening product development cycles through quality, cost, and delivery (QCD) activities to ensure timely product delivery.

Fujitsu has introduced a scientific development approach that uses simulation and has taken initiatives to reduce the Time To Market (TTM) through upstream development activities that target the building-in of quality.

In this paper we introduce our initiatives toward development that reduces TTM, using the development of mobile phones as an example.

2. Outline of initiatives toward development that reduces TTM

In 2003, we started initiatives toward development that reduces TTM through practical simulation, and in the following year, when we acquired the EMAGINE[2)] integrated electrical design CAD system for the development of mobile phones, we started full-fledged development activities.

The EMAGINE system provides a data integration function that integrates circuit information and implementation information with the various analysis tools that up to now operated as standalone devices, thereby enabling us to build complex simulated environments into the analysis tools with comparative ease.

The introduction of the EMAGINE system gave us the perfect opportunity to establish working groups (WGs) for the analysis of antennas, which is a constant issue in the development of mobile phones, as well as other issues such as static electricity and device ruggedness. The activities of these working groups are described below.

1) Antenna analysis WG

This group started using the ACCUFIELD[3)] electromagnetic field analysis tool in 2003 to analyze the antenna spectrum, radiation pattern, and other details.

In addition, by integrating the ACCUFIELD tool with the EMAGINE system, they established extensive applied technologies and used them to construct models of actual devices. These models enabled them to analyze the influence of components mounted in devices, the influence of the circuit board pattern and grounding, and the influence of electromagnetic interference (EMI) in devices and also perform predictive analysis of the effectiveness of shielding.

2) Static electricity countermeasures WG

The ACCUFIELD tool was used to determine the static electricity discharge routes and analyze the noise-generation mechanism. The results were fed back to the development team members responsible for the construction concept, ground design, component arrangement, and circuit board design at the concept design stage and have helped to improve the static electricity tolerance of mobile phones.

3) Improved ruggedness WG

To improve the pressure yield strength of liquid crystal displays (LCDs) and their drop/shock resistance, this group performed warp analysis of cases and circuit boards. Recently, the use of motion analysis together with warp analysis has become an established method for analyzing the case, resulting in a reduction in the number of components and assured delivery times for molds.

In the following sections, we describe these initiatives using some examples of their implementation.

3. Antenna simulation

In this section, we describe a simulation that was performed to improve the antenna performance of a mobile phone.

The performance demands for mobile phone antennas, for example, a closely defined radiation pattern, are difficult to obtain due to several reasons: 1) the broadband reception requirement, 2) the difficulty in achieving a stable ground plane[note 1)] when the antenna is mounted in a small case, and 3) coexistence with the electronic circuits and flexible printed circuits/connectors that easily provide unwanted electromagnetic coupling.

In particular, because mobile phones now use 3G networks and built-in antennas have become mainstream in keeping with the spread of broadband technology, complex electromagnetic field analysis has become indispensable. In 2003, when the development of 3G terminals was started in earnest, we introduced an electromagnetic field

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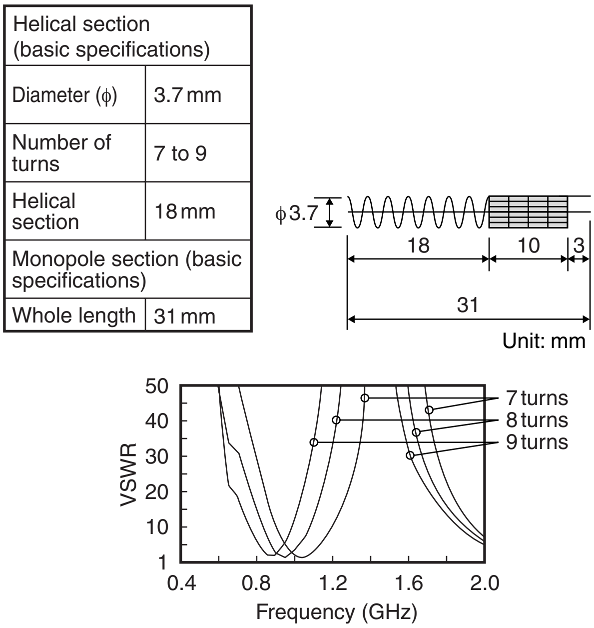
[note 1)] A wide-area ground pattern on printed circuit boards (PCBs) that grounds the electrical elements.

analysis tool called ACCUFIELD that uses Method of Moments (MoM)$^{\text{note 2)}}$ analysis and developed a system for conducting scientific analysis and optimized development.

The helical antenna's characteristics, countermeasures for antenna resonance current, influence of the flexible printed circuits on the voltage standing wave ratio (VSWR)$^{\text{note 3)}}$ and radiation pattern, countermeasures for resonance in the flexible printed circuits, and shield effectiveness are described below using examples of simulations made with ACCUFIELD.

1) Simulation of helical antenna characteristics

The results of the helical antenna simulation are shown in **Figure 1**. The optimal number of turns was determined from the VSWR characteristics for various numbers of turns. By introducing a waveform reduction ratio and dielectric model, we obtained a very close correlation with the actual values.

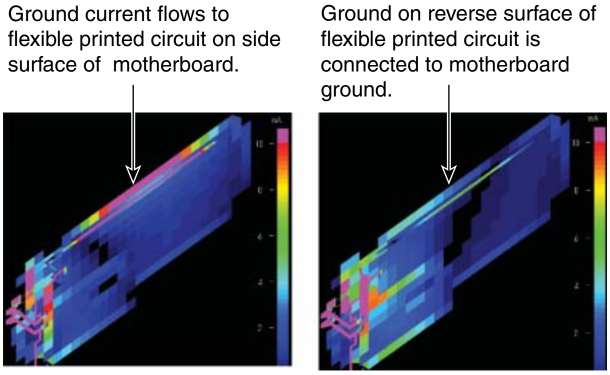


Helical section (basic specifications)	
Diameter (ϕ)	3.7 mm
Number of turns	7 to 9
Helical section	18 mm
Monopole section (basic specifications)	
Whole length	31 mm

Figure 1
Simulation of helical antenna characteristics.

2) Simulation of countermeasures for antenna resonance current

Antenna characteristics vary widely depending on how the antenna is installed in the device. A simulation of the state where antenna resonance current is flowing to the flexible printed circuits mounted on the edge of the motherboard is shown in **Figure 2**. This simulation shows that connecting the ground on the reverse surface of the flexible printed circuit to the ground on the motherboard reduces antenna resonance current.



(a) Before grounding
(b) After grounding

Figure 2
Influence of flexible printed circuit on motherboard edge.

3) Simulations of the flexible printed circuit's influence on the VSWR and radiation pattern

Simulations of the flexible printed circuit's

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note 2) In electromagnetic field analysis, the electric field distribution and electric current distribution are formularized as differential or integral equations. MoM performs numerical analysis by dividing the analysis area into elements and discretizing the integral equations.

note 3) If antenna adjustment has not been performed, some of the electromagnetic wave output from the transmitter is not radiated and a reflected voltage component that propagates back through the distribution cables is generated. The VSWR indicates the degree of this reflected voltage. It is generally assumed there will be no usage problems if the VSWR is 2.0 or less in the HF band and 1.5 or less in the VHF and higher bands. The VSWR is indicated by the following formula:

$$\mathrm{VSWR}=(1+|\rho|)/(1-|\rho|)$$
$$\rho=(Z-Z_0)/(Z+Z_0)=V_2/V_1,$$

where V_1 is the voltage of the progressive wave, V_2 is the voltage of the reflected wave, Z_0 is the characteristic impedance of the transmission line, Z is the load impedance, and ρ is the voltage reflection coefficient.

influence on the VSWR and radiation pattern are shown in **Figure 3**. The resonance current causes the upper null of the VSWR to shift to a lower frequency and also causes null points in the radiation pattern. However, by connecting the ground on the reverse side of the flexible printed circuit to the ground on the motherboard, these influences can be suppressed.

4) Simulation of effects of countermeasure for resonance in flexible printed circuits.

Figure 4 shows the results of an analysis of a significant problem that is affected by the human body when a device is held in the hand; namely, the concentration of the radiation electric field in the lower part of the fixed section due to resonance of the flexible printed circuit connecting the fixed section to the movable section.

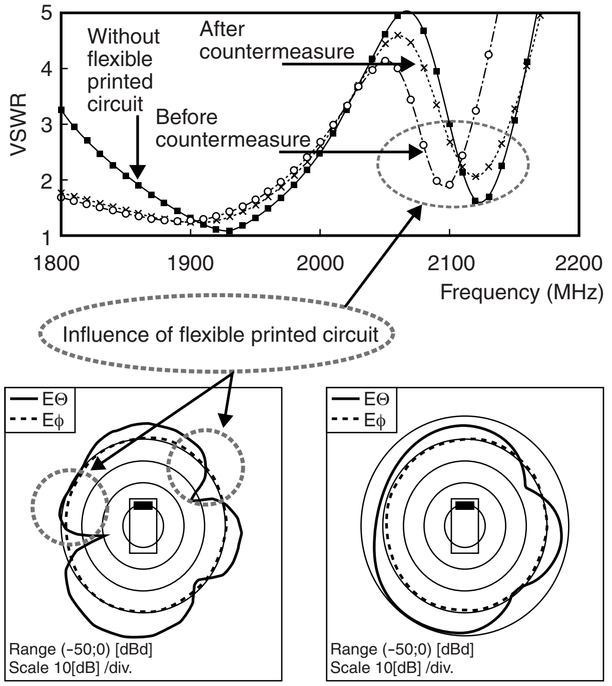
The countermeasure reduced this resonance, and as a result the electric field became more concentrated in the antenna and the distribution of electric field in the lower part of the fixed section was improved.

5) Simulation of shield effectiveness

The ACCUFIELD tool is also applicable to shield design. Mobile phones contain EMI sources such as logic circuits, LCDs, and cameras that are close to the antenna and cause signal interference. For this reason, a suitable EMI shield is essential.

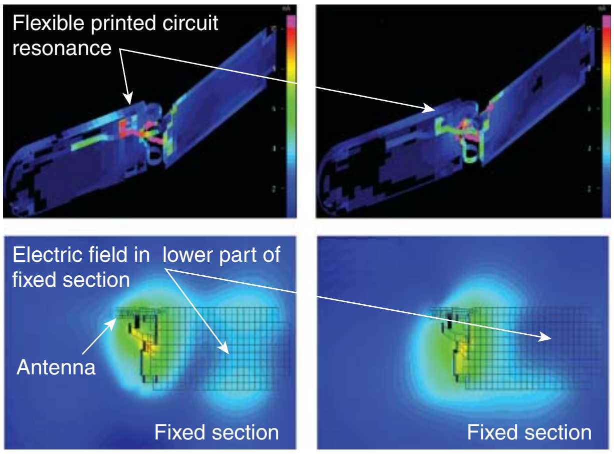
An example of a simulation of the effectiveness of a shield is shown in **Figure 5**. The figure shows that after the ground contact was improved, the shield attenuated the electric field radiated from the motherboard.

As we have shown above, using the ACCUFIELD tool enabled us to not only simu-



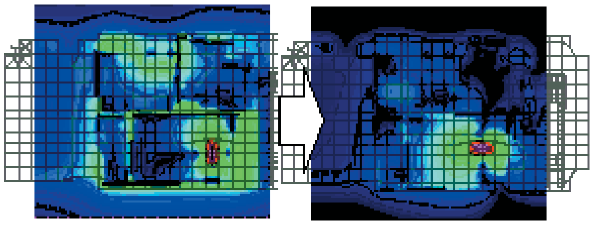
(a) Before grounding (b) After grounding

Figure 3
Simulated influence of flexible printed circuit on VSWR and directivity.



(a) Before countermeasure (b) After countermeasure

Figure 4
Influence of flexible printed circuit resonance on electric field.



(a) Before ground contact improvement (b) After ground contact improvement

Figure 5
Verification of shield effect.

late the characteristics of the antenna itself, but also to forecast the influence of structures and electrical circuits within the device at the initial development stages, thereby preempting the occurrence of problems in later process stages.

4. Simulation of static electricity

In this section, we describe a simulation done to improve quality with regard to static electricity in mobile phones.

Conventionally, static electricity is evaluated by repeating countermeasures based on past experience and know-how and then performing tests. However, it is difficult to visually follow electrostatic discharge (ESD), and countermeasures therefore tend to be performed haphazardly. For this reason, countermeasures vary widely, and problems have occurred because of the low reproducibility in the tests and other factors.

To solve this problem, Fujitsu developed an ESD visualization technology using an electromagnetic field simulator and countermeasure quantification technology. For the electromagnetic field simulator, we used Fujitsu's Poynting[4] software, which enables the representation of ESD transient characteristics using the finite-difference time-domain (FDTD) method.[note 4)]

A simulation model of a mobile phone and a simulation of static electricity based on this model are described below.

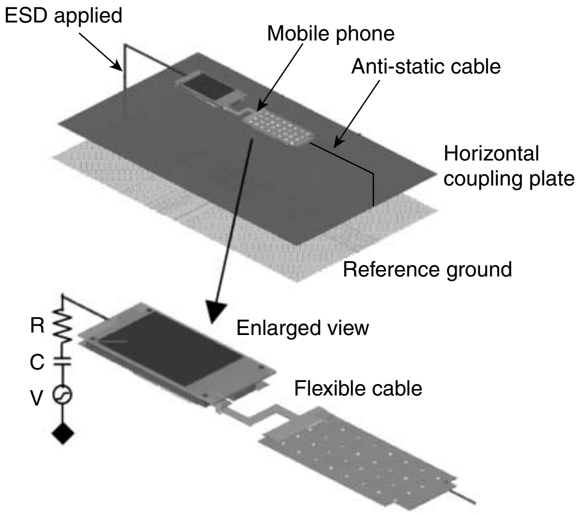


Figure 6
Simulation model of mobile phone.

1) Simulation model of a mobile phone.

A simulation model of a mobile phone is shown in **Figure 6**. The model consists of a motherboard, flexible printed circuit, and other components. After the test environment was specified for the reference ground and the horizontal coupling plate, an ESD wave source was created and applied to the desired locations.

2) Simulation of static electricity

A simulation of static electricity enables us to learn how the noise current generated from the point where an ESD is applied flows through the device and obtain the noise voltage generated on the LSI pins.

- Visualization of noise current caused by ESD

A visualization of the noise current generated by an ESD is shown in **Figure 7**.

Figure 7 (a) shows that before the countermeasure, current is flowing uniformly to the motherboard. Figure 7 (b) shows that after the countermeasure (appropriately separating the motherboard's ground patterns), a guiding passage has been formed and the current flowing to the motherboard has been reduced.

ESD visualization enabled us to accurately

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note 4) A method of calculating the behavior of electromagnetic waves. FDTD uses a difference method to obtain a transient or frequency response solution to Maxwell's equations with regard to time and space. MoM and the finite element method (FEM) can be used for antenna analysis. FDTD, however, is well known for its simple algorithms and superior accuracy, making it the ideal choice for analyzing complex substances, for example, for analyzing the characteristics of different materials in a substance. More specifically, even for dielectric materials, comparatively simple analyses can be done simply by changing constants such as the dielectric constant and the number of time steps. As an antenna analysis method, FDTD has the demerit that it takes more time than MoM and FEM. However, because of advances in computers, it has recently been gaining more attention.[5)-7)]

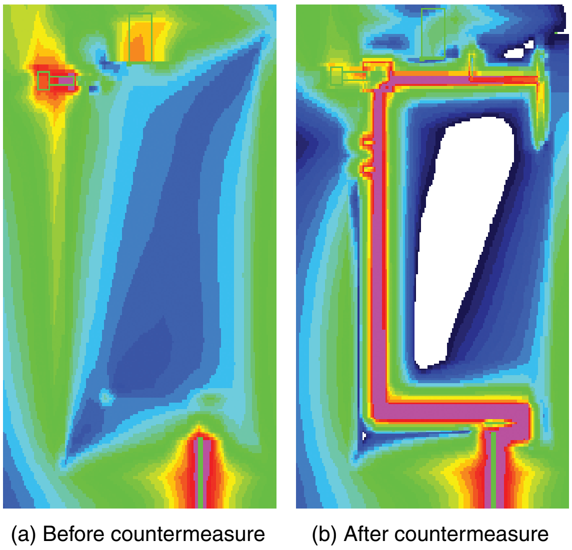

(a) Before countermeasure (b) After countermeasure

Figure 7
Visualization of noise current.

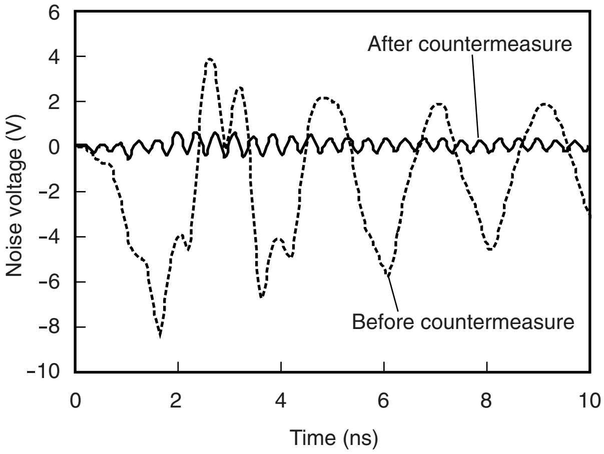


Figure 8
Noise voltage on LSI pin.

grasp the transmission path of the static electricity and thereby improve the LSI pin placement and shield the LSI pins to suppress the influence of ESD.

- Visualization of noise voltage generated by ESD at an LSI pin

The noise voltage generated by an ESD at the pin of an LSI is shown in **Figure 8**. As can be seen, the countermeasure (insertion of a filter) reduced the voltage's peak value.

These simulations enable us to quantify the effectiveness of countermeasures. The simulation results are reflected in the initial development stages, and they have helped eliminate the need for additive countermeasure components after design completion and reduce countermeasure production requirements.

As we have shown above, simulation in the development process is effective for improving design quality. We will expand our use of simulation in the future and implement this technology in the development of other information devices.

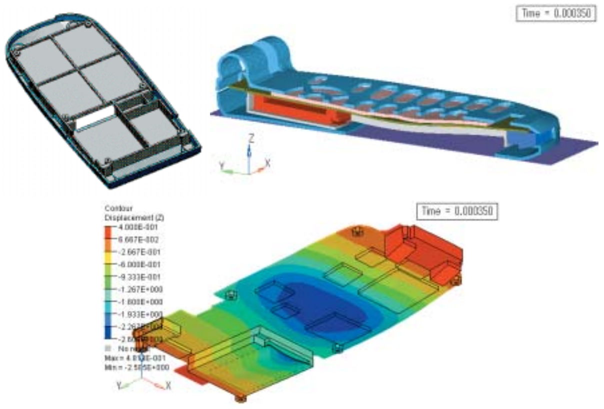
5. Simulation of structure with guaranteed ruggedness

In this section, we describe an example simulation aimed at increasing the ruggedness of a mobile phone.

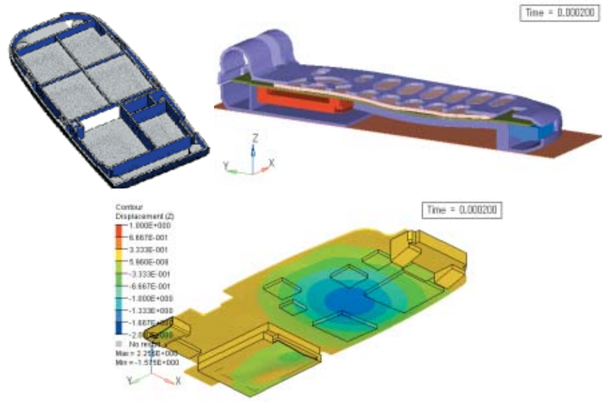
To be competitive, mobile phone manufacturers need to quickly develop and deliver small, lightweight products with high-performance functions. They also need to improve the reliability of their mobile phones and reduce the amount of trial production. It has therefore become necessary to perform simulations that include the load conditions of actual use.

The product development flow is as follows: product concept, product planning, basic design (structural design), detail design, trial production, mass-production, and shipment. To perform device development with trial production requirements kept to a minimum, simulations that act as a link between the basic design stage and detail design stage must be performed. Simulations enable design problems to be solved at the early stages, thereby preventing problems in later stages.

A wide range of verification tests can be performed through the use of simulation. In the movable section of a mobile phone, we can verify the yield strength deformation of the glass when pressure is applied in the vicinity of the LCD, the circuit board yield strength, and the yield strength of a newly mounted component such as a camera.



(a) With chassis



(b) Without chassis

Figure 9
Comparison of PCB strain with and without chassis.

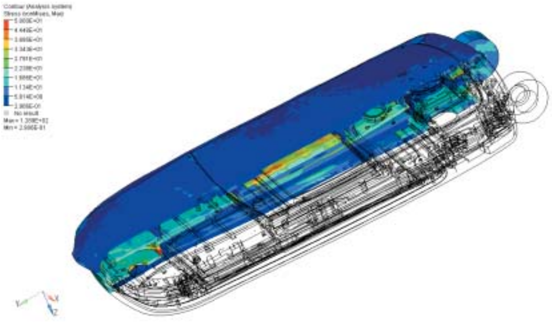


Figure 10
Simulated stress distribution during drop-shock to movable section.

In the fixed section, overall bending, key pressure, and the yield strength of newly mounted components can also be verified.[8)-10)]

Moreover, to guarantee the number of times the device can be opened and closed, we are currently verifying the stress life of the hinges and flexible printed circuits that connect the movable and fixed sections.[11)]

Guaranteed device reliability, particularly from the viewpoint of the user, is being sought for loads other than transient loads such as those applied when a device is dropped. We are currently performing simultaneous simulations of multiple conditions with devices in various states (e.g., open and closed) and various drop angles.

A simulation of the effect of drop-shocks on the PCB and the verification/evaluation of the stress distribution in the mounted components are described below.

1) Simulation of the effect of drop-shocks on the PCB

At the device's initial study stage, we simulated the effects of drop-shocks on the PCB with the internal chassis of the fixed part removed. Examples of the results of these simulations are shown in **Figure 9**. The simulations showed that removing the chassis reduces the maximum displacement in the central area of the PCB by about 40%.

In our study of this structure, by eliminating or solving predicted problem points at an early stage, we were able to perform front-loading, and we tested the suitability of high-strength case materials.

2) Verification/evaluation of stress distribution in the mounted components during drop-shocks

A simulation of the stress distribution in the mounted components of the movable section during a drop-shock is shown in **Figure 10**.

The simulation shows that the maximum stress is applied to the LCD glass around the hinge and there are no problems with the components' yield strengths.

Before completing the detail design, we review the stresses applied to each component by external shocks and provide countermeasures for failures and speedy feedback to the design engineers.

We have reached the point where we can use our stress simulation technology for verifying not only static problems, but also the dynamic problems described in the above examples.

To realize even higher precision in our simulations, we are studying the physical properties of non-linear materials and accumulating precision verification data using actual devices.

Through these simulations, we have established design methods aimed at LCD pressure yield strength and drop-shock resistance. The technologies for new, high-density mounting structures that realize ultra-slim designs and the technologies for hinge structures that enable diversified applications are becoming firmly established; however, an issue that has emerged in recent device development is the ability to respond to requests for even more advanced designs.

Through simulations for each development model and the experience accumulated from integration with actual models, we have reduced the number of components, designed a simpler structure without an internal chassis, and reduced the production costs. In addition, by using simulation, we have reduced the number of “cut & try” experiments in the trial production process and reduced the device development time.

6. Results

By integrating the divisions responsible for concrete development issues with divisions that have highly specialized knowledge about simulation technology, we are now able to establish a simulation-based approach to development, which previously was difficult to do. We realized effective, high-quality development of a mobile phone, starting at the initial development stage, by performing verification and design based on logical analysis, which in turn led to a reduction in the TTM.

Moreover, by establishing a system for simulating static electricity, we stabilized quality at an early stage and thereby reduced the development costs related to static electricity countermeasures to a fraction of the previous year’s costs.

In our initiatives to improve ruggedness, the completion of simulation in the upstream development stages enabled us to perform activities that boosted the front-loading percentage. As a result, we were able to improve the ruggedness from the initial shipment stage, which led to a reduction in the number of components needed for countermeasures and a reduction in complaints from end users.

7. Conclusion

In this paper, we introduced some simulation examples to explain our antenna analysis, static electricity countermeasure, and improved ruggedness initiatives for reducing the TTM for mobile phones.

The steady progression of development according to the development plan is an important factor in reducing TTM. However, the occurrence of unexpected failures that need to be examined will delay the TTM. Therefore, it is extremely important to handle foreseeable issues and problems in the upstream development stages, and therefore simulation that can reproduce virtual conditions is extremely effective as a substitute for the trial production of devices.

The follow-up analysis of problems that surface in the trial production stage still accounts for a comparatively large share of development work.

In the future, we plan to further refine our analysis method for mobile phones and establish its practical usage in the upstream development stages.

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