Technological Initiatives for Water-resistant and Thin Smartphones

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Smartphones are becoming larger as they start to contain higher-capacity batteries that allow for more sophisticated functions and longer operating times, and their screens are becoming larger so that the displayed items are easier to see. At the same time, however, people are essentially carrying them around for use in daily life, and this means smartphones must be easy to hold, compact and water-resistant, and be able to be used free of worry since they are not easily damaged. By satisfying these conflicting requirements and enhancing the design aesthetics as well, smartphones with improved overall marketability must be developed to meet the needs of the market. In order to develop salable smartphones, a product which is becoming diversified, it is important to have technological development in line with individual product concepts. Accordingly, we have been working on giving smartphones a water-resistant structure that suits their thinness and design while avoiding the restrictions that an ordinary water-resistant structure places on a phone design in terms of its size, shape and such like. We have also worked to make each and every component as thin as possible, and give smartphones a more efficient component layout. This paper presents technologies for achieving water-resistant and thin smartphones, which are in the market environment described above, and approaches to having those technologies further evolve.

1. Introduction

Fujitsu has continuously developed products that adopt the latest technologies in terms of thinness and water-resistant properties ever since the release of the thinnest model of the series F902iS in 2006 and water-resistant handset F703i in 2007, among feature phones. In 2011, we released the world's thinnest water-resistant smartphone models—the DOCOMO NEXT series ARROWS μ F-07D and au ARROWS ES IS12F—and they are only 6.7 mm thick.

In the process, the water-resistant performance evolved from IPX5/IPX7[note1)] to IPX8[note2)], the IP5X[note3)] dustproof rating has also been met, and the performance further developed to allow the phones to be used in the bath. Smartphones have also become thinner by 5.2 mm, going to 6.7 mm from 11.9 mm in one year between the winter 2010 and winter 2011 models.

This achievement required, in the development transition from feature phones to smartphones, new initiatives for water-resistant and thin structures to accommodate structural changes due to the increasingly

note1) IPX5 refers to a handset's ability to continue functioning as a telephone when sprayed with water at a rate of 12.5 L/min from a distance of approximately 3 m in all practicable directions using a nozzle with an inner diameter of 6.3 mm for at least 3 min. IPX7 refers to a handset's ability to continue functioning as a telephone when it has been sunk in still tap water at normal temperature and a depth of 1 m, left to stand for approximately 30 min, and then taken out.

note2) At Fujitsu, IPX8 refers to a handset's ability to continue functioning as a telephone when it has been immersed in tap water at normal temperature and a depth of 1.5 m, left to stand for approximately 30 min, and then taken out.

note3) IP5X is a protection rating and specifies that a handset should function as a telephone and remain safe to use when it has been put into a device containing dust particles with a diameter of up to 75 μm, which are stirred for 8 h, and then taken out.

higher-capacity batteries and larger screens.

This paper presents technologies for making Fujitsu's smartphones water-resistant and thin and the future evolution of technologies and performance.

2. Development of smartphone water-resistant structures

Smartphones have structures that prevent water from entering them, and this is achieved by compressing a packing material, which is made of rubber, or coating the relevant area with double-sided tape. The water-resistant structures using packing are mainly adopted for battery covers, interface caps and between the top and bottom cases. Water resistance achieved by double-sided tape is used for touchscreens and camera panels, which are characteristic components that smartphones have.

This section describes the structure to make battery covers water-resistant by using packing, which evolved along with the greater capacity of battery that smartphones now have to meet consumer needs.

2.1 Concept of water-resistant structures for battery covers

Water-resistant structures, achieved by compressing packing material, require that the covers are rigid and that the cases are sufficiently robust to withstand the elastic force of the packing and maintain a water-resistant performance. Battery covers are thin plastic plates and they are not very rigid, which makes it difficult to maintain a water-resistant performance with one battery cover alone. Accordingly, feature phones are provided with double structures consisting of metal and plastic plates to ensure rigidity, where the metal plate allows the phone to be water-resistant and the plastic cover gives a good appearance.

Smartphones, however, have large and high-capacity batteries and this increases the areas of their battery covers. As battery covers' area increases, the water-resistant area expands and requires higher rigidity. The method of making the metal and plastic plate thicker to ensure rigidity causes a weight increase and prevents products from having a thinner structure.

For the development of smartphones, it becomes necessary to have new water-resistant structures for battery covers to accommodate high-capacity batteries.

Amid these circumstances, we conducted a study on the two themes of thinning and narrowing for the development of water-resistant structures for battery covers. Our aim was to improve smartphones which are becoming diversified in various aspects, including battery capacity, screen size, ease of holding and use, and size and thickness reduction.

For battery covers that allow phones to be made thinner, the vertical compression method, in which packing material is compressed in the vertical direction, has been adopted. For battery covers that allow phones to be made narrower, the horizontal compression method, in which packing material is compressed in the horizontal direction, has been used.

2.2 Development of water-resistant structures for battery covers

In the vertical compression method, the packing is compressed in the direction which the battery cover opens and closes. Battery covers use thin-wall molding technology to make them thinner and have very low rigidity. In order to ensure that such covers can withstand the elastic force from the packing compression, prevent the battery cover from lifting, and ensure a water-resistant performance under these conditions, we have increased the number of catches to increase the fitting force between the battery cover and case. However, simply increasing the number of catches makes it harder to attach and detach the battery cover. Accordingly, we have made full use of strength analysis to achieve both water resistance and ease of attachment and detachment, and optimized the balance between the water-resistant performance, fitting force of the catches, and operability. We have thereby successfully realized a battery cover that allows phones to be made thinner without affecting the ease of cover attachment and detachment.

For the horizontal compression method, we adopted insert molding technology by liquid injection molding (LIM) to integrate the packing into the battery cover. With insert molding, a battery cover separately molded is set (mounted) on the mold of the packing and liquid rubber is poured into the mold of the packing so that it becomes integrated with the cover. To mold the packing, rubber is poured into a mold at a high temperature so that it is closely attached to and integrated with the battery cover. The temperature at which the packing is molded caused the battery cover temperature to rise, which made it difficult to ensure a high level of quality for the external surface, and it was not easy to use this method. Nevertheless, by analyzing how to adjust the mold temperature when molding the packing material, how temperature is transferred to the battery cover, the liquidity of the packing, and the effect of temperature on the coating distortion of the external surface, we could reduce the stress and distortion on the external surface. We successfully developed a battery cover that allows phones to be made narrower.

In this way, we have incorporated the latest manufacturing technologies and made use of analysis technologies to provide water-resistant structures optimized for smartphones, and thereby created unique products that combine reduced size and thickness with design aesthetics (**Figure 1**).

3. Development of world's thinnest water-resistant smartphone

With feature phones, we have continuously held the No. 1 thin mobile phone manufacturer position but the shift to smartphones has caused us to a struggle against the competition in the global markets. By merging its mobile phone handset department with Toshiba, Fujitsu released the first water-resistant smartphone model T-01C with a thickness of 11.9 mm in 2010. A competitor's product released around the same time was as thin as 7.7 mm, although it was not water-resistant. To win back the title of No. 1 thin mobile phone manufacturer, we set about developing the thinnest water-resistant smartphone not only in Japan but also in the world.

This section describes our initiatives for developing the world's thinnest water-resistant smartphone.

3.1 Smartphone thickness composition

As their basic structure, smartphones are composed of six constituents in terms of thickness: a touchscreen, display, backbone component, circuit board, battery and battery cover, in this order from the display screen side (**Figure 2**).

Of these constituents, only the backbone component and battery cover are controlled by Fujitsu from design to manufacturing, and the others are products of component manufacturers.

We have formulated three strategies to achieve the world's thinnest phone: make structural components thinner, adopt thin components, and reduce thickness by improving mounting efficiency.

1) Thinning of structural components

The backbone component is literally a structural component that supports the entire device. For this component, hybrid molding technology, in which a large metal plate is set on the mold of the outer casing for integrated molding, is used and the metal plate to serve as the backbone is provided to cover the whole area of the outer casing. This ensures the entire device is robust. Conventionally, the backbone metal plate was designed to be 0.3 mm thick so as to ensure strength, but this has now been reduced to 0.1 mm. As the robustness of the entire device naturally decreases when it is made thinner, we have used a composite metal plate with a 0.1 mm-thick planar section and

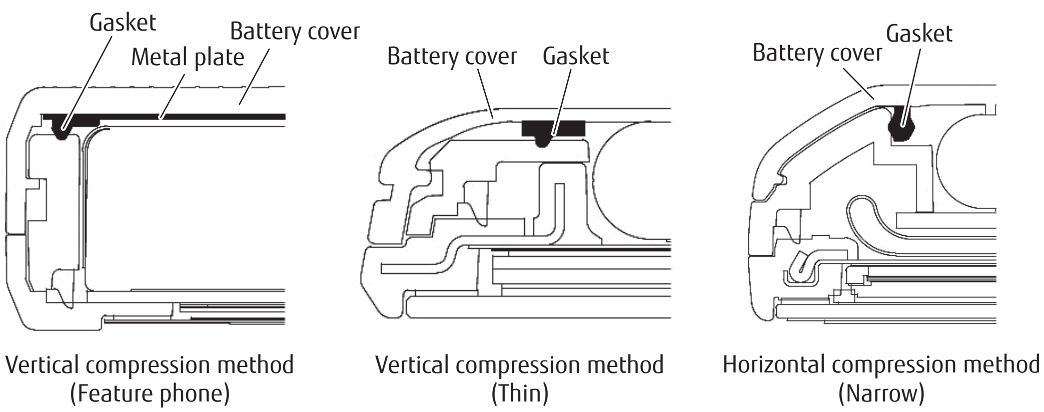

Figure 1
Making battery cover water-resistant.

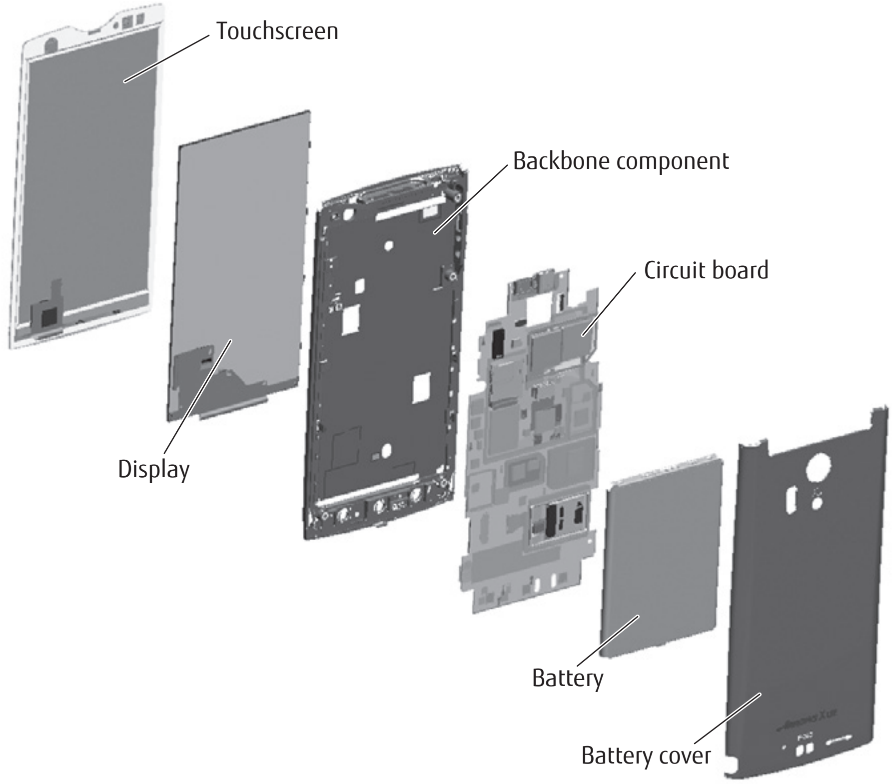

Figure 2
Smartphone thickness composition.

0.3 mm-thick side wall, welded together for hybrid molding, and thereby limited this decrease in rigidity (**Figure 3**).

For the battery cover, we have pushed plastic molding to its limits. With the size of a smartphone battery cover, 0.6 mm is generally regarded as the limit of molding thinness but we have attempted to achieve a thickness of less than 0.6 mm only for the area that extends over the battery. We have selected materials suited for thin-wall molding; optimized the molding injection speed, pressure and temperature by flow analysis; and, for the actual molding, carried out joint development with a manufacturer that provides molds of high-rigidity materials and owns technology for their precision machining to successfully reduce the battery cover thickness to 0.45 mm.

2) Adoption of thin components

We have taken part in the commercialization of the battery, starting with the manufacturer development phase, to test the limits of manufacturing batteries, and made them as thin as possible. In addition, we have taken advantage of the large size of a smartphone screen to provide a large projected area, and thereby successfully made a thin and high-capacity battery.

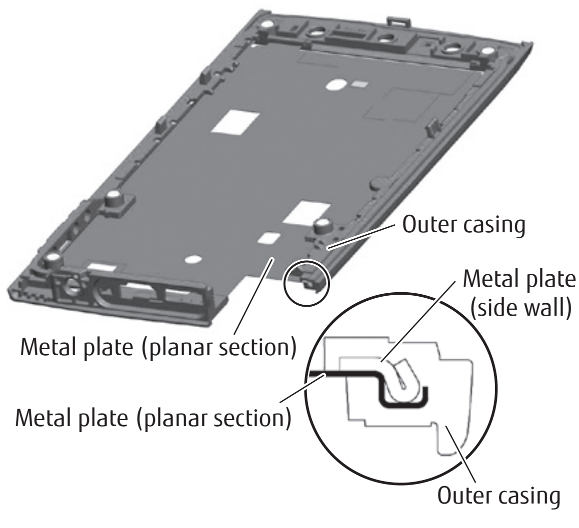

Figure 3
Backbone component.

We have worked to make phones both thin and strong by using an organic EL display, which is suitable for thin devices, for the display and especially hardened glass for the touchscreen and carefully selected components.

3) Reduction of thickness by improving mounting efficiency

With a two-layer structure including a circuit board and battery, increase of device thickness is unavoidable. To deal with this issue, we have considered a one-layer structure built by mounting the circuit board and battery side by side. While the mounting area of the circuit board is decreased by laying it adjacent to the battery, we have achieved high-density mounting by introducing the latest manufacturing facilities, adopting precision soldering technology, and using ultra-small components to accomplish a one-layer structure. As a result, the circuit board, which is a component that contributes to the thickness of a phone, has been eliminated and the phone has been made thinner.

3.2 Arrival of world's thinnest water-resistant smartphone

The three strategies for developing the world's thinnest phone worked in the sense that they successfully allowed us to build a framework for making devices thinner. We achieved this by identifying the respective challenges and studying and implementing measures to overcome them. However, simply making a device thinner causes the entire device to be less robust. Accordingly, we have made use of a technique that integrates Fujitsu's structural design and analysis technologies and carried out strength analysis. This analysis was done in the phase of designing the basic structure using 3D-CAD and the weak points were identified and fed back to the design. By repeating this process of analysis and design feedback, it helps us to ensure a device's robustness. In addition, giving a device the minimum required reinforcement has led to the development of a thin device without affecting its ease of use or design aesthetics. Furthermore, we have adopted ultra-tough guard coating with improved abrasion resistance for the outer casing to combine thinness and strength.

This is how the world's thinnest, 6.7-mm ultra-slim water-resistant smartphones, the DOCOMO NEXT series ARROWS μ F-07D and au ARROWS ES IS12F, have come into existence.

4. Evolution of water-resistant property and thinness

Smartphones are characterized by their simple appearance with a touchscreen extending over one side, and this makes it difficult to differentiate them by their shape, as with feature phones, and water-resistant property and reduced size and thickness are already part of their basic features. However, to stay one step ahead of our competitors in this smartphone age, we need to differentiate our products by their shape and must inevitably continue to refine technologies so that water-resistant properties and thinness can further evolve.

As an example, we are working on technological innovations such as reducing size and thickness by using a water-resistant material different from packing, and reducing size by means of narrow-width adhesion technology.

As approaches to reducing costs, we are putting even more energy than before into reducing the number of prototypes by manufacturing items without producing any product, mainly via 3D-CAD and analysis technology, and reducing the development and component costs by making use of technological development in cooperation with manufacturers and component manufacturers.

In this way, we are committed to pursuing both improved marketability, by evolution of water-resistant properties and thinness, and cost reduction.

5. Conclusion

This paper has described technological initiatives for and the evolution of water-resistant properties and thinness in Fujitsu's smartphone development.

As the Japanese mobile phone market is making a shift toward smartphones and overseas manufacturers are entering and becoming increasingly powerful in the domestic market, we are now convinced that continuous technological innovation to differentiate our products from those of our competitors is a must for competing in the market.

In order to survive and win in the global market and continue to offer better products to users in the future, we must comprehensively improve the marketability of our products, including ease of use and holding and design aesthetics, in addition to water-resistant properties and thinness. Accordingly, we will appropriately incorporate user needs through marketing and strictly set technological goals from a customer-oriented viewpoint.

We intend to continue working for further technological innovations in the future to bring appealing, trend-leading smartphones to the market.

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