

Large Size In-Cell Capacitive Touch Panel and Force Touch Development for Automotive Displays

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SUMMARY We have developed the world's largest 16.7-inch hybrid in-cell touch panel. To realize the large sized in-cell touch panel, we applied a vertical Vcom system and low resistance sensor, which are JDI's original technologies. For glove touch function, we applied mutual bundled driving, which increases the signal intensity higher. The panel also has a low surface reflection, curved-shaped, and non-rectangular characteristics, which are particular requirements in the automotive market. The over 15-inch hybrid in-cell touch panel adheres to automotive quality requirements. We have also developed a force touch panel, which is a new human machine interface (HMI) based on a hybrid in-cell touch panel in automotive display. This study reports on the effect of the improvements on the in-plane variation of force touch and the value change of the force signal under different environment conditions. We also introduce force touch implemented prototype.

key words: in-cell touch panel, low-temperature polysilicon TFT

1. Introduction

The increasing demand of autonomous driving in recent automotive markets has led to the improvement in car interior design. The importance of the touch panel as a human machine interface (HMI) is increasing; in particular, the demand for large size, curved-shaped, and non-rectangular shaped displays is increasing.

This study proposes to replace amorphous silicon (a-Si) TFT panels with low-temperature polysilicon (LTPS) TFT panels that offer high functionality. LTPS TFT has a high mobility, resulting in high resolution owing to the reduced TFT size and a built-in circuit in a panel that can reduce the number of gate driver and source driver ICs [1].

2. In-Cell Capacitive Touch Panel Method

LTPS TFT must have an in-built circuit for integrating touch functions in the panel. The development of touch panel in-cell technology has been accelerated with the increasing use of LTPS TFT. In-cell capacitive touch panels are roughly classified into hybrid in-cell and full in-cell touch panels [2]–[4].

Figure 1 shows a comparison of hybrid in-cell touch panels and full in-cell touch panels. Hybrid in-cell touch panels use a mutual sensing method. This panel comprises a receiver sensor (Rx) on the back side of the color filter

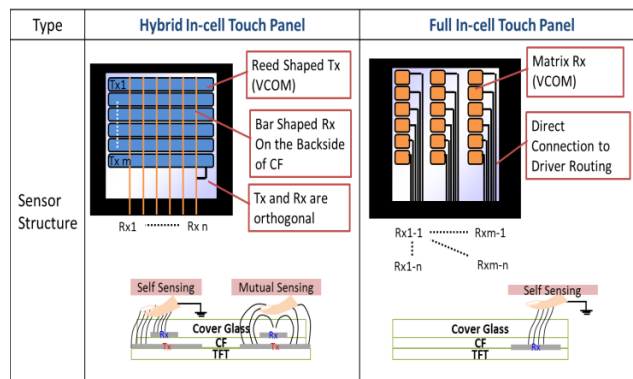


Fig. 1 Type of in-cell capacitive touch method

glass and a driving transmitter (Tx) with a Vcom (common electrode for display drive) layer on the TFT glass. A self-sensing method can also be realized using Tx and Rx electrodes as sensor electrodes. Hybrid in-cell touch panels can detect a floating conductor via mutual sensing and self-sensing. Therefore, it is possible to track a finger on the panel surface where water is attached.

In contrast, full in-cell touch panels only use the self-sensing method. Full in-cell touch panels are cost-effective because Rx electrodes are configured in the Vcom layer, which eliminates the needs for the flexible printed circuit mounted on the back side of the color filter glass.

In full in-cell touch panels, Rx electrodes located in a panel must be directly connected to the in-cell touch display drive IC. Therefore, the number of Rx electrodes considerably increases with increasing screen size. Therefore, hybrid in-cell touch panel is more advantageous than full in-cell touch panel when considering application to larger panels.

3. New Technologies and Results

3.1 16.7-inch Hybrid In-Cell Touch Panel Development

We have promoted the development of conventional hybrid in-cell touch panels in the mobile phone market [5], [6]. In the development of the 16.7-inch hybrid in-cell touch panel, we have applied advanced hybrid in-cell technologies, which involve vertical Vcom systems and low resistance materials on the top and bottom segments of the source line, as shown in Fig. 2.

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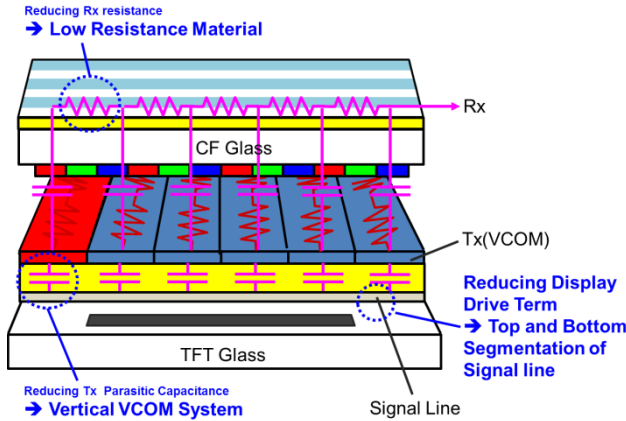


Fig. 2 Applied technologies to 16.7-inch hybrid in-cell touch panel

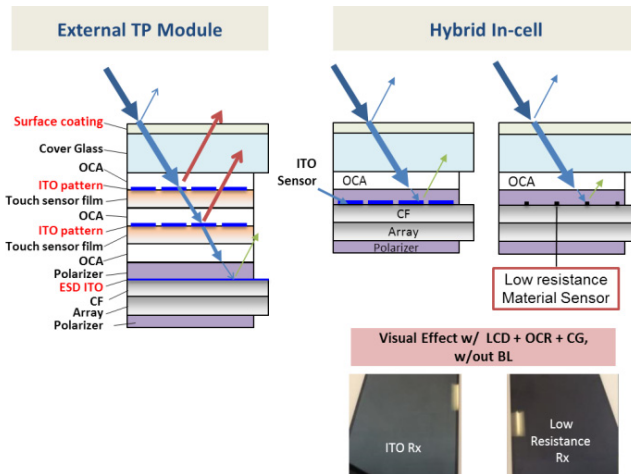


Fig. 3 Comparison of surface reflection between external TP module and hybrid in-cell

The vertical Vcom system divides the Vcom (Tx) in a parallel direction to the source line. Divided common electrodes function as transmitter electrodes (Tx). The parasitic capacitance between the Vcom and the source line can be reduced by modulating the source line with the Vcom voltage. As a result, the RC constant of Tx electrodes can be reduced. The ITO (indium tin oxide) layer to protect the panel elements from being destroyed by the ESD (Electro-Static Discharge) is conventionally used as Rx electrodes. We have replaced the ITO with a low resistance material. Application of the low resistance material has the effect of lowering sensor resistance.

Furthermore, there is also the effect of reducing reflection on the back side of the color filter glass, more so than the external touch module and conventional hybrid in-cell touch panels, as shown in Fig. 3.

In order to further shorten the driving period, we divided the signal lines into top and bottom segments. By using this method, the upper and lower sides of the panel are simultaneously written. Therefore, it is possible to shorten the display drive time by half.

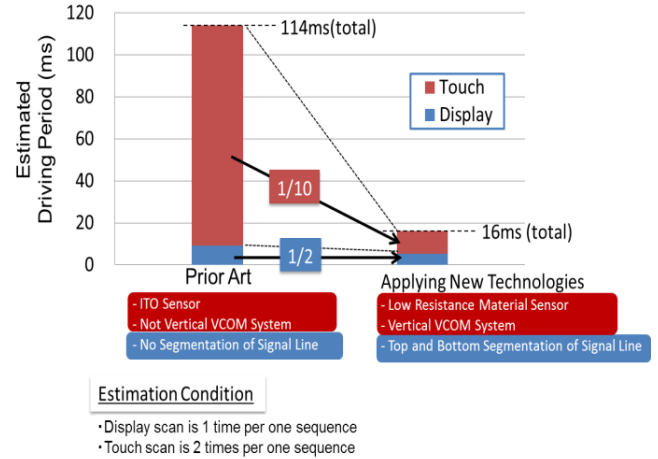


Fig. 4 Estimation of total driving period

Figure 4 shows an estimation of the total time of touch and display driving period. In prior art of our hybrid in-cell touch panel, the total period was estimated as 114 ms. Here the touch driving period could be reduced by 9/10, by applying the low resistance material as Rx electors and the vertical Vcom system. Display driving period could be reduced by half by applying the top and bottom segmentation of the signal line system. As a result, a total period of 16 ms was accomplished.

Mutual bundled driving, which is one of the hybrid in-cell evolution technologies previously developed [5], [6], is also applied to the 16.7-inch hybrid in-cell touch panel. Mutual bundled driving is important to support stylus pens; however, there is not much demand for this in the automotive market. Meanwhile, there is a great demand for glove support and using plastic materials for the cover lens.

In the case of glove touch, the distance between fingers and Rx electrodes becomes larger than in surface touch where the panel surface is touched by a finger. Plastic material typically has a lower dielectric constant compared to glass material. Therefore, in order to support glove touch with a plastic cover lens, the signal intensity needs to be strengthened. Figure 5 shows the principle of mutual bundled driving. Mutual bundled driving makes the Tx electrode width half of the conventional Tx width. Three narrow Tx electrodes are bundled and driven at the same time. The bundling of Tx electrodes is shifted by two, and Tx electrodes are driven in the same way. The signal intensity becomes 1.5 times higher and the sensor pitch resolution is the same as the surface driving by using mutual bundled driving.

We evaluated glove touch performance by using the bundled drive described above. The glove types used for the evaluation are shown in Fig. 6. Table 1 shows the evaluation result when the cover thickness and the cover material (glass or plastic) are changed. In the case of glass, all types of glove can be detected with 3 mm cover thickness. In the case of 2 mm plastic thickness, which is made of polycarbonate, all types of gloves can be detected when the Tx amplitude voltage is 5.5 V. In the case of 3 mm plas-

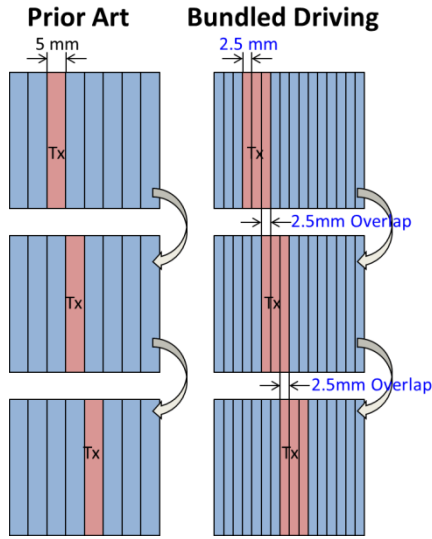


Fig. 5 Principle of Mutual bundled driving

Type	* Thickness / Effective ** relative permittivity	Type	Thickness / Effective relative permittivity
	 t: 3.0mmt ϵ_r : 3.32		 t: 2.0mmt ϵ_r : 2.05
	 t: 2.0mmt ϵ_r : 2.01		 t: 1.1mmt ϵ_r : 3.02
	 t: 1.7mmt ϵ_r : 2.34		 t: 0.6mmt ϵ_r : 1.75

* Thickness :
The value of Glove's total thickness which is the thickness of the glove in the compressed state by using a slide gauge divided by two.
** Effective relative permittivity :
The calculated value using the signal value when the surface of the prototype was touched with the Glove, the thickness of the Glove, and the signal value when the pseudo finger is placed on the acrylic resin (relative dielectric constant = 3.5) of known thickness (thickness: 4 mm to 7 mm) placed on the panel surface

Fig. 6 Glove type

tic thickness, all types of gloves can be detected when the Tx amplitude voltage is 7.5 V.

One of the negative effects of increasing glove detection is the detection of non-touch finger above the panel, called hover detection. The signals of gloves and hovers correlate with the ratio of the effective relative permittivity of the glove, the thickness of the glove, and the relative permittivity of the airgap ($\epsilon_r = 1$). Among the gloves used for evaluation, Leather2 had the lowest signal strength. When hover's airgap was 1.2 mm, the signal strength of the hover was equal to that of Leather2. That is, if a finger is placed above the panel and the airgap is less than 1.2 mm, there is a risk of hover detection.

Table 2 shows the specifications of the prototype. Figure 7 shows a prototype of the 16.7-inch hybrid in-cell touch

Table 1 Glove touch evaluation result x

Glass/Plastic *	Tx Amplitude	Leather1	Leather2	Ski	Industrial1	Industrial2	Golf
Glass: 1.1 mmt	5.5 V	o**	o	o	o	o	o
Glass: 2.2 mmt	5.5 V	o	o	o	o	o	o
Glass: 3.3 mmt	5.5 V	o	o	o	o	o	o
Plastic: 2.0 mmt	5.5 V	o	o	o	o	o	o
Plastic: 3.0 mmt	5.5 V	x***	x	x	x	o	o
Plastic: 3.0 mmt	7.5 V	o	o	o	o	o	o

* Plastic: Made of Polycarbonate

** o: Broken line doesn't occur. Line can be drawn smoothly.

*** x: Broken line occurs. Line cannot be drawn smoothly.

Table 2 Specification of prototype

Items	Specification
Panel Size (@ Largest Size)	16.7 inch
Number of Pixels (@ Largest Size)	1800RGB x 2880
Resolution	203 Pixel Per Inch
Curvature	Radius: 800 mm
Panel Shape	Hexagonal Shape
Backplane Technology	Low-Temperature Polysilicon TFT



Fig. 7 A prototype of the 16.7-inch hybrid in-cell touch panel

panel. We also succeeded in realizing a curved-shaped panel with curvature of 800 mm and a hexagonal type panel. Furthermore, we also developed an over 15-inch hybrid in-cell touch panel and it passed the in-vehicle quality requirements.

3.2 Force Touch Panel Development

Until now, we have been developing an improvement to the touch performance of an in-cell touch panel. In addition, in

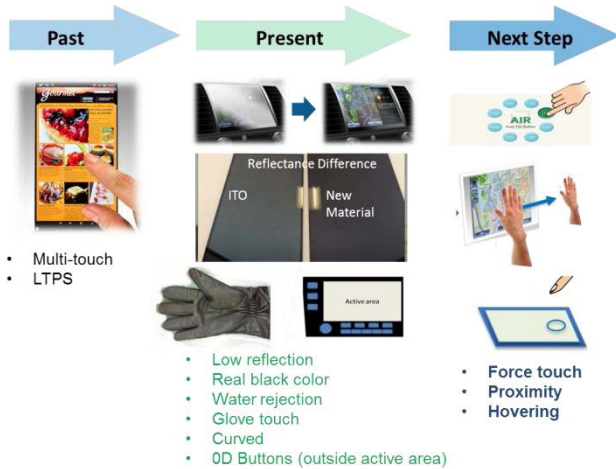


Fig. 8 In-cell touch panel technology evolution of JDI

the future, we are going to develop a new HMI, such as force touch technology, which detects pressure and incorporates proximity technology, which detects hands approaching or gesturing in the air, and hover technology, which detects finger coordinates in the air, as shown in Fig. 8. The assumed use-case situations are as follows:

- First step: the system is activated when a hand approaches a few centimeters above the screen
- Second step: the system selects a rough menu and wakes up an application by gesture or finger coordinates above the screen
- Third step: the system selects a detailed menu by finger touch
- Final step: the system confirms the final selection by finger pressure

To realize the use-case written above, we are aiming to develop the total system technology by combining the technologies of proximity, hover, and force touch. At this time, we will report on the development of force touch.

Figure 9 describes the operation principle of force touch. The system configuration is based on the conventional hybrid in-cell touch panel configuration. Rx electrodes for force touch are added to the bottom of the backlight materials. When a pressure is applied to the glass surface, the glass bends and the air gap changes. Force touch uses the capacitance change due to this air gap change. Since the amount of deflection of the glass, i.e., the amount of air gap change, depends on the pressure, it is possible to calculate the pressure from the capacity change.

Both surface touch and force touch use the mutual sensing method. In the surface touch case, the Vcom is used as a Tx electrode and the layer on the back side of the color filter is used as Rx. On the other hand, force touch uses the same Tx electrodes and a newly added layers on the backlight materials as Rx electrodes for force touch. Our force touch driving method has two benefits. The first is that additional time is not required because it is possible to detect surface touch and force touch at the same time. The second is

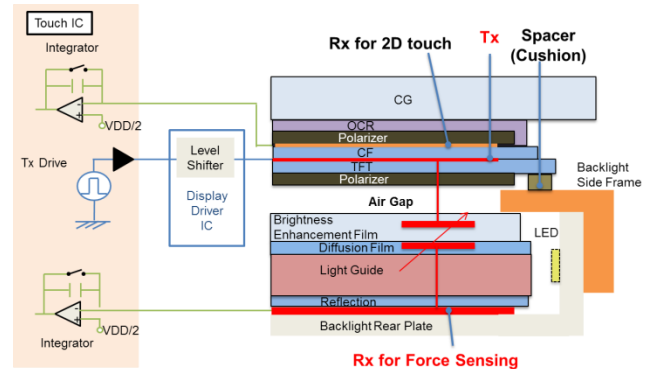
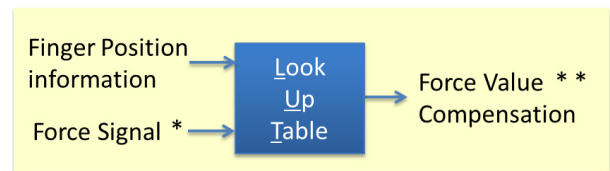


Fig. 9 Operation principle of force touch.



* Force Signal: Delta value when putting a weight and when not putting a weight.

** Force Value: Compensated from force signal. It is set the same value for the same weight

Fig. 10 Procedure of force value compensation

that the signals of a finger and force touch can be separated because the capacitance detection locations of surface touch and force touch are different. In the case of self-sensing, such as in full in-cell, the signals of a finger and force touch are merged. Therefore, it is necessary to separate them.

This force touch detection method has an in-plane dispersion of force signal. The amount of deflection (σ) depends on the distance between fulcrums (L) of the module, the strength of the press (W), and the elastic modulus of the module. Longer “ L ” and larger “ W ” make “ σ ” larger. Therefore, even if the strength of the press is constant, the amount of deflection varies depending on the location of the panel. The center of the panel is easy to deflect, and the edge of the panel is harder to deflect.

Figure 10 illustrates a procedure to compensate the in-plane variation of force signal, where the force value is compensated from the force signal and finger position information. The Look Up Table is preliminarily made by the following procedure: first, known weights are put on a panel with several positions, and second, the force signal for the known weight is correlated with the surface touch position. Since the place where the weight is put can be known by the surface touch force value, it is possible to compensate according to the position of where a finger is pressed (Fig. 11).

Since there are several variation tolerances, such as cushion pasting tolerance and backlight frame thickness tolerance, etc., in-plane compensation for each module is necessary.

We evaluated the force value variation with five samples before compensation and after compensation.

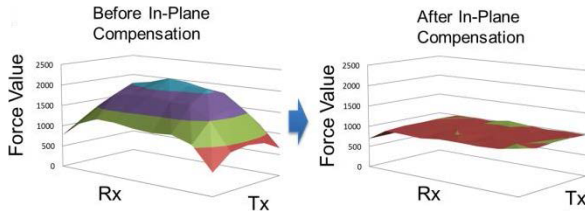


Fig. 11 Compensation method for in-plane variation of force signal

Table 3 Specification of force touch module

Format	Landscape
Size	10.1inch
Cover Glass	1.1 mmt
CF / TFT glass thickness	0.3 mmt / 0.3 mmt
Tx number	27
Rx number	58 (2D), 6 (Force)
Sensor pitch	Tx: 4.1 mm (Tx) Rx: 4.0 mm (2D) / 38.0 mm (Force)
Backlight unit thickness (Light Guide, Reflection sheet, etc.)	4.0 mm
Air Gap	2.0 mm

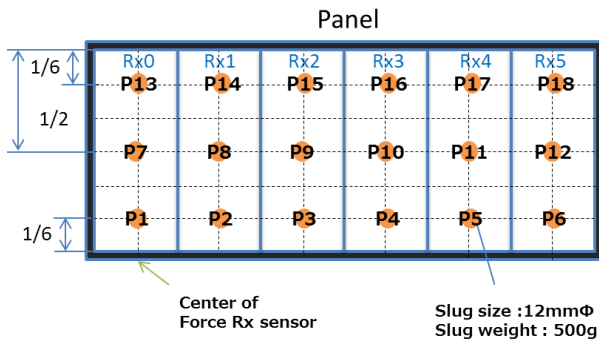


Fig. 12 Evaluation conditions

Table 3 shows specification of force touch module. We used these modules for evaluation. Evaluated positions are 18 points, as shown in Fig. 12. We used a 12 mm phi slug with 500g weight.

Figure 13 shows maximum force value variation before compensation and after compensation. The below procedure shows the calculation of maximum force value variation:

1. Calculate the standard deviation (σ) between five samples at each position (18 points)
2. Calculate the average force value between five samples at each position (18 points)
3. Normalize 3σ by the averaged force value at each position (18 points)
4. Select the maximum value from the outputs in the third procedure

Maximum in-plane variation after compensation de-

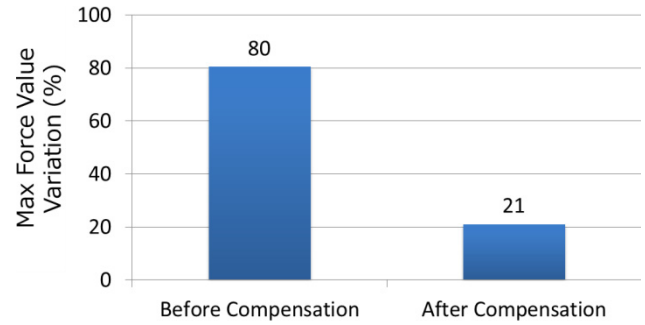


Fig. 13 In-plane variation of force signal (result of five samples)

creased from 82% to 21%, which is about one-fourth of that before compensation.

We would like to add the effects of thicker cover glass and cover plastic as well. In the case of the automotive market, cover glass of 1 to 2 mm thickness and cover plastic of 2 to 3 mm thicknesses are generally used.

First, we estimated the impact of thicker glass. When the same stress is applied to the center of the panel of the force touch prototype, and the thickness of the cover glass is increased from 1.1 mmt to 2.0 mmt, the glass deflection is reduced to about 40%. The deflection of the glass correlates with the signal strength of the force touch linearly. Therefore, when the amount of deflection of the glass is reduced to about 40%, the signal strength of force touch is also reduced to about 40%. The signal strength of force touch can be improved by applying a higher voltage or narrowing the airgap.

Second, we would like to comment on the impact of the cover plastic. The amount of deflection of the cover is determined by Young's modulus and stress as expressed by the following equation:

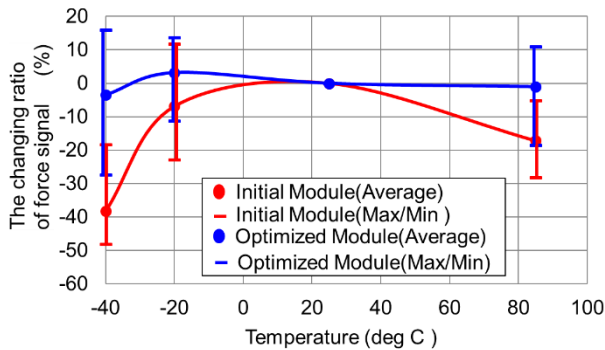
$$\varepsilon = \frac{\sigma}{E} \quad (1)$$

(ε : strain σ : stress E : Young's modulus)

The plastic cover made of polycarbonate has a sufficiently small Young's modulus to the cover glass. Therefore, the signal strength of the plastic cover is more sensitive than the signal strength of the cover glass.

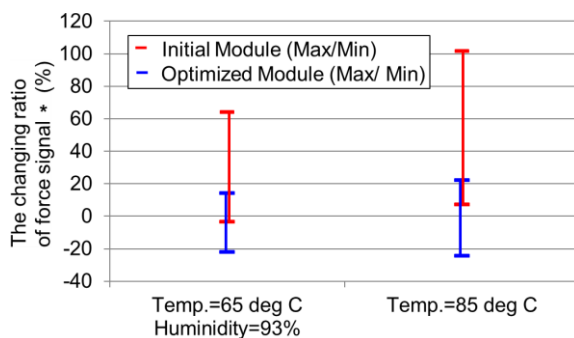
Further issues of force touch are reliability and temperature dependency. A module is composed of various materials such as cover glass, glue, polarizer, TFT glass, color filter glass, cushion, backlight unit, etc. The position, thickness, or elastic constant of these construction materials change due to temperature changes and aging. As a result, the force value deviates from the initial force signal. We evaluated the temperature dependence in the range of -40 deg C to 85 deg C. We have also evaluated the reliability at high temperature and high humidity (65 deg C, 93%) and high temperature (85 deg C) under the condition of operating the panel.

The result of temperature dependence is shown in Fig. 14. The vertical axis shows the changing ratio of force value with respect to the force value at 25 deg C. In the ini-



* The changing ratio of force signal with respect to the force signal at 25 degrees C.

Fig. 14 Temperature dependence test (–40 deg C to 85 deg C)



* The changing ratio of force signal with respect to the force signal before the reliability test.

Fig. 15 Reliability test (after 1000hr w/ operation)

tial module configuration, the force value decreases by 48% at maximum. This behavior is observed at low temperatures. The main factor is that the elastic constant of the construction materials increases at low temperatures. By optimizing the construction materials of the module, the change ratio of force signal was improved up to 27%, at the maximum.

The reliability test result is shown in Fig. 15. The vertical axis shows the changing ratio of force value with respect to the force value before the reliability test. In the case of the initial module configuration, the force value increases by 64%, at the maximum, in the high temperature and high humidity condition (65 deg C, 93%) and by 102%, at the maximum, in the high temperature condition (85 deg C). In the reliability test condition, an irreversible structural change such as warpage occurs. By optimizing the construction materials, the irreversible structural change hardly occurs and the rate of change of force value was improved up to 22%, at the maximum, in the high temperature and high humidity condition, and by 25%, at the maximum, in the high temperature condition.

4. Conclusion

We have succeeded in developing the world's largest 16.7-inch hybrid in-cell touch panel as well as passing the automotive quality requirements with the over 15-inch hybrid in-cell touch panel.

We also have developed force touch technology based on the 10.1-inch hybrid in-cell touch panel.

We have tried to improve the in-plane variation of force touch, the force value change due to temperature change, and the force value change due to the reliability test.

Maximum in-plane variation after compensation decreased from 82% to 21%, which is about one-fourth of that before compensation.

We have also succeeded in suppressing the changing ratio of force signal in the temperature dependence and reliability test. The changing ratio of force signal was 27% with respect to the force signal at 25 degrees C, at the maximum, in the temperature dependence test and 25% with respect to the force signal before the reliability test, at the maximum, in the reliability test.

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