Novel Connector Mechanism Using Anisotropic Conductive Rubber for Trillion-Node Engine as an IoT Edge Platform

Kenichi Agawa
Toshiba Electronic Devices & Storage Corporation
Kawasaki, Japan
kenichi.agawa@toshiba.co.jp

Tokihiko Mori
Department of Electrical Engineering and Information Science
The University of Tokyo
Tokyo, Japan

Ryoji Ninomiya
Toshiba Electronic Devices & Storage Corporation
Kawasaki, Japan

Minoru Takizawa
Toshiba Electronic Devices & Storage Corporation
Kawasaki, Japan

Takayasu Sakurai
Department of Electrical Engineering and Information Science
The University of Tokyo
Tokyo, Japan

***Abstract*—An IoT edge platform, where desired IoT nodes are realized selecting and connecting several single-function printed circuit boards (PCBs) such as a sensor, microprocessor, and power supply unit with anisotropic conductive rubber (ACR) connectors, is demonstrated. The PCBs are called “leaf PCBs” and their dimensions are typically 2 cm x 2 cm. Small rubber connectors are employed to connect these PCBs so that soldering is unnecessary and removable and replaceable structure is realized for customizability of IoT nodes. A wire connection mechanism is also developed to connect wires between leaf PCBs and external devices such as motors and sensors. It is smaller than conventional terminal blocks. To investigate important performance of the proposed connection schemes, temperature cycle tests for ACR connectors and retention strength tests for wire connection mechanisms are carried out.**

Keywords—IoT edge platform, anisotropic conductive rubber connector, wire connection mechanism, Trillion-Node Engine

I. Introduction

It is expected that one-trillion Internet-of-Things (IoT) nodes will be in use in the 2030s. And not only IoT devices provided by engineers of industries but also those provided by individuals, that is, non-engineers are necessary for market expansion. A development platform or system of IoT devices, where individuals can embody their ideas and create their IoT prototype devices easily, is crucial. Moreover, IoT sensor nodes require customizability as well as small size and low-power operation, because various functions are necessary for them according to their applications. To deal with this diversity, a platform should support customizability of IoT nodes.

We study on a platform realizing customizability easily, where desired IoT devices are realized selecting and connecting several single-function printed circuits boards (PCBs) such as a sensor, microprocessor, and power supply unit. We prepare those PCBs with each specific LSIs. The PCBs are called “leaf PCBs” and their dimensions are typically 2 cm x 2 cm. To make compact electronic devices, stacking PCBs is effective. The main barrier for this scheme is how PCBs are connected to one another. Though a micro-connector is ordinarily used to stack two boards, connection becomes unstable and screwing is needed when more than two boards are stacked and connected. Moreover, solder crack might develop due to excessive stress if micro-connectors and screwing are used at the same time. Thus, we present anisotropic conductive rubber (ACR) connectors as novel connection technology between PCBs, or equivalently as novel connection technology between circuit blocks. The connectors consist of silicone rubber and many tiny metallic pins embedded vertically in the silicone rubber. Pin length is around 2.2 mm and almost the same as rubber height, and pin diameter is 30 µm. The pins are aligned at a pitch of 50 µm.

We have designed 2-row-configuration 29-pin connection structure where a pad pitch is around 1 mm. All that is needed is to define a pad layout on leaf PCBs. The pad layouts on the surface and reverse side of a PCB are the same and the corresponding pads are connected via through holes. Electrical connection between the pads on two PCBs is realized setting a rubber connector between the PCBs. A plastic holder supporting a rubber connector is also presented so that everyone can stack PCBs and connectors easily like playing with a block toy. The holder has hooks to attach itself to the PCB. The dimensions of connectors are 13 mm (L) x 2 mm (W), and their height is 2 mm after PCBs and connecters are stacked and screwed.

The connection technology has the features that soldering is unnecessary and removable and replaceable structure is realized on site outside factories. Even though non-engineers are not capable to do soldering, everyone can assemble IoT devices like playing with a block toy. The proposed technology has no structure where male and female connecters are fitted to each other, and enables low-profile devices. Moreover, rubber connectors need not to be in hand when we produce PCBs and can be attached later. This can reduce lead time for prototyping. We call the above-mentioned platform "Trillion-Node Engine [1-3]."

In this paper, a concept of Trillion-Node Engine is introduced in Section II. The way how an IoT module is assembled using rubber connectors, plastic holders, nuts and screws is demonstrated in Section III. In Section IV, we develop 58-pin connection structure using two connectors on each PCB, and have realized high-performance 32-bit micro-controller unit (MCU) leaf PCB. Performance of rubber connector is studied in Section V. In Section VI, a wire connection mechanism is demonstrated. Section VII is dedicated to conclusions.

II. Concept of Trillion-node Engine

Rapid penetration of IoT nodes is expected, and an image of future IoT market is illustrated in Fig. 1. Outer region indicates IoT market expansion. Not only IoT devices provided by engineers of industries but also those provided by individuals and Makers, people representing a technology-based extension of DIY, are necessary for IoT market expansion. Thus, a platform or system, where individuals and Makers are empowered to embody their ideas and create their IoT prototype devices easily, is crucial.

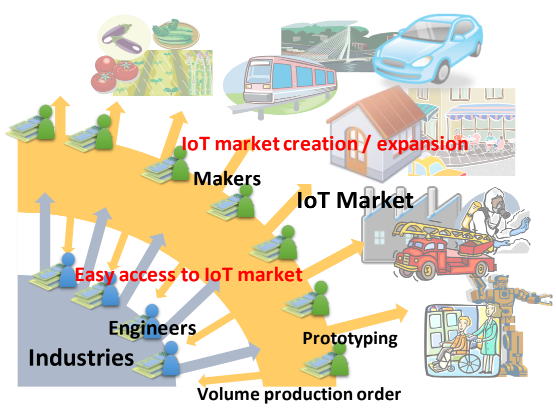


Fig. 1. Future of IoT market.

IoT nodes typically contains four circuit blocks such as a digital circuit block, analog circuit block, power supply block, and wireless circuit block as shown in Fig. 2. Though it is possible that the digital circuit block is realized using a common microprocessor LSI, the other circuit blocks might result in various circuits. For instance, the analog circuit block should deal with a sensor or speaker or motor, and the wireless circuit block should deal with Bluetooth® or Wi-Fi or LoRa or other various wireless communication standards [4-8]. If we try to create a dedicated LSI incorporating specific analog and wireless and power supply circuit blocks, a lot of time and cost are required. Thus, a scheme where desired IoT nodes are realized combining several PCBs with each specific LSIs, is desired.

Fig. 3 shows a sample of IoT node module after four leaf PCBs are assembled based on our Trillion-Node Engine platform. The platform provides several specific modules as leaf PCBs as shown in Fig. 4.

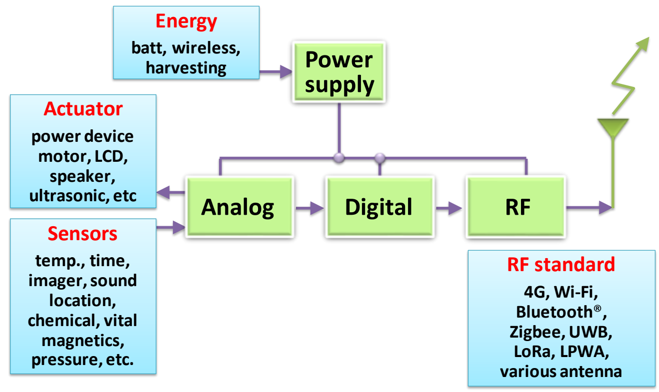


Fig. 2. Electrical structure of typical IoT node.

Fig. 3. Photograph of proposed module consisting of four leaf PCBs.

III. Rubber Connector and Leaf PCB

The way how leaf PCBs is connected to one another using rubber connectors is demonstrated in this section. A rubber connector and leaf PCB are shown in Fig. 5. In our proposed connection scheme, what is limited for leaf PCBs is only the pad layout on them. The bus area consisting of pads is confined to 20 mm × 5.5 mm specified by the rectangle in Fig. 5. Leaf PCBs are typically 20 mm × 20 mm, but can be any size if the bus specification is observed.

The pad layouts on the surface and reverse side of PCBs are the same and the corresponding pads are connected via through holes. Electrical connection between stacked PCBs is realized setting a rubber connector between them. Leaf PCBs communicate electronically among each other through a 29-pin bus, named the Leafony bus.

The way how an IoT module is assembled using rubber connectors, holders, nuts and screws is shown in Fig. 6.

(1) A plastic holder supporting a rubber connector is designed. A rubber connector is set inside a holder and is supported at six points of the holder.

(2) The holder containing the rubber connector has hooks to attach itself to a PCB. It has other hooks to attach itself to another holder so that leaf PCBs and holders can be easily stacked, like playing with a block toy.

(3) After the required leaf PCBs are stacked, they are screwed. The leaf PCBs and rubber connectors are pressed, and electrical connection becomes firmer. Electrical connection between multi-layer PCBs is realized by multi-layer rubber connectors.

(4) We usually stock and deliver a leaf PCB with an ACR connector and a holder already installed.

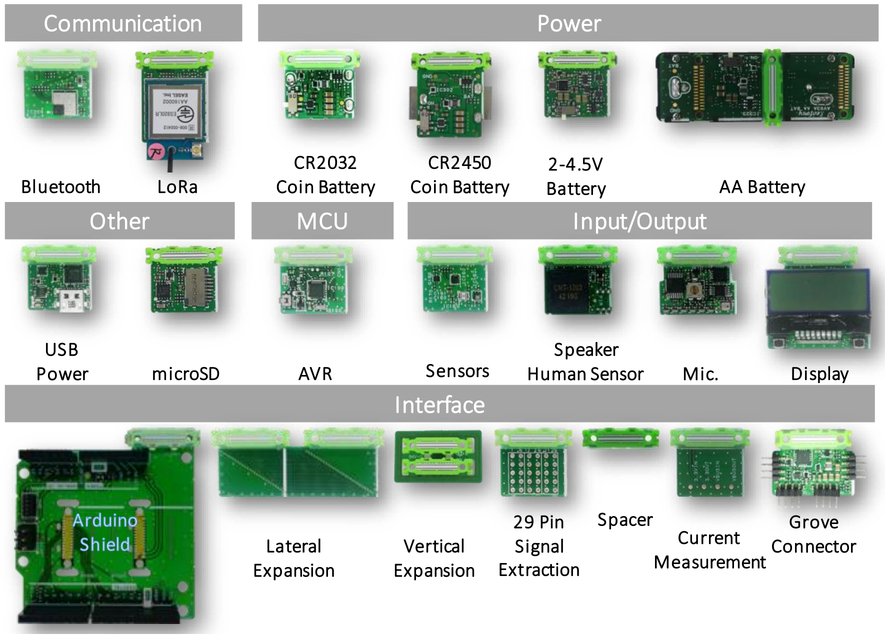


Fig. 4. Samples of proposed leaf PCBs.

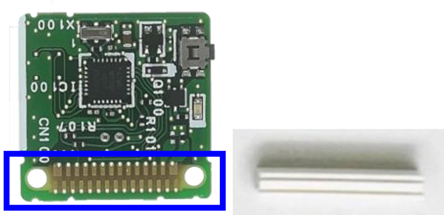


Fig. 5. Leaf PCB and rubber connector.

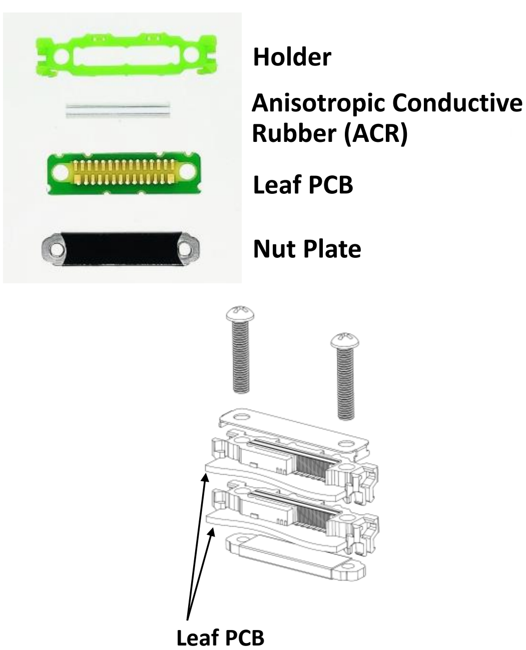


Fig. 6. Assembly of Leaf PCBs and rubber connectors.

A magnified top view of a rubber connector is shown in Fig. 7. The connector consist of silicone rubber and many tiny metallic pins embedded vertically in the silicone rubber. Pin length is around 2.2 mm and almost the same as rubber height, and pin diameter is 30 µm. The pins are aligned at a pitch of 50 µm, which is 1/10 less than a pad width.

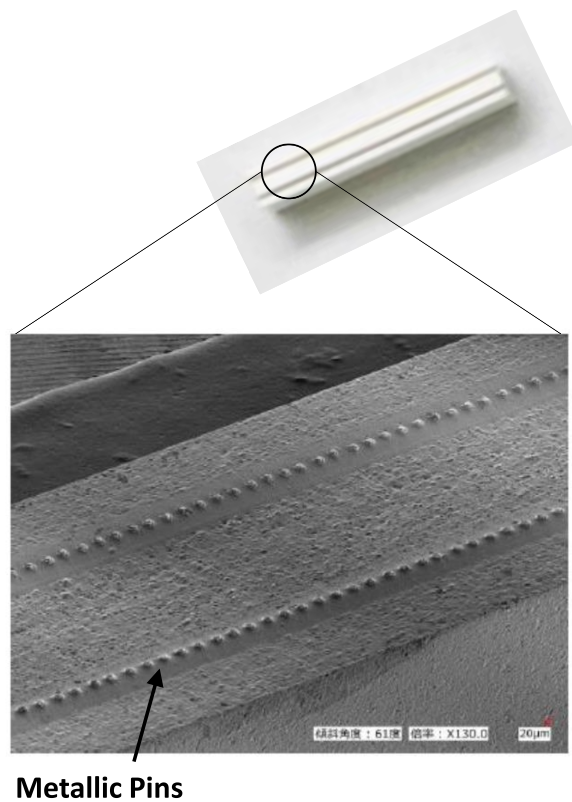


Fig. 7. Photograph of rubber connector.

IV. Expansion of the Number of Pins for 32-bit MCU Leaf PCB

We have developed 58-pin connection structure using two connectors on each PCB, and have realized high-performance 32-bit micro-controller unit (MCU) leaf PCB.

The conventional 8-bit MCU leaf PCB mounts Atmel AVR microprocessor, Atmega328P, and its processing performance and memory space of Flash memory and SRAM [9] are not enough to realize desired IoT nodes. Therefore, we have developed 32-bit MCU leaf PCB, which mounts STMicroelectronics STM32 microprocessor, STM32L452. Since the microprocessor has 64 pins, 58-pin connection structure is useful and we can accommodate 32 digital I/O pins on MCU leaf PCB.

The 32-bit MCU leaf PCB is shown in Fig. 8, and its small dimensions is 2 cm x 2.8 cm. Together with a wireless communication leaf PCB, the MCU leaf PCB can realize a high performance IoT device, for instance, supporting artificial intelligence (AI) applications.

We develop 58-pin connection structure using two rubber connectors and holders in back-to-back manner. We can connect two modules, for example a camera module and sensor module, on top and realize high packaging density as shown in Fig. 9 and Fig. 10.

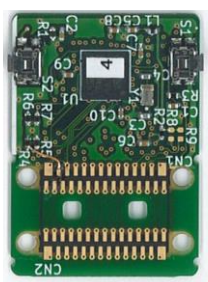


Fig. 8. 32-bit MCU leaf PCB with 58-pin bus connection.

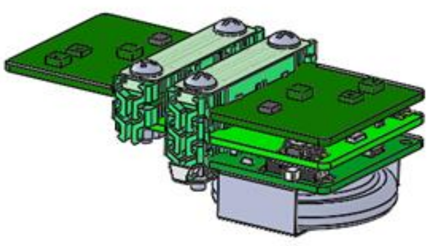


Fig. 9. Proposed 58-pin connection.

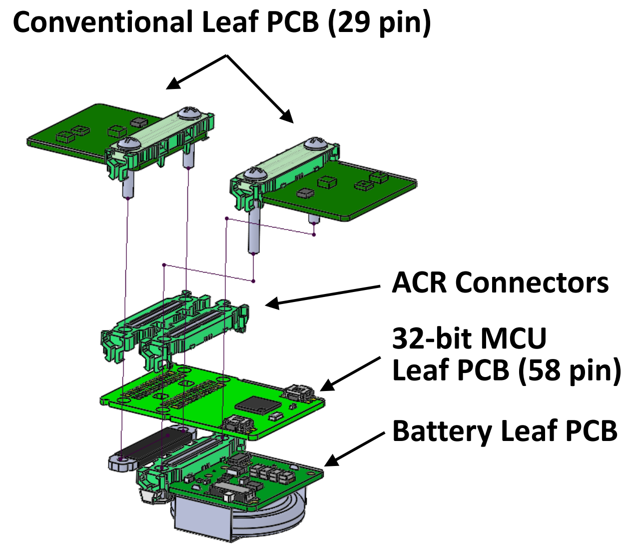


Fig. 10. Assenbly for 58-pin connection.

V. Performance and Reliability of ACR Connector

The signal transmission property of a rubber connector is shown in Fig. 11. Less than 1 dB loss from the 1st leaf PCB to 4th leaf PCB of a four-layer module is observed up to 500 MHz. The graph shows three data of various three signal paths. 500 MHz is sufficiently high, considering the fact that the bus data rate is less than 10 MHz in typical IoT nodes.

A change in resistance when a leaf PCB stacked module is assembled and disassembled 100 times is also shown in Fig. 12. The connector may endure reassembly 100 times.

We also carried out environmental test of connectors: A high-temperature and high-humidity test for 1000 hours at 85 °C and at humidity of 85%, and a low-temperature test for 1000 hours at −40 °C. The resistance corresponding to one pin is shown in Fig. 13. The resistance of connection is seen to be stable.

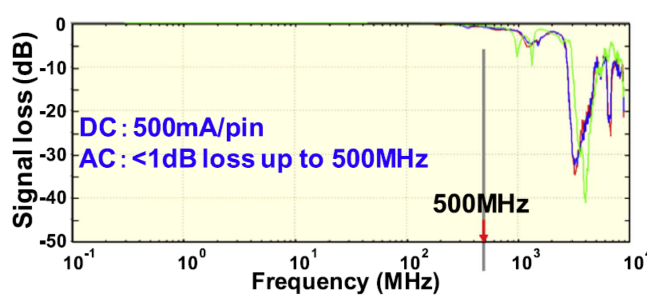


Fig. 11. Performance of connectors on signal loss.

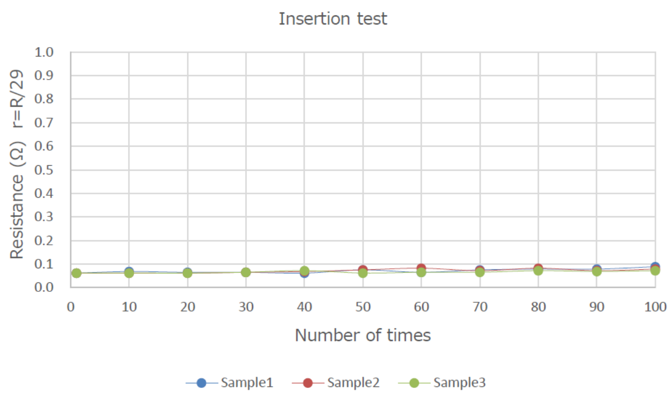
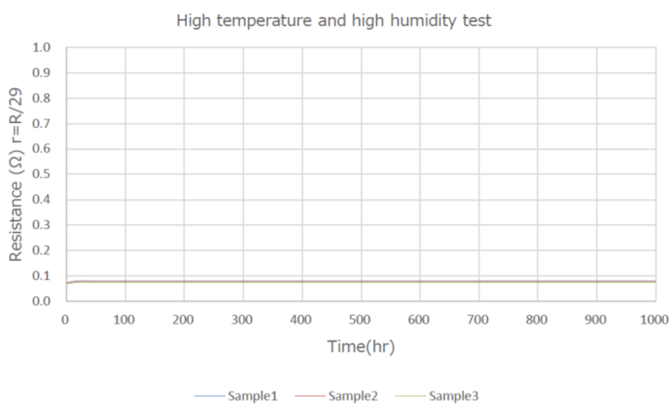
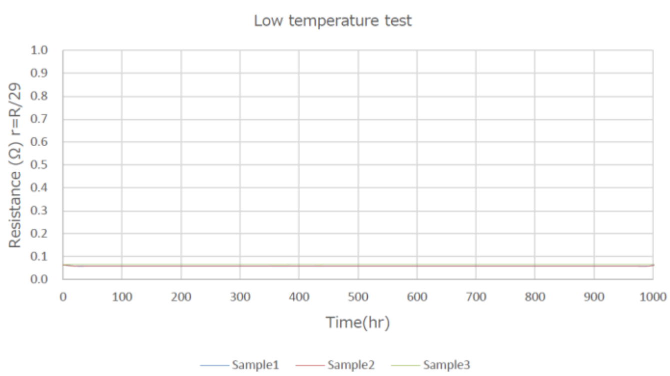


Fig. 12. Performance of connectors on reassembling test.



(a)



(b)

Fig. 13. Test results for (a) high-temperature, high-humidity test and (b) low-temperature test.

The impact of expansion and contraction of rubber connectors by temperature has been carefully investigated. Since linear expansion coefficient of silicone for rubber connectors is around 400x10^{-6}/°C and one of polyacetal (POM) for plastic holders is around 85x10^{-6}/°C and they are around 5 times different, strain might occur inside rubber connectors. Therefore, the temperature cycle test is also carried out as shown in Fig. 14. The results are shown in Fig. 15. We investigate on the dependence of connection resistance on temperature variation, $\Delta T = T_H - T_L$, and temperature change rate, $T_R = \Delta T / t_r = \Delta T / t_f$. In Fig. 15(a), T_L is constant and it is −10 °C. In Fig. 15(b), ΔT is also constant and it is 35 °C. We find out the resistance of connection has slight dependence on ΔT, and resistance variation is small when ΔT is less than 52.5 °C. The dependence on T_R is seen to be small.

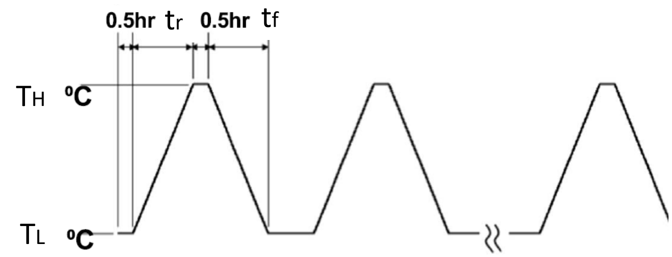
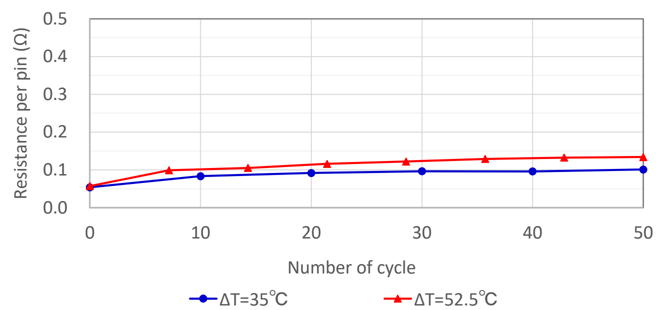
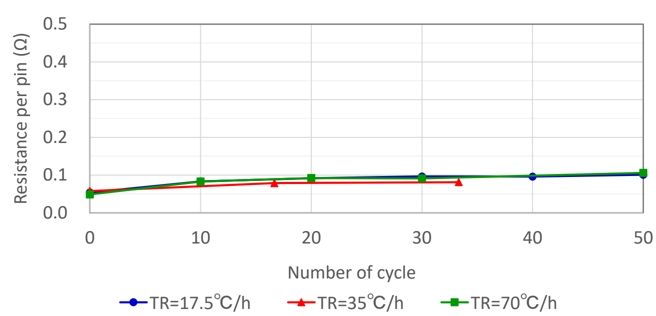


Fig. 14. Temperature change pattern in temperature cycle test.



(a)



(b)

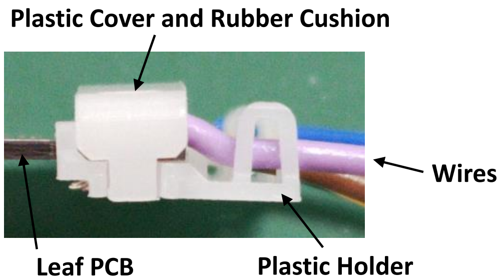
Fig. 15. Test results for temperature cycle test. (a) ΔT dependence at T_R=17.5 °C/h and (b) T_R dependence at ΔT=35 °C.

VI. Wire Connection Mechanism

Another connection is required for some IoT devices in addition to 29-pin/58-pin bus connection. For example, wires are needed between motor-controller PCBs and motors. We present a novel connection technology for them, which has the features that soldering is unnecessary and removable and replaceable structure is realized. A wire connection mechanism is developed to fix wires to leaf PCBs. We have designed plastic holders for aligning the wires to the dedicated pads on leaf PCBs, and rubber cushions and plastic covers for fixing the wires on the pads as shown in Fig.16. It is smaller than conventional terminal blocks. The wire connection structure can support up to

6 wires and wire thickness of AWG24 to 28 on UL1007 using elastic rubber cushions.

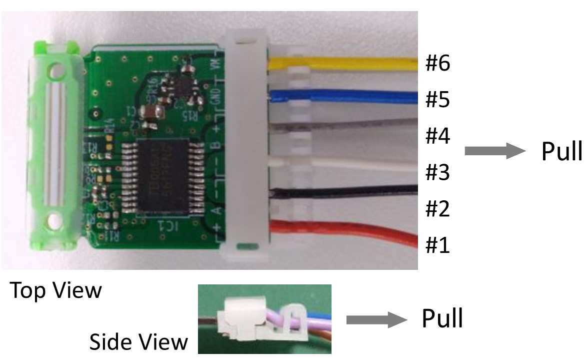
We investigate on retention strength between wires and PCBs as shown in Fig. 17. A tensile force of more than 3N, namely around 300gf, is obtained for all 6 wires thanks to elastic rubber cushions.



(a)

(b)

Fig. 16. (a) Wire connection mechanism, which is smaller than conventional terminal blocks. (b) Wire connection mechanism mounted on motor driver leaf PCB.



Wire ϕ	Tensile Force					
	Wire 1	Wire 2	Wire 3	Wire 4	Wire 5	Wire 6
AWG24	> 3 N	> 3 N	> 3 N	> 3 N	> 3 N	> 3 N
AWG26	> 3 N	> 3 N	> 3 N	> 3 N	> 3 N	> 3 N
AWG28	> 3 N	> 3 N	> 3 N	> 3 N	> 3 N	> 3 N

Fig. 17. Retension strenght test for wire connection mechanism.

VII. Conclusion

An IoT edge platform, where desired IoT nodes are realized combining several single-function leaf PCBs with anisotropic conductive rubber (ACR) connectors, is proposed. The IoT platform, where soldering is unnecessary and removable and replaceable structure is realized for customizability of IoT nodes, is demonstrated.

58-pin bus connection structure using two connectors on each PCB is proposed, and high-performance 32-bit MCU leaf PCB is realized, the small dimensions of which is 2 cm x 2.8 cm. The temperature cycle test is also carried out, and resistance variation of rubber connectors is small when temperature variation, ΔT, is less than 52.5 °C.

A wire connection mechanism is also developed to connect wires between PCBs and external devices such as motors and sensors. We investigate on retention strength between wires and PCBs, and a tensile force of more than 3N is obtained.

Acknowledgment

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