AUTOMATED DATA CHECK AND CALIBRATION SYSTEM USING MATRIX SWITCH PROTOTYPE WITH SMALL CHANGE OF LINE-RESISTANCE

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ABSTRACT

In this paper, the hardware performance of a matrix switch prototype with small resistance deviation of each route and an automated data check and calibration system are described. The matrix consists of 12 rows and 3 columns, and the key switch connecting the rows and columns has a small on-resistance change even when the input voltage changes, so the matrix can keep the resistance deviation of each route small. Data check and calibration of circuits that are sensitive to errors due to lead-wires can also be automated with this matrix system to save time and reduce human error.

Keyword: Matrix switch, MOSFET, On-resistance, Automation

INTRODUCTION

In the telemetry device, the data acquisition board acquires data measured by sensors such as temperature, strain, and vibration. In order to data check whether the data acquisition board is operating normally and to reduce measurement errors, data check and calibration for each measurement channel are required. In the case of telemetry capable of multi-channel measurement, since it can have a large number of channels, automating the data check and calibration system using a matrix system that can route every row to every column can reduce time and human error. However, in most of the matrix systems we know, the deviation of resistance of each route is large and not constant. Measurement methods such as 3-wire RTD, in which errors due to lead-wires are directly reflected in measurement results, cannot use this matrix system. To overcome this problem, a matrix switch prototype was designed by applying the theory described in the paper “A Matrix Switch based on Back-To-Back Structure MOSFET with Small Change of On-resistance by Applying Variable Gate Voltage Circuit” [1]. In the next chapter, the hardware performance of the prototype is verified to confirm that the theory is correct, and the operation procedure of the automated data check and calibration system using control software is introduced and the performance is verified.

HARDWARE OVERVIEW

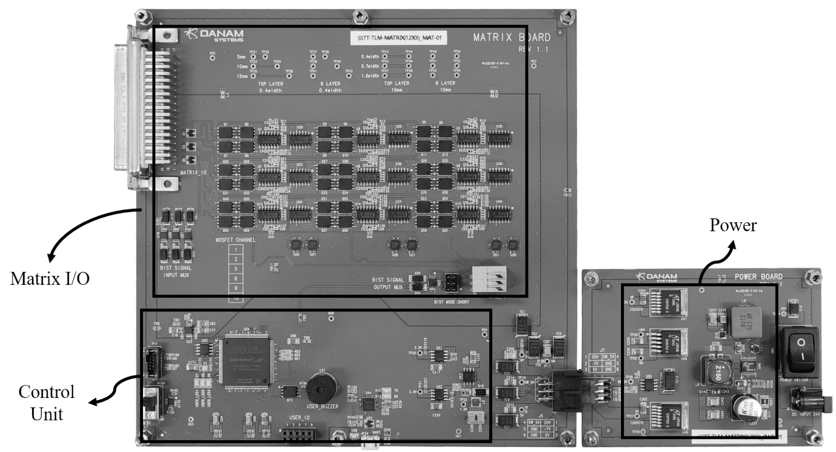


Figure 1 Matrix Switch Prototype with Power Board

Table 1 Hardware Specification

Matrix I/O		12 rows and 3 columns
Cross Point		36
Switch Type		N-MOSFET
Control Unit Type		FPGA
Operating Voltage (V)		24
Current Consumption in Idle State	20V (mA)	111
	-7V (mA)	112
	5V (mA)	100
	5V (mA) (For activating mosfet switch)	less than 1
Input Range (V)		-6 ~ 9
Total Path Resistance, Row-to-Column	Min (Ω)	0.178
	Max (Ω)	0.187
Size	Matrix Board (mm)	184 x 182
	Power Board (mm)	100 x 74

The matrix switch prototype consists of matrix I/O, control, and power supply. Matrix I/O has 12 rows and 3 columns. The switch connecting each row and column consists of two N-MOSFETs (Common Source Back-To-Back MOSFET) whose sources are connected to each other and a variable gate voltage circuit that keeps the change in line resistance small. The input range to keep the change in line resistance as small as possible is -6V as the minimum and 9V as the maximum.

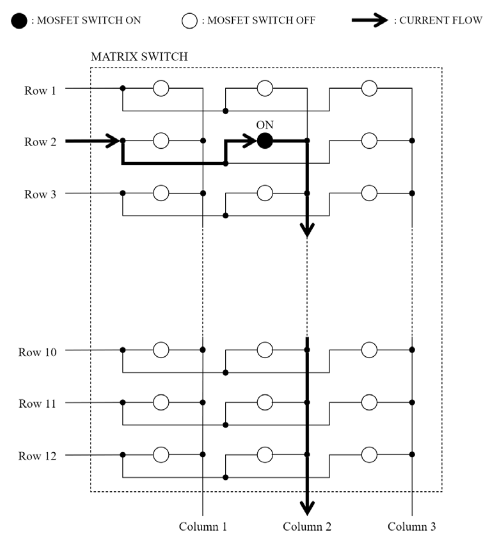


Figure 2 Diagram of the Matrix I/O Structure (Connect Row 2 and Column 2)

Figure 2 is a diagram of the matrix I/O structure. If the MOSFET switch of the cross point of the 2nd row and the 2nd column is activated and the current is input to the 2nd row, the current cannot pass through the deactivated MOSFET switch, so the current cannot pass through the 1st and 3rd columns and only passes through the 2nd column.

VARIABLE GATE VOLTAGE CIRCUIT WITH BACK-TO-BACK MOSFET

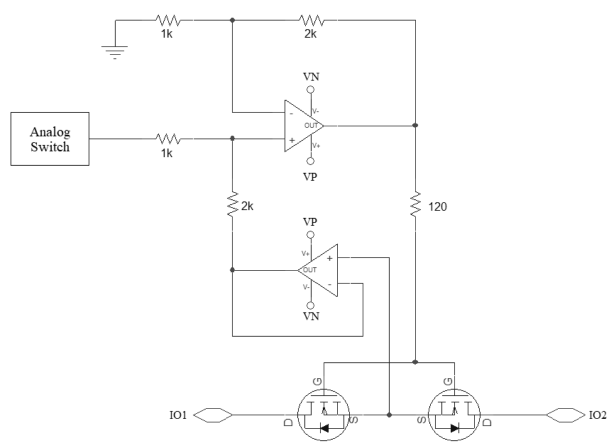


Figure 3 Variable Gate Voltage Circuit with Back-to-Back MOSFET

Figure 3 shows a switch that can connect rows and columns in a matrix switch prototype. It consists of a common source Back-To-Back MOSFET like a bi-directional switch and a variable gate voltage circuit. The Back-To-Back MOSFET is activated or deactivated by the gate-source voltage, and when activated, it has on-resistance, which is the inherent resistance of the MOSFET. Since the on-resistance changes with the gate-source voltage, the gate-source voltage must always be kept constant to have a constant on-resistance. In the matrix switch prototype, the MOSFET drain is connected to the input or output of the matrix switch, and when the

MOSFET is activated, the MOSFET source voltage is changed by the input signal. If the gate voltage is not changed to match the source voltage level, the on-resistance of the MOSFET will not be constant. The variable gate voltage circuit changes the gate voltage according to the MOSFET source voltage, so the MOSFET always has a constant gate-source voltage. This allows the MOSFETs in the matrix switch prototype to keep their on-resistance constant even when the input voltage changes [1].

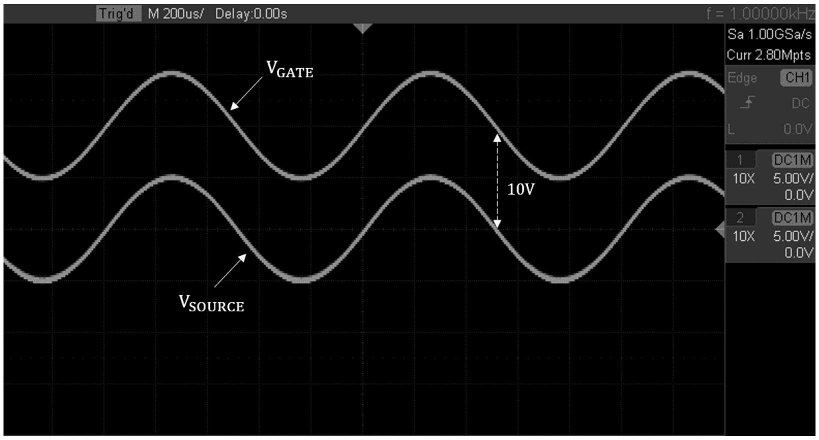


Figure 4 Source and Gate Voltages of a MOSFET Switch When Inputting a Sine Wave (Activation)

Figure 4 shows the source voltage and the gate voltage that changes according to the source voltage when the MOSFET switch is activated and a sine wave with 5Vpp amplitude and 1Khz frequency is input. Due to the variable gate voltage circuit, the switch can be stably activated because it always has a constant gate-source voltage.

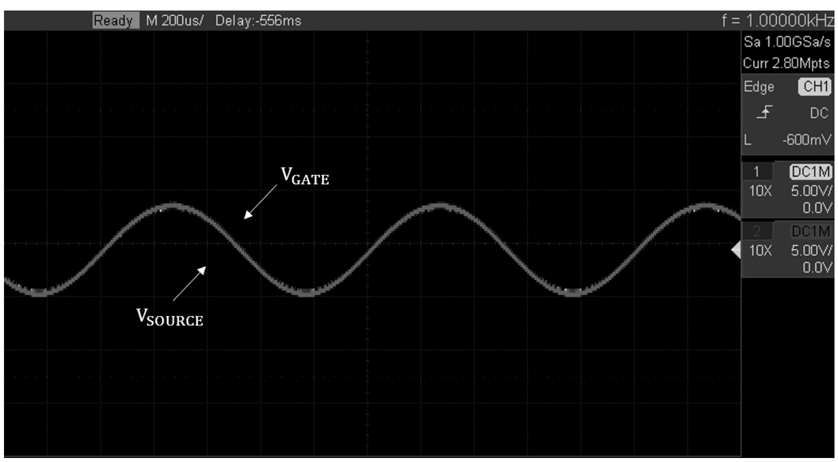


Figure 5 Source and Gate Voltages of a MOSFET switch When Inputting a Sine Wave (Deactivation)

Figure 5 shows the source voltage and the gate voltage that changes according to the source voltage when the MOSFET switch is deactivated and a sine wave with 5Vpp amplitude and 1Khz frequency is input as before. Since the gate voltage follows the source voltage due to the variable gate voltage circuit, the gate-source voltage has about 0V. Therefore, it is possible to prevent a situation in which a MOSFET is unintentionally activated due to input of a negative voltage.

ON-RESISTANCE CHANGE BY INPUT VOLTAGE

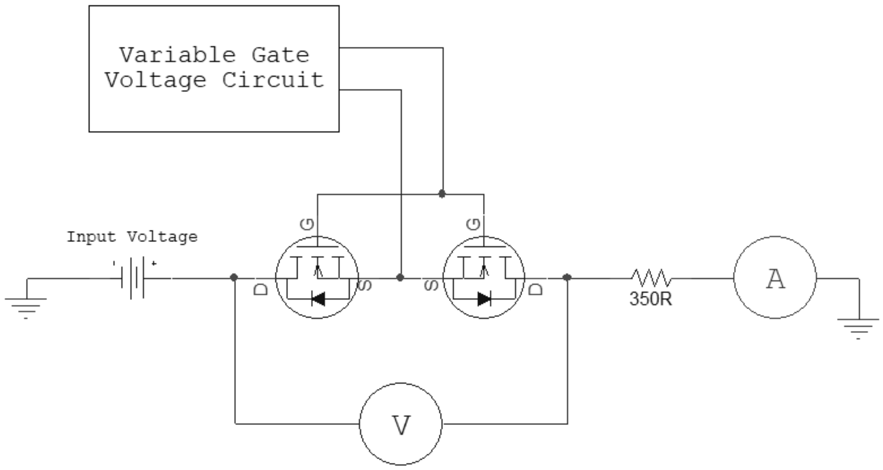


Figure 6 On-Resistance Measurement Circuit

Figure 6 is a circuit for measuring whether the on-resistance of a MOSFET changes with input voltage. The resistance is calculated by measuring the voltage at both ends of the MOSFET and the current through the MOSFET. The input voltage starts from -6V, increases by 0.5V, and applies up to 9V.

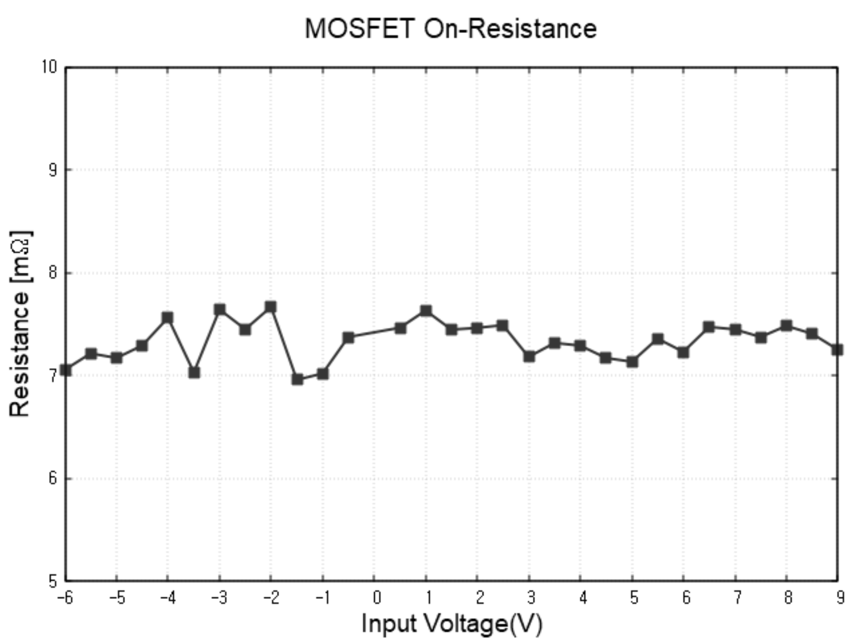


Figure 7 MOSFET On-Resistance Change with Input Voltage

As shown in Figure 7, the average resistance is about 7.3mΩ and the maximum-minimum is about 0.7mΩ. Due to the variable gate voltage circuit, it can be seen that the change in MOSFET on-resistance is very small even when the input voltage is changed.

I/O PATH RESISTANCE

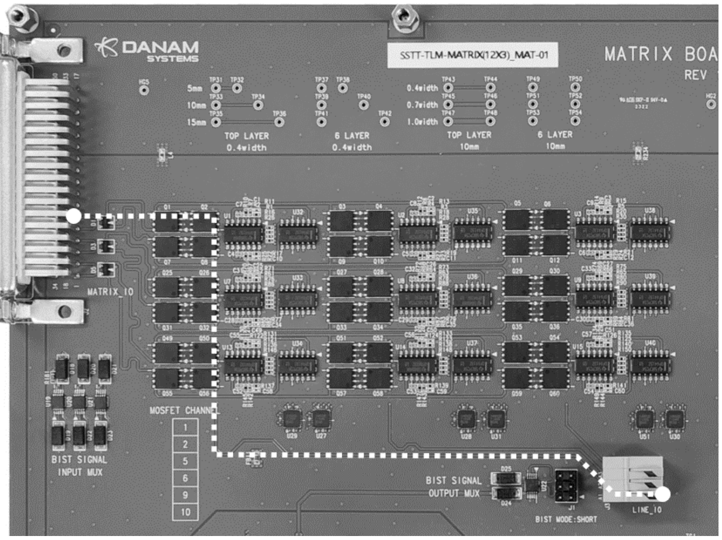


Figure 8 Path to Measure I/O Resistance

When each path through the 36 MOSFET switches (cross point) is activated, the path (row to column) resistance deviation must be as small as possible. The total path resistance is measured by the 4-wire measurement method.

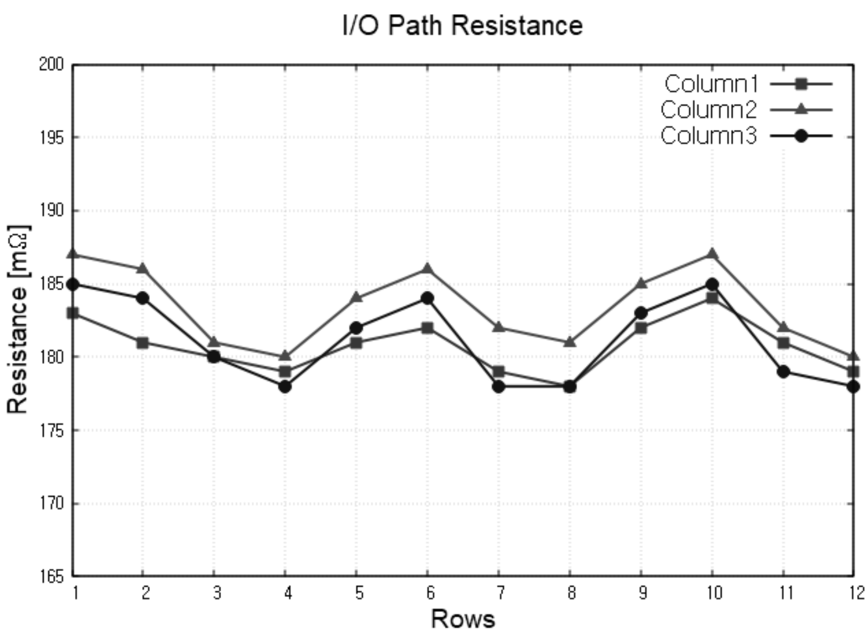


Figure 9 I/O Path Resistance

Figure 9 shows the resistance of the input and output paths when each of the 36 MOSFET switches is activated. The prototype was designed to minimize the resistance deviation of all paths. The average resistance is about 181.8mΩ and the maximum difference is about 9mΩ.

SOFTWARE OVERVIEW

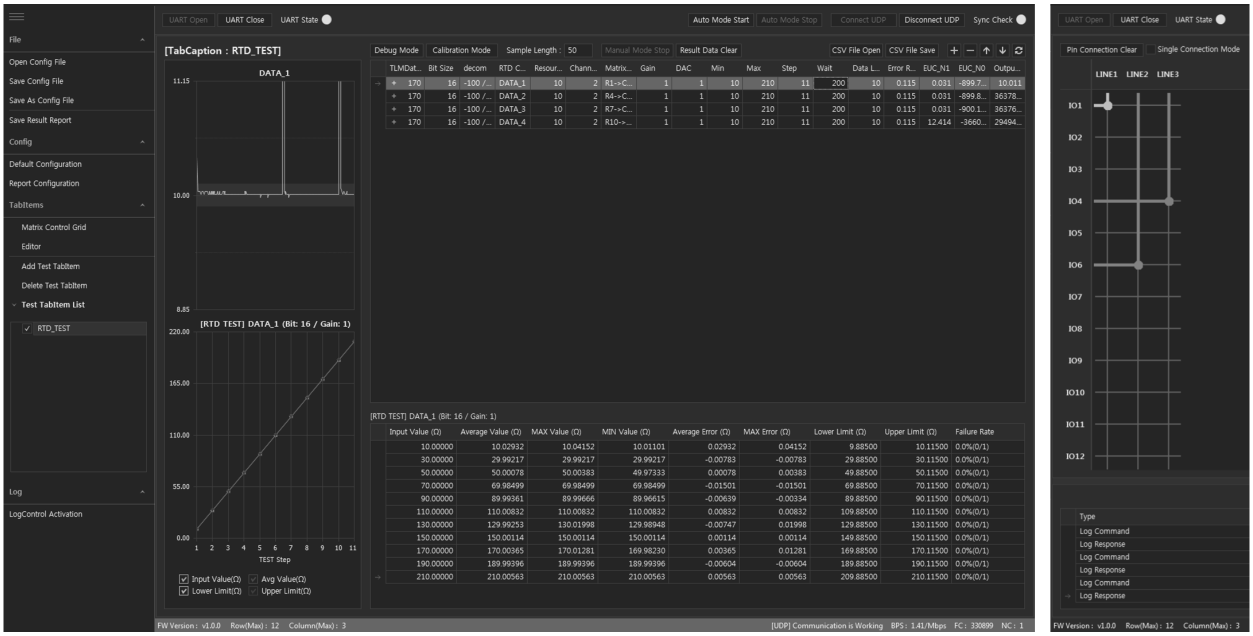


Figure 10 Data Acquisition Board Data Check Process and Matrix Setting Process in Control Software

The control software is developed in C# and controls matrix hardware and data checks and calibrations telemetry acquisition data. Users can activate/deactivate individual MOSFET switches on the matrix control grid screen and can check in real time whether the data is in the valid range on the data check screen.

MATRIX SWITCH CONTROL

Packet Structure

(Bit)

16	8	8	variable	16
Sync code	Cmd/Res code	Number of data bits	Data	CRC-16 CCITT

Figure 11 Packet Structure for Matrix Control

The matrix switch prototype and control software send/receive data through UART communication and form packets to give commands/responses. The basic packet structure consists of a 16-bit sync code, an 8-bit command/response code, and an 8-bit data length, followed by data bits and CRC-16 bits. The command code consists of hardware connection checks, soft resets, and enabling/disabling of each MOSFET switch. The response code indicates an ACK code indicating that the response is normal or an error code. When a command is sent from the software, the matrix switch performs an operation corresponding to the command code and sends an ACK response or an error response.

DATA CHECK AND CALIBRATION PROCESS

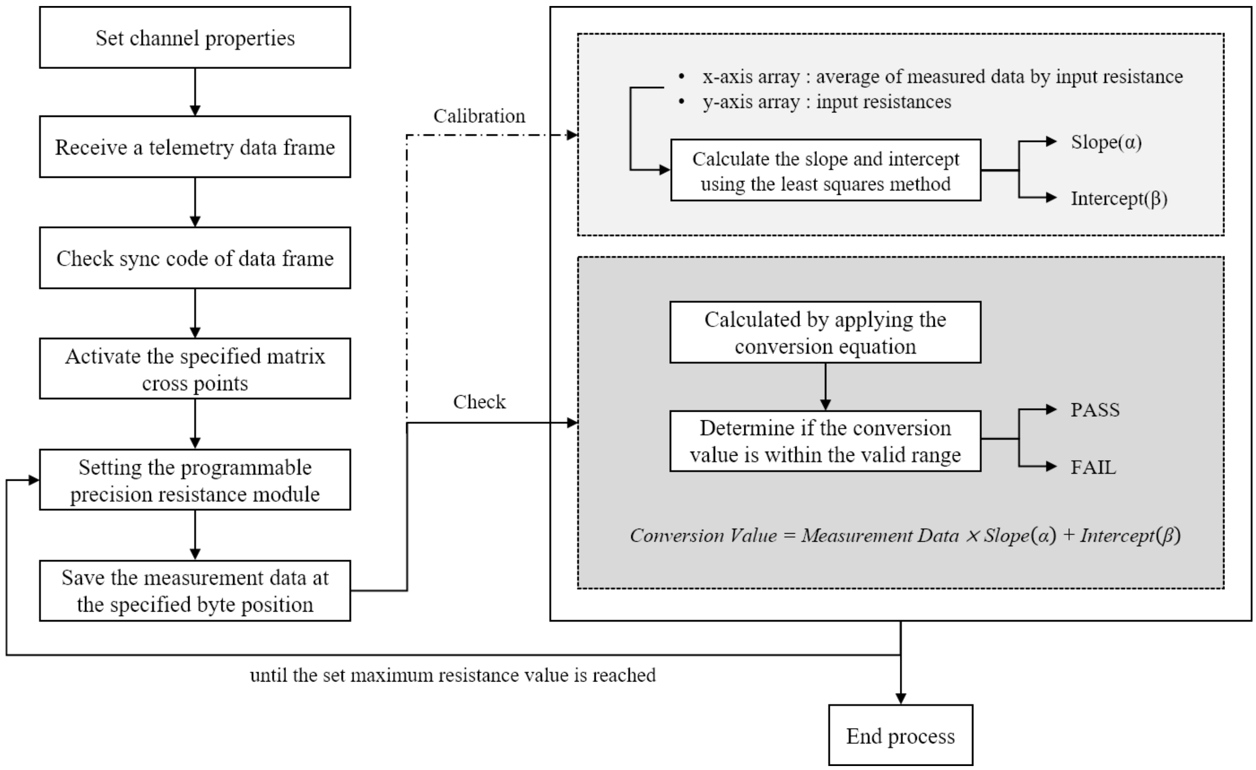


Figure 12 Data Check and Calibration Process (Manual Mode)

In order to extract specific data from a telemetry data frame received as a UDP(User Datagram Protocol) packet, channel information such as sync code, bit rate, and byte position is set in the control software. If the software is in a state of receiving data frames and is communicating with the matrix switch through UART, channel data check and calibration can be performed. Users can manually data check and calibration a single channel or run all channels automatically. When performing a channel data check and calibration, the software activates the designated row/column switch on the matrix switch and controls the programmable precision resistor module to set the resistance. After that, the data at the designated byte position in the data frame is saved, and pass/fail is determined whether the measured value is within the error range. Again, the next resistance is set, and the pass/fail determination process is repeated up to the specified maximum resistance. Acquisition values must be determined pass/fail by applying a conversion equation, which is calculated through calibration. Calibration is the same as data check, up to the operation of setting the resistance with a programmable precision resistance module and saving the data of the designated location in the data frame. To calculate the slope and intercept of the conversion equation, the average of measured data for each input resistance value is stored as an x-axis array and the input resistances are stored as a y-axis array. Then, the slope (α) and the intercept (β) are calculated using the least squares method. A conversion value can be calculated by multiplying the slope (α) by the acquired data and adding the intercept (β).

AUTOMATED DATA CHECK AND CALIBRATION OF 3-WIRE RTD BOARD

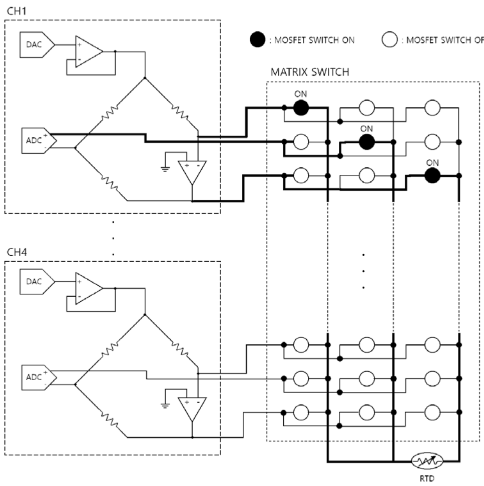


Figure 13 RTD Channel 1 and Matrix Connection

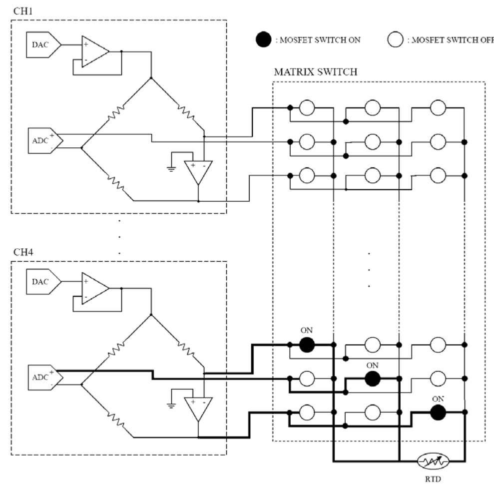
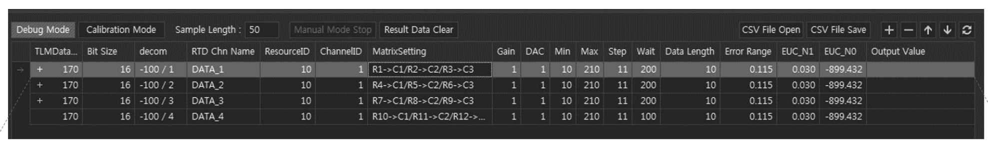


Figure 14 RTD Channel 4 and Matrix Connection

The matrix switch prototype is 12 rows and 3 columns, so users can connect 4 channels of 3-wire RTDs. If the user wants to data check and calibrate the 3-wire RTD CH1, the user can activate row 1/column 1, row 2/column 2, row 3/column 3 as shown in Figure 13. A deactivated MOSFET switch has a very high resistance, so it can be seen as a short circuit.



Debug Mode | Calibration Mode | Sample Length : 50 | Manual Mode Stop | Result Data Clear | CSV File Open | CSV File Save

TLMData...	Bit Size	decom	RTD Chn Name	ResourceID	ChannelID	MatrixSetting	Gain	DAC	Min	Max	Step	Wait	Data Length	Error Range	EUC_N1	EUC_N0	Output Value
+ 170	16	-100 / 1	DATA_1	10	1	R1->C1/R2->C2/R3->C3	1	1	10	210	11	200	10	0.115	0.030	-899.432	
+ 170	16	-100 / 2	DATA_2	10	1	R4->C1/R5->C2/R6->C3	1	1	10	210	11	200	10	0.115	0.030	-899.432	
+ 170	16	-100 / 3	DATA_3	10	1	R7->C1/R8->C2/R9->C3	1	1	10	210	11	200	10	0.115	0.030	-899.432	
170	16	-100 / 4	DATA_4	10	1	R10->C1/R11->C2/R12->...	1	1	10	210	11	100	10	0.115	0.030	-899.432	

Byte Pos	Bit Size	Decom Type	Channel Name	Resource ID	Channel ID	Matrix Setting	Gain	DAC	Min	Max	Step	Wait	Data Length	Error Range	EUC N1	EUC N0	Output Value

- Byte Pos : Position of the channel's measurement data in the data frame
- Bit Size : Number of bits of measurement data
- Decom Type : Measurand type of measurement data (ex: supercom, subcom, normalcom)
- Resource ID, Channel ID : Option to set up a programmable precision resistance module
- Matrix Setting : The switch position to activate on the matrix switch.
- Min : Minimum value of input resistance
- Max : Maximum value of input resistance
- Step : Number of input resistance sections
- Data Length : Number of data to store
- Error Range : Valid range of measurement data
- EUC_N1 : The slope of the conversion equation
- EUC_N0 : The intercept of the conversion equation
- Output Value : Measured value calculated by conversion equation

Figure 15 Screen to Input Channel Information and Detailed Description

Figure 15 is an explanation of the items to input information about the channel to data check and calibrate in the control software. Decom Type is subcom if the first symbol is (-), supercom if it is (+), and normalcom if it is blank. As shown in Figure 15, if Byte Pos is set to 170 and Decom Type to -100 / 1, 16-bit data located at the 170th byte excluding the header is stored in a data frame with 100 cycles and a Minor Frame ID 1.

```
[RTD TEST] DATA_1 (Bit: 16 / Gain: 1)
DATA_1 Input Value : 10 | Output Values Average : 29823.14 | StdDev : 0.6
DATA_1 Input Value : 30 | Output Values Average : 30478.2 | StdDev : 0.4
DATA_1 Input Value : 50 | Output Values Average : 31133.4 | StdDev : 0.49
DATA_1 Input Value : 70 | Output Values Average : 31787.8 | StdDev : 0.4
DATA_1 Input Value : 90 | Output Values Average : 32443.72 | StdDev : 0.449
DATA_1 Input Value : 110 | Output Values Average : 33099.94 | StdDev : 0.237
DATA_1 Input Value : 130 | Output Values Average : 33755.3 | StdDev : 0.458
DATA_1 Input Value : 150 | Output Values Average : 34411.14 | StdDev : 0.347
DATA_1 Input Value : 170 | Output Values Average : 35066.94 | StdDev : 0.237
DATA_1 Input Value : 190 | Output Values Average : 35722.6 | StdDev : 0.49
DATA_1 Input Value : 210 | Output Values Average : 36378.02 | StdDev : 0.14
DATA_1 Calibration Result | EUC_N1 : 0.031 | EUC_N0 : -899.834| meanSquaredError : 0
---<End to Calibrate DATA_1>---
```

Figure 16 Calibration Result of RTD Channel 1

[RTD TEST] DATA_1 (Bit: 16 / Gain: 1)

	Input Value (Ω)	Average Value (Ω)	MAX Value (Ω)	MIN Value (Ω)	Average Error (Ω)	MAX Error (Ω)	Lower Limit (Ω)	Upper Limit (Ω)	Failure Rate
	10.00000	10.02016	10.04152	10.01101	0.02016	0.04152	9.88500	10.11500	0.0%(0/1)
	30.00000	29.99522	30.02268	29.99217	-0.00478	0.02268	29.88500	30.11500	0.0%(0/1)
	50.00000	50.00688	50.03434	50.00383	0.00688	0.03434	49.88500	50.11500	0.0%(0/1)
	70.00000	69.98804	70.01550	69.98499	-0.01196	0.01550	69.88500	70.11500	0.0%(0/1)
	90.00000	89.98140	89.99666	89.96615	-0.01860	-0.00334	89.88500	90.11500	0.0%(0/1)
	110.00000	110.00832	110.00832	110.00832	0.00832	0.00832	109.88500	110.11500	0.0%(0/1)
	130.00000	129.99253	130.01998	129.98948	-0.00747	0.01998	129.88500	130.11500	0.0%(0/1)
	150.00000	150.00419	150.03165	150.00114	0.00419	0.03165	149.88500	150.11500	0.0%(0/1)
	170.00000	170.00670	170.01281	169.98230	0.00670	0.01281	169.88500	170.11500	0.0%(0/1)
	190.00000	189.99701	190.02447	189.99396	-0.00299	0.02447	189.88500	190.11500	0.0%(0/1)
→	210.00000	210.00868	210.03613	210.00563	0.00868	0.03613	209.88500	210.11500	0.0%(0/1)

Figure 17 Calibration Result of RTD Channel 1

Calibration is performed first to calculate the slope and intercept of the conversion equation before data checking the channel. If the user inputs the resistance by increasing 30Ω from 10Ω to 210Ω in RTD channel 1 and performs calibration, slope: about 0.031, intercept: about -899.834 can be calculated (Figure 16). The conversion equation is automatically entered in the fields of EUC_N1 and EUC_N0. Afterwards, when the channel data check is performed, a conversion equation is used to determine pass/fail whether the acquired value is in the valid range. Figure 17 is the result of data check after calibration. Since the average error is less than ±0.115Ω set as the valid range, all input ranges passed.

CONCLUSIONS

Even when the voltage input to the matrix I/O line changes, the variable gate voltage circuit maintains the gate-source voltage of the MOSFET switch stably, and it was verified that the change in the on-resistance of the MOSFET was small. Therefore, the matrix switch prototype composed of a variable gate voltage circuit and a back-to-back MOSFET as one cross point can have a small resistance deviation of each route. In addition, it was confirmed that data check and calibration can be automated through control software by connecting a circuit sensitive to errors due to lead-wires, such as a 3-wire RTD, to the matrix switch.

The prototype did not have many matrix I/Os, so it was not possible to connect many measurement circuits during verification. Now that the key functionality has been verified, Matrix I/O can be expanded to automate data checks and calibrations for more channels. And in this paper, only the RTD sensor circuit was used for verification, but there are many types of telemetry sensor measurement boards such as strain, vibration, analog and discrete signals. If these are verified, data check and calibration of the telemetry data acquisition board will be possible quickly and accurately.

REFERENCES

[1] Nahyeok Lee, Seongjong Kim, "A Matrix Switch based on Back-To-Back Structure MOSFET with Small Change of On-resistance by Applying Variable Gate Voltage Circuit," Journal of the Institute of Electronics and Information Engineers, vol. 59, pp. 77-89, Aug. 2022.