14-bit ADC as voltage monitoring device for power supply module 6 using I2C interface

Edison R. Castillo[1], Catherine D. Samson[2], Glenn N. Ortiz[3], Mark Joseph B. Enojas[4]
[1,2]Analog Devices Inc., General Trias Cavite, Philippines
[3]Industry-based Program, Technological University of the Philippines Taguig, Philippines
[4]Bachelor of Engineering and Allied Department, Technological University of the Philippines Taguig, Philippines

Article Info	ABSTRACT
	There are recorded downtime in the current testing processes of microelectronic packages. The available test equipment, the isolation of the power supply modules, and the processes of testing must be changed in order to minimize the downtime. This study presents the design and development of a voltage monitoring device made of a 14-bit analog to digital converter (ADC) interfaced through inter-integrated circuit (I2C) for power supply module 6 (PS6). It is built to address the downtime in isolation and testing process of PS6. This setup is able to monitor and display three output voltages operating in 4-12 V signals through a thin film transistor (TFT) monitor. Tests were conducted for the nominal voltage and current settings called the three-point tests. In result, the fault detection and calibration process of PS6 are able to minimize downtimes. The developed voltage monitoring device has an acceptable percentage of 0.04572% which also can be a replacement for digital multimeters (DMMs) for specific applications to PS6.

Corresponding Author:

Edison R. Castillo
Analog Devices Inc. General Trias Cavite, Philippines
Technological University of the Philippines Taguig, Philippines
Km, 14 East Service Rd. Western Bicutan, Taguig City, Philippines
Email: edison.castillo@analog.com

1. INTRODUCTION

Device testers in the manufacturing of microelectronic packages require higher integrity for better product quality. These testers used for devices and equipment in the production line from basic voltmeters to signals analysis devices, such as oscilloscopes and signal generators, should conform to the standards. Some modern studies to improve the capability of testing devices have been conducted, such as in automated testing equipment (ATE) [1], signal generators [2], and board checkers for fast loop circuitry [3]. The use of microcontroller-based voltmeter has been utilized by some researchers for devices which need to have visuals such as liquid crystal display (LCD) displays with field programmable gate array (FPGA) processors [4].

Isolation of the testers' digital subsystem is one of the major sources of long downtime in the production of microelectronic packages. It undergoes the process of fault finding, troubleshooting, and eventually, if the problem is identified, isolation or pulling out of the digital subsystem costs a lot of wasted time [5]. Previous developments are the use of on-chip monitoring or integrated circuits in order for the system operation conditions to be tracked easily without pulling out some components when testing [6], [7]. Other considerations such as the environmental electromagnetic presence can also affect the measurement of the testers [8]. Small signal analysis plays a vital role in the characterization and test of microelectronic products. Thus, close monitoring of voltage is needed considering all parameters, even transmission lines [9]-[11].

Power supplies are usually tested and evaluated based on their integrity, quality, and capability to adapt to certain changes in loads in small and in large scale distribution [12]-[15]. Remote power supplies should not be taken for granted beginning in the rise of remote power supplies [16]. Power supplies modules come as embedded devices on several systems of applications [17]-[19]. Different parameters such as noise, current, voltages, and even temperature are being monitored to achieve good performance with added switching capabilities [20]-[24]. Current developments even realize the need for intelligent and scientific management and monitoring that can be accessible online [25]-[27]. In all these realizations, still there are needs that have to be addressed especially in multiple power supply voltage monitoring using handheld or field devices such as used in microelectronic packaging processes.

Power sources such as power supply module 6 (PS6), which supplies the digital subsystem, appear to have no display monitor of the output voltage as in a case study conducted in one of the Philippine semiconductor companies. PS6 has a triple output switching type of power supply. There are 8 formatters that can be connected to PS6 with nominal voltage and current ratings of +5.10 V ±2% at 90 amps, -5.20 V ±2% at 90 amps, and -1.75 V ±2% at 72 amps. It is the source of direct current (DC) power to the formatters of the digital subsystem testers. In the study conducted, the repair takes an average of 7 to 8 hours to regain production. See Figure 1, the former process used is manual cross checking with trimmers which results in the delay of setup time and is also prone to human error.
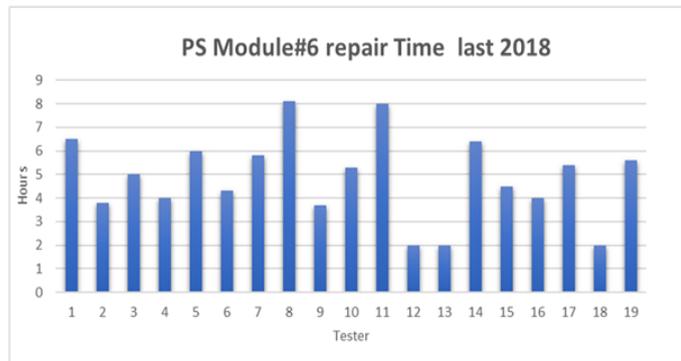
Figure 1. Case study for PS6 repair time log for 2018

This study attempts to address the bottle neck in the testing of PS6 by developing a 14-bit ADC voltage monitoring device in I2C interface [28]-[30]. The I2C is used because of its resilience in digital interfacing. The quad I2C of Analog Devices, Inc. (ADI) is used with the following configuration in Figure 2. A TFT shield is needed to connect a TFT as a monitor, see Figure 3, the voltages in the digital subsystem are monitored to easily identify the faulty PS6s. This process is critical since small fluctuations in the voltages often lead to malfunctions in the process. A linear technology corporation (LTC) 2990, a 14-bit ADC interface, is used for digital compensation. Positive and negative swings of voltages can both be detected in this project. The formatter serves as the load of the supply.
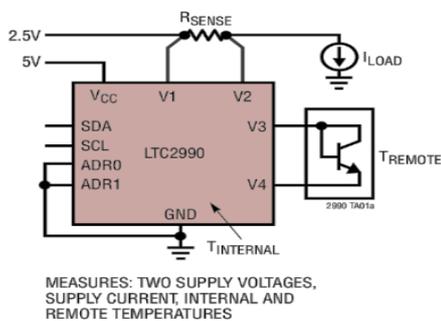
Figure 2. QUAD I2C, LTC 2990 by ADI

Figure 3. ADI TFT shield

2. METHODOLOGY

2.1. Monitoring voltages process flow

The process flow in monitoring the voltages can be summarized into three different sections; i) signal transformation and conditioning, ii) signal transmission, and iii) signal reception and conversion for display monitor. This is illustrated in Figure 4. The analog signal from the PS6 will be the analog input signal to the microcontroller shield. This undergoes signal conditioning and conversion through op-amps and ADC respectively, and sent to the microcontroller unit (MCU) through I2C to finally evaluate and be displayed in the TFT monitor. Since the MCU can only interpret positive signals, an inverter can preferably be used with a flag signal for negative values.
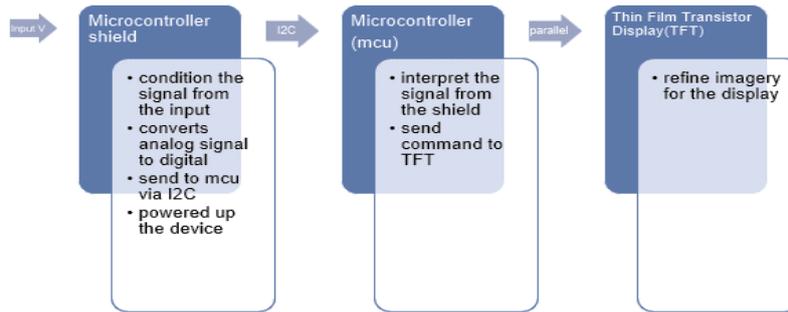
Figure 4. Voltage monitoring process flow

The conventional process flow for repairing the PS6 in Figure 5 can be simplified following the block diagram of Figure 6 using the developed monitoring device (see Figure 7). The manual trimmer adjustments and measurements of the voltage output are minimized in just a single adjustment using the developed prototype. Conventionally, the process of checking and repairing PS6 uses a quick 3-point adjustment done by the technician in the beginning of the test for tolerance checking. These 3 points, as mentioned in section 1, are the +5 V, -5.2 V, and -2 V, for each trimmer respectively. The trimmers are adjusted several times until they satisfy the desired levels. After such adjustments, a more profound check is conducted to verify the congruence of signals within 11 or more points.
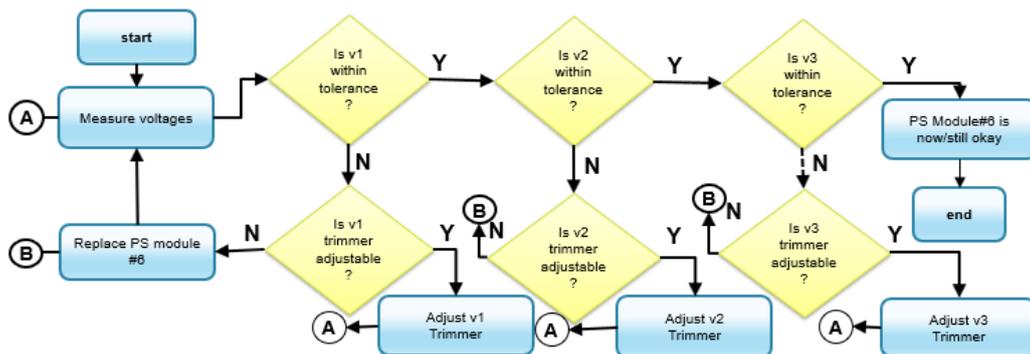
Figure 5. Conventional repair process flow of PS6
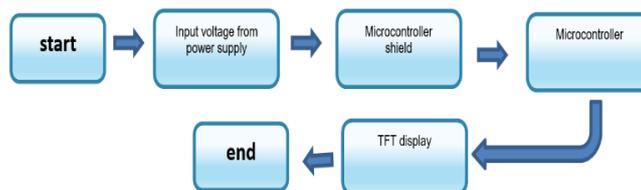
Figure 6. PS6 monitoring block diagram
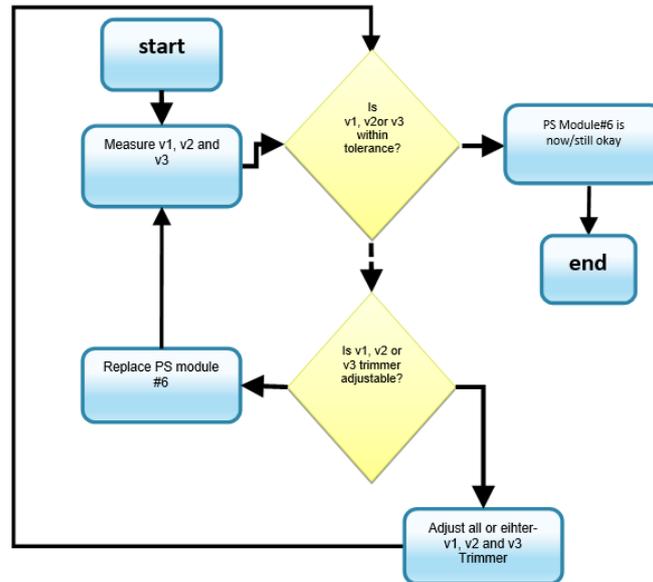
Figure 7. New process flow for repair and calibration of PS6

The new process flow is a reduced process of the conventional process. It only has a single adjustment of the trimmers since all the three voltages can be seen live in the TFT monitor. This is illustrated in a simple block diagram in Figure 5. The devices integration is illustrated in Figure 8. Since the microcontroller used only has 10 bits, which is equivalent to 10 pins, the 14-bit ADC microcontroller shield can still be connected through an I2C interface.
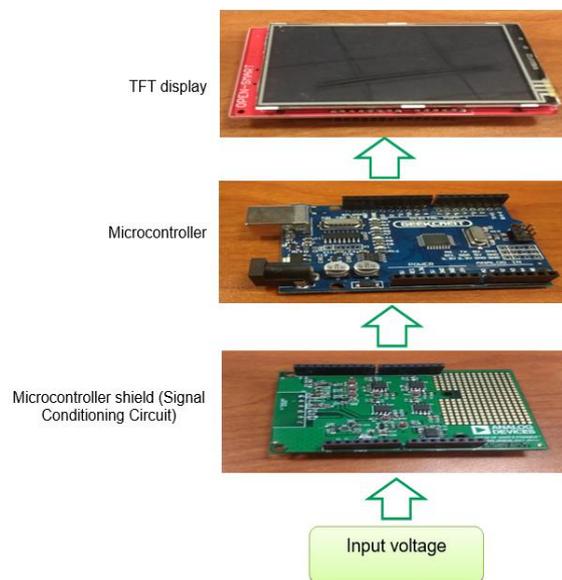
Figure 8. Monitoring device integration

2.2. Development of voltage monitoring device

The MCU shield, the MCU and the TFT display are integrated to form the voltage monitoring device. See Figure 8. Each pin should be compatible to fit its particular pair. This is enclosed in a fabricated fiber casing with the terminals exposed, as presented in Figure 9. The critical ranging in signal conversion is done by programming the microcontroller. This determines the accuracy of measurement despite some losses in the transmission. Several trials have been conducted and data has been collected to have the most accurate settings.

(a)   (b)
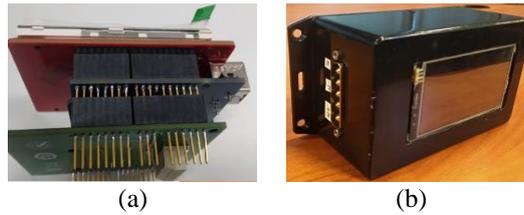
Figure 9. These figures are; (a) integrated components and (b) with enclosure

2.3. Tests and evaluation

A digital multi-tester with an accuracy tolerance of 0.1% at +5 mV and 0.05% at +10 mV to 20 mV is used as a reference tester. Each channel of the developed tester is tested and evaluated to further program and adjust parameters in the microcontroller unit based on the data collected. The data collected using the DMM and the experimental setup output are evaluated and compared. This will enable us to see the acceptability of the prototype. To test for the accuracy of the prototype in reference to a known calibrated DMM, a three-point test is conducted. This three-point test is based on the working voltage ranges of the three channels of PS6. Multiple tests are conducted and averaged according to the three points of reference.

3. RESULTS AND DISCUSSION

3.1. Accuracy test

The comparative analysis was conducted using the three-point test. The reference voltage comes from the PS6. Simultaneously, the voltages are read and compared for both the experimental and the DMM readings. See Figure 10, comparing the DMM readings to that of the experimental readings yield offsets presented in Table 1. The full test is conducted with the following test points. The accuracy is presented based on the percent error (% error). The results significantly present acceptable experimental outputs with an accuracy in terms of percent error of from 0.015% to 0.019% where ±2% is the ideal acceptable range of error based on the user requirements.

(a)   (b)

(c)   (d)
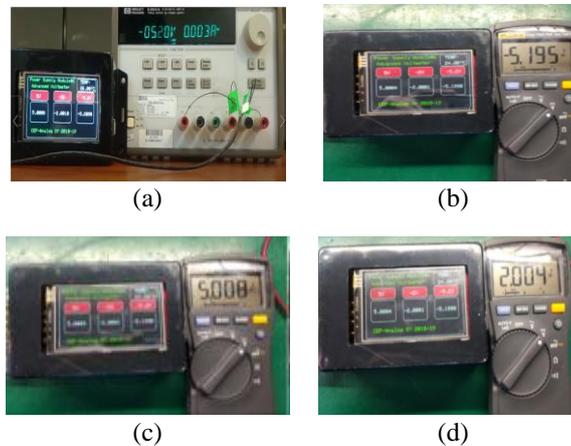
Figure 10. These figures are; (a) basic test and calibration setup of PS6, (b)-(d) measurement of voltages for 3 channels using the prototype and comparing it with DMM readings

Table 1. Accuracy test results

Channel	Reference (V)	Readings (V)		Offset (mV) DMM-Prototype	% Error
		DMM	Experimental		
1	5	5.008	5.0004	7.6	0.015
2	-5.2	-5.195	5.119	4	0.0769
3	-2	-2.004	-2.0001	3.9	0.1946

3.2. Comparative analysis of error

The comparative analysis in the error measurement determines the acceptability of the developed voltage monitoring device. The voltage monitoring device is adjusted to the best possible output that it can

have. The experimental data is the data referring to the output of the developed voltage monitoring device. There were 11 points of voltage levels tested ranging specifically from 4.7, 4.75, 4.85, 4.9, 4.95, 5.0, 5.05, 5.1, 5.15, 5.25, 5.3 volts. These values serve as the reference voltages coming from the PS6. Figure 11 shows the comparison of voltages between the experimental data and the DMM.

Absolute error is measured by comparing the output data of both DMM and the developed voltage monitoring device. Figure 12 shows the comparison between the DMM and Experimental data errors. The percent error of the experimental data can be computed by comparing it to the reference voltages and is displayed in Figure 13. The average percent error is equivalent to 0.04572%, which is an acceptable margin of error for calibrating and repairing PS6 which is at ±2%.
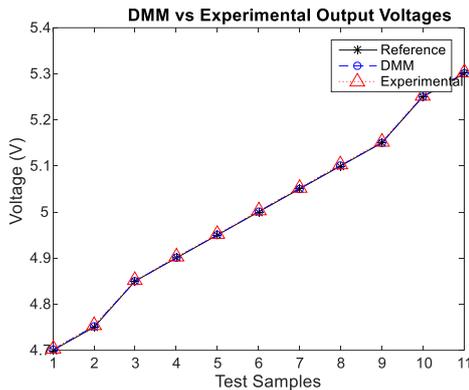
Figure 11. DMM vs. experimental output voltages
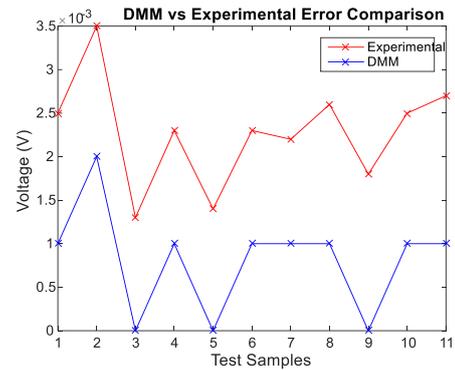
Figure 12. Error comparison between DMM and experimental data
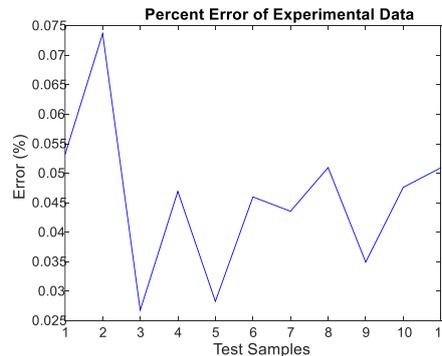
Figure 13. Experimental data percent error

4. CONCLUSION

The use of PS6 is very critical in the production of microelectronic packages. In the calibration and repair of PS6, the testers should have high reliability and have high data measurement integrity. Another parameter to be considered is the speed of measurement and calibration. In this research, a voltage monitoring device was developed to speed up the process of testing, calibration, and repair of PS6 using a 14-bit ADC interfaced via I2C with multiple displays from TFT. The experimental data shows an acceptable percent error of 0.04572%, which has a maximum limit of ±2%. Therefore, it can act as a DMM that can simultaneously display 3 voltages for this specific range of voltage application only. The new test process has been proven to be faster since transferring of DMM from one terminal to another is eliminated with the use of the prototype developed. The fault detection process is made easier because of the multiple display of the TFT.

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REFERENCES

[1] J. E. Bombita, J. R. Alsado, G. N. Ortiz, and M. J. B. Enojas, "Comprehensive Measurement System for Electromechanical Relay," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 1, pp. 199–204, 2020, doi: 10.30534/ijatcse/2020/3591.12020 .

[2] L. R. Landicho, I. B. Garcia, G. N. Ortiz, and M. Joseph B. Enojas, "Measuring Signal Generator Response Through An Adc Evaluation Board," *International Journal of Scientific & Technology Research*, vol. 9, no. 04, pp. 2086–2090, 2020.

[3] J. P. Abillar, I. Journal, J. P. Abillar, M. A. Aceron, G. N. Ortiz, and M. Joseph B. Enojas, "Development and Implementation of a Board Checker for Fast Loop Circuitry in Testing Microelectronic Packages," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 1, pp. 1–6, 2020, doi: 10.30534/ijatcse/2020/4891.32020.

[4] R. Blaine Foist, X. Xu, T. Gage, S. Truitt, and M. Hans Schmidt, "A First-Year Electronics Lab Project-Design of Basic Voltmeter plus Soldering Tutorial," *2018 FYEE Conference*, Glassboro, New Jersey, 2018.

[5] K. Takenaka, Y. Mizuno, and A. Yoshida, "Condition Monitoring of Damaged AC Power Supply Cord Using Voltage Waveform," *2018 Condition Monitoring and Diagnosis (CMD)*, 2018, pp. 1-5, doi: 10.1109/CMD.2018.8535679.

[6] H. Aoki, M. Ikeda, and K. Asada, "On-chip voltage noise monitor for measuring voltage bounce in power supply lines using a digital tester," *ICMTS 2000. Proceedings of the 2000 International Conference on Microelectronic Test Structures (Cat. No.00CH37095)*, 2000, pp. 112-117, doi: 10.1109/ICMTS.2000.844416.

[7] C. Chen, S. Member, D. Wang, J. Li, C. Wang, and S. Member, "A Voltage Monitoring IC With HV Multiplexer and HV Transceiver for Battery Management Systems," *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, vol. 23, no. 2, pp. 244–253, 2015, doi: 10.1109/TVLSI.2014.2303989.

[8] T. Rahman and Z. Yan, "Designing of a Voltage Monitor for Measuring the Voltage of Sensitive Component on the PCB in EM Environment," *2011 4th IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications*, 2011, pp. 7-10, doi: 10.1109/MAPE.2011.6156246.

[9] Y. Liao, T. Sun, L. Zhang, B. Feng, M. Liu, and Yang Xu, "Power cable condition monitoring in a cable tunnel: Experience and inspiration," *2016 International Conference on Condition Monitoring and Diagnosis (CMD)*, 2016, pp. 594-597, doi: 10.1109/CMD.2016.7757910.

[10] K. Agarwal, S. Nassif, F. Liu, J. Hayes, and K. Nowka, "Rapid Characterization of Threshold Voltage Fluctuation in MOS Devices," *2007 IEEE International Conference on Microelectronic Test Structures*, 2007, pp. 74–77, doi: 10.1109/ICMTS.2007.374458.

[11] H. Qiu, Y. Zhongdong, and D. Yajing, "Multi-Level Voltage Quality Adjustment Device Based on FPGA Control," *2010 5th IEEE Conf. on Industrial Electronics and App.*, 2010, pp. 985-988, doi: 10.1109/ICIEA.2010.5515742.

[12] L. Yu, B. Nazir, and Y. Wang, "Intelligent power monitoring of building equipment based on Internet of Things technology," *Computer Communications*, vol. 157, pp. 76-84, 2020, doi: 10.1016/j.comcom.2020.04.016.

[13] M. Yuan, Y. Liu, S. Member, R. Liu, and X. Niu, "Monitoring and Analysis of Power Supply Reliability of Low Voltage Consumers," *2006 International Conference on Power System Technology Monitoring*, 2006, pp. 1–4, doi: 10.1109/ICPST.2006.321772.

[14] C. Zhu, M. Hu, Z. Wu, X. Dou, and S. Zhao, "Design and realization of regional power quality monitoring system," *2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*, 2008, pp. 2023-2027, doi: 10.1109/DRPT.2008.4523740.

[15] A. Nazarychev, A. Tadzhibaev, and Y. Solovyev, "Monitoring of Technical Condition of the Power Supply System's Equipment and Operating Reliability," *Power Quality and Supply Reliability Conference*, no. 1, 2008, pp. 20–23.

[16] M. Wade, A. Chew, and R. Geraghty, "Monitoring battery performance in remote-area power-supply (RAPS) systems," *J. Power Sources*, vol. 35, no. 4, pp. 421–430, 1991, doi: 10.1016/0378-7753(91)80062-3.

[17] N. Yamashita, K. Tsukamoto, and T. Yachi, "A board-mounted power supply module using a new low power dissipation-control IC," *IEEE Transactions on Power Electronics*, vol. 8, no. 4, pp. 362-367, Oct. 1993, doi: 10.1109/63.261005.

[18] E. R. Motto, J. F. Donlon, M. Honsberg, F. Tametani, and G. Str, "A New Intelligent Power Module with Enhanced Diagnostics and Protection," *2013 Twenty-Eighth Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2013, pp. 2398–2401, doi: 10.1109/APEC.2013.6520631.

[19] R. Ø. Nielsen and A. Elkiær, "Innovative use of power integrated modules for DC power supplies," *15th European Conference on Power Electronics and Applications (EPE)*, 2013, pp. 6-11, doi: 10.1109/EPE.2013.6634644.

[20] H. Tamamoto, H. Yokoyama, and Y. Narita, "Random Current Testing for CMOS Logic Circuits by Monitoring a Dynamic Power Supply Current," *Proceedings EURO-DAC '92: European Design Automation Conference*, 1992, pp. 480-485, doi: 10.1109/EURDAC.1992.246200.

[21] V. Bolshev, A. Vinogradov, M. jasiński, T. Sikorski, Z. Leonowicz, and R. Gono, "Monitoring the Number and Duration of Power Outages and Voltage Deviations at Both Sides of Switching Devices," *IEEE Access*, vol. 8, pp. 137174- 137184, 2020, doi: 10.1109/ACCESS.2020.3011836.

[22] Z. Hong, X. Jian, Z. Liang, Y. Fei, and C. Jiong, "Research on Adaptive Switching Power Supply Control Technology," *2018 IEEE International Conference of Safety Produce Informatization (IICSPI)*, 2018, pp. 742-745, doi: 10.1109/IICSPI.2018.8690395.

[23] X. Jun-jun, H. Hua, and D. Xiao-pin, "Design of Power Supply State Monitoring System for Active Electronic Current Transformer," *2018 China International Conference on Electricity Distribution*, 2018, pp. 1896-1904, doi: 10.1109/CICED.2018.8592020.

[24] J. Rius Vazquez and J. Pineda de Gyvez, "Power Supply Noise Monitor for Signal Integrity Faults," *Proceedings Design, Automation and Test in Europe Conference and Exhibition*, vol. 2, 2004, pp. 1406-1407, doi: 10.1109/DATE.2004.1269109.

[25] X. Liu, J. Zou, and X. Zhang, "A new DC power supply centralized monitoring system," *2008 International Conference on Condition Monitoring and Diagnosis*, 2008, pp. 786-789, doi: 10.1109/CMD.2008.4580402.

[26] H. Shihui, Y. Zhongliang, and Z. Yu, "An Intelligent Power Online Monitoring and Measurement System of FGC Wind Photovoltaic Storage Integrated Power Station," *2018 IEEE International Telecommunications Energy Conference (INTELEC),* 2018, pp. 1-4, doi: 10.1109/INTLEC.2018.8612320.

[27] T. Lu, J. Yin, Q. Lv, Y. Wu, X. Lou, and Z. Lin, "A Novel Network-Accessible and Localizable Power Monitor," *2019 IEEE 2nd International Conference on Computer and Communication Engineering Technology-CCET A*, 2019, pp. 245–248, doi: 10.1109/CCET48361.2019.8988955.

[28] W. Andrysiewicz, D. Kościelnik, and M. Miśkowicz, "I2C Hardware Master Serial Interface for Asynchronous ADCs," *2015 IEEE International Symposium on Systems Engineering (ISSE)*, 2015, pp. 2–6, doi: 10.1109/SysEng.2015.7302736.

[29] T. Addabbo, A. Fort, M. Mugnaini, S. Parrino, A. Pozzebon, and V. Vignoli, "Using the I2C bus to set up Long Range Wired Sensor and Actuator Networks in Smart Buildings," *2019 4th International Conference on Computing, Communications and Security (ICCCS)*, 2019, doi: 10.1109/CCCS.2019.8888085.

[30] C. Grecu and C. Ache, "Portable I2C Monitor and Debugger," *2015 IEEE 21st International Symposium for Design and Technology in Electronic Packaging (SIITME)*, 2015, pp. 131–134, 2015, doi: 10.1109/SIITME.2015.7342310.

BIOGRAPHIES OF AUTHORS

Edison R. Castillo is a graduate of mechanical engineering technology at the Technological University of the Philippines Visayas, Bacolod, Philippines. He is also a graduate of bachelor of science in electronics and communications engineering at the Technological University of the Philippines Taguig. Currently, he is working as test equipment engineer in analog devices inc., general trias cavite, Philippines. Email: edison.castillo@analog.com.

Catherine D. Samson is a graduate of electronics engineering technology at the Technological University of the Philippines Visayas, Bacolod, Philippines. She is also a graduate of bachelor of science in electronics and communications engineering at the Technological University of the Philippines Taguig. Currently, she works as an equipment maintenance technician in analog devices inc., general trias cavite, Philippines. Email: catherine.samson@analog.com.

Glenn N. Ortiz is a graduate of bachelor of science in electronics and communications engineering at the University of the East in Manila Philippines. He is also a graduate of master of technology management in University of the Philippines Diliman, Quezon City Philippines. His research interests are in industrial automation, manufacturing, and electronics. He is currently the director of the industry-based program of the Technological University of the Philippines Taguig. E-mail: glenn_ortiz@tup.edu.ph.

Mark Joseph B. Enojas received a degree of bachelor of science in electronics and communications engineering from Technological University of the Philippines Taguig in 2009, master of information technology in University of the Philippines Los Baños, Laguna, Philippines and is currently pursuing Ph. D. in electrical and electronics engineering at University of the Philippines Diliman, Quezon City Philippines. His research interests are on automation, mechatronics, industrial automation, and soft robotics. E-mail: markjoseph_enojas@tup.edu.ph.