3rd International Conference on Computational Intelligent Systems 2024 (ICCIS2024)

Thermoelectric Energy Harvesting System for Wearable Electronics

Presented By:

Mujeeb Ur Rahman
Faculty of Electrical Engineering
GIKI of Engineering Sciences and Technology
Swabi, Pakistan
mujeeb1024@gmail.com

Presentation Agenda

1. Introduction
2. Literature Review
3. Problem Statement
4. Research Methodology
5. Block Diagram
6. Implementation
7. Results
8. Conclusion and Future work

Introduction (1/4)

Renewable sources of energy

- Resources naturally-restore human timescale,
- Sunlight, Wind, Rain, tides, Waves, and Heat $\longrightarrow$ replenished naturally
- Produce lower greenhouse effect

Introduction (2/4)

Solar energy

- Use photovoltaic cells
- Sunlight ⟶ electricity

Wind energy

- Employing wind turbines to gen

Hydroelectric power

- Kinetic energy of flowing water

Geothermal energy

- Heat beneath the Earth's surfac

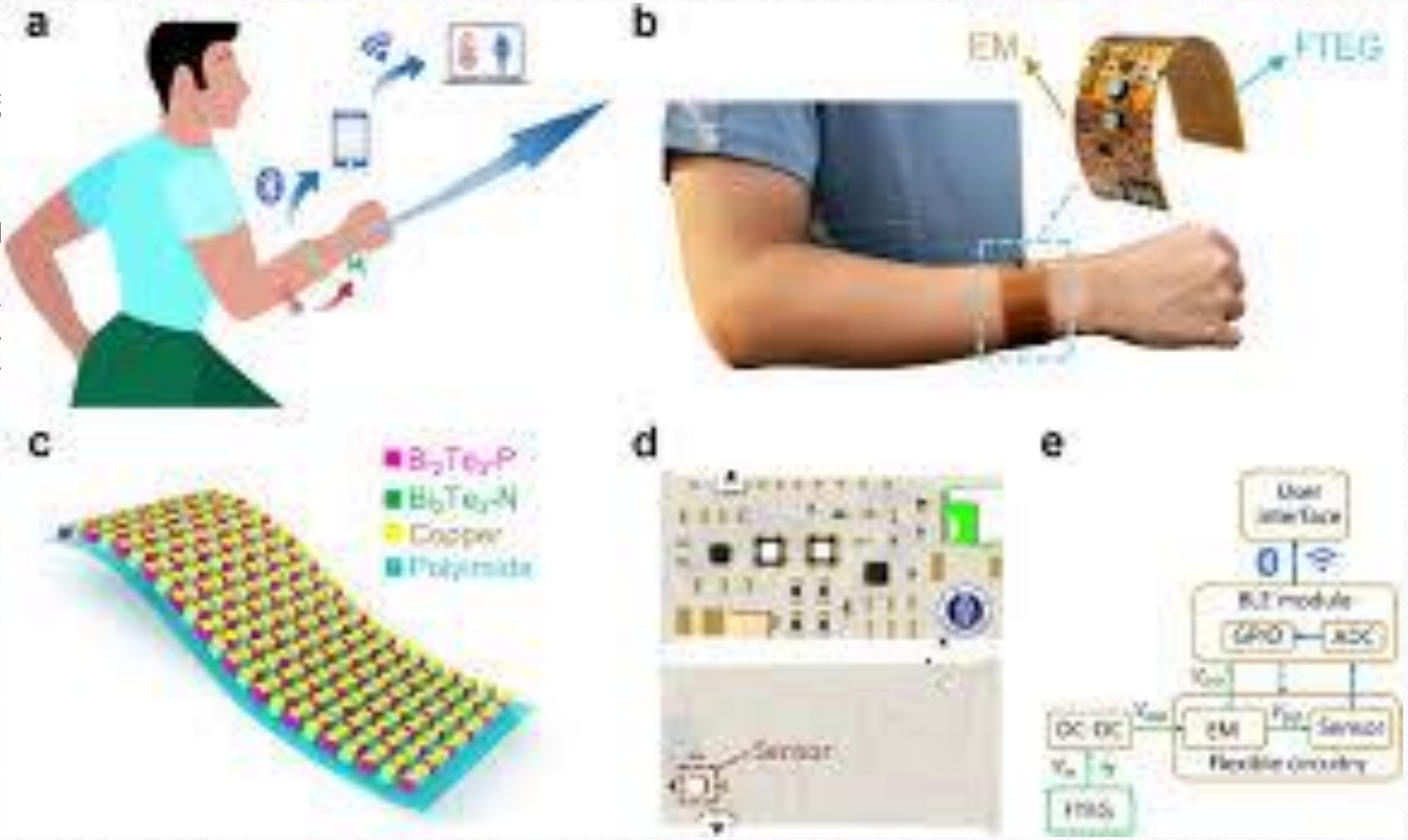
Thermal energy

- Thermo electric generator conv

Introduction (3/4)

Human body heat harve

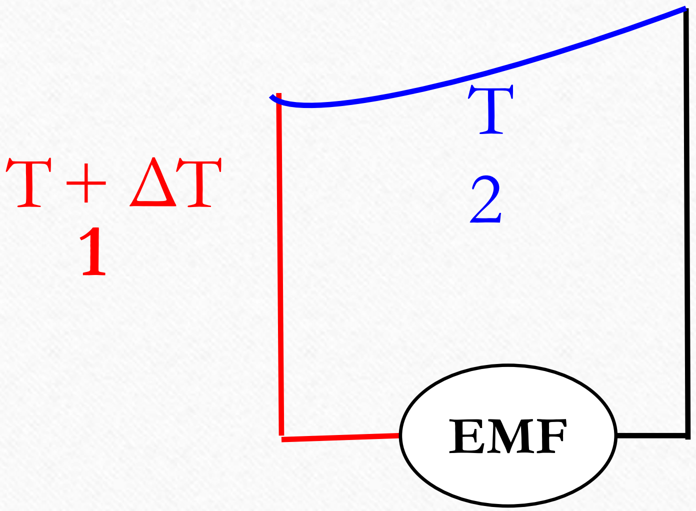
- Normal human body
- Body temperature can
- Use TEG for harvesti
- **Output voltage ∝ ΔT**



Introduction (4/4)

Thermoelectric generator (TEG)

- Direct thermal energy into electrical energy.
- Principle-"Seebeck effect" [3].
- **Seebeck effect –** two different metals at different temperature create EMF



Seebeck effect

Literature review (1/2)

Literature about TEG based systems

Reference Number	Authors	Title	Journal/Conference	Year
[1]	D. Champier	Thermoelectric generators: A review of applications	Energy Conversion and Management	2017
[2]	O. H. Ando Jr., N. H. Calderon, S. S. de Souza	Characterization of a thermoelectric generator system for waste heat recovery	Energies	2018
[3]	F. Cao, J. Zhang, H. Wu, H. Hu, Y. Xing, X. Ma	A dual-input Boost-Buck converter with coupled inductors for TEG applications	IEEE Energy Conversion Congress and Exposition	2013
[4]	C. Aoughlis, A. Belkaid, M. A. Kacimi, et al.	A Novel Dynamic and Self-Adaptive Incremental Conductance Technique for Hybrid PV-TEG Systems	Electric Power Components and Systems	2024
[5]	R. Y. Kim, J. S. Lai	Aggregated modeling and control of a boost-buck cascade converter	IEEE Applied Power Electronics Conference and Exposition	2008

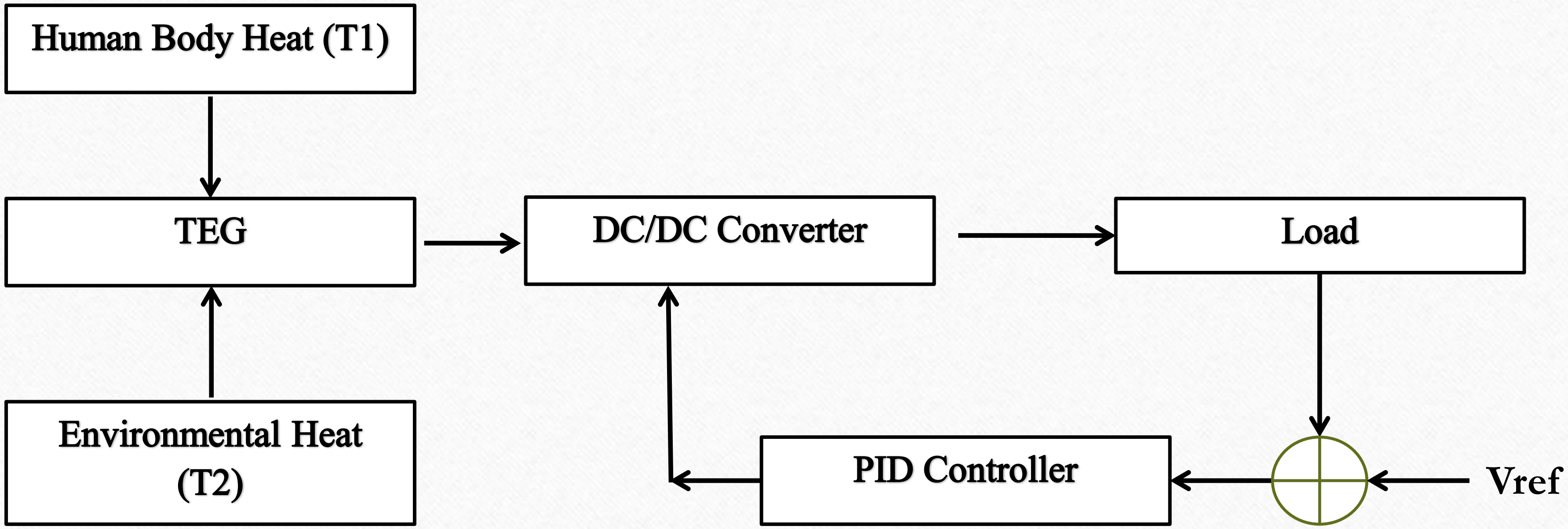
Research Gap

- Above TEG based systems require high temperature gradient which can’t be used for human body-based applications (lower temperature)
- DC-DC buck-boost converter to step-up ultra-low voltage

Problem Statement

The paper addresses the challenge of powering wearable electronics sustainably by developing a thermoelectric generator (TEG) system that harvests body heat and uses a Buck-Boost converter to amplify and stabilize low-voltage outputs.

Block Diagram



Research Methodology

Literature survey

- TEG based systems
- Buck-Boost converter
- Controller (PI, PD and PID)

Design of Buck-Boost converter

Simulation

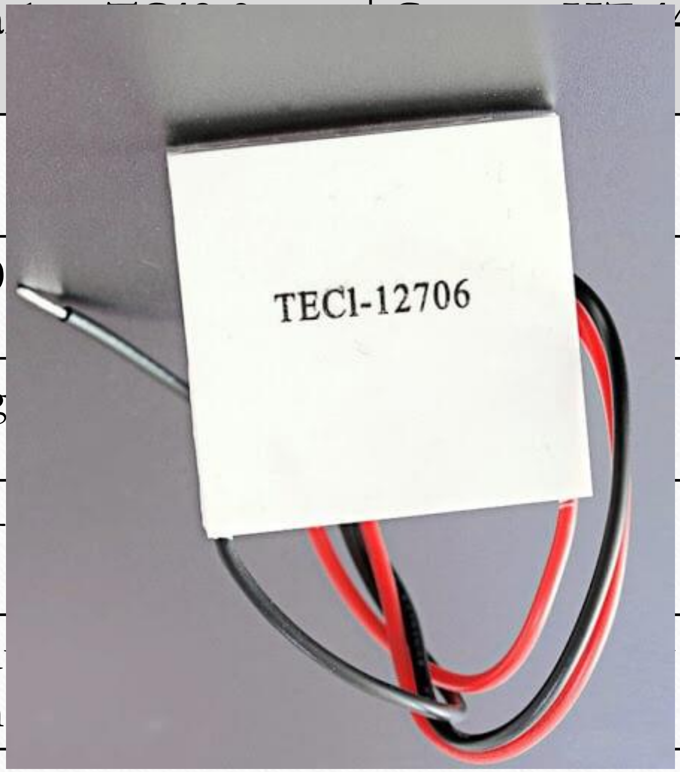
- Controller design
- Printed Circuit board

Result validation

Implementation (1/11)

Survey on TEGs

Specification	**Ma**	**4**	**TEC1-12706**
Maximum Voltage	5V		15.4V
Optimum ΔT	200		70°C
Cost	Hig		Low
Internal resistance	~4-		~1.5Ω
Usage	Ind gen	power	Prototyping, small-scale gen.



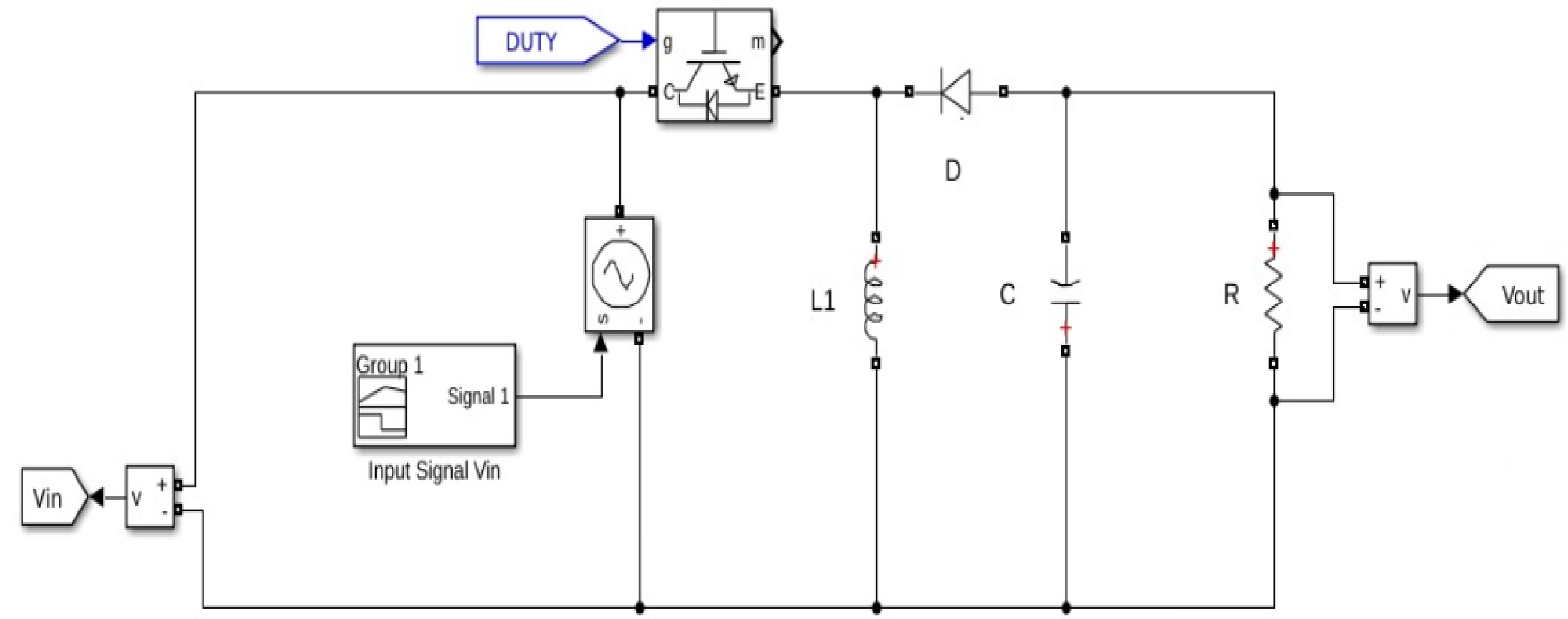
Implementation (2/11)

- The output voltage by using TEC1-12706 and body heat is very low
- Use special type of DC-DC converter
- Design Buck-Boost DC-DC converter

Implementation (3/11)

Converter type	Function	Types	Applications
DC-DC converter	Convert DC to different DC	Buck, Boost, Buck-Boost	Portable devices, EVs, solar systems, LED drivers
AC-DC Converter	Convert AC to DC	Rectifiers (Half-Wave, Full-Wave, Bridge), PFC, SMPS	Power supplies, battery charging, industrial power, LED lighting
DC-AC Converter	Convert DC to AC	Inverters (Square Wave, Modified Sine Wave, Pure Sine Wave)	Renewable energy systems, UPS, motor drives, home appliances
AC-AC Converter	Convert AC to different AC	AC Voltage Regulators, Cyclo-converters, Matrix Converters	Motor speed control, frequency conversion, voltage regulation

Implementation (4/11)



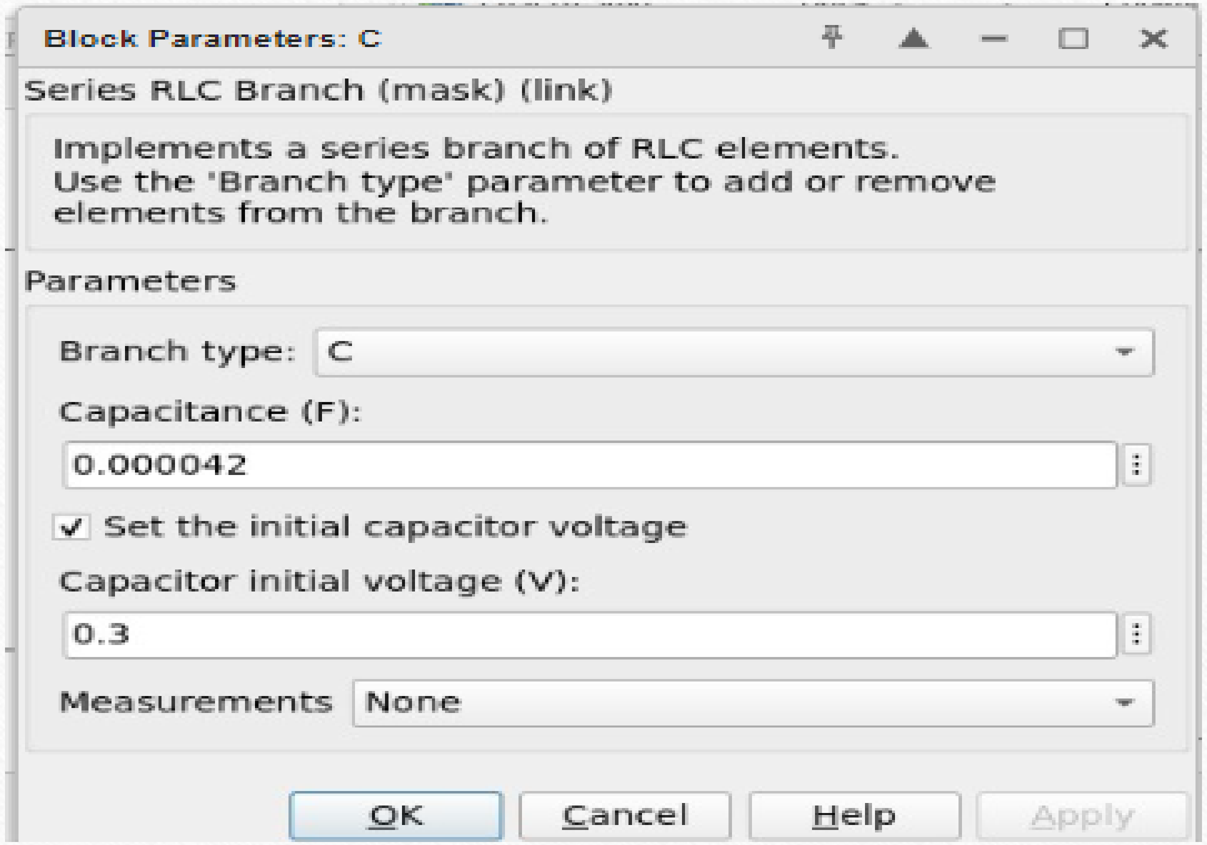
DC-DC Buck Boost converter

Implementation (5/11)

Aspect	PI Controller	PD Controller	PID Controller
Components	Proportional (P) + Integral (I)	Proportional (P) + Derivative (D)	Proportional (P) + Integral (I) + Derivative (D)
Control Equation	$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau$	$u(t) = K_p e(t) + K_d \frac{d}{dt} e(t)$	$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$
Proportional Term (P)	Responds to present error	Responds to present error	Responds to present error
Integral Term (I)	Eliminates steady-state error	Not present	Eliminates steady-state error
Derivative Term (D)	Not present	Responds to rate of change of error	Responds to rate of change of error
Steady-State Error	Eliminates steady-state error	May have steady-state error	Eliminates steady-state error
Response Speed	Moderate	Fast	Fast

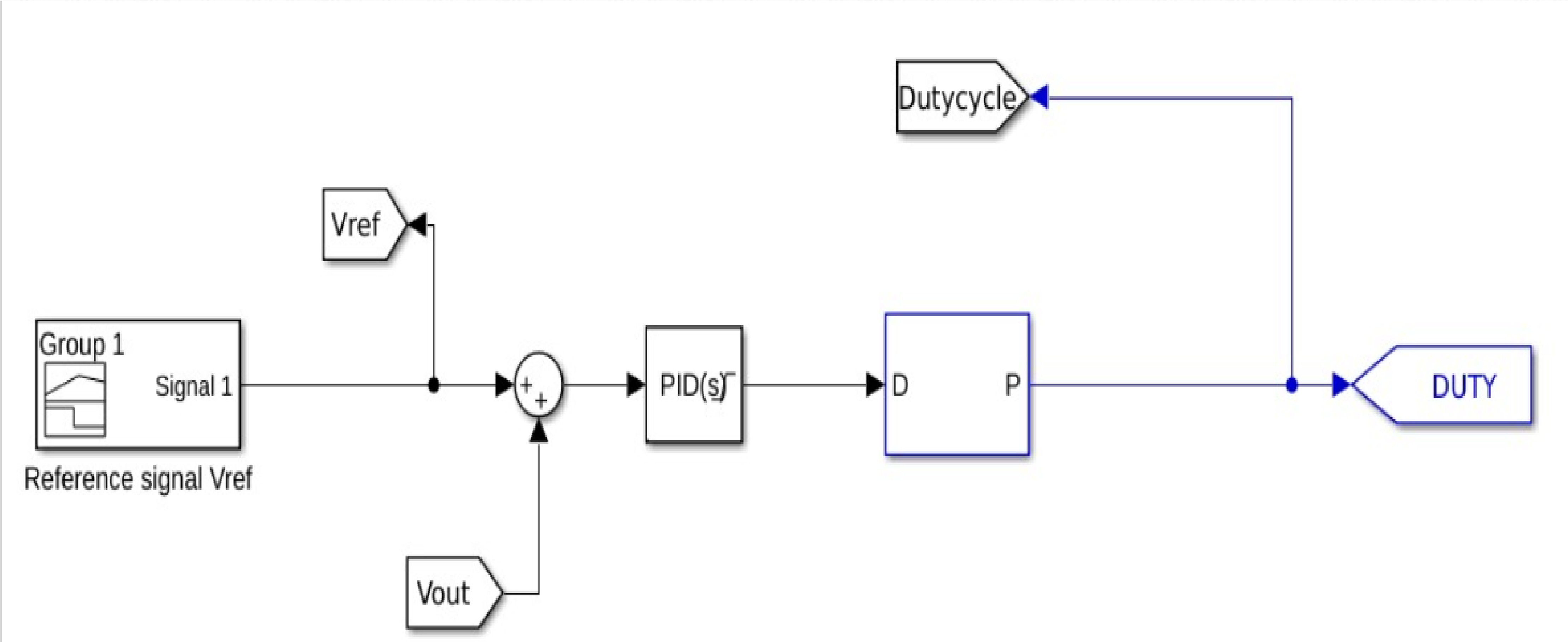
Implementation (6/11)

PID Controller's specifications



Parameters of PID controller

Implementation (7/11)



PID controller

Implementation (8/11)

- On survey I find the following converters related to project
- Designed booster- integration of Coupled Inductors “LPR6235” and “LTC3108” 300mA
- Obtained output step up to 1:100
- Further step-up by LTC3108 from millivolts to volts
- Designing of new model is shown in next slide using EasyEda

Implementation (9/11)

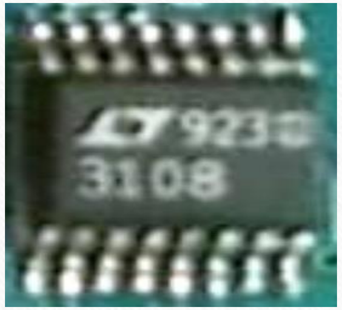
LTC3108

Input voltage	20 mV to 500 mV
Output voltage dependent “R”	2.35V, 3.3V, 4.1V, and 5V

LPR6235

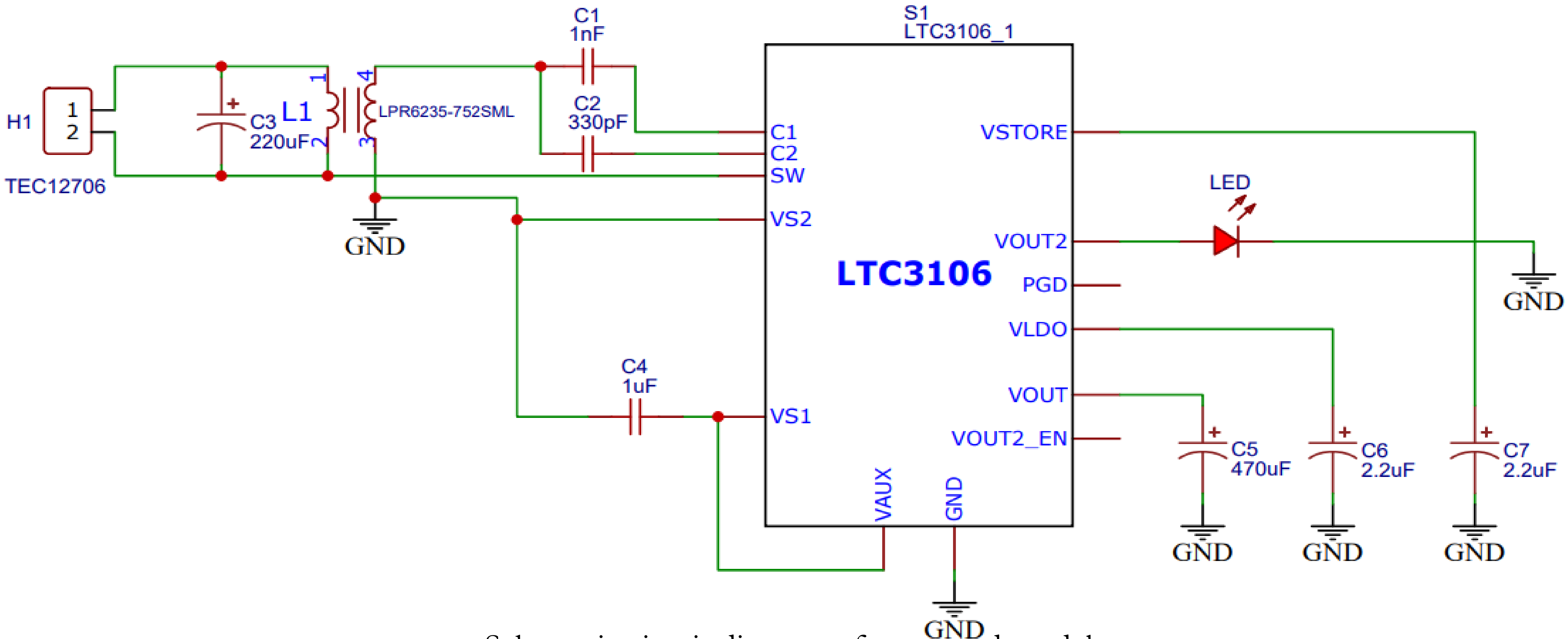
Input Voltage	2V to 7V
Output Voltage dependent “R”	3V to 8V

(a). LPR6235



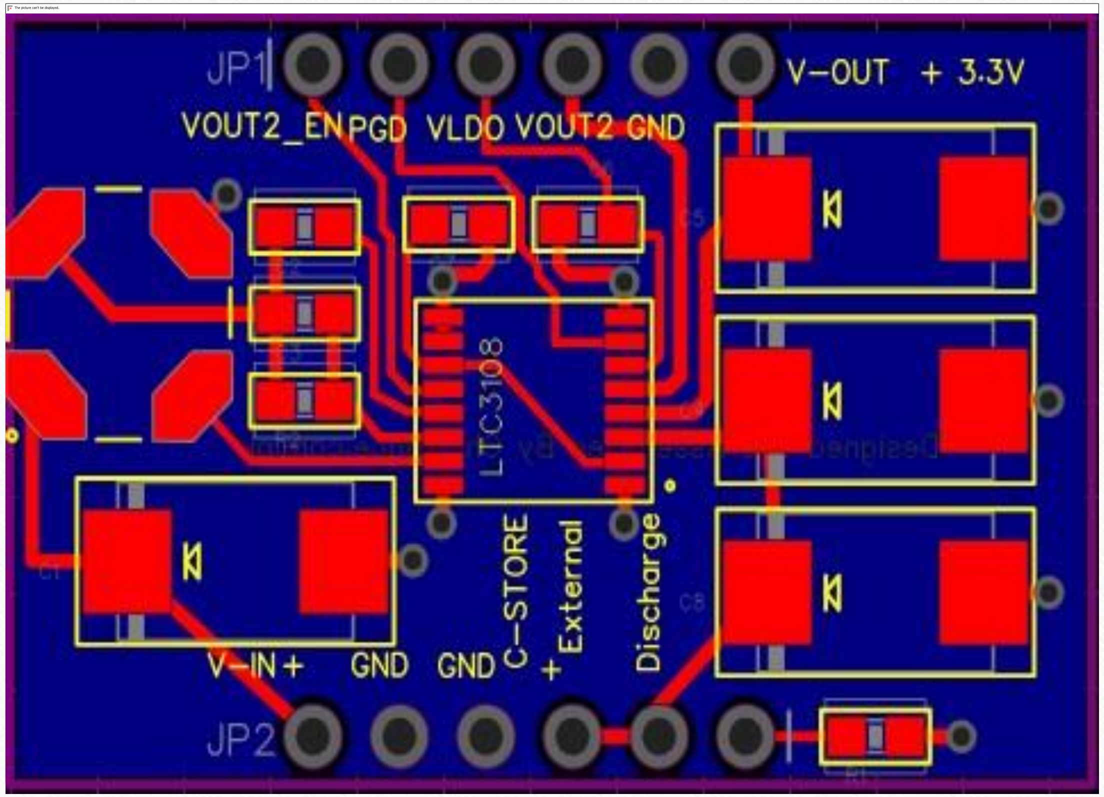
(b). LTC3108

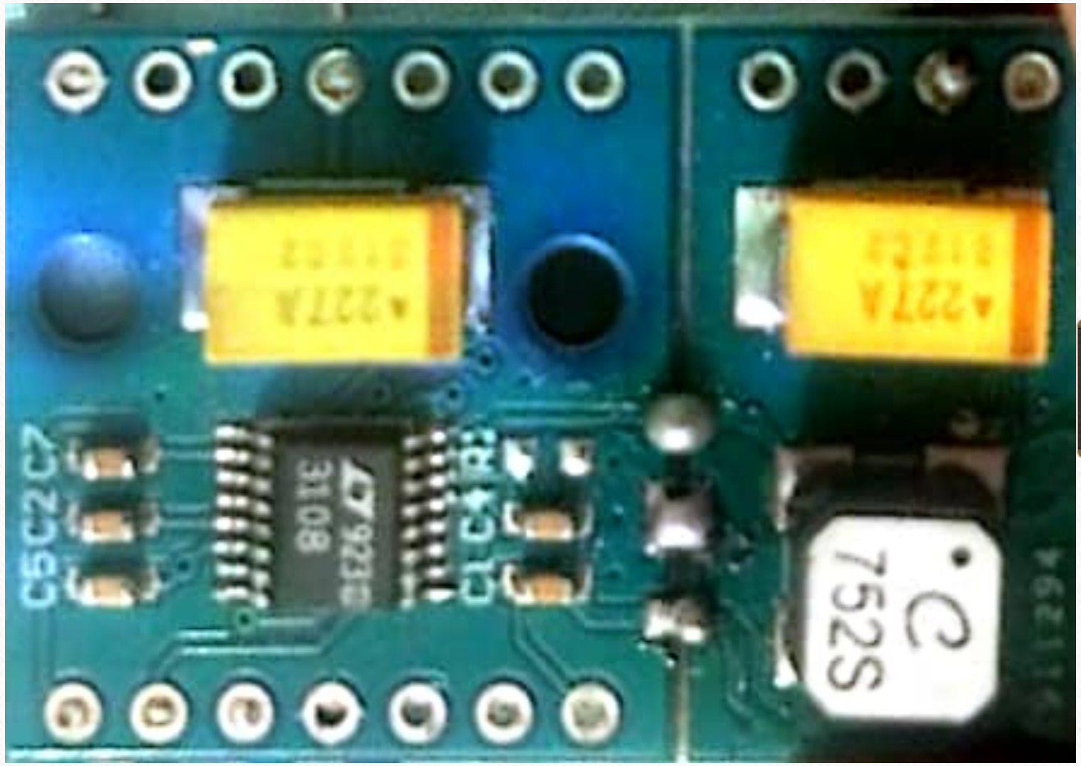
Implementation (10/11)



Schematic circuit diagram of proposed model

Implementation (11/11)



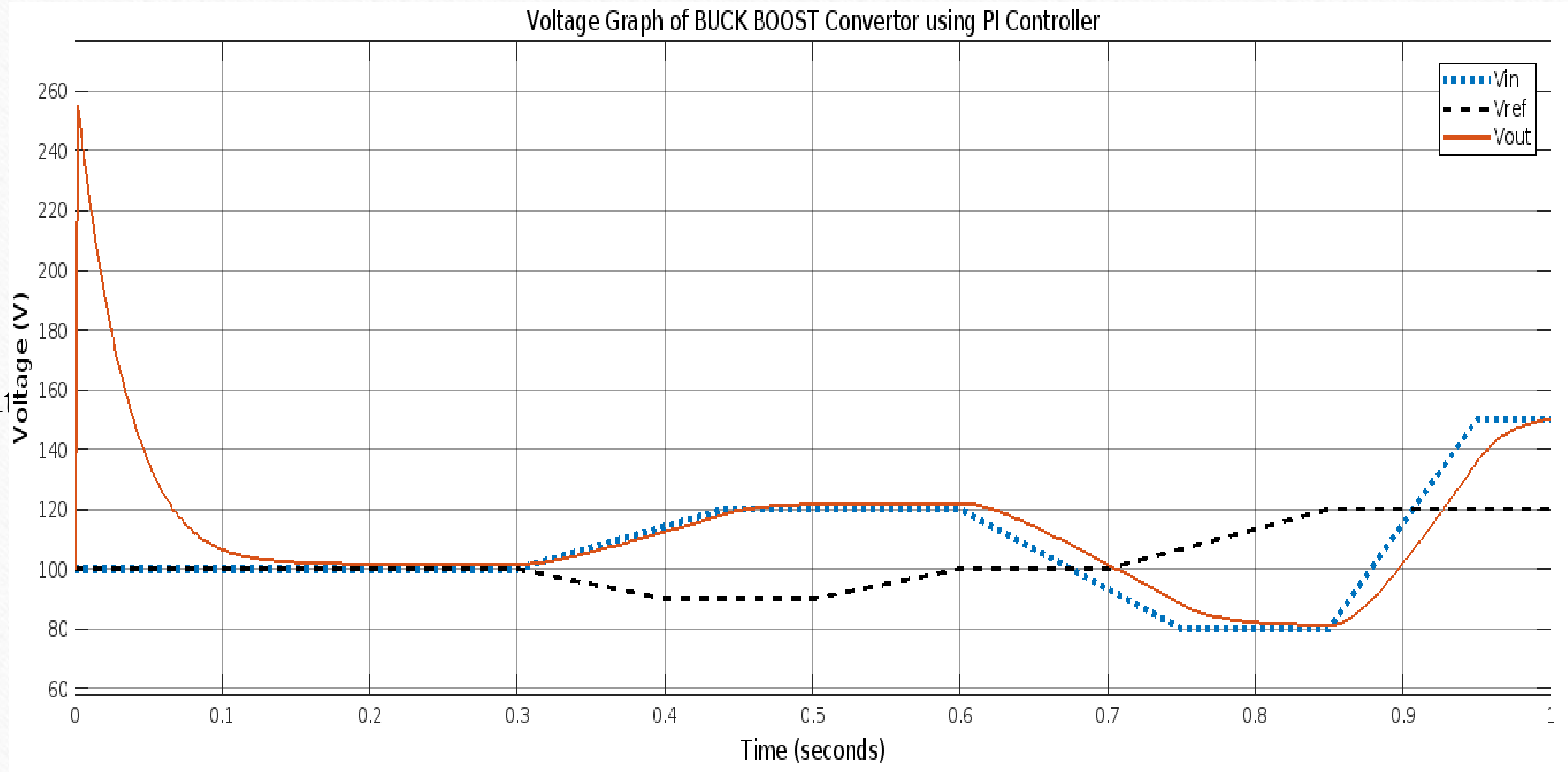


(a) PCB Design of proposed booster module (b). Obtained Booster module

Results (1/4)

Effect of switching frequency (f_s) on PI controller

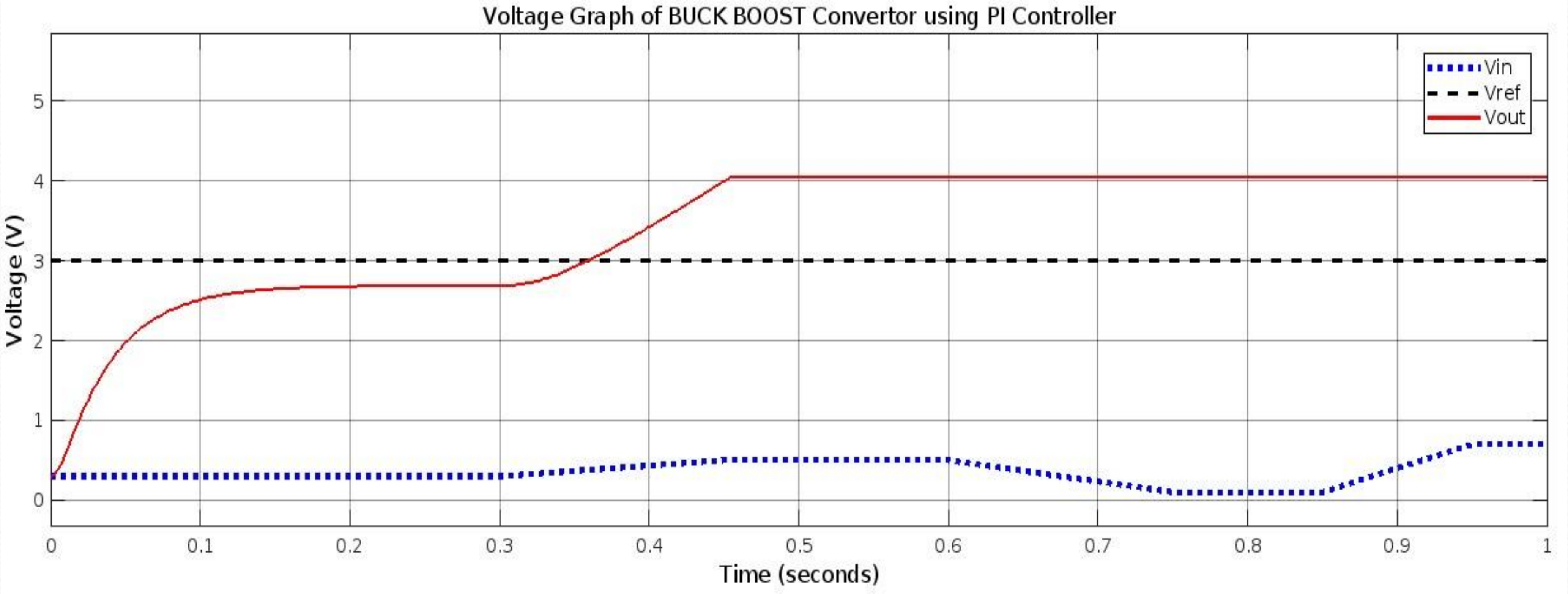
fs =1000Hz _ Du



Results (2/4)

Effect of capacitor on PI controller

- Increase value of C from 0.000042F to 0.42F

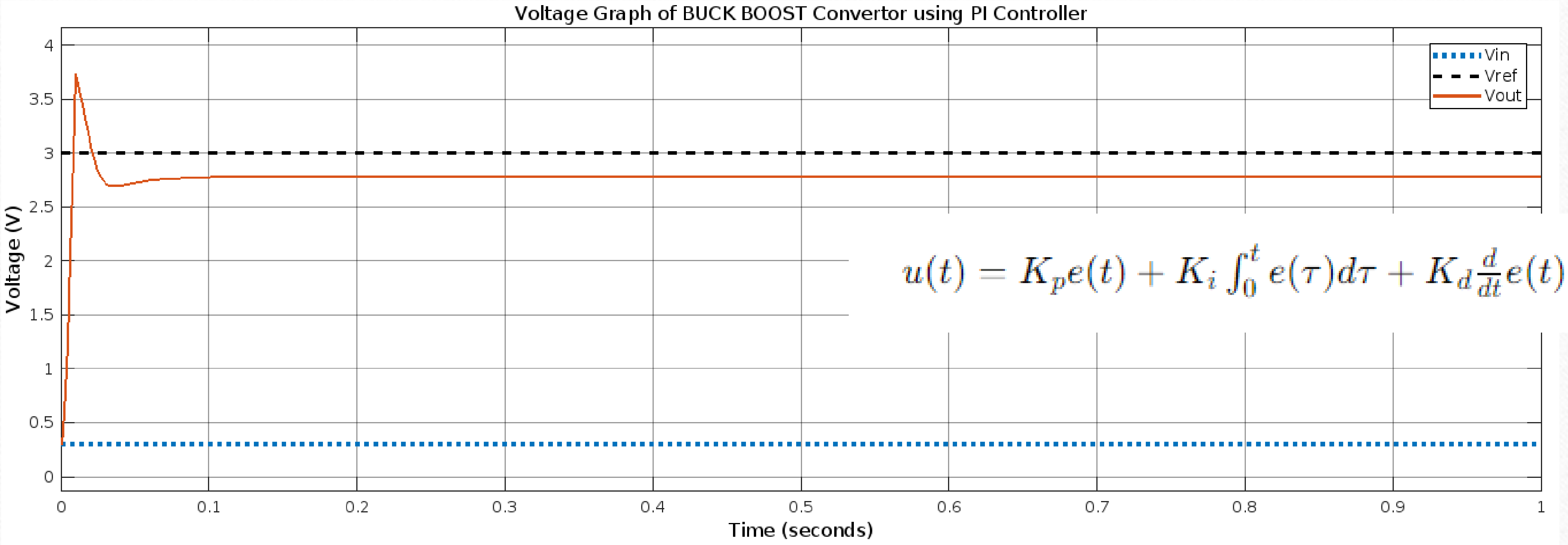


Output Graph at C=0.42F

Results (3/4)

PID Controller for lower voltage case:

- Input 300mV
- output 3V

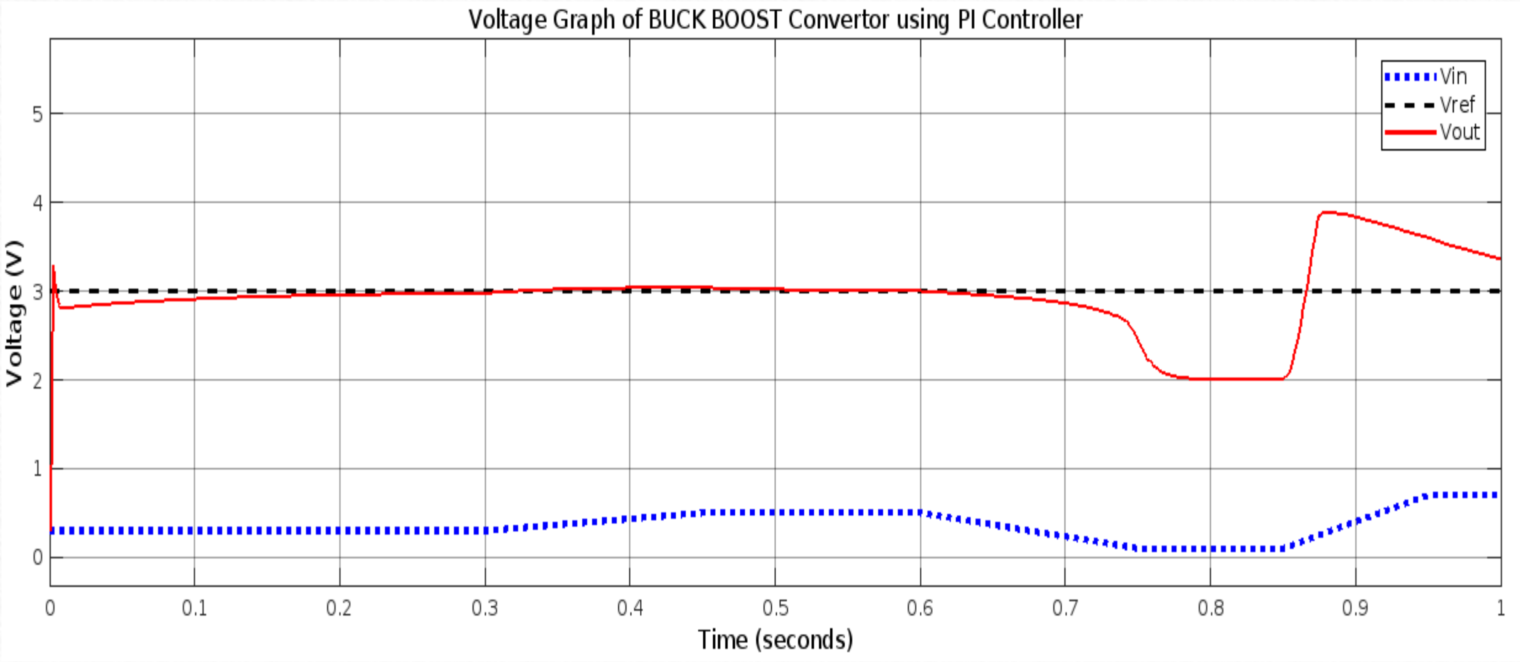


$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t)$$

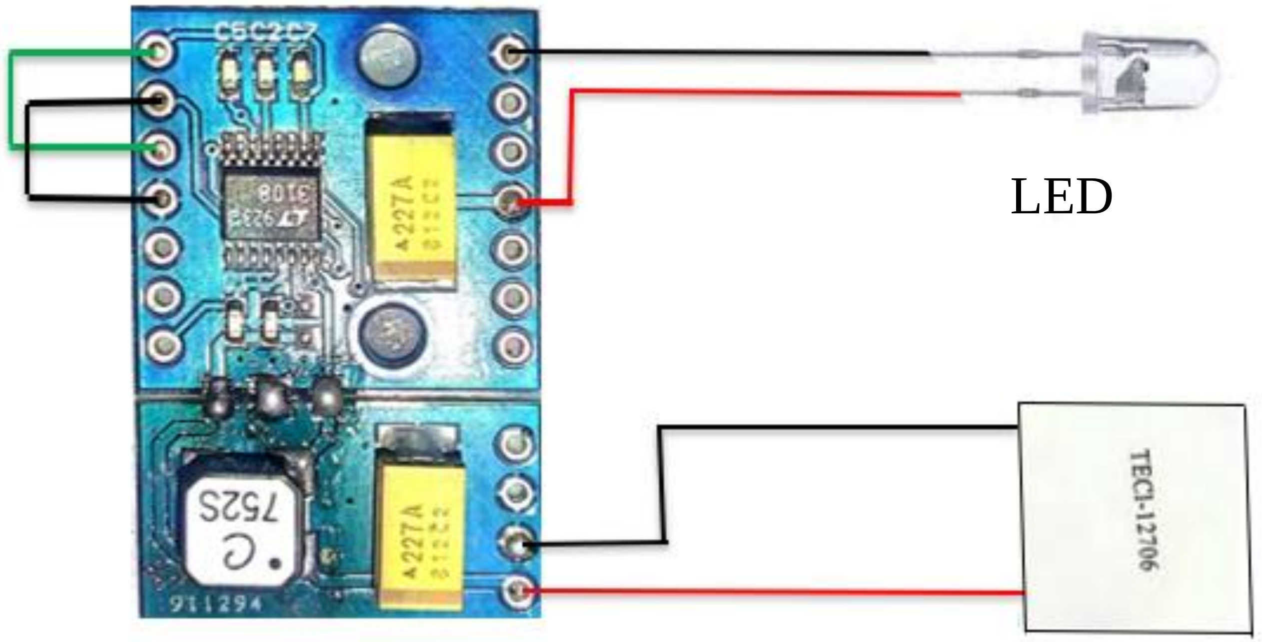
Results (4/4)

Random input signal

- Slight change in input_ huge change in output



Conclusion (1/4)



Resultant design system

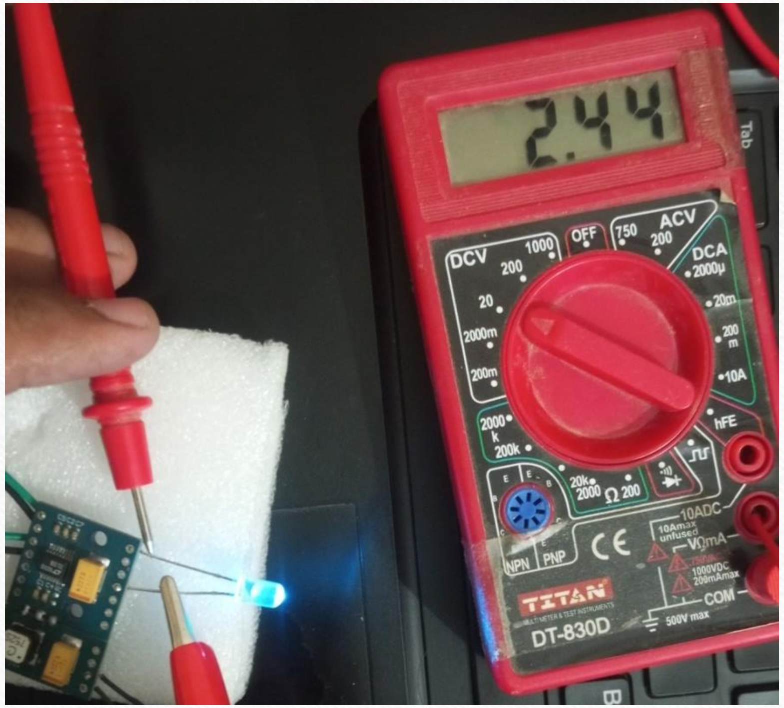
Conclusion (2/4)

Table 2. Output values in volts of TEC module

Cold Temperature T_c	**Hot temperature T_h**	**Temperature gradient (ΔT)**	**Output value of TEG**
18°C	36°C	18°C	2.44 V

Conclusion (3/4)

- Output values of the design system was checked by multi-meter
- value of the design Buck-booster module is higher than input
- Buck-Booster O/P Supplied to LED - can easily operate LED.



Output value of design system

Conclusion (4/4)

- We have designed self-powered system that can operate without any external power sources.
- With the help of a TEG module and DC-DC Buck-booster or Booster, the LED operates using the human body heat.
- The designed system is dependent on temperature gradient. Whenever temperature of the human body increases, the temperature gradient increases, which results in better brightness of LED.

Future work

- Making the designed system independent of temperature gradient.
- Design a special type of TEG module for this system which has very low or zero resistance with human body.
- Should Design and simulate using other software like NI Multisim and COMSOL etc.

Thank You

Questions!

References

[1]. Champier, D. (2017). Thermoelectric generators: A review of applications. Energy conversion and management, 140, 167-181.

[2]. Ando Junior, O. H., Calderon, N. H., & De Souza, S. S. (2018). Characterization of a thermoelectric generator (TEG) system for waste heat recovery. *Energies*, *11*(6), 1555.

[3]. Cao, F., Zhang, J., Wu, H., Hu, H., Xing, Y., & Ma, X. (2013, September). A dual-input Boost-Buck converter with coupled inductors for TEG applications. In 2013 IEEE Energy Conversion Congress and Exposition (pp. 2020-2025). IEEE.

[4]. Aoughlis, C., Belkaid, A., Kacimi, M. A., Colak, I., Guenounou, O., Bakir, T., & Brikh, L. (2024). A Novel Dynamic and Self-Adaptive InCre Technique Based on PI Control and EO Optimization for Hybrid PV-TEG Conversion Systems. Electric Power Components and Systems, 52(9), 1569-1580.

[5]. Kim, R. Y., & Lai, J. S. (2008, February). Aggregated modeling and control of a boost-buck cascade converter for maximum power point tracking of a thermoelectric generator. In 2008 Twenty-Third Annual IEEE Applied Power Electronics Conference and Exposition (pp. 1754-1760). IEEE.

[6]. Andria, G., Cavone, G., Carducci, C. G. C., Spadavecchia, M., & Trotta, A. (2016, June). A PWM temperature controller for themoelectric generator characterization. In 2016 IEEE Metrology for Aerospace (MetroAeroSpace) (pp. 291-296). IEEE

[7]. Hyland, M., Hunter, H., Liu, J., Veety, E., & Vashaee, D. (2016). Wearable thermoelectric generators for human body heat harvesting. Applied Energy, 182, 518-524.

[8]. Thielen, M., Sigrist, L., Magno, M., Hierold, C., & Benini, L. (2017). Human body heat for powering wearable devices: From thermal energy to application. Energy conversion and management, 131, 44-54.

The end

Thank you ☺