Design and Layout of DC-DC Buck Converter

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Abstract: Integrated power management circuits play a pivotal role in portable electronic applications, where high efficiency, compact form factors, and robust transient response are critical requirements. These circuits, often realized as DC-DC converters, are indispensable in managing power distribution effectively within a system while minimizing energy losses. The focus is placed on achieving precise voltage regulation and minimizing ripple content to ensure stable operation under varying load conditions. This paper details the design, simulation, and implementation of a voltage control mode DC-DC buck converter, specifically tailored to achieve high efficiency and reliable operation. The proposed design is demonstrated through the development of a 4 MHz prototype fabricated using 180 nm CMOS technology. The prototype effectively regulates an output voltage while sourcing a maximum load current of 100 mA from a 1.8 V input supply, catering to the demands of low-power portable applications.The circuit architecture incorporates critical components, including an error amplifier, comparator, and compensator, to establish a robust feedback stabilization mechanism. A Type-II compensator is employed to enhance the system's phase margin and ensure stable operation across a wide range of operating conditions. The design process is supported by extensive simulation-based validation to optimize the system's dynamic response and steadystate performance. Experimental measurements, conducted with external filter components (inductor L=6.8H, capacitor C=10 H, reveal favourable performance characteristics. The results highlight the converter's ability to maintain a well-regulated output voltage while exhibiting minimal ripple and rapid transient response to load changes.

1 INTRODUCTION

Voltage regulators are essential components used to ensure a constant voltage supply to connected circuits, providing stable operation and protecting sensitive electronics from voltage fluctuations. These regulators are broadly classified into two categories: linear and switching regulators. Among switching regulators, the buck converter, also known as a step-down converter, plays a crucial role in efficiently reducing DC voltage levels from a higher input to a lower output. A buck converter operates by rapidly switching on and off using semiconductor devices such as MOSFETs, transistors, or IGBTs. This switching action is controlled by a pulse-width modulation (PWM) signal, which adjusts the duty cycle to regulate the output voltage. Unlike linear regulators, which dissipate excess energy as heat, buck converters achieve high power efficiencies, often exceeding 90%, by transferring energy between the input and output using inductors, capacitors, and switches. This efficiency makes buck converters ideal for applications requiring significant power savings and minimal heat generation. For instance, they are commonly used to step down higher voltages, such as 12V, to lower levels like 5V, 3.3V, or 1.8V. These lower voltages are crucial for powering modern electronic devices, including USB ports, CPUs, DRAM modules, and various integrated circuits. The versatility and high efficiency of buck converters have driven their widespread adoption across numerous industries. With the proliferation of portable electronic devices, aerospace systems, and automotive technologies, the demand for efficient DC-DC converters has surged. Portable devices like smartphones, tablets, and laptops rely on these converters to maximize battery life while maintaining performance. Similarly, aerospace systems use buck converters to power critical subsystems, en-

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suring reliability in extreme environments. In automotive applications, they are integral to electric and hybrid vehicles, where they manage power distribution for infotainment systems, sensors, and electric motor controllers. Unlike AC systems that adjust voltage levels using transformers, DC systems depend on converters like buck regulators for voltage adjustment. This distinction underscores the importance of buck converters in modern electronic systems, particularly as DC power sources become more prevalent in renewable energy systems, data centers, and transportation infrastructure. Buck converters offer several advantages that make them indispensable in modern electronics, including high efficiency, compact design, the ability to operate with a wide input voltage range, and reliable performance across diverse environmental conditions. Their ability to step down DC voltages with high efficiency and low energy loss makes them essential for powering a wide range of devices, from consumer electronics to critical aerospace and automotive systems. As technology advances and the demand for portable and sustainable power solutions grows, the role of buck converters will continue to expand, ensuring stable and efficient power delivery across an ever-widening array of applications.

2 LITERATURE SURVEY

The paper (Sudharshan et al., 2018) "Design and Simulation of DC-DC Buck Converter using Cadence Tool" details the development of a buck converter designed to step down a variable input voltage between 3V and 8V to a stable 1.2V output, using a switching frequency of 1MHz. The design employs PMOSFET and NMOSFET switches in the power stage, an error amplifier with an 84dB gain and 20MHz unity-gain bandwidth, and a comparator for PWM signal generation. Implemented with Cadence software and 180nm technology, the simulations confirmed effective voltage regulation, which was validated through a hardware prototype that demonstrated consistent performance with the simulated results. This approach is particularly suited for low-power applications such as mobile devices and LED lighting. Article (Anvekar et al., 2024) develops a folded cascode CMOS op-amp in 0.18µm technology, DC gain of 55dB, a phase margin of 66.87 degrees, and the amplifier's bandwidth is reported at 222kHz (-3dB) for a 1pF load. The paper (Zhang et al., 2015) proposed design of a two-level recursive gain-boosted amplifier is devised to augment the gain while preserving the overall bandwidth. The design intricately considers the interplay among the core amplifier's gain bandwidth product (GBP), regulation amplifiers, and nested gain boosters. Remarkably, the design attains an exceptionally high DC gain of 94.8 dB alongside a phase margin of 56 degrees.

The paper(Tabbat et al., 2020) presents a study and analysis of a DC-DC soft switched buck converter, focusing on enhancing efficiency and reducing losses in power conversion. The proposed converter incorporates an auxiliary inductor and two capacitors to achieve zero-voltage switching during turn-on and near soft switching during turn-off, eliminating switching and reverse recovery losses. The research highlights the converter's experimental and theoretical efficiencies, demonstrating a 96.experimental efficiency at 200 W output power and a 96.78% theoretical efficiency, surpassing other structures in terms of efficiency and simplicity.The paper (Soheli et al., 2018) references the work of R. L. Steigerwald on high-frequency resonant transistor DC-DC converters, emphasizing the importance of efficient power conversion in industrial electronics. It also cites J. Tucker's technical brief on using a buck converter in an inverting buckboost topology, highlighting the relevance of various converter configurations for specific applications. Additionally, the paper mentions M. Iulian's research on a topology for a positive buck-boost switching regulator, showcasing the continuous advancements and ongoing research in the field of DC-DC converters. The paper (Gupta and Phulambrikar, 2014) presents a generalized model of a buck converter aimed at reducing the size, space, and weight of converter/inverter circuits through the use of high switching frequency devices. A decision matrix was employed to select the optimal buck converter topology, taking into account factors such as linearity, voltage transfer ratio, and ease of component implementation. The operation of the buck converter is described by equations for different states, including when the switch is on, off, or both the switch and diode are off. The study underscores the importance of a control circuit for the buck converter, identifying the microprocessor as the optimal choice for control circuit implementation.

The paper (Masri et al., 2012) extensively delves into operational amplifiers (opamps) and their practical applications, with a specific focus on comparing the performance of folded cascode and telescopic cascode configurations. It scrutinizes these topologies in both single-staged and two-staged setups, elucidating their respective advantages and drawbacks. Notably, it highlights a distinctive feature of folded cascode op-amps: their capability to manage input common-mode levels near the supply voltage. Folded cascode op-amps offer high gain and a wide output swing, functioning as single-pole op-amps, thus ensuring stability and a substantial phase margin. The paper concludes by presenting a performance matrix that compares various op-amp topologies.The paper(Baharudin et al., 2018) examines a DC-DC buck converter designed for renewable energy applications, focusing on efficient DC voltage conversion. It emphasizes the critical role of adjusting the duty cycle to match the output voltage with load requirements. To tackle challenges such as voltage drops across diodes and harmonic issues, the paper proposes using a second MOSFET to enhance efficiency. The study highlights the importance of hardware implementation and testing, which includes measuring output waveforms, voltage readings, and current flow for thorough validation and analysis.

The paper (Soheli et al., 2021) introduces a highly efficient DC-DC buck converter designed for sustainable electronic applications, aiming to surpass the efficiency of conventional converters. It details the two operational modes, Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM), emphasizing the use of ideal components for accurate values and improved power efficiency. The proposed converter's performance is compared to traditional converters based on switching frequency and load variations, demonstrating superior efficiency and stability. The paper references various works on DC-DC converter designs, power electronics integration, and control strategies for switching power converters. The paper (Kumar et al.,) objective is to develop and validate a Low Voltage Folded Cascode CMOS Operational Amplifier employing gpdk 0.18μM CMOS technology. An NMOS differential pair is selected to minimize power consumption and uphold a high Unity Gain Frequency (UGF). The design accomplishes a gain of 68.6dB, a Phase Margin of 500, and a UGF of 13.1MHz, while consuming merely 30μW of power. Additionally, it integrates a sub-threshold start-up circuit with dynamic body biasing tailored for boost converters in thermoelectric energy harvesting.

3 OBJECTIVES

Develop a DC-DC buck converter with an input voltage of 1.8V and an output voltage of 0.8V, capable of delivering a load current of 100mA. The design should operate at a switching frequency of 4MHz and prioritize maximum power efficiency. Implement the design using 180nm CMOS technology in the Cadence tool, including its complete layout.

3.1 Specification

The objective is to achieve these specifications in the design of the DC-DC converter.

Table 1: Specifications for the Closed Loop Buck converter

Design Variable	Description	Value	Unit
V_{DD}	Supply voltage	1.8	V
V_{OUT}	Output Voltage	0.8	V
I_{LOAD}	Current	100m	A
F_{sw}	Switching Frequency	4M	Hz

4 METHODOLOGY

When a DC input voltage is supplied to a power MOSFET, the circuit operates with two switches: a PMOS acting as switch 1 and an NMOS acting as switch 2. These MOSFETs are configured to facilitate efficient DC-DC conversion. Despite the DC input, inherent noise may be present in the system, which can interfere with the operation and stability of the circuit. To mitigate the effects of noise, a low-pass filter is employed. An LC low-pass filter is preferred over an RC low-pass filter for this purpose. Inductors (L) and capacitors (C) are lossless components, making them more efficient than resistors (R), which dissipate energy as heat. The LC filter effectively suppresses high-frequency noise while allowing the desired DC component to pass through. The choice of an LC filter ensures minimal power loss and enhances the overall efficiency of the system. The output voltage of the circuit is determined by the product of the input voltage and the duty cycle of the pulse-width modulation (PWM) signal driving the MOSFETs. The inductor current ripple ΔI_L is related to the switching frequency and is calculated as:

$$\Delta I_L = \frac{V_{\text{out}}(1-D)}{\Delta I_L \cdot f_s} \tag{1}$$

The output capacitor C_{out} is determined by:

$$C_{\text{out}} = \frac{\Delta I_L}{8 \cdot f_s \cdot \Delta V_{\text{out}}} \tag{2}$$

The output voltage ripple due to the equivalent series resistance (ESR) is given by:

$$\Delta V_{\text{out}}(\text{ESR}) = \text{ESR} \cdot \Delta I_L \tag{3}$$

4.1 Open Loop System

An open-loop buck converter is a simple DC-DC converter that regulates output voltage by modulating the switching behaviour of its signal. It consists of a power switch, inductor, diode, and capacitor. The switching characteristics influence the average output voltage, with higher on-time periods yielding higher voltages. Open-loop designs lack feedback components like compensators and error amplifiers, simplifying design and reducing costs but compromising precision and stability, especially under varying input or load conditions. They are suitable for applications requiring basic voltage regulation in stable environments. In an open-loop configuration, the system lacks dynamic control over the output voltage. Any changes in load conditions can directly affect the output voltage, as the control voltage (Vctrl) cannot be adjusted dynamically. This limitation makes the system less robust and prone to variations in output voltage.

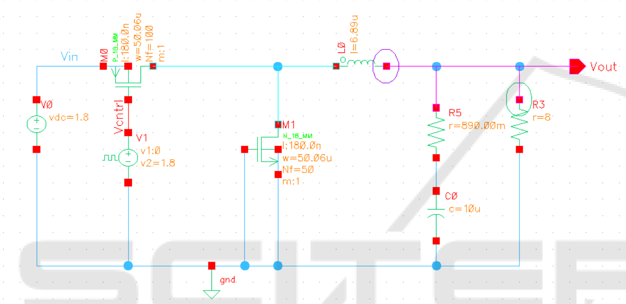

Figure 1: Open Loop Buck Converter

4.2 Closed Loop Systems

In contrast, closed-loop buck converters address the need for precise and stable voltage regulation. They use feedback circuits to compare the actual output voltage with a reference voltage (Vref), dynamically adjusting the switching behaviour to compensate for input or load variations. This ensures accurate and stable output voltage levels, making them ideal for applications requiring reliability. PWM buck converters, a common type, use high-frequency PWM signals to regulate voltage. During the "on" period, the inductor charges, and during the "off" period, it discharges to maintain constant voltage. PWM converters are efficient, responsive, and adaptable to varying input and output conditions. They are widely used in power supplies, battery chargers, LED lighting, and motor control due to their reliability and performance. In the closed-loop system, a voltage divider is used to derive a feedback signal (Vfeedback) proportional to the output voltage (Vout). This feedback signal is fed into an error amplifier along with the reference voltage (Vref). The error amplifier computes the difference between Vfeedback and Vref, generating an error signal (Verror). This error signal is then multiplied by the gain factor of the amplifier to produce the control voltage Vctrl, which determines the duty cycle of the PWM signal. The error amplifier incorporates a compensator to ensure system stability and optimal dynamic response. Different types of compensators are employed based on the performance requirements: 1. Type I (Integrator): Provides high DC gain to eliminate steady-state error. Has limited improvement in phase margin, suitable for low-bandwidth systems. 2. Type II (Proportional-Integral): Enhances phase margin and stability. Maintains low steady-state error, suitable for medium-speed applications. The choice of compensator depends on the desired trade-off between stability, speed, and accuracy. Here we have Type II as mentioned below. The transfer function for a Type-II compensator is given by:

$$\mathrm{TF} = \frac{R_c \cdot C_c \cdot (s+1)}{R_1 \cdot R_{c1} \cdot C_{c1} \cdot C_{c2} \cdot s^2 + C_{c1} \cdot R_1 \cdot s} \quad (4)$$

```
CLOSED_loop =

            3.568e-13 s^2 + 0.0001282 s + 14.4
  -----------------------------------------------------------
  9.844e-22 s^4 + 1.871e-13 s^3 + 2.414e-08 s^2 + 0.002474 s
```

Figure 2: Closed loop transfer function of type2

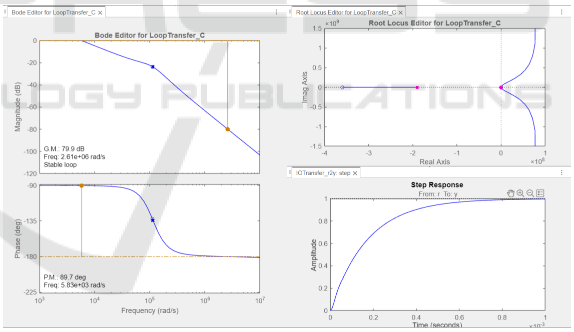

Figure 3: TYPE-II MATLAB result

Following the error amplifier, a comparator compares the error signal with a ramp signal . The output of the comparator is a PWM signal, where the duty cycle is proportional to the magnitude of Verror. This PWM signal drives the MOSFETs to regulate the output voltage. PWM signals often exhibit irregularities due to variations in the ramp signal or the control voltage. To address this, a driver circuit is employed. The driver circuit consists of multiple buffers, which amplify the PWM signal to ensure it has sufficient strength to drive the gates of the MOSFETs. This step is crucial for maintaining efficient switching and minimizing power losses. The circuits of compensators, error amplifier, comparator, driver were designed according to the requirement and were integrated and was simulated.

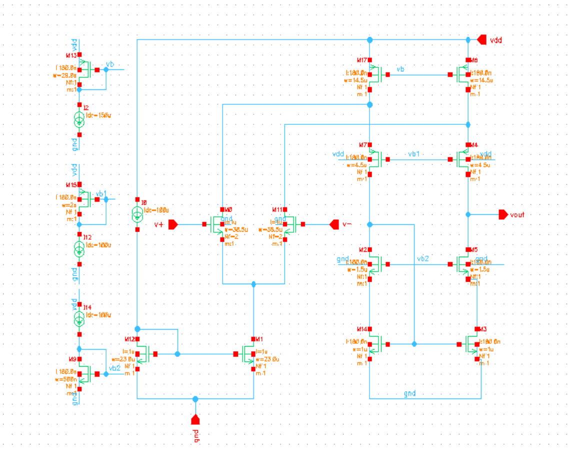

Figure 4: Error Amplifier

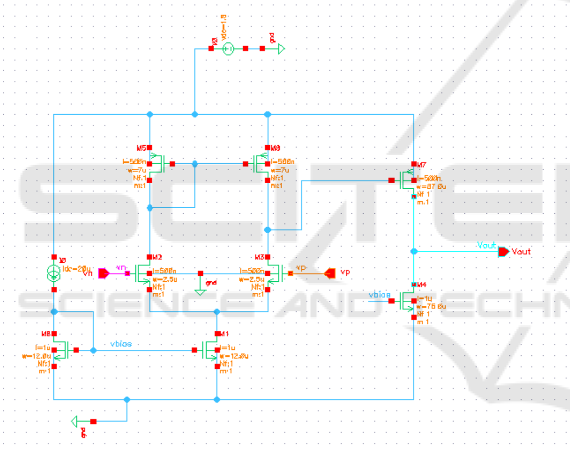

Figure 5: Comparator

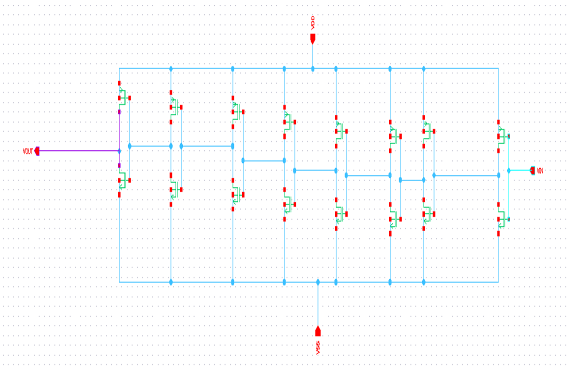

Figure 6: Driver Circuit

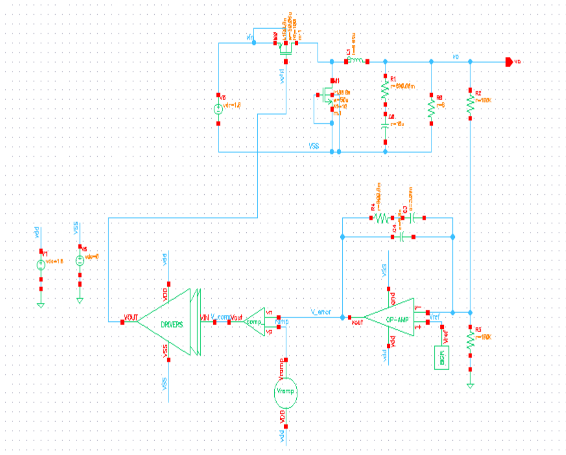

Figure 7: Closed loop Buck converter circuit

5 RESULTS AND DISCUSSIONS

Initially, the open-loop configuration of the circuit was simulated, and the corresponding results were thoroughly analyzed to understand its behavior and performance metrics. Following this, the feedback network was incorporated into the design to enable closed-loop operation, and a detailed analysis of the system's behavior under feedback control was conducted, as illustrated in the accompanying figure. Finally, the performance table provides a concise summary of the key parameters and performance metrics, calculated based on the derived simulation results and observations.

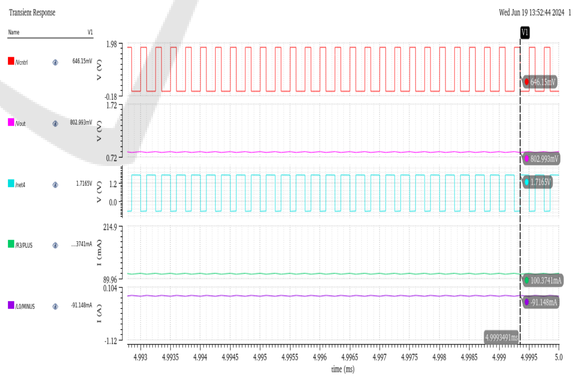

Figure 8: Open loop Buck converter results

The layout was designed for the remaining circuits after excluding the filter components (inductor and capacitor) and the compensator, as these components were selected to be off-chip.

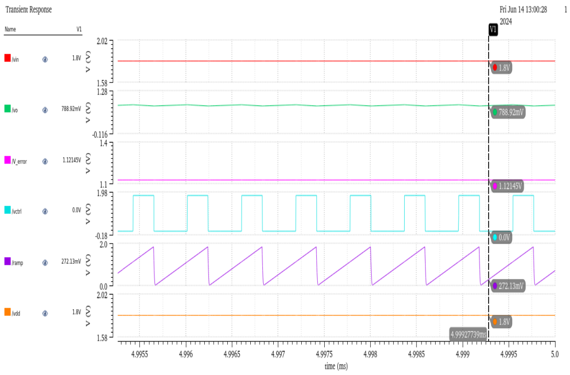

Figure 9: Closed loop Buck converter results

Table 2: Performance Summary

Parameter	**Value**	**Unit**
Process technology	180	nm
Input voltage, (V_{in})	1.8	V
Output voltage, (V_{out})	0.8	V
Load current, (I_{Load})	100	mA
Line transient response overshoot	207.475	mV
Line transient response undershoot	98.75	mV
Line transient response settling time	3.089	ms
Load transient response overshoot	314	mV
Load transient response undershoot	340	mV
Load transient response settling time	10	µs
Area	23024	μm^2

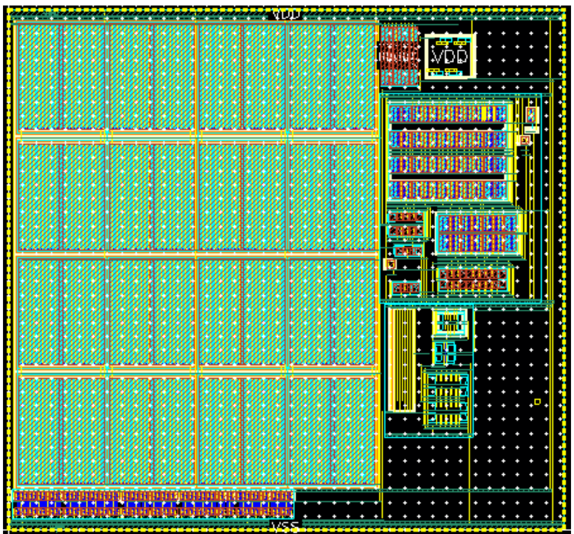

Figure 10: Buck Layout

6 CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusion

The closed-loop DC-DC converter system effectively addresses the inherent limitations of open-loop configurations by ensuring precise and stable voltage regulation across varying operating conditions. By incorporating an LC low-pass filter, the system minimizes output voltage ripple, enhancing overall performance. An error amplifier with compensator circuitry dynamically adjusts the duty cycle, ensuring rapid response to fluctuations in input voltage or load current. Additionally, a robust PWM generation mechanism provides accurate control over the switching process, optimizing efficiency. The feedback mechanism forms the backbone of the system, enabling real-time adjustments and ensuring stable operation even under transient conditions. This comprehensive design approach results in a highly reliable and efficient power conversion solution, capable of meeting the stringent demands of modern electronic applications. This paper presents the complete design, simulation, and implementation of a high-frequency DC-DC step-down converter that steps down a 1.8V input to a regulated 0.8V output at a switching frequency of 4MHz. The converter leverages Cadence design tools and 180nm CMOS technology, yielding successful simulation results that validate its performance. With its compact design and efficient operation, the converter is well-suited for power-sensitive applications such as mobile devices, LED lighting systems, and portable electronics. Moreover, the design methodology and principles discussed in this work can be extended to other DC-DC converter architectures, paving the way for versatile power management solutions.

6.2 Future Scope

As designs incorporate more components to reduce board size, heat management becomes a key challenge. Lower material costs are expected to improve converter efficiency, increase operating frequencies, and reduce sizes. With new applications, advanced materials, and stricter energy standards, the market for DC/DC converter modules is growing rapidly. The future of DC/DC buck converters is especially promising, with ongoing technological advancements driving compact, cost-effective, and efficient power solutions

REFERENCES

Anvekar, S., Anusha, A. D., Giriraddi, G., Hegde, B., and Kotabagi, S. (2024). Single stage folded-cascode operational amplifier. *International Journal of Microsystems and IoT*, 2(4):745–752.

Baharudin, N., Tunku Mansur, T. M. N., Hamid, F., Ali, R., and Irwanto, M. (2018). Performance analysis of dc-dc buck converter for renewable energy application. *Journal of Physics: Conference Series*, 1019:012020.

Gupta, M. and Phulambrikar, S. P. (2014). Design and analysis of buck converter. *International Journal of Engineering Research & Technology*, 3(3):2346–2350.

Kumar, K., Praveena, V., Vijetha, J. K., Harikrishna, G., and Kinara, B. Design of folded cascode operational amplifier using 1.8 micron cmos technology. *Journal of Emerging Tech*.

Masri, S., Mohamad, N., and Hariri, M. H. M. (2012). Design and development of dc-dc buck converter for photovoltaic application. In *2012 International Conference on Power Engineering and Renewable Energy (ICPERE)*, pages 1–5.

Soheli, S. N., Aney, U. S., and Mahmud, S. I. (2021). Designing a highly effective dc-dc buck converter for sustainable electronic applications. In *2021 2nd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST)*, pages 178–182.

Soheli, S. N., Sarowar, G., Hoque, M. A., and Hasan, M. (2018). Design and analysis of a dc -dc buck boost converter to achieve high efficiency and low voltage gain by using buck boost topology into buck topology. pages 1–4.

Sudharshan, K., Anilkumar, C., Pallavi, R., Yatheesh, H. G., Santosh, and Siva Reddy, S. (2018). Design and simulation of dc-dc buck converter using cadence tool. In *2018 3rd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)*, pages 2198–2202.

Tabbat, P., Babaei, E., Mohseni, P., and Marzang, V. (2020). Study and analysis of a dc-dc soft switched buck converter. *IET Power Electronics*, 13.

Zhang, S. et al. (2015). A 90-db dc gain high-speed nested gain-boosted folded-cascode opamp. In *2015 11th Conference on Ph. D. Research in Microelectronics and Electronics (PRIME)*. IEEE.