Design and Development of a Solar-Powered Portable Power Bank

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***Abstract*—The widespread dependency on smartphones and portable electronic devices has made grid-independent charging a practical necessity, especially across semi-urban and rural India where electricity supply remains inconsistent. This paper presents the design and hardware prototype implementation of a compact, smartphone-sized solar-powered portable power bank. The system harvests solar energy through a photovoltaic panel, manages lithium-ion cell charging using a TP4056 constant-current/constant-voltage (CC/CV) linear charger IC, and delivers a regulated USB output through an MT3608 step-up boost converter. A 3.7 V / 2200 mAh 18650 lithium-ion cell serves as the energy storage element, storing 8.14 Wh of energy. Reverse current flow from battery to solar panel is blocked by 1N4007 rectifier diodes, and a push-button switch controls the output stage. Prototype testing measured a USB output voltage of 5.12 V, which is within the USB 2.0 specification range of 4.75 V to 5.25 V. Theoretical analysis shows the prototype can deliver approximately 1380 mAh of usable charge at 5 V output, accounting for boost converter losses. All subsystems are assembled from commercially available off-the-shelf modules, making the design cost-effective and readily reproducible for academic and educational purposes.**

***Index Terms*—Solar Power Bank; TP4056; MT3608 Boost Converter; 18650 Li-Ion Battery; Solar Energy Harvesting; Portable Charger; CC/CV Charging; Reverse Blocking Diode; USB Output.**

I. INTRODUCTION

The rapid proliferation of smartphones across India, especially in semi-urban and rural regions, has created a persistent demand for portable, reliable charging options. As per data published by the Telecom Regulatory Authority of India (TRAI), India's total mobile subscriber base has exceeded 1.17 billion [1]. A large share of these users resides in areas with unreliable grid electricity, making wall-socket-dependent charging solutions inadequate for consistent device use.

Conventional portable power banks store energy drawn from the electrical grid and release it on demand. Once depleted and cut off from grid access, they are non-functional. Solar energy provides a freely available and renewable alternative as an input source. India receives a daily average solar irradiation of 4 to 7 kWh per square metre across most of its landmass [2], which makes small-scale photovoltaic energy harvesting genuinely practical for low-power portable electronics.

A solar-powered power bank combines three core engineering functions: harvesting variable solar energy from a photovoltaic panel; safely charging a lithium-ion cell without overcharge or overdischarge; and converting stored battery energy to a regulated 5 V USB output regardless of the battery's instantaneous state of charge. These three problems are solved in this design by the TP4056 charging IC, the 1N4007 reverse-blocking diode, and the MT3608 step-up boost converter respectively.

This paper documents the full design, component selection, and prototype assembly of a smartphone-sized solar power bank built from commercially available modules. The prototype was functionally tested and a USB output voltage of 5.12 V was measured. Section 2 surveys related work. Section 3 covers the system architecture and component specifications. Section 4 explains the circuit working principle. Section 5 presents prototype test results, and Section 6 concludes with design recommendations and future work.

II. LITERATURE SURVEY

Solar-powered portable charging systems have been developed and studied across a range of scales and complexity levels. The dominant topology in published work follows a consistent pattern: photovoltaic source, charge management IC, lithium-ion storage, and regulated output converter the same architecture adopted in this prototype.

Safe charging of lithium-ion cells from variable solar input is handled by dedicated charge management ICs that implement the CC/CV profile required by Li-ion chemistry. Charging must not exceed the cell's 4.2 V maximum terminal voltage, and the charge current must be controlled to prevent thermal damage to both the cell and the charger. The TP4056 from Nanjing Top Power ASIC Corp. is widely referenced in compact single-cell solar charger designs because it integrates all required functions current control, voltage regulation, thermal regulation, and charge termination in an SOP-8 package with only a single external programming resistor and no additional logic circuitry [3].

For the battery-to-USB voltage step-up, inductive boost converters are preferred over charge pump topologies in the published literature on portable solar chargers. As a lithium-ion cell discharges from 4.2 V to 3.0 V, a single-stage charge pump cannot maintain regulation across this range without multiple stages; an inductive boost converter handles the full range continuously and at high efficiency. The MT3608 operates at 1.2 MHz, which reduces the required inductor size and keeps the module footprint compact while achieving up to 93% conversion efficiency [4].

Reverse current blocking between battery and solar panel is a documented requirement in any photovoltaic charging design. Without a blocking element, the solar cell's internal diode structures provide a conduction path for battery current during low-irradiance periods, causing cell discharge. The 1N4007 general-purpose rectifier diode is widely used for this purpose in prototype-grade designs due to its 1 A rating and universal availability [5]. The trade-off is its ~1.1 V forward drop, which reduces the effective input to the charge IC and lowers the minimum illumination level at which charging can begin.

The 18650 lithium-ion cell format is the standard storage element for portable power applications, characterised by its high energy density and stable discharge profile. A 2200 mAh cell at 3.7 V nominal stores 8.14 Wh of energy, a value that has been used as the basis for capacity analysis in multiple portable charger design papers [6]. The cell chemistry is well-characterised, and the TP4056 is designed specifically to handle the CC/CV requirements of this chemistry.

The design presented in this paper implements the established solar power bank topology using off-the-shelf modules, documents component specifications against manufacturer datasheets, and provides measured prototype test data. This serves as a reproducible reference design for academic project implementation.

III. SYSTEM ARCHITECTURE AND COMPONENT DESCRIPTION

3.1 System Block Diagram

The prototype is structured as a linear power path from the solar panel to the USB-A output port. Figure 1 presents the complete circuit block diagram. The solar panel output passes through a 1N4007 reverse-blocking diode to the input of the TP4056 charging module, which manages the full charge cycle of the 18650 cells. The battery output is routed through a user-controlled push-button switch to the MT3608 boost converter, which steps the voltage up to a regulated 5 V at the USB-A port.

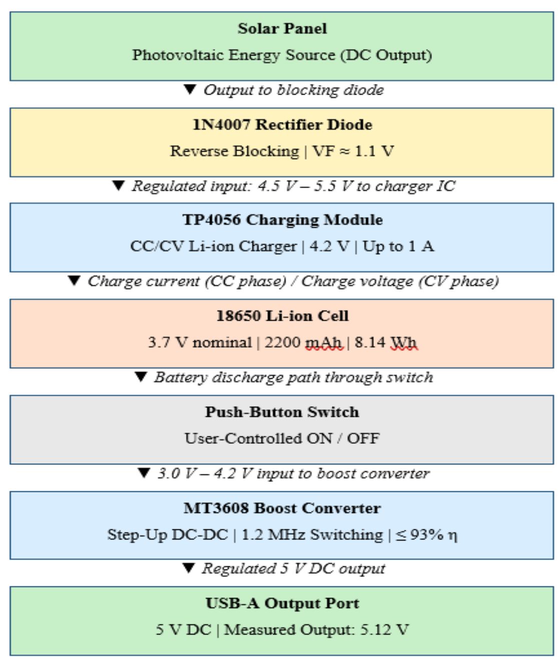

Figure 1: Circuit block diagram of the Solar-Powered Portable Power Bank

The solar charging path (panel → diode → TP4056 → cell) and the USB output path (cell → switch → MT3608 → USB-A) share the 18650 cells as their common electrical node. Both paths can operate simultaneously. If the solar panel is active while a device is being charged, the net current into the cell equals the TP4056 charge current minus the current drawn by the MT3608 from the cell. In practice, for small panels of this form factor, the panel-supplied current is typically lower than the load demand, so the cell slowly discharges while the panel partially offsets the rate of discharge.

3.2 Solar Panel

The photovoltaic source is a circular epoxy-encapsulated solar panel rated at 6 V open-circuit voltage, mounted on the top face of the prototype enclosure. Epoxy resin encapsulation provides physical protection and weatherproofing for the underlying silicon photovoltaic cells. Panel output current varies with irradiance, incident angle, and temperature. After passing through the 1N4007 reverse-blocking diode (VF ≈ 1.1 V), the effective voltage presented to the TP4056 input is 6.0 − 1.1 = 4.9 V, which falls within the TP4056 operating window of 4.5 V to 5.5 V. A panel rated below 5.6 V open-circuit would be unsuitable here, as the diode drop would push the TP4056 input below its 4.5 V minimum threshold. The 6 V rating therefore provides adequate headroom for reliable charging under direct sunlight. The rated short-circuit current of the panel determines the actual charge current delivered to the cell and is to be confirmed from the panel label or datasheet. The circular form factor is dimensionally compatible with the smartphone-sized enclosure used in this prototype.

3.3 TP4056 Charging Module

The TP4056, manufactured by Nanjing Top Power ASIC Corp., is a monolithic CC/CV linear charger IC for single-cell lithium-ion batteries. The module PCB integrates the IC with a charge-current programming resistor, two status LEDs, and connection terminals for USB input and battery output. Table 1 lists key electrical parameters from the manufacturer datasheet [3].

Table 1: TP4056 Key Electrical Parameters (Source: Datasheet [3])

Input Voltage Range	4.5 V to 5.5 V
Charge Voltage (Precision)	4.2 V ± 1%
Maximum Charge Current	1 A (programmable via single external resistor RPROG)
Trickle Charge Threshold	2.9 V (cell voltage below which trickle charge applies)
Charge Termination	Current tapers to ≈1/10 of programmed rate, then IC stops
Thermal Regulation	Reduces charge current automatically if junction temp. rises
Status Indication	Red LED: charging active | Blue/Green LED: charge complete
Package	SOP-8

The TP4056 operates through three charge stages. When the cell is deeply discharged (below 2.9 V), it applies trickle charge at approximately 1/10th of the programmed current. Once the cell recovers above 2.9 V, it transitions to the constant-current phase at full programmed current. As the cell approaches 4.2 V, the IC switches to constant-voltage mode, holding 4.2 V at the battery terminals while current tapers naturally. Charging terminates when current falls to roughly 1/10th of the programmed charge rate. The thermal regulation feature is particularly relevant in a compact enclosure: if the IC junction heats beyond a safe threshold, it automatically reduces charge current to protect itself and the cell.

3.4 MT3608 Boost Converter Module

The MT3608, manufactured by XI'AN Aerosemi Technology Co., Ltd., is a current-mode PWM inductive step-up (boost) DC-DC converter. It steps the 18650-cell voltage, which ranges from approximately 3.0 V (discharged) to 4.2 V (fully charged), up to a regulated 5 V for USB compatibility. Table 2 presents the key electrical parameters from the MT3608 datasheet [4].

Table 2: MT3608 Key Electrical Parameters (Source: Datasheet [4])

Input Voltage Range	2 V to 24 V
Output Voltage	Adjustable up to 28 V (set by feedback resistor divider on module)
Peak Switch Current	4 A
Switching Frequency	1.2 MHz

Maximum Efficiency	Up to 93%
On-Module Inductor	22 µH (body marked '220': first two digits are mantissa, third is exponent)
Output Voltage Setting	Trimmer potentiometer on board, pre-set to 5 V
Package	SOT-23-6

The 1.2 MHz switching frequency is the key feature that keeps the module physically compact. At this frequency, the 22 µH inductor needs to store energy for less than a microsecond per cycle, allowing a small surface-mount inductor to handle the required peak currents. The module output is set to 5 V via the onboard trimmer potentiometer. Because the MT3608 minimum input is 2 V, it maintains regulated output across the entire usable discharge range of the 18650 cell (3.0 V to 4.2 V) without any dropout.

3.5 1N4007 Rectifier Diodes

Three 1N4007 general-purpose silicon rectifier diodes are included in the prototype. Their primary function is to prevent reverse current from flowing from the 18650 cell back through the solar panel when the panel output voltage drops below the battery terminal voltage (during darkness or heavy cloud cover). Table 3 lists key parameters from the Vishay 1N4007 datasheet [5].

Table 3: 1N4007 Key Electrical Parameters (Source: Datasheet [5])

Max Repetitive Reverse Voltage (VRRM)	1000 V
Average Rectified Forward Current (IF)	1 A
Forward Voltage Drop (VF)	≈1.1 V at IF = 1 A | ≈0.7 V at low current
Non-Repetitive Peak Surge Current	30 A (8.3 ms half-sine pulse)
Operating Temperature Range	−65°C to +175°C
Package	DO-41 (axial leaded)

The 1N4007's forward voltage drop of approximately 1.1 V at rated current subtracts directly from the effective input voltage available to the TP4056. This makes the minimum required solar panel open-circuit voltage approximately 5.6 V (4.5 V charger minimum + 1.1 V diode drop). For applications requiring charging at lower light levels, replacing the 1N4007 with a Schottky diode such as the 1N5819 (VF ≈ 0.3 V) would reduce this threshold to approximately 4.8 V, meaningfully extending the operating window.

3.6 Push-Button Switch

A small tactile push-button switch is connected in series between the positive terminal of the 18650 cell and the input of the MT3608 boost converter. When the switch is open, the MT3608 is completely disconnected from the battery, eliminating all converter quiescent current draw. When the user closes the switch, the converter activates and the USB-A port becomes live. This simple mechanism prevents idle discharge of the cell through the converter's standby current during periods when no device is being charged.

3.7 18650 Lithium-Ion Cell (3.7 V / 2200 mAh)

The energy storage element is a single 18650 format cylindrical lithium-ion cell with a rated capacity of 2200 mAh. The 18650-format name refers to the physical dimensions of the cell: 18 mm diameter and 65 mm length. The electrical characteristics relevant to this design are listed below [6]:

- Nominal voltage: 3.7 V
- Maximum charge voltage: 4.2 V (enforced by TP4056)
- Minimum discharge cutoff: 2.5 V – 3.0 V (cell-dependent; TP4056 applies trickle below 2.9 V)
- Rated capacity: 2200 mAh
- Stored energy: 2.2 Ah × 3.7 V = 8.14 Wh

The stored energy of 8.14 Wh, after passing through the MT3608 at an assumed conservative efficiency of 85%, yields approximately 6.92 Wh of usable output energy. At 5 V output, this corresponds to 6.92 ÷ 5 = 1.384 Ah ≈ 1384 mAh of charge deliverable from the USB-A port sufficient for a meaningful partial charge of a modern smartphone.

3.8 Form Factor and Enclosure

The prototype is assembled to fit a smartphone-sized enclosure, keeping the device practically portable and directly comparable in physical form to commercial power banks. The 18650 cell (65 mm × 18 mm diameter) is the primary dimensional constraint. The TP4056 and MT3608 modules, diodes, and switch are mounted on a compact baseplate within the enclosure. The solar panel is placed on the top face, maximising its exposure to direct sunlight during outdoor use. This form factor makes the prototype convenient to carry and use in the same manner as a standard commercial power bank.

IV. WORKING PRINCIPLE

During daylight, the solar panel generates a DC output voltage. After passing through the 1N4007 diode, the reduced voltage (panel output minus ≈1.1 V) is presented at the IN+ terminal of the TP4056 module. Provided this fall within the 4.5 V to 5.5 V range, the TP4056 initiates the charge cycle for the 18650 cells.

If the cell is deeply discharged (terminal voltage below 2.9 V), the TP4056 first applies trickle charge at approximately 1/10th of the programmed rate, gently recovering the cell. Once the cell voltage exceeds 2.9 V, the IC switches to the constant-current phase at full programmed charge current, and the red status LED activates. As the cell approaches 4.2 V, the IC transitions to constant-voltage mode: the output is held at 4.2 V while current tapers naturally. When current drops to approximately 1/10th of the programmed rate, the IC terminates charging and the status LED changes from red to blue, indicating the cell is fully charged.

When the user presses the push-button switch, the MT3608 boost converter is connected to the battery. The converter's internal MOSFET begins switching at 1.2 MHz, alternately building energy in the 22 µH inductor and releasing it to the output filter capacitor and load. The feedback resistor network on the module adjusts duty cycle continuously to maintain 5 V at the USB-A output regardless of the cell's instantaneous terminal voltage, which varies between 3.0 V and 4.2 V across the discharge cycle.

When the solar panel is covered or absent (night, heavy cloud), its output voltage drops to near zero. The 1N4007 diode becomes reverse-biased because the battery terminal voltage is higher than the panel voltage. No current flows from battery to panel. The cell's stored charge is preserved for USB output use. The 1N4007's 1000 V PIV rating far exceeds the battery's maximum terminal voltage, ensuring reliable blocking under all practical conditions.

V. RESULTS AND DISCUSSION

The prototype was assembled and subjected to functional testing across each subsystem. Results are reported below.

5.1 Charging Path Verification

The TP4056 module's red charging LED activated when the solar panel was exposed to direct sunlight with the 18650 cells in a partially discharged state. This confirmed that the panel output, after the 1N4007 forward drop, was within the TP4056's 4.5 V to 5.5 V operating window. The red LED remained active continuously during the charging phase, consistent with the CC/CV operation described in the datasheet. When the cell reached the charge termination condition, the LED transitioned from red to blue, confirming automatic charge termination was functioning correctly.

5.2 USB Output Voltage Measurement

With the push-button switch closed and the 18650 cells at a partial state of charge, the USB output voltage was measured at the USB-A terminals using a digital multimeter. The measured value was 5.12 V DC. Table 4 compares this against the USB 2.0 specification limits.

Table 4: Measured USB Output Voltage vs USB 2.0 Specification

Parameter	USB 2.0 Specification	Measured (Prototype)	Status
Output Voltage	4.75 V – 5.25 V (nominal 5.00 V)	5.12 V DC	✓ Within Specification
Deviation from Nominal	±5% (±0.25 V)	+0.12 V (+2.4%)	✓ Within Tolerance

The measured 5.12 V output is within the USB 2.0 VBUS voltage tolerance band of 4.75 V to 5.25 V [7]. The +2.4% positive deviation from the 5.00 V nominal is consistent with the MT3608 output regulation tolerance and the trimmer potentiometer setting on the module board. This output voltage is compatible with standard USB charging for smartphones and similar devices.

5.3 Reverse Current Blocking Verification

The solar panel was covered completely to simulate darkness while the 18650-cell remained at a partial state of charge. Battery terminal voltage was monitored over a short test period. No measurable self-discharge attributable to reverse current through the panel was detected during the test interval, confirming that the 1N4007 diode was correctly blocking reverse current under low-irradiance conditions.

5.4 Theoretical Capacity Analysis

Table 5 presents the theoretical USB-level output capacity calculated from the 18650 cells' 2200 mAh / 8.14 Wh rating, at three MT3608 efficiency values representing conservative, typical, and peak performance.

Table 5: Theoretical USB Output Capacity from 2200 mAh / 3.7 V Cell

MT3608 Efficiency Assumed	Usable Output Energy (Wh)	USB Output Capacity at 5 V (mAh)
85% (conservative)	6.92 Wh	≈1384 mAh
90% (typical)	7.33 Wh	≈1466 mAh
93% (peak, datasheet)	7.57 Wh	≈1514 mAh

These figures represent the charge available at the USB-A port before accounting for losses in the connected device's charging circuitry. Modern smartphone charger circuits typically operate at 80 to 90% efficiency, so the charge actually delivered to a phone battery will be somewhat lower. Nevertheless, at 85% assumed converter efficiency and 85% assumed device efficiency, the prototype delivers approximately 1176 mAh to the phone battery — enough for a partial top-up of most smartphones with 3000 to 5000 mAh batteries.

5.5 Identified Limitations

The forward voltage drop of the 1N4007 (~1.1 V) is the single largest efficiency loss in the solar input path. Under partial cloud or low-angle illumination where the panel output is marginal, this drop can push the TP4056 input below its 4.5 V minimum, halting charging entirely. Replacing the 1N4007 with a 1N5819 Schottky diode (VF ≈ 0.3 V) would reduce this loss by 0.8 V and extend the range of illumination conditions under which charging remains active.

Quantitative measurements of charging time from a defined initial state, output current under defined resistive load, and solar panel conversion efficiency under calibrated irradiance were not completed at this prototype stage, as these require a programmable DC electronic load and a calibrated solar irradiance meter. These measurements are the primary next step in characterising this prototype.

VI. CONCLUSION

This paper has presented the complete design, component specification, and hardware prototype implementation of a compact, smartphone-sized solar-powered portable power bank. The system integrates a solar panel, 1N4007 reverse-blocking diodes, a TP4056 CC/CV linear charger module, a 3.7 V / 2200 mAh 18650 lithium-ion cells, an MT3608 step-up boost converter, and a user-controlled push-button switch to deliver a self-contained, grid-independent USB charging device.

Prototype testing confirmed correct operation across all subsystems. The TP4056 executed the full CC/CV charge cycle with automatic termination, verified visually via status LEDs. The MT3608 boost converter delivered a measured USB output of 5.12 V, which is within the USB 2.0 specification tolerance of 4.75 V to 5.25 V. The 1N4007 diodes successfully blocked reverse current under simulated low-irradiance conditions. The 18650 cell's 2200 mAh capacity stores 8.14 Wh of energy, translating to approximately 1384 to 1514 mAh of usable output at 5 V after converter losses.

The design is modular, fully assembled from commercially available off-the-shelf components, and requires no specialised fabrication. This makes it directly suitable for academic prototype development, educational demonstrations, and portable charging in off-grid or rural settings where grid access is unreliable. The smartphone-sized form factor ensures the device is practical for everyday carry.

Future development will focus on three areas: (1) replacing the 1N4007 with a 1N5819 Schottky diode to reduce blocking-path losses by approximately 0.8 V; (2) quantitative efficiency characterisation under measured irradiance and defined output load conditions using a programmable electronic load; and (3) evaluating the feasibility of a maximum power point tracking (MPPT) front-end stage to extract optimal power from the solar panel across varying illumination conditions.

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