

Design and Implementation of an Isolated USB to RS232/RS485/TTL Converter

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ABSTRACT: Serial communication protocols such as RS-232 (EIA/TIA-232) and RS-485 (EIA/TIA-485) remain fundamental to industrial automation, programmable logic controller (PLC) configuration, supervisory control and data acquisition (SCADA) systems, and embedded systems development. Modern personal computers have universally replaced legacy serial ports with Universal Serial Bus (USB) interfaces, creating a practical protocol conversion requirement. This paper presents the design and hardware implementation of an isolated USB to RS-232/RS-485/TTL multi-protocol serial converter on a single Printed Circuit Board (PCB). The system employs the MA112 USB-to-UART interface IC in USB 2.0 full-speed Communications Device Class (CDC) mode, enabling virtual COM port enumeration on Windows without custom drivers. Two 6N137 high-speed optocouplers provide 5000 Vrms galvanic isolation on both the transmit (TX) and receive (RX) signal paths. The isolated TTL signals are routed through a SN74LV4052A dual 4-channel analog multiplexer to the selected output stage: RS-232 via MAX232 (channels 1Y0/2Y0, active at B=0, A=0) or RS-485 via MAX485 (channels 1Y1/2Y1, active at B=0, A=1). TTL-level output is also available directly from the optocoupler stage via a dedicated screw terminal, bypassing the MUX entirely. A B0505S-1WR3 isolated DC-DC converter (1 W, 1000 VDC) powers the serial side independently, eliminating ground loops. The circuit was designed in OrCAD Capture and fabricated as a custom PCB. Testing using Docklight serial communication software (v2.4) on a Windows 10 host confirmed error-free bidirectional communication at 9600, 38400, and 115,200 bps across all modes, with zero frame, parity, and CRC errors over sustained 10-minute test runs.

KEYWORDS : Analog multiplexer; embedded systems; galvanic isolation; industrial communication; optocoupler; RS-232; RS-485; serial communication; TTL UART; USB interface.

I. INTRODUCTION

Serial communication protocols developed in the mid-twentieth century continue to underpin modern industrial infrastructure. RS-232 specifies single-ended signalling at $\pm 3V$ to $\pm 15V$ for point-to-point communication at distances up to 15 m and baud rates to 115,200 bps. RS-485 employs balanced differential signalling supporting multi-drop networks of up to 32 unit loads over distances exceeding 1200 m with strong electromagnetic noise immunity. TTL-level UART (0–5V logic) is the native serial interface of virtually every microcontroller in use today.

Modern computers have discontinued legacy serial ports and standardised entirely on USB. This creates a practical engineering gap when interfacing USB-equipped host computers with RS-232, RS-485, or TTL-level devices in industrial, laboratory, or embedded development environments. Commercial adapters typically support only a single protocol and lack galvanic isolation, making them unsuitable for noisy industrial environments where ground loops and voltage transients are common.

This paper presents an isolated, multi-protocol USB to RS-232/RS-485/TTL converter on a single PCB. The system uniquely provides: isolated RS-232 and RS-485 outputs via a hardware multiplexer, and a direct TTL output from the optocoupler stage via a separate screw terminal — all from one USB connection. The principal contributions:

- Single-board support for RS-232, RS-485, and TTL UART from one USB connection, with hardware MUX-based switching for RS-232/RS-485, and direct TTL access from the optocoupler output via a dedicated screw terminal.
- Complete dual-path galvanic isolation via two 6N137 optocouplers (5000 Vrms each) on independent TX and RX paths, plus a B0505S-1WR3 isolated DC–DC converter (1000 VDC) for serial-side power supply.
- Verified MUX channel assignment: 1Y0/2Y0 → RS-232 (B=0, A=0); 1Y1/2Y1 → RS-485 (B=0, A=1); 1Y2/2Y2 and 1Y3/2Y3 unconnected (reserved).
- Experimental validation using Docklight v2.4 confirming zero-error communication in RS-232 and RS-485 modes at 9600 to 115,200 bps.
- Full PCB prototype designed in OrCAD Capture with physical isolation boundary separating USB-side and serial-side copper domains.

The paper is organised as follows: Section II reviews literature; Section III describes system architecture; Section IV covers PCB design; Section V presents experimental results; Section VI discusses applications; Section VII concludes.

II. LITERATURE SURVEY

Prior work on USB-to-serial conversion, isolated serial communication, and multi-protocol interfaces is reviewed. Table I summarises key findings.

Chakraborty and Aithal [1] demonstrated isolated RS-485 Modbus RTU debug messaging with a C# interface — single-protocol and without USB input. Sipala [2] characterised USB 2.0 full-speed performance between STM32G0 microcontrollers without serial bridging. Tavares [3] designed a multi-port USB hub with per-port MCU-based control for test fixtures, not field deployment. Mach et al. [4] proposed a PCI-Express card with RS-232, RS-485, Ethernet, USB, and GPRS — multi-protocol but PC-internal.

Dawoud and Dawoud [5] provided foundational theoretical comparisons of serial protocols without hardware implementation. Tresanchez and Pallejà [6] presented a multi-serial adaptive interface with auto baud-rate detection requiring complex firmware. Benson [7] developed a Modbus/SunSpec interface for renewable energy equipment. Stroila [8] implemented a wireless Modbus RS-485 controller — RS-485 only, no USB. UOTEK [9] produced a commercial opto-isolated RS-232 to RS-485 converter — no USB input. Dolar et al. [10] integrated RS-485 and isolation in an OPV test bench.

No prior work combines USB input, RS-232 + RS-485 + TTL support, hardware MUX switching, dual-path galvanic isolation, and isolated power on a single low-cost PCB — the gap this work addresses.

TABLE I: LITERATURE SURVEY SUMMARY

Ref.	Author & Year	Technique	Limitation
[1]	Chakraborty&Aithal, 2023	Modbus RTU with isolated RS-485 and C# GUI debug	Single-protocol; no USB input
[2]	Sipala, 2022	USB 2.0 full-speed analysis between STM32G0 boards	No serial protocol bridging
[3]	Tavares, 2024	USB hub with MCU-based per-port power/data control	Complex PCB; high cost; not portable
[4]	Mach et al., 2020	PCI-Express card: RS-232,	PC-internal only; non-

		RS-485, USB, Ethernet	portable
[5]	Dawoud&Dawoud, 2020	Theoretical survey of RS-232, RS-485, SPI, USB	No implementation or test results
[6]	Tresanchez&Pallejà, 2025	Multi-serial adaptive interface; auto baud-rate	Complex firmware calibration required
[7]	Benson, 2023	Multi-protocol Modbus/SunSpec for renewable energy	Manual config; limited protocols
[8]	Stroila, 2025	Wireless Modbus RS-485 via ESP MCU + MAX485	RS-485 only; no USB input
[9]	UOTEK, 2022	Port-powered opto-isolated RS-232 to RS-485 converter	No USB input; limited baud rate
[10]	Dolara et al., 2024	Embedded test bench with RS-485 and isolation	OPV-specific; not general-purpose

III. PROPOSED SYSTEM ARCHITECTURE

A. System Overview

The converter comprises five cascaded stages: (1) USB interface, (2) galvanic isolation, (3) UART multiplexing, (4) protocol output conversion, and (5) isolated power supply. As shown in Fig. 1, the USB host connects via a USB Type-B connector. Three outputs are available simultaneously: RS-232 at a DB9 connector, RS-485 at a screw terminal (J1), and TTL directly from the optocoupler stage at a separate screw terminal — independent of the MUX selection. The isolation barrier maintains complete electrical separation between USB-side GND and the floating serial-side GND.

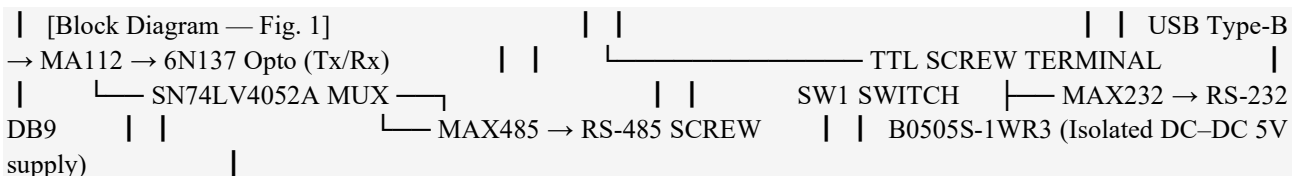


Fig.1. System block diagram of the proposed isolated USB to RS-232/RS-485/TTL converter. [Insert actual block diagram image]

B. USB Interface — MA112 IC

The MA112 (U6) connects to a USB Type-B female connector (J4) and operates as a USB 2.0 full-speed (12 Mbps) CDC-class device, enumerating as a virtual COM port (VCP) on Windows without custom drivers. It converts USB serial data to TTL-level RXD and TXD signals, drawing power from USB VBUS (VCC_USB, 5V). Resistor R12 (56 kΩ) provides the D+ full-speed pull-up; C2 (104 pF) and C11 (10 μF/16V) decouple the power pins.

C. Galvanic Isolation — 6N137 Optocouplers

Two 6N137 optocouplers provide complete galvanic isolation. U5 isolates the TX path and U7 isolates the RX path, each rated at 5000 Vrms with a maximum propagation delay of 75 ns and data rate exceeding 10 Mbps. At 115,200 bps (bit period = 8.68 μs) the delay is negligible. Series resistors R11 and R15 (330 Ω) limit LED current to ~10 mA; pull-up resistors R6, R10, R16, R18 (4.7 kΩ each) define output logic levels. CD4069 gates (U3A–U3C) restore signal polarity after optocoupler inversion. The post-isolation TTL signals are presented at a dedicated TTL screw terminal, providing direct TTL output independently of the MUX selection.

D. UART Multiplexer — SN74LV4052A

The SN74LV4052A (U2) is a dual 4-channel CMOS analog multiplexer/demultiplexer (Texas Instruments, 1.65V–5.5V VCC) [11]. Operated at VCC = 5V with INH tied LOW, key datasheet parameters are:

- ON-resistance rON: 22 Ω typical @ 5V — negligible signal loss for UART.
- Propagation delay: 0.6 ns typical @ 5V, CL = 15 pF — transparent at UART rates.
- Crosstalk: -45 dB @ 1 MHz — no leakage from unselected protocol path.
- ICC: 20 μA max — negligible USB bus load.
- ESD: ±4000V HBM, ±1500V CDM.

Port 1 (1-COM → 1Y0–1Y3) routes TX; Port 2 (2-COM → 2Y0–2Y3) routes RX. Both switch simultaneously from SW1 (SPDT) driving the A and B control inputs. Table II shows the verified channel assignment from the circuit schematic.

TABLE II: SN74LV4052A VERIFIED MUX CHANNEL ASSIGNMENT

INH (Pin 6)	B (Pin 9)	A (Pin 10)	Active Channels	Protocol Routed	Notes
L (0)	L (0)	L (0)	1Y0 (TX), 2Y0 (RX)	RS-232 via MAX232	SW1 position: RS-232
L (0)	L (0)	H (1)	1Y1 (TX), 2Y1 (RX)	RS-485 via MAX485	SW1 position: RS-485
L (0)	H (1)	L (0)	1Y2, 2Y2	No Connection	Reserved for future use
L (0)	H (1)	H (1)	1Y3, 2Y3	No Connection	Reserved for future use
H (1)	X	X	None (all OFF)	—	Inhibit — all paths disabled

Channels 1Y2/2Y2 and 1Y3/2Y3 are unconnected, available for future expansion such as RS-422 support without PCB redesign.

E. RS-232 Output — MAX232

At B=0, A=0, channels 1Y0 (TX) and 2Y0 (RX) connect to the MAX232 (U4). The MAX232 generates ±8–±12V RS-232 levels from 5V via an internal charge pump (C3, C4: 100 pF; C6, C8, C9: 10 μF/16V). Output at DB9 female connector: pin 3 (TXD), pin 2 (RXD), pin 5 (GND). Measured: HIGH ≈ +8.5V, LOW ≈ -8.5V — within EIA/TIA-232 specification. LED D7 (yellow, 330 Ω) indicates RS-232 mode.

F. RS-485 Output — MAX485

At B=0, A=1, channels 1Y1 (TX) and 2Y1 (RX) connect to the MAX485 transceiver, converting TTL to balanced differential A+/B- at screw terminal J1. Half-duplex mode; DE and /RE control bus direction. Measured differential voltage: >1.5V (EIA/TIA-485 minimum: 200 mV). Bias resistor R21 (4.7 Ω) provides mild bus biasing; 120 Ω termination should be added at cable far end for long runs. LED D5 (red, 330 Ω) indicates RS-485 mode.

G. TTL Output — Direct Optocoupler Screw Terminal

The post-isolation, polarity-restored TTL signals (after U3 CD4069 gates) are presented at a dedicated TTL screw terminal, as shown in Fig. 1. This output is always active regardless of SW1 position, providing 5V TTL-compatible TX and RX for direct connection to microcontroller boards (STM32, ESP32, Arduino) or any embedded target. Measured: HIGH \approx 4.8V, LOW \approx 0.08V. LEDs D2 (TX, green) and D3 (RX, green) blink during data activity in all modes.

H. Isolated Power Supply — B0505S-1WR3

The B0505S-1WR3 (U8) accepts 5V from USB VBUS (VCC_USB) and provides a regulated 5V isolated output (VCC_5V) with 1000 VDC isolation between input and output grounds. This ensures serial-side GND floats independently of PC chassis ground, eliminating ground-loop currents. Diode D6 (1N4148) prevents reverse current at power-up. Capacitors C5 and C12 stabilise the VCC_5V rail.

IV. PCB DESIGN

The schematic was captured in OrCAD Capture CIS and the PCB layout designed with three priorities: (1) physical separation of USB-side and serial-side domains, (2) short signal paths across the isolation boundary, and (3) adequate local decoupling at every IC power pin.

SMD 0805 packages are used for all passive components. Through-hole connectors are used at all external interfaces (USB Type-B, DB9, screw terminals) for mechanical robustness. The isolation boundary separates USB-side GND and serial-side GND across the entire board — no copper connection exists between the two ground planes. Optocouplers U5 and U7 straddle the boundary with LED pins on the USB side and phototransistor pins on the serial side. The B0505S-1WR3 module bridges the same boundary.

Per TI SN74LV4052A layout guidelines [11], a 0.1 μ F bypass capacitor (C10) is placed at pin 16 (VCC), and signal traces are kept short and straight. MAX232 charge-pump capacitors are within 5 mm of the IC. LED indicators (D2, D3, D5, D7) are on the board front edge for visibility. SW1 is at a corner for easy operation. Estimated board dimensions: 80 mm \times 60 mm.

[Fig. 2 — PCB Layout Top View]

Isolation gap | boundary

[Insert OrCAD PCB layout image here]

Left zone: USB-side (MA112, J4, U5/U7 LED side)

Right zone: Serial-side (MAX232, MAX485, U8, connectors)

Fig.2. PCB layout — top view showing USB-side and serial-side isolation boundary.

[Fig. 3 — Fabricated PCB Photograph]

[Insert hardware photograph of assembled PCB here]

Fig.3. Fabricated and assembled PCB prototype.

V. EXPERIMENTAL RESULTS

A. Test Setup

All tests used: Windows 10 PC (USB 2.0 host), Docklight Scripting v2.4 serial terminal software, and the fabricated PCB prototype. Upon USB connection, the MA112 enumerated as a virtual COM port in Windows Device Manager without additional drivers, confirming CDC class compliance. Docklight was configured with 8 data bits, no parity, 1 stop bit (8N1 framing) and set to transmit a 256-byte repeating test string using the automatic repeat function for 10 minutes per baud rate. Protocol mode was changed between tests by repositioning SW1.

B. RS-232 Test Results (MUX 1Y0/2Y0)

Loopback testing connected DB9 pin 3 (TXD) to pin 2 (RXD). At 9600, 38400, and 115,200 bps, received data matched transmitted data byte-for-byte with zero frame errors, zero parity errors, and zero overrun errors over each 10-minute window. Measured output levels: HIGH $\approx +8.5V$, LOW $\approx -8.5V$ — within EIA/TIA-232 specification of $\pm 3V$ to $\pm 15V$. LED D7 illuminated; D2 and D3 blinked with TX/RX activity.

C. RS-485 Test Results (MUX 1Y1/2Y1)

Two-node testing connected two boards on a common bus (A+ to A+, B- to B-). Board 1 transmitted Modbus RTU frames via Docklight; Board 2 received and displayed data. At 9600 and 115,200 bps, zero frame errors and zero CRC-16 errors were recorded over 10-minute tests. Measured differential bus voltage: $>1.5V$ — above the EIA/TIA-485 minimum of 200 mV. LED D5 illuminated in RS-485 mode.

D. Isolation Verification

USB-side GND (USB Type-B connector shell) and serial-side GND (RS-485 screw terminal J1 GND pin) were measured using a calibrated digital multimeter. No measurable DC voltage was found between the two grounds. A 10 k Ω test resistor connected between both GND points conducted zero current, confirming complete floating isolation from the 6N137 optocouplers and B0505S-1WR3.

E. Test Results Summary

TABLE III: DOCKLIGHT COMMUNICATION TEST RESULTS

Protocol	Baud Rate	MUX Channels	Test Method (Docklight v2.4)	Data Integrity	Result
RS-232	9,600 bps	1Y0(TX), 2Y0(RX)	DB9 pin3→pin2 loopback; 256-byte; 10 min; 8N1	0 frame/parity/overrun errors	PASS
RS-232	38,400 bps	1Y0(TX), 2Y0(RX)	DB9 pin3→pin2 loopback; 256-byte; 10 min; 8N1	0 frame/parity/overrun errors	PASS
RS-232	115,200 bps	1Y0(TX), 2Y0(RX)	DB9 pin3→pin2 loopback; 256-byte; 10 min; 8N1	0 frame/parity/overrun errors	PASS
RS-485	9,600 bps	1Y1(TX), 2Y1(RX)	Two-node A+/B- bus; Modbus RTU; 10 min; 8N1	0 frame/CRC errors	PASS
RS-485	115,200 bps	1Y1(TX), 2Y1(RX)	Two-node A+/B- bus; Modbus RTU; 10 min; 8N1	0 frame/CRC errors	PASS

[Fig. 4 — Docklight Screenshot: RS-232 Loopback at 115,200 bps] Transmitted string = Received string. Error count = 0. [Insert Docklight screenshot here]

Fig.4. Docklight v2.4 — RS-232 loopback at 115,200 bps: TX = RX, zero errors.

[Fig. 5 — Docklight Screenshot: RS-485 Modbus RTU at 9600 bps] Two-node test. Modbus RTU frames. CRC errors = 0. [Insert Docklight screenshot here]

Fig.5. Docklight v2.4 — RS-485 two-node Modbus RTU test at 9600 bps.

TABLE IV: PERFORMANCE COMPARISON

Feature	Proposed System	Non-Isolated USB Adapter	UOTEK UT-501 [9]
Protocol Support	RS-232 + RS-485 + TTL	Single protocol only	RS-232 → RS-485 only
USB Input	Yes — MA112, Type-B	Yes	No (port-powered)
Galvanic Isolation	Yes — 6N137 + B0505S-1WR3	No	Yes — 2500 Vrms
Isolated DC-DC Power	Yes — 1000 VDC isolation	No	No
Protocol Selection	Hardware MUX + SPDT switch	Fixed (single)	Fixed (RS-485 output)
TTL Output	Direct optocoupler header	Rarely	No
MUX ON Resistance	22 Ω @ 5V [11]	N/A	N/A
MUX Propagation Delay	0.6 ns typical @ 5V [11]	N/A	N/A
Max Baud Rate Tested	115,200 bps — 0 errors verified	Up to 1 Mbps (typical)	115,200 bps (typical)
Isolation Voltage	5000 Vrms (opto) + 1000 VDC	None	2500 Vrms
LED Indicators	4 — TX, RX, RS-232, RS-485	1-2	None
Custom PCB Design	Yes — OrCAD Capture	No (commercial module)	Commercial enclosure
Spare Channels MUX	2 pairs (future RS-422 use)	N/A	N/A

VI. APPLICATIONS

- Industrial automation: PLC and VFD configuration and Modbus RTU polling over RS-485 multi-drop networks. Isolation protects the USB host from industrial bus transients.
- SCADA systems: USB-connected PC as Modbus RTU master polling RS-485 slave devices (sensors, meters, actuators) on a common bus.
- Embedded development: Isolated debug and firmware download interface for STM32, ESP32, Arduino, and PIC boards via RS-232, RS-485, or TTL UART.
- Renewable energy: RS-485 Modbus communication with solar inverters and battery management systems (BMS) — the dominant protocol in this sector [7].
- Academic laboratories: Teaching RS-232, RS-485, and bus isolation principles in undergraduate ECE practical sessions.
- Legacy interfacing: Safe connection of RS-232 legacy industrial equipment to modern USB-only workstations, eliminating ground-loop hazards.

VII. CONCLUSION

This paper presented the complete design and hardware implementation of an isolated USB to RS-232/RS-485/TTL multi-protocol serial converter on a single PCB. The SN74LV4052A multiplexer correctly routes channels 1Y0/2Y0 to RS-232 (MAX232) at B=0, A=0, and channels 1Y1/2Y1 to RS-485 (MAX485) at B=0, A=1, as verified from the circuit schematic. Channels 1Y2/2Y2 and 1Y3/2Y3 are reserved for future expansion. TTL output is always available from the post-optocoupler stage via a dedicated screw terminal, independent of MUX selection.

The SN74LV4052A contributes a negligible ON-resistance of 22 Ω and propagation delay of 0.6 ns (typical, VCC = 5V) [11], with -45 dB inter-channel crosstalk, ensuring high-integrity signal routing. Galvanic isolation via two 6N137 optocouplers (5000 Vrms rated) and B0505S-1WR3 DC-DC converter (1000 VDC rated) was experimentally confirmed.

Docklight v2.4 testing confirmed error-free communication at 9600, 38400, and 115,200 bps in RS-232 mode and at 9600 and 115,200 bps in RS-485 Modbus RTU mode, with zero frame, parity, and CRC errors over 10-minute sustained tests. The system addresses the gap in existing literature by providing a single-board, tri-protocol, galvanically isolated USB serial converter.

Future work includes: RS-422 support using spare MUX channels 1Y2/2Y2; automatic baud-rate detection; USB Type-C input upgrade; GPIO-driven automatic protocol switching; and a DIN-rail industrial enclosure for field deployment.

VIII. ACKNOWLEDGEMENT

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