TECHNICAL FEASIBILITY REPORT

LTE Cat 1bis Retrofit of the Nokia 2190

Preserving the original ABS enclosure, keypad, monochrome display and acoustic interface

148 x 56 x 25 mm	LTE Cat 1bis	2.0 A Peak	2.5-3.5 Ah
Host Envelope	Single Antenna	Modem Burst Path	18650 Capacity

Core Architecture

ESP32-S3 · SIM7672G · ES8388 · nPM1300

Fabrication Ecosystem

Metro Vancouver · Richmond · Burnaby

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1. Executive Summary

The shutdown of legacy 2G and 3G networks has rendered a large population of historically significant mobile devices inert, reducing fully operational handsets to display objects. These devices are defined by a monochrome, single-purpose interface and a mechanically robust chassis, an operating constraint that contemporary smartphones have discarded entirely.

The Nokia 2190 is one of them. It is the North American GSM 1900 variant of the Nokia 2110 family, released in the mid-1990s. It introduced the dual dynamic softkey interface, SMS capability, and a set of ergonomic standards that the industry spent the next decade copying. The chassis features matte black ABS plastic, rubberized side grips, and screw-secured battery compartments.

The central question is whether modern LTE capability, specifically Voice over LTE, can be installed inside this enclosure without altering anything a user would see or touch.

The obvious first hypothesis is donor transplantation: extract the motherboard from a modern low-cost feature phone and place it inside the vintage shell. The approach is conceptually direct and practically fatal. Modern feature phones use TFT displays and rigidly spaced tactile dome matrices that bear no dimensional relationship to the optical viewing window or flexible rubber membrane keypad of the 2190. Closed-source real-time operating systems further prevent software-level remapping of GPIO pins or display framebuffers.

The definitive path requires a custom embedded system designed, fabricated, and programmed for this specific enclosure. This report establishes the complete framework for that modernization. It is built on an LTE Cat 1bis baseband, a dual-core microcontroller, an integrated power management IC, and the fabrication resources available around Richmond, British Columbia.

Recommended Design Direction

Use a purpose-built replacement PCB around the ESP32-S3, SIM7672G, ES8388 and nPM1300. The architecture preserves the handset's visible and tactile identity while avoiding the display, keypad and firmware constraints of donor-board transplantation.

Table 1. Donor-board transplant versus purpose-built replacement PCB

Criterion	Donor Feature-Phone Board	Custom Replacement PCB	Decision
Display fit	2.4-inch TFT is cropped by the 2190 bezel	Original monochrome module is driven directly	**Custom PCB**
Keypad mapping	Requires fragile trace cutting and magnet-wire remapping	Matrix geometry designed around the original membrane	**Custom PCB**
Firmware control	Closed RTOS prevents GPIO and framebuffer remapping	FreeRTOS + LVGL provide full control	**Custom PCB**
RF / antenna	Board geometry and antenna routing are fixed	Single-antenna Cat 1bis layout can be optimized for the shell	**Custom PCB**
Iteration	Changes require invasive rework of an alien board	Electrical and mechanical revisions remain under design control	**Custom PCB**

2. Spatial and Volumetric Architecture of the Host Chassis

Before any internal modification begins, the host chassis requires a spatial audit. The Nokia 2190 was manufactured when surface-mount component densities were low, discrete parts were physically large, and EMI shielding consumed real volume behind heavy metallic cages. The device was assembled with physical screws rather than the fragile plastic clips used in contemporary smartphones, which means non-destructive teardown is straightforward.

External dimensions of the Nokia 2110/2190 family are documented at 148.0 x 56.0 x 25.0 mm, with a stock weight of 236 grams. Twenty-five millimeters of depth is enormous by modern standards. It is not, however, a hollow cavity waiting for arbitrary components. The original internal architecture occupies that volume in several tightly integrated physical layers.

The main PCB is a thick, multi-layer fiberglass substrate built around the legacy Hitachi H8/536 chipset, spanning nearly the full X and Y footprint. Above it sits the display assembly, a monochrome graphic LCD module typically governed by a Philips PCD8544 or Epson SED1565 controller, mounted to the upper chassis and aligned with the transparent polycarbonate viewing window. Below the display, the keypad matrix uses a flexible membrane layer resting over tactile dome switches integrated directly into the copper traces of the main PCB.

The upper portion of the device holds a physical, retractable telescopic antenna. The rear is dominated by a battery compartment sized for a 550 mAh Nickel-Metal Hydride pack. Discard the obsolete Hitachi logic board and the degraded NiMH cells, but retain the original ABS plastics, keypad membrane, LCD module, and metal fasteners. The result is a large, mechanically protective volumetric envelope suited precisely for a custom replacement PCB.

Table 2. Packaging constraints carried into the replacement-board design

Element	Nominal Value	Design Implication	Pre-release Check
Host enclosure	148 x 56 x 25 mm	Custom PCB must follow original X-Y footprint and screw locations	3D scan / caliper audit
Stock handset	236 g	Weight can change, but balance and battery retention should remain comfortable	Assembled mass + drop test
Display window	Approx. 1.3-inch diagonal	Rendering must remain inside the fixed optical aperture	Visible-pixel mask
Battery cavity	18650: 18 x 65 mm	Refit original pack shell around a protected cylindrical cell	Clearance + insulation
Cat 1bis module	24 x 24 x 2.4 mm	Smaller plan area and single antenna reduce routing pressure	Verify selected variant drawing
Cat 4 reference	30 x 30 x 2.5 mm	Larger footprint and diversity antenna are poor fits for the host	Reference only

Dimensional Control Point

Treat all published dimensions as nominal. The final PCB outline, display standoff height, keypad switch positions and antenna keep-out must be taken from the specific handset and components selected for the build.

3. The Motherboard Transplant Failure Mode

The instinctive approach is to purchase a contemporary low-cost 4G feature phone, extract the motherboard, and mount it inside the vintage case. Plausible candidates include entry-level HMD Global devices such as the Nokia 225 4G, Nokia 215 4G, and Nokia 105 4G. These operate on modern cellular networks and use highly integrated SoCs such as the Unisoc T107 or T117.

An alien motherboard forced into a chassis designed thirty years earlier fails across two domains simultaneously: optical display alignment and physical keypad matrix translation. Neither failure is recoverable within the constraints of the donor hardware.

3.1 Optical Display Alignment

The Nokia 2190 has a fixed, unalterable transparent plastic window molded into the upper chassis, sized for a monochrome screen measuring approximately 1.3 inches diagonally. Modern feature-phone donors use 2.4-inch QVGA TFT LCD panels at 320x240 pixels. Mount a donor motherboard behind the 2190's front casing and the TFT display is immediately cropped by the thick plastic bezels of the vintage shell.

The cropping is not cosmetic. Battery indicators, signal strength bars, caller ID text, and softkey labels are anchored to the absolute edges of the display matrix by the donor's operating system. All of them disappear behind the bezel. Physically separating the LCD from its motherboard and offsetting it introduces extreme electrical fragility. Modern displays use high-density Flexible Printed Circuits soldered via microscopic surface-mount pads; extending those connections requires exact impedance matching.

The software path is closed. The proprietary RTOS running on these donor devices (S30+ or Mocor OS) cannot be decompiled or modified to restrict the rendering area to the visible pixels behind the 2190's viewing window.

3.2 Keypad Matrix Translation

The fatal flaw is the human interface. The external buttons of the Nokia 2190 must physically actuate switches connected to the donor motherboard. However, the button spacing, layout, and ergonomic geometry of a 2190 are completely alien to a modern Nokia 225 4G. No external button aligns with a tactile dome on the donor PCB.

Bridging the gap requires severing microscopic copper traces on the donor board, exposing bare copper beneath the solder mask, and soldering dozens of enameled magnet wires from the donor's matrix test points to corresponding points on the 2190's original PCB. The process is tedious, fragile, and rarely yields a one-to-one electrical mapping. Because the S30+ RTOS is locked, GPIO pin remapping in software is unavailable. A hardware-level logic gate or intermediary microcontroller would have to be spliced between the vintage keypad and the donor board. The cascading failures terminate the donor-board pathway entirely.

4. Core Processing Architecture: The ESP32-S3

The professional path is a custom embedded system built from a blank schematic. A new printed circuit board, modeled to the physical dimensions and mounting hole locations of the original 2190 mainboard, carries a central microcontroller. This chip is responsible for managing the cellular baseband, driving the graphical interface, scanning the keypad matrix, and executing the RTOS.

The microcontroller is the Espressif ESP32-S3, a dual-core Xtensa 32-bit LX7 system-on-chip operating at up to 240 MHz. The S3 variant is the correct choice for this application. Its LX7 cores include vector instructions that accelerate neural network and signal processing workloads. These are critical for real-time audio noise cancellation and echo suppression during VoLTE calls, functions that previously required a dedicated DSP.

The ESP32-S3 provides native USB 2.0 OTG support, enabling direct USB interfacing with the LTE modem via TinyUSB rather than relying on slower UART serial buses. This facilitates PPP dial-up network access, allowing the modernized 2190 to simultaneously serve as a portable 4G Wi-Fi hotspot. Up to 8 MB of Octal SPI PSRAM provides the framebuffer depth required for advanced graphical rendering while emulating the vintage operating system aesthetic.

Table 3. Core component and interface map

Component	Primary Role	Main Interfaces	Critical Constraint
ESP32-S3	Application processor, UI, task scheduling, bridge logic	UART / USB, SPI, GPIO, I2S, I2C	Deterministic audio and modem-event handling
SIM7672G	LTE Cat 1bis registration, data, SMS and VoLTE	UART / USB, PCM, RF	Burst current and carrier/band compatibility
ES8388	Digital-to-analog and analog-to-digital audio conversion	I2S, I2C, analog audio	Clock format, gain and earpiece drive
nPM1300	Charging, power path, fuel gauge and low-power states	USB-C, VSYS, buck / LDO, I2C	Modem bypass path and transient decoupling
PCD8544 / SED1565	Original monochrome user interface	SPI-like serial control	Controller variant and visible-pixel mapping
Keypad matrix	Original mechanical input	GPIO rows / columns	Switch geometry and reliable debounce
18650 cell	Primary energy storage	VBAT / protection	Safe retention, insulation and discharge capability

5. RF Transmission and AT Command Interface

The ESP32-S3 communicates with the SIM7672G over a UART serial bus using the Hayes AT command set. The RTOS operates as a finite state machine, polling the modem for Unsolicited Result Codes such as RING on an incoming call or +CMTI on an arriving SMS.

When the user initiates an outgoing call, the ESP32-S3 issues an ATD command with the dialed number. The SIM7672G independently executes LTE network registration, establishes the IP bearer for VoLTE, and signals the ESP32-S3 upon connection. The entire cellular stack runs on the modem; the microcontroller never touches it.

Table 4. Representative modem events and firmware responses

User / Network Event	Modem Command or Indication	ESP32-S3 Response
Incoming call	RING and call-state indications	Open incoming-call screen, prepare audio path, await accept/reject input
Outgoing call	ATD<number>	Track setup state, update the UI and route call audio after connection

Incoming SMS	+CMTI	Read the indexed message, store it and notify the UI task
Registration change	Network-registration URCs	Update signal/service state and apply retry or backoff policy

Table 5. LTE module comparison (Cat 4 vs Cat 1bis)

Metric	SIM7600G-H (Cat 4)	SIM7672G (Cat 1bis)	Retrofit Relevance
Max downlink	150 Mbps	10 Mbps	Cat 1bis sufficient for voice, messaging and light data
Max uplink	50 Mbps	5 Mbps	Lower throughput reduces complexity without affecting core use case
Antenna requirement	Primary + receive diversity	Single antenna	Simplifies routing inside the narrow upper enclosure
Nominal dimensions	30.0 x 30.0 x 2.5 mm	24.0 x 24.0 x 2.4 mm	Reduces plan area by approximately 36%
VoLTE support	Supported	Supported	Voice service remains the decisive requirement

6. Acoustic Translation and Digital Audio Subsystem

The persistent challenge in modernizing vintage cellular hardware is the gap between a high-speed digital baseband and the analog acoustic transducers that defined the original experience. The goal is to preserve the 2190's original electret microphone and dynamic earpiece speaker.

Older 2G modems included analog audio amplifiers. The SIM7672G does not. It is an IoT modem optimized for data telemetry; its designers stripped the analog audio circuitry to save space and cost. What remains is a digital PCM interface carrying a 16-bit linear bitstream. Translating that bitstream into an analog waveform the vintage earpiece can reproduce requires an external audio codec IC.

The codec is the Everest Semiconductor ES8388, a low-power stereo codec featuring dual ADCs and DACs, operating within a 1.7 V to 3.6 V logic range. It is the standard audio codec for ESP32-based telecommunications applications.

6.1 I2S and PCM Protocol Routing

The audio routing requires precision clock synchronization across multiple buses. The SIM7672G transmits and receives call audio via digital PCM lines in PCM master mode with short frame sync. The ES8388 communicates via I2S.

The ESP32-S3 serves as master clock generator and digital audio bridge. Its firmware ingests the PCM stream from the SIM7672G via the ESP-IDF I2S driver, applies digital filtering and volume scaling matched to the impedance curve of the 2190's vintage 32-ohm earpiece, and transmits the processed I2S stream to the ES8388.

The ES8388 receives the I2S stream, drives the vintage earpiece through its integrated pop-noise-free headphone amplifier, and simultaneously amplifies the weak analog signal from the 2190's electret microphone. The codec's ADC digitizes the microphone input and passes it back to the LTE modem. Internal registers are configured by the ESP32-S3 over an I2C control bus, providing programmatic control of microphone gain, equalization, and ambient noise reduction.

Audio Integration Checkpoint

Confirm the exact SIM7672G PCM timing mode and the ES8388 I2S clock configuration on the bench. The firmware bridge should be validated for clock stability, end-to-end latency, gain, sidetone and acoustic echo before mechanical integration.

7. Power Delivery Network and Thermal Management

The power requirements of a modern telecommunications platform bear no resemblance to the analog and 2G era. The entire power delivery network must be rebuilt.

The original Nokia 2190 carried a Nickel-Metal Hydride pack rated at roughly 550 mAh. NiMH improved on Nickel-Cadmium, but it remains a chemistry with low energy density, severe voltage depression under load, and rapid self-discharge. The SIM7672G is relatively efficient while idling in sleep, but LTE tower registration and burst data transmission can draw transient peaks of up to 2.0 A. An aged, degraded 550 mAh NiMH pack cannot deliver that current. Its internal resistance would collapse the voltage, trigger immediate brownout, and trap the modem in an endless boot loop.

7.1 Lithium-Ion Cell Integration

The original battery housing is hollowed out, the obsolete NiMH chemistry safely recycled, and the empty plastic shell refitted with a modern Lithium-Ion cell. The volumetric space inside the original casing accommodates a standard 18650 cylindrical cell measuring 18.0 mm in diameter and 65.0 mm in length. High-quality 18650 cells offer capacities from 2,500 mAh to 3,500 mAh, a six-fold increase over the factory NiMH pack. The nominal voltage of a standard Li-Ion cell is 3.7 V, which aligns with the 3.4 V to 4.2 V input range required by the SIM7672G.

7.2 The nPM1300 Power Management IC

Earlier custom builds used discrete, piecemeal power solutions: a TP4056 for USB charging, separate buck converters for 3.3 V logic, and a standalone fuel gauge IC. This approach consumes PCB area and lacks system-level coordination.

The replacement is the Nordic Semiconductor nPM1300, an integrated PMIC designed for battery-operated IoT devices. It consolidates the entire power delivery network into a single component.

- **Dynamic Power-Path Management and USB-C Negotiation:** The nPM1300 detects the connected USB source (Standard Port, Host, or USB-C 1.5 A), sets the input current limit accordingly, and routes power to the system while the battery charges simultaneously. The phone operates even with a deeply discharged 18650 cell.
- **Algorithmic Fuel Gauging:** Voltage-based battery monitoring is unreliable under the variable loads imposed by LTE. The nPM1300's built-in fuel gauge measures voltage, current, and temperature to calculate State of Charge within 2% error. The ESP32-S3 reads this telemetry over I2C.
- **High-Efficiency Voltage Regulation:** Two 200 mA buck regulators and two 50 mA LDOs operate with automatic PWM-to-hysteretic mode transitions for light-load efficiency. The 200 mA output is sufficient for the ESP32-S3 and ES8388, but the SIM7672G's peak transmission bursts exceed it. The modem draws power directly from the nPM1300's unregulated VSYS output (up to 2 A from battery or 1.5 A from USB). The VSYS trace requires heavy buffering with low-ESR ceramic capacitors placed physically close to the modem's power pins.
- **Hardware Watchdog and Ship Mode:** If the ESP32-S3 firmware crashes, the PMIC's hardware watchdog cycles the power rails to force a reboot. Ship Mode draws 370 nA, allowing the modernized 2190 to remain in storage for years without meaningful battery degradation.

Table 6. nPM1300 power-allocation summary

Requirement	nPM1300 Function	Application in the Retrofit
Battery chemistry	Li-ion / Li-poly / LiFePO4 charging	Charges the 3.7 V 18650 Li-ion cell that replaces the vintage NiMH pack
Logic power (3.3 V)	Two 200 mA buck regulators	Supplies the ESP32-S3, monochrome LCD and ES8388 codec
Modem power (high current)	Unregulated VSYS path (up to 2.0 A)	Routes battery current to the SIM7672G and supports short LTE transmission bursts with local low-ESR decoupling
Battery telemetry	Algorithm-based fuel gauge	Provides state-of-charge telemetry to the RTOS over I2C, targeting less than 2% error
Power-state control	Watchdog and 370 nA ship mode	Recovers from firmware lockups and minimizes storage current during long inactive periods

Power-Path Design Rule

Do not route the modem through a 200 mA regulated logic rail. Keep the LTE current path short and wide, place bulk and ceramic decoupling at the module, and verify voltage droop with an oscilloscope during registration and transmit bursts.

8. Graphical User Interface and Firmware Reconstruction

Preserving the 1995 visual aesthetic requires reusing the original monochrome graphic LCD module, governed by its Philips PCD8544 or Epson SED1565 controller. These vintage controllers operate at 3.3 V and connect directly to

ESP32-S3 GPIO pins without logic level shifting. The microcontroller transmits bitmap data to the display controller over SPI.

The firmware does not drive this display with raw low-level drawing code. It uses LVGL (Light and Versatile Graphics Library), an open-source embedded graphics library purpose-built for constrained hardware. LVGL supports monochrome displays natively and provides an object-oriented framework for dynamic screens, modals, scrolling lists, and focus-based navigation. This is critical for a device driven entirely by a mechanical matrix keypad rather than a capacitive touchscreen.

8.1 RTOS Task Segregation and Matrix Multiplexing

A mobile phone is inherently asynchronous. Network events, display refreshes, and keypad debouncing must run concurrently. The ESP32-S3 runs FreeRTOS to manage these obligations.

The 2190's roughly 18 physical keys are interfaced through a diode-multiplexed matrix to conserve GPIO resources. The firmware configures row pins as inputs and sequentially grounds the column pins. When a user presses a key, its conductive carbon pill bridges the corresponding row and column. A high-priority FreeRTOS task polls this matrix continuously. After a non-blocking debounce timer filters electrical noise, the validated keypress value is pushed into a FreeRTOS message queue. A lower-priority LVGL rendering task consumes the queue, navigating the UI or triggering an AT command string to the modem.

Table 7. Recommended firmware task partitioning

Task	Trigger / Cadence	Priority Intent	Key Outputs
Audio bridge	Continuous while a call is active	Real-time / highest	PCM-to-I2S conversion, filtering and gain
Modem event task	URCs and command responses	High	Call, SMS and network state events
Keypad scan	Fast periodic row / column scan	High	Debounced key events
LVGL UI task	Queued events and timed refresh	Medium	Monochrome screens, icons and softkeys
Power monitor	Low-rate I2C polling and interrupts	Low / supervisory	SOC, low-battery policy and watchdog handling

8.2 Reconstructing the DCT-3 Operating System

Authenticity requires more than a working telephone. The interface rendered by LVGL must clone the visual language of the original Nokia operating system, the early iteration of what became the DCT-3 software architecture.

Using vintage service software such as the Rolis DCT3 Flasher and Dejan .fls flash files, developers have extracted raw hexadecimal firmware payloads from original Nokia ROM chips. Custom C-based CLI tools (export-dct3-bitmap and export-dct3-font) parse those decrypted flash files and extract the exact .pbm bitmap assets for every system graphic, icon, and character font present in the original 1990s firmware.

Import these authentic DCT-3 bitmaps and fonts into the LVGL asset pipeline, and the result is a C++ user interface visually indistinguishable from the original 1995 hardware, running entirely on a modern, concurrent ESP32-S3 RTOS. Contemporary projects such as the nokia-dct3-emulator and M17_3310-fw have already ported reconstructed Nokia UI environments to ARM Cortex and RP2350 microcontrollers, confirming that the approach is viable.

9. Fabrication and Prototyping Infrastructure in Metro Vancouver

Converting a digital CAD schematic into a physical device requires fabrication machinery. Final multi-layer PCB manufacturing is typically outsourced to global fabrication houses via Gerber file submission. However, the mechanical integration requires cutting and drilling the legacy chassis, mapping keypad traces, and designing custom internal mounting sleds. This demands hands-on physical prototyping.

The Greater Vancouver and Richmond, British Columbia region provides a local ecosystem of fabrication facilities and electronic suppliers sufficient to support this class of hardware work. Local sourcing eliminates international shipping delays during the iterative design loop.

9.1 Mechanical Fabrication and Digital Manufacturing

The mechanical alignment of the custom PCB inside the 2190 chassis is critical. The vertical spacing between tact switches on the new board and the external rubber membrane must be exact to preserve the tactile click of the original buttons. Custom internal mounting sleds and battery housing brackets must be fabricated to tolerances the ABS shell enforces.

FiiNGO Makerspace (2088 No. 5 Road, Richmond, BC) is a collaborative digital fabrication hub operating seven days a week. Its 3D printing labs allow rapid iteration on physical test brackets using ABS or PETG filaments. Advanced metalworking equipment, including the Inventables Shapeoko 4 XXL CNC Router and King Industrial milling machines, supports precision fabrication of custom aluminum heat sinks if the ESP32-S3 or SIM7672G requires thermal management during sustained LTE transmission.

Richmond Media Lab (Richmond Cultural Centre Annex) and the Richmond Public Library Launchpad (Brighouse branch) provide additional 3D printing and CAD resources for iterative chassis prototyping and low-cost PLA fit checks before committing to higher-end machining.

9.2 Electronic Component Sourcing and PCB Prototyping

Hardware prototyping stalls when a specific discrete component is unavailable. Metro Vancouver mitigates this through local storefronts. Lee's Electronic Components on Fraser Street in Vancouver carries a deep immediate inventory of semiconductors, passives, and electromechanical switches. RP Electronics in Burnaby supplies heavier gauge wiring, specialized interconnects, and industrial power supplies.

Waiting weeks for an overseas fabrication house to deliver a prototype PCB is incompatible with iterative design. A Bantam Tools Desktop PCB Milling Machine handles double-sided FR-1 blanks with 6 mil trace-and-space precision at spindle speeds up to 28,000 RPM, importing Gerber files directly from Fusion 360 and producing a functional prototype board in an afternoon. This localized milling is critical for testing the physical alignment of keypad matrix test points against the 2190's rubber membrane before committing the design to a multi-layer offshore production run.

Table 8. Local fabrication resources and their role in the iteration loop

Resource	Location / Access	Best Use in This Project	Stage
Lee's Electronic Components	Vancouver storefront	Immediate sourcing of passives, connectors, switches and development parts	Early bench work
RP Electronics	Burnaby storefront	Wire, interconnects, power supplies and general electronic hardware	Bench + assembly
Bantam Tools desktop mill	Local lab / owner access	Fast double-sided FR-1 boards for outline and keypad alignment tests	Electrical prototype
FiiNGO Makerspace	Richmond	3D printing, CNC routing and metalworking for sleds, brackets and heat spreaders	Mechanical integration
Richmond Media Lab	Richmond Cultural Centre Annex	CAD and 3D-printing support for iterative enclosure fixtures	Mechanical prototype
RPL Launchpad	Brighouse branch	Low-cost PLA iterations before higher-fidelity fabrication	Early fit checks

9.3 Integration Validation Priorities

Table 9. Pre-release validation plan

Risk / Unknown	Why It Matters	Validation Method	Pass Criterion
LTE burst brownout	A short supply collapse can reset the modem or trap it in a boot loop	Oscilloscope capture at VSYS during registration, call setup and uplink bursts	No reset; rail remains inside module input limits
Antenna detuning	ABS shell, battery and original antenna hardware can alter impedance	VNA / return-loss check followed by network tests in multiple orientations	Stable registration and call performance
PCM / I2S compatibility	Clock polarity, framing or sample-rate mismatch produces silence or distortion	Loopback and live-call tests with logic-analyzer capture	Bidirectional intelligible audio with stable clocks
LCD controller variant	PCD8544 and SED1565 require different initialization and addressing	Identify controller, run full-pixel pattern and map visible aperture	No missing columns, ghosting or clipped UI elements

Keypad mechanics	Incorrect switch height or position destroys original tactile feel	Printed alignment jig, force/travel checks and long-cycle key testing	All keys register consistently without pre-load or double activation
Thermal behavior	Sustained RF and charging loads can heat a sealed enclosure	Instrumented call / data / charge soak at worst-case ambient	Temperatures remain within component and user-contact limits

10. Conclusions

The modernization of the Nokia 2190 is an exercise in embedded systems architecture. It is the complete fusion of 1990s industrial design with contemporary telecommunications protocols, executed at a scale where every millimeter of the original enclosure participates in the constraint set.

The donor motherboard transplant fails on contact with the physical chassis and stays failed. The custom PCB unlocks the volumetric potential of the vintage ABS shell. The ESP32-S3 provides the computational foundation for FreeRTOS scheduling, LVGL rendering, and native USB debugging. The SIMCom SIM7672G LTE Cat 1bis baseband eliminates the dual-antenna routing problem of Cat 4 modules and delivers native global VoLTE in a single-antenna footprint.

The ES8388 preserves acoustic fidelity across the digital-analog boundary. The Nordic nPM1300 consolidates battery management, charging, fuel gauging, and LTE transient buffering into one IC. Fabrication depends on local infrastructure such as FiiNGO's machining tools, Vancouver's component suppliers, and desktop PCB milling.

The Nokia 2190 was built to survive a decade of daily use. The retrofit asks whether it can survive another one, on a network its designers never anticipated.

Decision Summary

The enclosure is large enough to support a modern custom electronics stack, but success depends on disciplined co-design of power, RF, audio, display and keypad mechanics. The custom-board pathway is feasible in principle; the validation plan in Section 9.3 determines whether the integrated prototype is production-worthy.

- End of Report -