White Paper

VIAVI Solutions

OTA PHY Performance Characterization of a Massive MIMO O-RU Using VIAVI's PHY Performance Mode

Deterministic. Repeatable mMIMO O-RU Validation at Full Scale

PHY PERFORMANCE CHARACTERIZATION IN OVER-THE-AIR (OTA)

VIAVI PHY Performance Mode

VIAVI's PHY Performance Mode is a test capability within the VIAVI O-RU Tester that characterizes the physical layer RF performance of an O-RU without requiring a live protocol stack above the PHY layer.

How It Works

Pre-generated IQ vectors — referred to as tvg (test vector generator) files — are synthesized offline. Each vector encodes a specific test waveform, fully defined by MCS, DL and UL Configuration, code rate, number of spatial layers, bandwidth, subcarrier spacing, DMRS configuration, MIMO mode and beam IDs. These parameters are locked at vector generation time, making every test run bit-identical and fully reproducible.

The VIAVI O-RU Tester (DU Emulator) replays these vectors continuously over a standard eCPRI/O-RAN 7.2x LLS-C1/C3 fronthaul interface, fully respecting all timing windows as specified by O-RAN Alliance WG4. From the O-RU's perspective, the incoming traffic is indistinguishable from a compliant DU transmission — correctly formed eCPRI U-plane and C-plane messages, on-time delivery, correct eAxC IDs and beam IDs. The O-RU processes the received IQ data through its complete transmit chain: fronthaul receive -> IFFT -> DAC -> PA -> antenna radiation. On the receive side, a VIAVI TM500 test mobile operating in PDCP Mode receives the radiated signal and measures throughput and BLER .

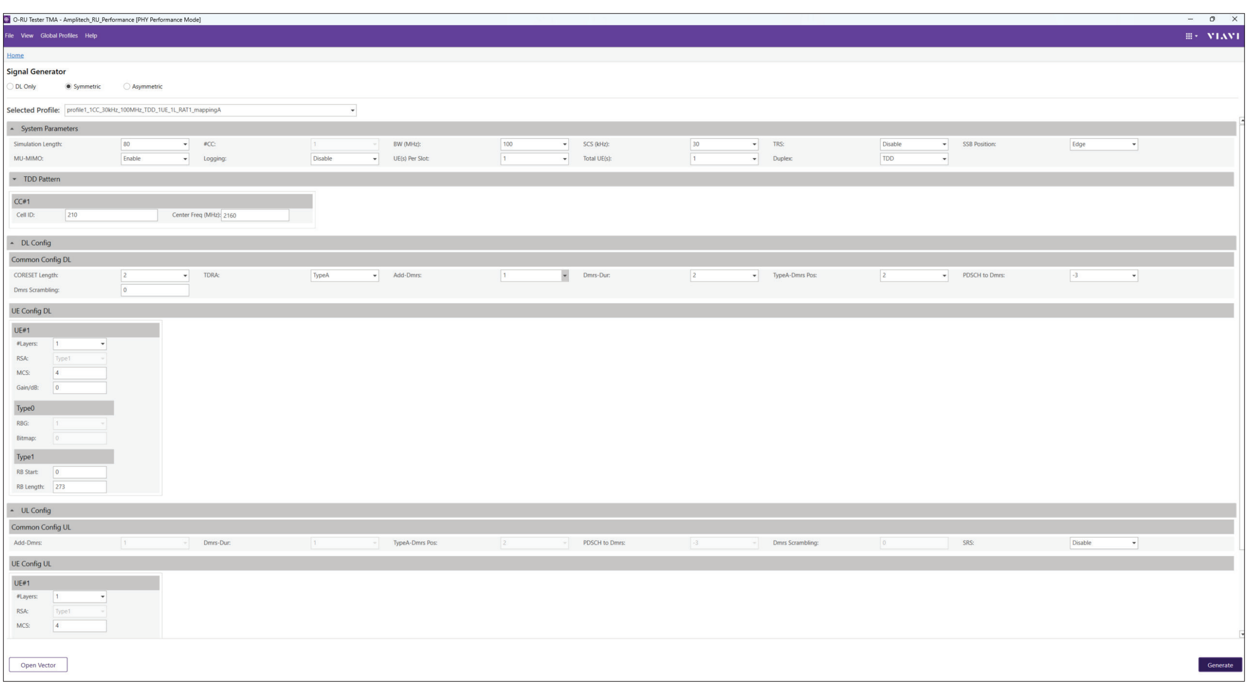


Figure 1. VIAVI'S O-RU TESTER PHY Performance Mode Signal Generation UI

What PHY Performance Mode Bypasses

PHY Performance Mode bypasses the 5G protocol stack above the PHY layer. The AMF, RRC, PRACH, and random-access procedure are all absent — TM500 never attaches to anything. Normal 5G bring-up requires a live MAC scheduler, RRC layer, and 5G Core to drive the full sequence: PRACH -> Random Access -> RRC Setup -> NAS Registration -> PDU Session -> data. None of those exist here. The VIAVI O-RU Tester injects pre-generated High-PHY IQ vectors over eCPRI — there is no DCI scheduling, no RRC signaling, no core network behind it. TM500 is pre-configured before the test with a fixed C-RNTI and a fixed PDSCH allocation — PRBs, MCS, layers, and DMRS config all locked in — and skips straight to PDSCH decoding.

This is by design: PHY Performance Mode tests pure RF and PHY layer behavior — beam quality, fronthaul timing integrity, EVM, and OTA link budget — under deterministic, fully controlled conditions. It does not test registration latency, mobility, or core connectivity. Full protocol testing is a separate test dimension.

Key Advantages

- Deterministic: identical vector replayed every run — results are fully reproducible across sessions, labs, and units
- Controlled: exact MCS, layer count, compression, and beam configuration specified at vector generation time
- MIMO Ready: Capable of validating SuMIMO and MuMIMO Configurations
- Full-scale: exercises the complete 32T32R/64T64R mMIMO fronthaul at production data rates
- OTA-ready: characterizes the O-RU's complete transmit chain including the antenna radiation path

Test Setup and Equipment

Test Topology

The test topology connects four elements via a 25GbE eCPRI fronthaul switch: the VIAVI O-RU Tester acting as the DU simulator, the 64T64R Massive MIMO O-RU, the VIAVI MTS-5800 providing PTP grandmaster timing, and the VIAVI TM500 test mobile receiving the radiated signal via four RF inputs in the anechoic chamber.

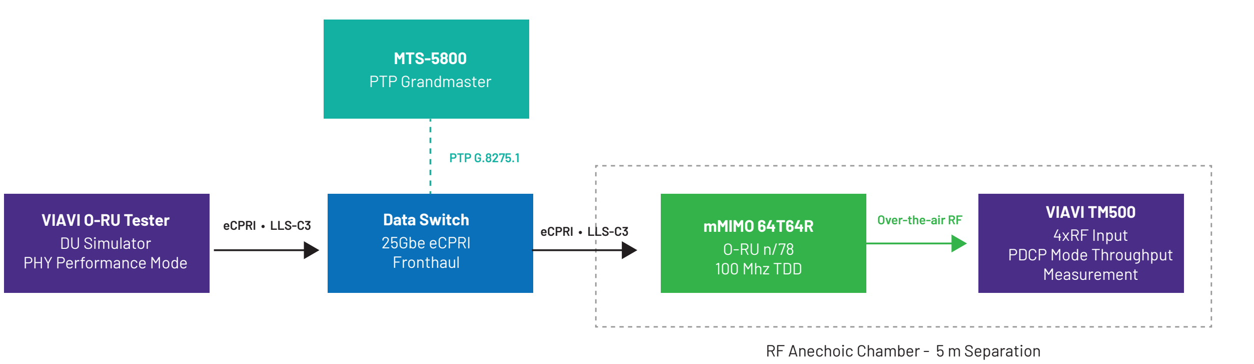


Figure 2. PHY Performance Mode test topology: VIAVI O-RU Tester (DU Simulator) -> Switch -> 64T64R Massive MIMO O-RU -> over-the-air -> VIAVI TM500. VIAVI MTS-5800 provides PTP grandmaster timing (G.8275.1, Domain 24).

Equipment

Equipment	Role	Specification
VIAVI O-RU Tester	DU Simulator/PHY Performance Mode	Pre-gen IQ vector injection, eCPRI O-RAN 7.2x LLS-C3
64T64R Massive MIMO O-RU	O-RU under test	64T64R, n78, 100 MHz TDD, Category B beamforming
VIAVI TM500	Test Mobile	4 RF inputs, PDCP mode throughput measurement
VIAVI MTS-5800	Timing Reference	PTP grandmaster, G.8275.1, Domain 24, FORWARDABLE
25GbE Ethernet Switch	Fronthaul transport	eCPRI LLS-C3 switching
RF Anechoic Chamber	OTA test environment	5m RU-to-receive-antenna separation

Test Configuration (Validated in Lab)

Parameter	Value
Frequency Band	n78/3.5 GHz
Channel Bandwidth	100 MHz
Subcarrier Spacing	30 kHz
Number of PRBs	273
Duplexing	TDD (5 ms periodicity)
Fronthaul Compression	9-bit STATIC
Spatial Layers	4
Beamforming	Category B Static predefined, Beam IDs 1, 3, 5, 7
Active Antenna Ports	16 (4 beams x 4 ports each, interleaved)
PTP Profile	G.8275.1, Domain 24, FORWARDABLE multicast
OTA Separation	5 m

O-RU Validation

Prior to PHY Performance Mode characterization, the O-RU under test was validated against O-RAN WG4 conformance test cases to confirm fronthaul timing integrity and RF modulation quality.

Fronthaul Timing Conformance

Downlink timing conformance (test case 3.2.5.2.1) was executed with the O-RU Tester driving U-Plane and C-Plane traffic. Results confirmed zero timing violations across the measurement window – all RX_ONTIME packets with zero LATE, EARLY, CORRUPT, or DUPLICATE events. Uplink conformance was validated with a two-port active configuration, confirming correct UL fronthaul timing in both directions.

3GPP RF Conformance Validation

The O-RU was also validated against key 3GPP TS 38.141 conducted base station RF requirements. Base station output power, EVM across all modulation orders (QPSK through 256QAM), and ACLR were measured and confirmed compliant. These results establish that the O-RU's RF transmit chain meets 3GPP NR requirements independently of the O-RAN fronthaul layer.

256QAM EVM Validation

The O-RU demonstrated clean 256QAM modulation quality prior to performance testing. Downlink measurement results, captured on an R&S VSE signal analyzer, confirmed the O-RU's RF transmit chain meets 5G NR EVM requirements at the highest modulation order. A tight, well-formed constellation with low EVM confirms the O-RU's RF path is operating correctly before multi-layer performance characterization begins.

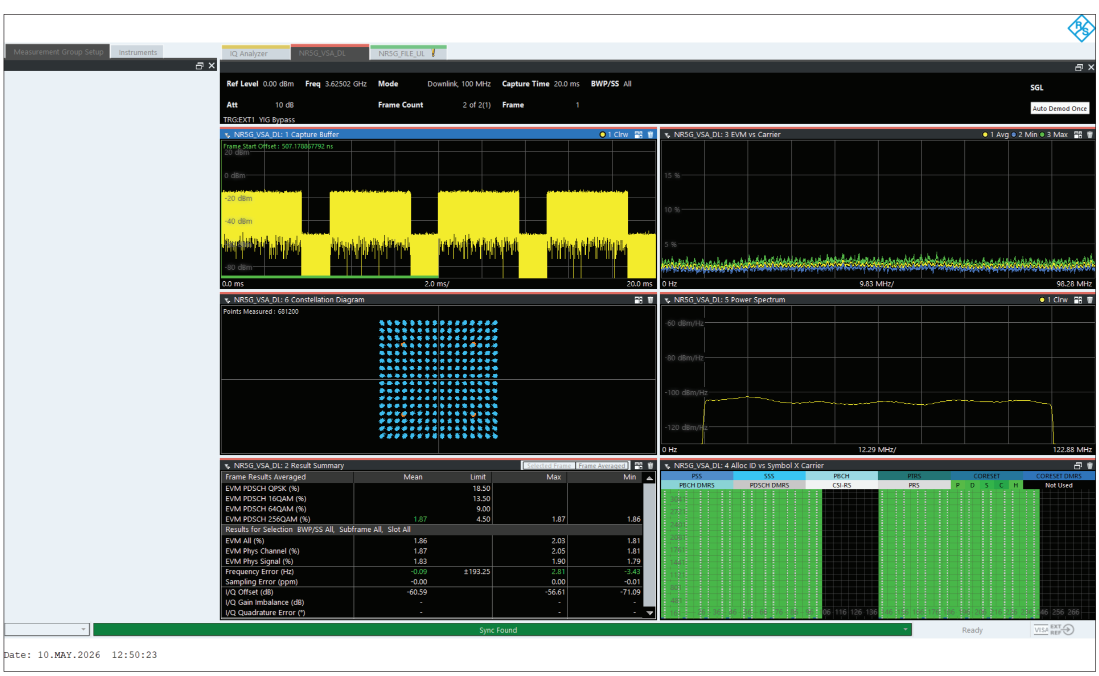


Figure 3. R&S VSE downlink measurement results: 256QAM constellation diagram and EVM summary on the O-RU under test, confirming clean RF modulation quality prior to PHY Performance Mode characterization.

The constellation diagram shows a tight, well-formed 256QAM pattern with clearly separated amplitude levels and minimal phase noise. The EVM result confirms the O-RU's transmit chain is operating well within the 3GPP requirements for 256QAM. Low EVM at the highest modulation order is a strong indicator of PA linearity, DAC precision, and fronthaul IQ fidelity — all critical prerequisites before advancing to multi-layer spatial multiplexing characterization.

Beam Configuration

The O-RU under test operates as a CAT-B O-RU — beamforming is performed internally using beam weight tables stored in the RFSoC fabric. The O-RU Tester sends a beam ID in the eCPRI C-plane message; the O-RU applies the corresponding pre-stored weights to map the fronthaul IQ streams onto physical antenna ports.

For the four-layer spatial multiplexing test, four beam IDs were configured with non-overlapping, spatially separated port assignments across the first RFSoC (ports 0-15). Each beam activates four antenna ports in an interleaved pattern, ensuring spatial decorrelation between layers:

Beam ID	Active Ports	Pattern	Layer
1	3, 7, 11, 15	Every 4th port from port 3	Layer 1
3	2, 6, 10, 14	Every 4th port from port 2	Layer 2
5	1, 5, 9, 13	Every 4th port from port 1	Layer 3
7	0, 4, 8, 12	Every 4th port from port 0	Layer 4

The interleaved configuration distributes each beam’s active ports across the full 16-port span, providing spatial decorrelation between layers. The VIAVI O-RU Tester references beam IDs in the C-plane only; all weight tables reside entirely within the O-RU.

Performance Results

Fronthaul Compression

Two compression configurations were evaluated. With 16-bit STATIC (uncompressed) IQ, the O-RU produced a clean single-dot constellation per layer. With 9-bit STATIC compression, same clean constellation has been seen. DL EVM passed at both bitwidths. All throughput results use 9-bit STATIC compression, representative of a realistic deployed fronthaul configuration.

Conducted Baseline

A conducted MCS sweep with four active layers established the baseline throughput ceiling prior to OTA testing.

MCS	Modulation	Peak Throughput	BLER	Result
4	QPSK	192 Mbps	0	Pass
12	16QAM	410 Mbps	0	Pass
18	64QAM	780 Mbps	0.006	Pass
22	256QAM	950 Mbps	0.0005	Pass
25	256QAM	1120 Mbps	<0.01	Pass
27	256QAM	~1200 Mbps	<0.07	Pass

Conducted peak throughput: 1200 Mbps at MCS 27, 4-layer, 100 MHz, n78 band.

Over-the-air (OTA) Results - Anechoic Chamber

With the O-RU mounted on the chamber RF pole and four receiver antennas positioned at 5m separation — providing four independent receive paths to the TM500 — the OTA characterization confirmed peak downlink throughput exceeding 1 Gbps at MCS 25 with four active spatial layers.

The OTA result validates the complete end-to-end path: eCPRI fronthaul -> O-RU internal processing -> 64T64R antenna array -> over-the-air propagation -> TM500 PDCP mode decode. All four spatial layers were decoded simultaneously with clean BLER performance, confirming sufficient spatial separation for rank-4 operation.

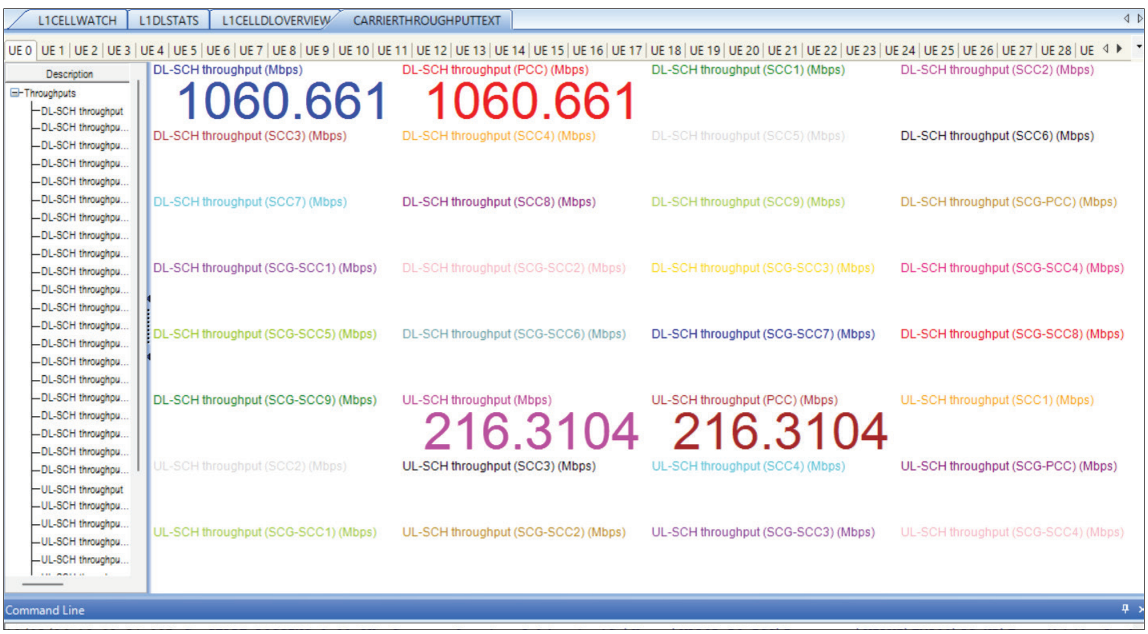
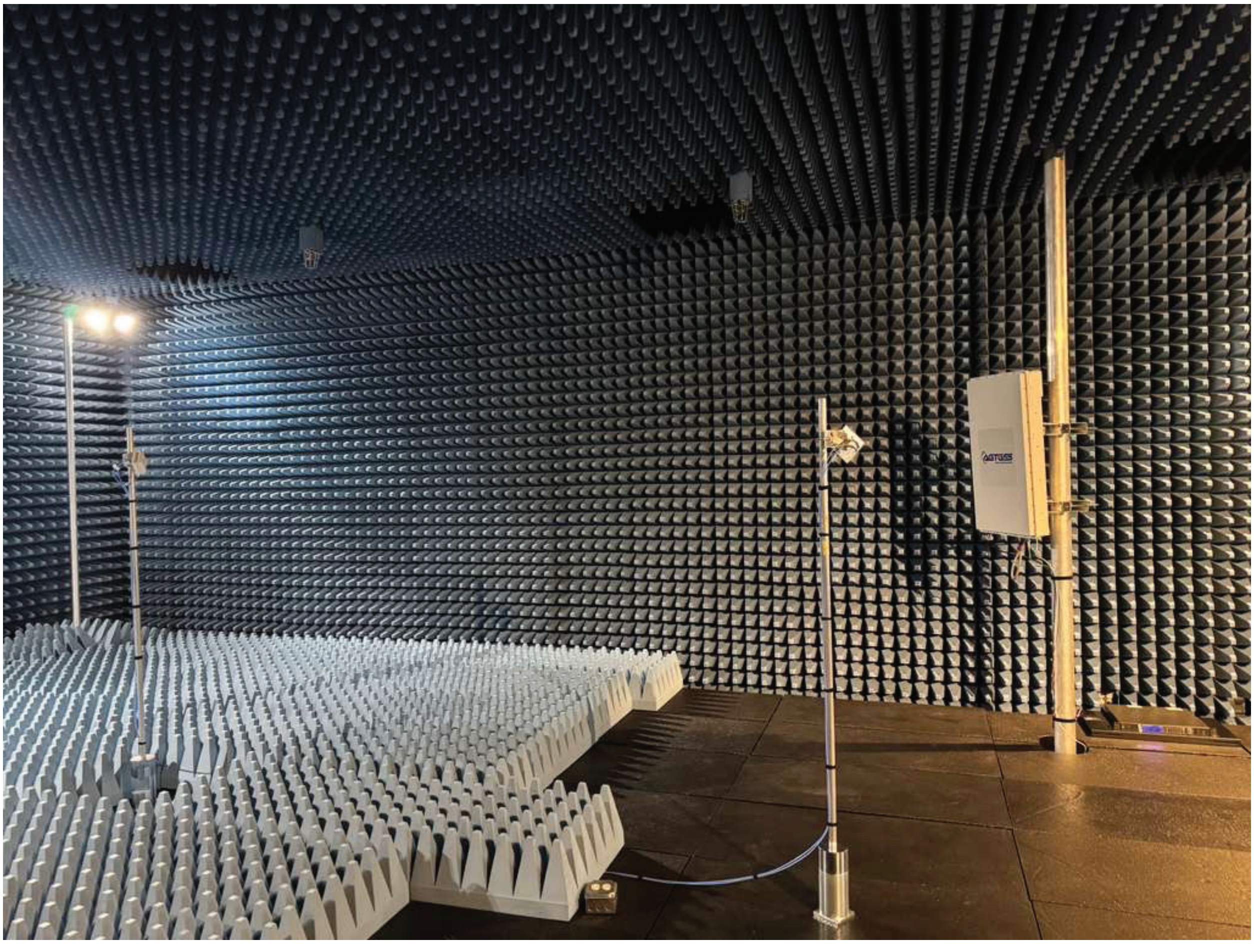


Figure 4. VIAVI O-RU Tester PHY Performance Mode OTA result: 1060 Mbps downlink throughput, 4-layer spatial multiplexing, MCS 25, 100 MHz TDD, n78 band (3.5 GHz). Measured at VIAVI TM500 PDCP mode in RF anechoic chamber.

The TM500 measurement confirms a downlink SCH throughput of 1060.661 Mbps across four spatial layers at MCS 25, 100 MHz TDD, n78 band. The result was sustained with clean BLER, confirming stable rank-4 spatial multiplexing over the air in the anechoic chamber environment.

OTA Test Environment



The VALOR LAB RF Anechoic Chamber provides a controlled, reflection-free environment that eliminates multipath and external interference, isolating the O-RU's intrinsic OTA performance. The 64T64R O-RU was mounted on the chamber RF pole at a fixed height, with two dual-port receive antennas positioned at 5 m separation to provide four independent spatial receive paths to the TM500. The antenna spacing was optimized during testing to maximize spatial decorrelation between the four receive streams, a critical factor for stable rank-4 MIMO decoding.

Conclusion

This white paper has demonstrated PHY performance characterization in Over-the-Air environment with a 64T64R massive MIMO O-RU using VIAVI's PHY Performance Mode. The following results were achieved:

- Peak OTA downlink throughput exceeding 1 Gbps (1060 Mbps) at MCS 25, 4-layer spatial multiplexing, 100 MHz TDD, n78 band
- Clean 256QAM EVM confirmed on the O-RU prior to performance characterization
- O-RAN WG4 fronthaul timing conformance validated: zero timing violations on DL and UL
- 9-bit STATIC IQ compression with no degradation in peak throughput
- Category B predefined beamforming with spatially separated 16-port beam weights enabling rank-4 spatial multiplexing over the air

VIAVI's PHY Performance Mode provides a deterministic, repeatable methodology for characterizing mMIMO O-RUs at full 64T64R scale — over the air, with complete control over every PHY layer parameter. As industry moves toward large-scale deployment of massive MIMO radios, the ability to validate O-RU RF performance with precision and repeatability is critical. VIAVI is uniquely positioned to deliver this capability.

References

[1] O-RAN Alliance, "O-RAN Fronthaul Working Group, Control, User and Synchronization Plane Specification," O-RAN.WG4.CUS.0-v13.00, 2024

[2] O-RAN Alliance, "O-RAN WG4 Conformance Test Specification," O-RAN.WG4.CONF.0-v10.00, 2024

[3] 3GPP TS 38.214, "NR; Physical layer procedures for data," Release 17

[4] 3GPP TS 38.141-1, "NR; Base Station Conducted Testing," Release 17

[5] Claude/AI Model use for document creation

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