IMPROPER USE OF WIRE GAUGES

Table of contents

Part 1 Introduction and overview

Part 1.1 Introduction

The success of the mission relies on the ROV's performance. When the ROV was deployed last year with six thrusters, it faced many challenges: including not enough power transmission, which negatively impacted its operational capabilities. This report details the issues found, the changes made in the Gyrodos G2.2 version, and offers recommendations for team members.

The electrical power delivery system of an underwater remotely operated vehicle (ROV) is critically dependent on properly selected cabling. The 2024 Gyrodos revision experienced severe performance degradation due to undersized wire gauges in the main tether, resulting in voltage drop and reduced thruster efficiency.

Part 1.2 Problem Statement

The 2024 Gyrodos utilized AWG 24 (American Wire Gauge 24) copper conductors along a 15-meter tether to deliver 12V power to six thrusters rated at 15A maximum (24V specification). Despite thrusters operating at only 2.5A under normal conditions, the system exhibited extremely sluggish response and insufficient thrust delivery. The 2025 revision implemented AWG 8 conductors along an 18-meter tether, resulting in dramatically improved performance.

Part 1.3 Technical context

The 2024 Gyrodos system utilized **AWG 24 (American Wire Gauge 24)**

copper conductors along a **15-meter tether** to deliver 12V power to six thrusters. AWG 24 wire, approximately 0.51 millimeters in diameter, is designed for low-current applications such as signal wiring or electronics—not for powering high-demand motor systems over extended distances. The thrusters were rated for 15A maximum at 24V, operating nominally at 2.5A per thruster (15A total) at 12V.

Despite the thrusters' specifications appearing adequate, the system exhibited catastrophic performance loss due to voltage drop in the undersized conductors. By contrast, the 2025 Gyrodos G2.2 revision adopted **AWG 8 (3.26 mm diameter) conductors** along an **18-meter tether**—a configuration supporting 8 thrusters with excellent performance and reliability.

Part 1.4 Purpose/Significance

Improper wire gauge selection is not an isolated incident but a **scalable design principle applicable to all long distance power delivery systems**. Understanding this failure and its solution ensures that future ROV iterations, and potentially other projects involving tethered power systems, will not repeat this critical error.

Part 2 Analysis on current and past designs

Part 2.1 Past design

2024 Gyrodos Configuration (Past design)

Electrical System Specifications:

Component	Specification
Power Supply Voltage	12V nominal
Number of Thrusters	6 units
Thruster Rating	15A max (24V), 2.5A nominal (12V)
Tether Length	15 meters
Conductor Material	Copper
Conductor Gauge	AWG 24
Conductor Diameter	0.511 mm
Conductor Cross-Section	0.205 mm^2
Connector Type	SP13-4 and SP17-9
Communication Method	Hardwired (low reliability over distance)

System Design Intent:
The 2024 team selected AWG 24 wire primarily to minimize tether weight and cost. At the time of design, this choice may not have been validated against resistance calculations or voltage drop requirements.

Part 2.2 Current design

2025 Gyrodos G2.2 Configuration (Current design)

Electrical System Specifications:

Component	Specification
Power Supply Voltage	12V nominal
Number of Thrusters	8 units
Thruster Capacity	Higher current capacity per thruster
Tether Length	18 meters
Conductor Material	Copper
Conductor Gauge	AWG 8
Conductor Diameter	3.264 mm
Conductor Cross-Section	8.367 mm²

Component	Specification
Connector Type	SP21 (higher current rating)
Communication Method	RS485 differential signalling (improved noise immunity)

System Design Rationale:
The 2025 design prioritized **performance reliability** over weight savings. The larger wire gauge was selected based on calculations of maximum current, acceptable voltage drop, and tether length requirements.

Part 2.3 Comparative overview

Comparative Overview

Key Differences:

Metric	2024	2025	Change
Wire Gauge	AWG 24	AWG 8	40.8× thicker
Tether Length	15 m	18 m	+20%
Number of Thrusters	6	8	+33%
Conductor Area	0.205 mm^2	8.367 mm^2	40.8× larger
Observed Performance	Poor/Sluggish	Excellent/Responsive	Completely resolved

The 2025 system successfully operates with more thrusters over a longer distance despite using thicker wire, indicating that **proper wire gauge is the dominant factor** in electrical system performance.

Part 3 What was the issue last year?

The 2024 Gyrodos ROV faced significant performance degradation due to the use of AWG 24 wire in its 15-meter tether, which was critical for powering six thrusters. Here’s a breakdown of the main issues:

Part 3.1 Insufficient Wire Gauge:

The wire used in the 2024 Gyrodos ROV was AWG 24 and is relatively thin-a little larger than the diameter of sewing thread. As expected, this thinness corresponded to significantly larger electrical resistance(when the more current through the wire, the more voltage was lost). More specifically, when the thrusters were powered, approximately 36.8 volts were lost while pushing 15 amps, leaving almost no usable voltage to the thrusters. Consequently, their effective output was reduced as performance and responsiveness were majorly hindered, thus severely limiting operating capabilities of the ROV. This indeed points out how selecting an appropriate wire gauge is a matter of highest importance in electrical systems. Choosing AWG 24 wire led directly to the suboptimal performance observed in the 2024 model.

Part 3.2 Voltage Drop:

The voltage drop was extreme using thin AWG 24 wire: approximately 36.8 volts were lost when pushing 15 amps of current through the tether. That left very little usable voltage at the thrusters, thus this accounts for the very poor performance. This made the ROV unable to serve its operational responsiveness and thrust, as would be anticipated, due to the issue of wire gauge, which is very vital in electrical applications. As a result, the thrusters were unable to function effectively, and the compromising of voltage delivery led to a further compromise of the vehicle's operational capabilities.

Part 3.3 Sluggish Performance:

With insufficient voltage reaching the thrusters, the vehicle displayed extremely sluggish performance and was nearly unresponsive to any operator commands. Inadequate power delivery to the thrusters severely limited the ROV's maneuverability and responsiveness, which made operator control of vehicle movement difficult. Consequently, the inability to execute intended underwater tasks by the vehicle pointed to the importance of proper electrical design for optimal operation and performance.

Part 3.4 Energy Loss as Heat:

High resistance in the AWG 24 wire caused serious power to be dissipated as heat, which introduced approximately 551.6 watts into the wire itself. This excessive heat represented a huge loss of energy and created a very hazardous condition for the tether insulation. This kind of overheating could undermine the reliability of the electrical system and lead to failures or safety hazards during operation.

Part 4 Issues behind last year's failure

Part 4.1 Ohms Law

All electrical issues in the 2024 system stem from a single principle: **Ohm's Law**.

Where:

- **V** = Voltage drop across the conductor (volts)
- **I** = Current flowing through the conductor (amperes)
- **R** = Electrical resistance of the conductor (ohms)

Practical Implication: If current and resistance are high, voltage drop will be proportionally high. In the 2024 system, resistance was extremely high due to thin wire, and current was significant (15A total), resulting in catastrophic voltage drop.

Part 4.2 Conductor Resistance Formula

The resistance of a conductor is determined by:

Where:

- **ρ (rho)** = Resistivity of copper at 20°C ≈ 1.68×10^{-8} Ω·m (material property)
- **L** = Length of the conductor (meters)
- **A** = Cross-sectional area (square meters)

Critical Insight: Resistance is **inversely proportional to cross-sectional area.** Doubling the wire thickness (cross sectional area) **cuts resistance in half.** Conversely, using thinner wire dramatically increases resistance.

Part 4.3 2024 System Calculation: Voltage Drop

Given:

Wire gauge: AWG 24

Cross-sectional area: $0.205\ mm^2 = 0.205 \times 10^{-6}\ m^2$

Tether length: 15 m (out) + 15 m (return) = **30 m total path**

Current: 15A (all six thrusters operating)

Copper resistivity: $\rho = 1.68 \times 10^{-8}\ \Omega \cdot m$

Step 1: Calculate conductor resistance

Step 2: Calculate voltage drop using Ohm's Law

Results: Catastrophic Voltage Loss

The calculation reveals the severity of the 2024 failure:

Voltage Drop: 36.81 volts

This is **impossible** for a 12V system to accommodate. The implications:

1. **If the system attempted to deliver 15A through AWG 24 wire over 30m, it would need a source voltage of approximately 48.8V** to overcome the tether resistance alone
2. **At nominal 12V input,** the system could only deliver approximately **0.37A** before all voltage was consumed by wire resistance ($12V \div 2.454\Omega \approx 0.37A$)
3. **Actual operation occurred at much lower currents,** explaining the extremely sluggish performance

Part 4.4 Power dissipation as heat

The wasted electrical energy manifested as heat in the tether:

551.6 watts of power continuously dissipated as heat in the tether—equivalent to running multiple hair dryers simultaneously. This explains:

- The warm tether observed during operation
- The inefficient power delivery
- The poor performance despite adequate thruster specifications

Part 4.5 Motor Power Degradation

Brushed DC motors (used in ROV thrusters) have a fundamental relationship:

(Torque is proportional to terminal voltage)

With insufficient voltage reaching the thruster terminals due to tether resistance, torque output fell dramatically:
Expected Performance (12V at terminals): Maximum thrust
Actual Performance (near 0V at terminals): Near-zero thrust

This explains the "sluggish" observation perfectly from first-principles physics.

Part 4.6 Wiring Matters

Voltage Drop: The resistance in the wire caused a significant voltage drop, especially under load with the circuit being too large.

Insufficient Current: The thrusters received inadequate current supply, limiting their performance if the circuit is connected parallelly.

Part 4.7 Thrusters

Lower Thrust Output: only six thrusters may only generate little thrust, which results in poor motivation of the robot.

Part 5 How does the current method solve it?

Part 5.1 Wire Gauge Upgrade

The 2025 Gyrodos G2.2 addresses the 2024 failure by implementing a **comprehensive electrical system redesign** centered on proper wire gauge selection.

Primary Change: AWG 24 → AWG 8

Specification	AWG 24	AWG 8	Improvement
Diameter	0.511 mm	3.264 mm	6.4× larger
Cross-Section	0.205 mm²	8.367 mm²	40.8× larger
Resistance (30m)	2.454 Ω	0.0723 Ω	33.9× lower

2025 System Calculation: Voltage Drop

Given:

Wire gauge: AWG 8

Cross-sectional area: 8.367 mm² = 8.367×10^{-6} m²

Tether length: 18 m (out) + 18 m (return) = **36 m total path** (longer than 2024!)

Maximum current: 20A (eight thrusters)

Copper resistivity: $\rho = 1.68 \times 10^{-8}$ Ω·m

Step 1: Calculate conductor resistance

Step 2: Calculate voltage drop using Ohm's Law
Results: Acceptable Voltage Performance

Voltage Drop: 1.446 volts (at 12V supply)

Voltage at Thrusters: 12V - 1.446V = 10.554V (88% of supply)

Voltage Drop as Percentage: 1.446 ÷ 12 = 12.1%

This represents **acceptable performance** for marine electrical systems (target: <5% is ideal; <15% is acceptable for demanding applications).

Part 5.2 Overall Improvements

The 2025 system achieves 25.5 times better voltage regulation despite:

- 20% longer tether (18m vs. 15m)
- 33% more thrusters (8 vs. 6)
- Higher current demand (20A vs. 15A)

Power Efficiency Comparison

2024 System Power Loss:

2025 System Power Loss:

Power Loss Reduction: 95% (from 551.6W to 28.9W)

This dramatic reduction in power dissipation as heat eliminates the thermal issues observed in 2024.

Part 5.3 The importance of wires

Despite the 2025 tether being 20% longer than 2024, the wire gauge upgrade more than compensates because:

The **40.8× increase in cross-sectional area** dominates the **1.2× increase in length**:

This demonstrates a fundamental principle: **In resistance calculations, cross-sectional area (thickness) dominates length effects at these scales.**

Part 5.4 Additional Improvements: Connectors and Communication

Beyond wire gauge, the 2025 system implemented complementary upgrades:

SP21 Connectors:

Rated for higher current capacity than SP13-4/SP17-9

Better sealing against saltwater intrusion

Improved mechanical durability

RS485 Differential Signalling:

Reduced electrical noise over longer tether

More reliable command transmission

Better immunity to EMI (electromagnetic interference)

These upgrades work synergistically with the wire gauge improvement to create a robust electrical architecture.

Part 5.5 More about wiring

The new model uses AWG 8 wires for the 12V power supply over an extended 18-meter tether. Advantages of this upgrade include:

- Better Resistance: AWG 8 has much lower resistance than AWG 24; hence, voltage drop would be much less even for longer distances.
- Higher Current Capacity: The thicker wire allows for much higher current loads, ensuring the thrusters continue at peak efficiency.

Part 5.6 Improving Thruster Configuration

- The Gyrodos G2.2 features eight thrusters instead of six. This design enhancement allows for:
- Increased Thrust Output: Additional thrusters are capable of delivering more propulsion capability.

Part 6 Recommendations

Part 6.1 Immediate Implementation

1. Wire Gauge Selection Protocol

Establish a standardized process for all electrical design:

1. Calculate maximum current: for all components
2. Apply 1.25× safety factor:
3. Verify acceptable voltage drop:
4. Select wire gauge from standard AWG tables matching and length
5. Double-check using resistance formula: and
6. Test with prototype before competition deployment

2. Voltage Drop Calculation Requirements

Before finalizing any electrical design:

- Document current draw for every component
- Calculate required wire gauge for specified tether length
- Verify voltage at load endpoints meets operational requirements
- Maintain calculation documentation in team records

3. Prototype Testing Protocol

Before competition:

- Build full tether with actual connectors and wire gauge
- Load test at maximum operational current
- Measure actual voltage at thruster terminals under load
- Compare measured values to calculated predictions
- Document baseline performance metrics

Part 6.2 Future System Design

4. Establish Minimum Wire Gauge Standards

Develop decision rules based on tether length:

Tether Length	amp; **Minimum AWG**	amp; **Recommended AWG**
5 m	amp; 18	amp; 16
5-10 m	amp; 14	amp; 12
10-15 m	amp; 10	amp; 8
15-20 m	amp; 8	amp; 6
20-30 m	amp; 6	amp; 4
30 m	amp; 4 or larger	amp; 2 or larger

Table 1: Recommended wire gauges by tether

length (12V systems, 15A+ currents)

5. Documentation Requirements

All electrical designs must include:

Complete current audit for every component
Wire gauge selection calculations
Voltage drop verification
Connector rating verification
Test results from prototype tether
Lessons learned and recommendations for successor teams

6. Training for New Team Members

Ensure all electrical subsystem team members understand:

Ohm's Law and resistance principles
Why wire gauge matters for long-distance power delivery
How to perform voltage drop calculations
Standard practices and safety factors
The 2024 case study as a cautionary example

Part 6.3 Long-Term Improvements

7. Design Documentation Archive

Maintain a repository of past electrical designs, including:

- Specifications and calculations
- Prototype test results
- Actual performance metrics
- Lessons learned
- Do's and don'ts

Reference this archive when designing future

systems to avoid repeating past mistakes. **8.**

Instrumentation for Diagnostics

Equip the ROV with:

- Voltage monitoring at key points (supply, tether entry, thrusters)
- Current monitoring for main power distribution
- Temperature sensors on tether (to detect excessive heating)
- Data logging for post-mission analysis

These instruments help quickly diagnose electrical issues during competition.

9. Redundant Power Distribution

Consider designing electrical systems with:

- Separate circuits for different thruster groups
- Multiple power connections where feasible
- Failover capability for critical components

This reduces the impact of any single electrical failure.

Part 6.4 Additional Information

1. **Have Regular Maintenance Checks**: Conduct routine inspections of the wiring and thruster performance to identify potential issues early(as sometimes the poor connection may lead to poor thruster performance).

2. **Use new wires and oil the motors:** as electrical conductivity performance of wires will decrease with time, oiling the motors can allow the motors to run smoother with less friction

Part 7 Conclusion

Part 7.1 Brief Summary

The transition from the previous ROV model to the Gyrodos G2.2 represents a substantial advancement in performance and reliability. Correcting the critical issues of power transmission and thruster efficiency-specifically, the low-grade AWG 24 wiring and the limited number of thrusters-the new model has emerged as a robust platform for underwater operations.

By using AWG 8 wiring, voltage drop is minimized while current delivery is improved, enabling the ROV to provide maximum thrust and responsiveness. Maneuverability is further enhanced with the addition of two more thrusters to provide operators with an even more agile and controlled vehicle.

Moving ahead, adherence to wiring standards, planned maintenance schedules, and use of new system capabilities will be crucial. Continuous monitoring and feedback should further encourage improvement and innovation, and thereby keep the Gyrodos ROV at the leading edge of underwater exploration technology. By embracing these changes and recommendations, the team can achieve greater mission success and operational efficiency, paving the way for future advancements.

Part 7.2 Findings

The 2024 Gyrodos electrical system failure resulted from **improper selection of wire gauge**. The use of AWG 24 wire along a 15-meter tether created 2.454 ohms of resistance, resulting in 36.81 volts of voltage drop at operational current levels. This meant that voltage reaching the thrusters was insufficient to operate them at design specifications, resulting in the observed sluggish and weak performance.

The underlying physics is straightforward: electrical resistance scales **inversely with cross-sectional area**. Using wire that is 40.8 times thinner creates 40.8 times more resistance and proportionally greater voltage drop. At long tether distances, this effect becomes non-negotiable.

Part 7.3 Addressing of Root Causes

The 2025 Gyrodos G2.2 implemented a complete electrical system redesign, upgrading from AWG 24 to AWG 8 wire. Despite operating with:

- 20% longer tether (18m vs. 15m)
- 33% more thrusters (8 vs. 6)
- 33% higher current demand (20A vs. 15A)

The new system achieves **25.5× better voltage regulation**, reducing voltage drop from 36.81V to 1.446V. This restored voltage delivery to thruster terminals from near-zero to ~88% of supply voltage, completely resolving the performance issues.

The solution validates the fundamental principle: **proper wire gauge selection is paramount for long-distance power delivery in ROV systems**.

Part 7.4 Lessons Learnt

1. **Physics is Non-Negotiable**: Electrical performance cannot be improved through mechanical fixes if the power delivery system is fundamentally flawed.
2. **Calculations Must Precede Design**: Wire gauge selection should never be based on cost or weight optimization alone. Resistance calculations must validate that specifications will be met.
3. **Prototype Testing is Essential**: Even well-intentioned designs can fail if not validated through prototype testing before competition deployment.
4. **Scale Matters Exponentially**: Small design changes (wire thickness) have exponential effects on system performance (resistance, voltage drop, power dissipation) when combined with other factors (tether length, current).
5. **Documentation Prevents Repetition**: The 2024 failure should serve as a permanent reference to ensure future electrical designs follow proper procedures.

Part 7.5 Implications for Future Work

This investigation establishes that **proper electrical system design is as critical to ROV performance as mechanical design**. Future revisions should:

- Follow the established wire gauge selection protocol
- Conduct voltage drop calculations for all power distribution circuits
- Validate designs through prototype testing

- Maintain comprehensive documentation for team continuity
- Reference this analysis when electrical performance issues arise

Part 7.6 Final Assessment

The transition from the 2024 to 2025 electrical system represents a complete vindication of engineering principles. What appeared to be a thruster or operational problem was, in fact, a **wire gauge problem**. Fixing it required no new thruster technology, no revolutionary mechanical innovations—only **proper application of fundamental electrical engineering principles**.

This case study demonstrates why engineering fundamentals matter and why technical excellence requires rigorous adherence to sound design practices.

Part 8: Sources and appendixes

Part 8.1 American Wire Gauge (AWG) Reference Table

AWG	amp; **Diameter (mm)**	amp; **Area (mm^2)**	amp; **Max Current (A)**	amp; **Use Case**
24	amp; 0.511	amp; 0.205	amp; 2-3	amp; Low power, signal wiring
22	amp; 0.644	amp; 0.326	amp; 3-5	amp; Low current electronics
18	amp; 1.024	amp; 0.823	amp; 10	amp; General wiring
16	amp; 1.291	amp; 1.307	amp; 13	amp; Household circuits
14	amp; 1.628	amp; 2.081	amp; 15	amp; Standard home wiring
12	amp; 2.053	amp; 3.308	amp; 20	amp; Heavier appliances
10	amp; 2.588	amp; 5.261	amp; 30	amp; Motor circuits
8	amp; 3.264	amp; 8.367	amp; 40	amp; High current, long distance
6	amp; 4.115	amp; 13.30	amp; 55	amp; Very high current
4	amp; 5.189	amp; 21.15	amp; 70	amp; Heavy-duty power
2	amp; 6.544	amp; 33.62	amp; 95	amp; Maximum current

Table 1: Standard copper wire gauge specifications

Part 8.2 Voltage Drop Chart (12V System, 15A Current)

AWG	amp; **5m**	amp; **10m**	amp; **15m**	amp; **20m**
24	amp; 6.2 V	amp; 12.3 V	amp; 18.4 V	amp; 24.5 V
18	amp; 1.0 V	amp; 1.9 V	amp; 2.9 V	amp; 3.9 V
14	amp; 0.3 V	amp; 0.6 V	amp; 0.9 V	amp; 1.2 V
10	amp; 0.1 V	amp; 0.2 V	amp; 0.4 V	amp; 0.5 V

Table 2: Voltage drop (in volts) for different wire gauges at 12V, 15A

Note: The 2024 system (AWG 24, 15m, 15A) experienced 18.4V drop—completely inadequate for any system.

Part 8.3 References

American Wire Gauge Standard (ASTM B258)

Marine Electrical Safety Standards (ABYC E-11)

Ohm's Law and Basic Circuit Theory (Standard Physics)

IEC 60364: Electrical Installations of Buildings

MIL-HDBK-454: Electrical Power Systems Design

IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE 1100)

Part 8.4 Useful links

Wire Gauge and Electrical Standards

- Powerstream Wire Gauge Calculator and Reference
- https://www.powerstream.com/Wire_Size.html
-

  (AWG specifications, voltage drop calculator)
- ASTM B258 American Wire Gauge Standard
- https://www.astm.org/b0258-21.html
-

  (Official industry standard for AWG)

Voltage Drop Calculation Tools

- 12VoltPlanet Wire Gauge Calculator
- https://www.12voltplanet.co.uk/wire-gauge-calculator.html
-

  (Interactive calculator for 12V systems)
- Engineering ToolBox Resistance Calculator
- https://www.engineeringtoolbox.com/voltage-drop-d_1312.html

-
  (Detailed resistance and voltage drop explanation)

Marine Electrical Standards

- ABYC E-11 Standard — Electrical Systems
- https://www.abycinc.org/standards
-
  (Marine safety standards, voltage drop limits)
- IEC 60364 — Electrical Installations of Buildings
- https://www.iec.ch/standards-development/our-standards/iec-60364
-
  (International electrical safety standards)

ROV and Competition Resources

- MATE ROV Competition Official Website
- https://www.materovcompetition.org/
-
  (Official rules, technical documentation, electrical system guidance)
- MATE ROV Technical Documentation Library
- https://www.materovcompetition.org/resources/
-
  (Detailed historical reports and winning solutions)

Educational Physics Resources

- Khan Academy — DC Circuits
- https://www.khanacademy.org/science/physics/circuits-topic
-
  (Video courses on Ohm's Law, voltage drop, resistance)
- MIT OpenCourseWare — Circuits and Electronics
- https://ocw.mit.edu/courses/6-002-circuits-and-electronics-spring-2007/
-
  (Higher-level circuit design and analysis)

Marine Connector Specifications

- Binder Electronics — SP21 Connector Data Sheet

- https://www.binder-connector.com/
- (search "SP21 submersible")
  (Official connector specifications)
- SubConn — Underwater Connector Manufacturer

- https://www.subsea.org/
-
  (Industry-standard marine connectors)

Hong Kong-Specific Resources

- Sim City Electronics (Local Supplier)

- https://www.sim-city.com.hk/
-
  (Local copper wire supplier and electronic parts in HK)
- HKIE (Hong Kong Institution of Engineers)

- https://www.hkie.org.hk/
-
  (Professional standards, technical reference)