Microwave Wireless Power Transfer Between Moving Ships: A Technical Analysis

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1. Introduction

Wireless power transfer has become an exciting technology that can be used in the delivery of electrical energy without any physical connections. Microwave Wireless Power Transfer (MWPT) among other methods can be used to transmit energy by electromagnetic waves with transmitting antennas and receiving rectenna systems. This report explores the possibility of MWPT to transfer electrical power between two moving vessels at a distance of 10 to 100 m with a necessary power level of 1 kW to 25 kW. Analysis is done on feasibility, efficiency, equipments needed, and the cost as per the results of the recent literature.

2. Feasibility of MWPT for Ship-to-Ship Power Transfer

Transmission of power over short distances (10100 meters) at kilowatt levels can be done technically using MWPT. The initial studies showed that rectifying antennas (rectennas) could successfully convert microwave energy to usable electrical power, and successful transmission of power at kilowatt levels under controlled conditions, was demonstrated. Subsequent developments in phased-array antennas and beamforming methods confirmed that MWPT systems have the ability to provide power at meaningful levels in a directional fashion.

Nevertheless, the situation at hand puts even more complexity as both ships are in motion and move at a speed of 0 to 5 m/s. The MWPT systems are very demanding in terms of accurate positioning of the transmitter and the receiver. Any minor deviations can lead to a lot of energy loss. Thus, although the system is theoretically sound, it is difficult to apply in practice in a dynamic marine environment because it has to be constantly moved and aligned.

3. Efficiency of MWPT Systems

MWPT systems can be highly effective under environmental conditions and system design. Modern rectenna systems have shown efficiencies of over 50 in laboratory conditions and optimized systems of up to 80 efficiency have been achieved. These measurements are obtained in controlled situations when the alignment is ideal and when there is minimum interference with the environment.

In practice, efficiency is much less in the real world, particularly in the sea. Energy losses are caused by factors like beam misalignment, atmospheric absorption, humidity and sea surface reflections. The literature points out that efficiency in the lab does not directly result in real world efficiencies and the efficiency as it is featured in the real world is generally between 30 and 60 percent. Hence although MWPT has the potential to provide usable power high efficiency is only possible under favorable conditions with advanced control systems.

4. Required Equipment and System Components

MWPT between two ships involves a number of advanced components to implement. On the transmitting end, an electromagnetic generator with high power is employed to generate electromagnetic waves. High-efficiency RF amplifiers normally support this generator. The energy produced is delivered via a phased-array antenna system that allows beamforming and directional control of the microwave signal.

At the receiving end a rectenna array is employed to receive the transmitted microwave energy and convert it into direct current electrical power. Recent rectenna antenna systems can be made with many antenna elements and rectifying circuits to maximise energy conversion efficiency .

Besides these essential elements, dynamic environments like the moving ships need sophisticated tracking and alignment systems. These include:

- Artificial intelligence (AI) beam trackers.
- GPS-assisted alignment mechanisms
- Gyro-stabilized antenna platforms

These technologies make sure that the beam sent is well concentrated on the ship to be received despite movement and other disturbances in the environment.

5. Cost Analysis

The complexity and sophistication of the required components makes the cost of MWPT systems rather high. Phased-array antennas, high-power RF amplifiers and rectenna arrays are another factor that increases the cost of the entire system. Also, the necessity of real-time tracking and control systems adds to the cost of capital and operations.

The literature points out that phased-array systems and rectenna technologies are key cost drivers, and hence, MWPT systems are costly in comparison to the conventional wired power transmission. Consequently, there is no commercialization of MWPT large-scale or high-power applications yet, particularly in dynamic settings like maritime operations.

Table: Estimated Cost Breakdown

No.	Component / Item	Description	Estimated Cost Range (USD)
1	RF Power Source + Amplifier	High-power RF generator and GaN-based amplifier	$10,000 – $50,000
2	Phased Array Antenna System	Beamforming antenna system for power transmission	$20,000 – $100,000
3	Rectenna Array	Microwave energy receiver and rectifying antenna array	$10,000 – $40,000
4	Beam Tracking System (AI + Sensors)	AI-based tracking with sensors for dynamic alignment	$5,000 – $25,000
5	Control & Processing Unit	Control electronics, signal processing and system management	$5,000 – $15,000
6	Installation & Integration	System installation, calibration and integration on ships	$5,000 – $20,000
	Total Estimated Cost		**$55,000 – $250,000+**

6.Equipment Required for MWPT System

Table: Equipment Required for MWPT System

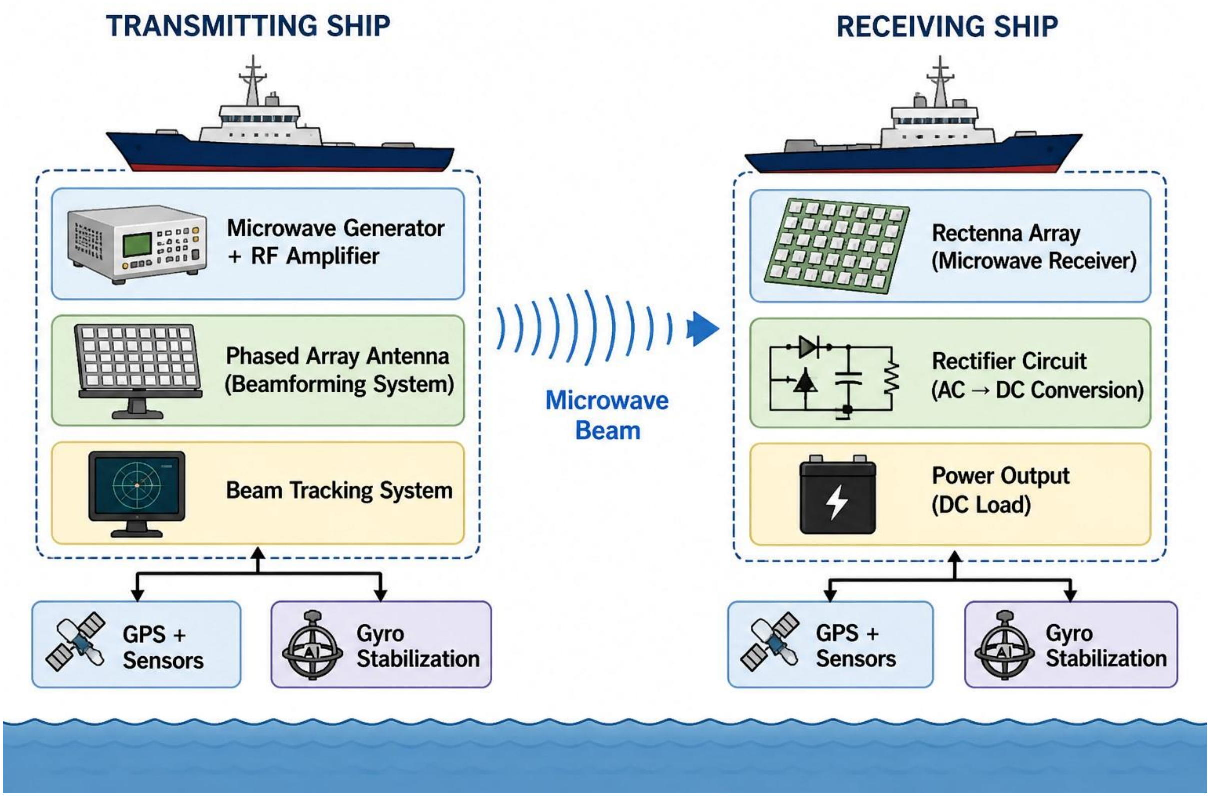
Component	Function	Description
Microwave Power Source	Generate energy	High-power RF generator (kW level)
RF Power Amplifier (GaN-based)	Boost signal power	Amplifies microwave signal to high power
Phased-Array Antenna (Transmitter)	Beam transmission	Directs and focuses microwave beam toward receiving ship
Beam Control System	Alignment control	Electronically steers beam direction
Rectenna Array (Receiver)	Energy reception	Captures microwave energy and converts it to electrical power
Rectifier Circuit	AC to DC conversion	Uses diodes (e.g., Schottky) for conversion
AI Beam Tracking System	Dynamic tracking	Tracks moving ship and adjusts beam
GPS + Sensors	Position detection	Provides real-time location data
Gyro-Stabilized Platform	Stability	Maintains antenna alignment on moving ships

7. Conclusion

Finally, transfer between two moving ships over a distance of 10 to 100 meters by using MWPT is technically feasible. The system is capable of supporting power levels ranging between 1 kW and 25 kW and, thus, can be used in the specified application. But in practice it is quite difficult as the beam alignment, environmental losses and the complexity of the system are some of the problems.

MWPT systems are efficient under ideal conditions, however, their efficiency reduces significantly in the real-world conditions, especially in the marine environment. The system must have complex hardware, such as phased-array antennas, rectenna arrays and smart tracking systems, which are also expensive.

On the whole, although MWPT can be an effective solution in terms of wireless energy transfer, its implementation in the context of a moving ship needs to be enhanced with the help of the further technological progress in order to become more efficient and less costly and to be more reliable.1



TRANSMITTING SHIP
Microwave Generator + RF Amplifier
Phased Array Antenna (Beamforming System)
Beam Tracking System
GPS + Sensors
Gyro Stabilization
Microwave Beam
RECEIVING SHIP
Rectenna Array (Microwave Receiver)
Rectifier Circuit (AC → DC Conversion)
Power Output (DC Load)
GPS + Sensors
Gyro Stabilization

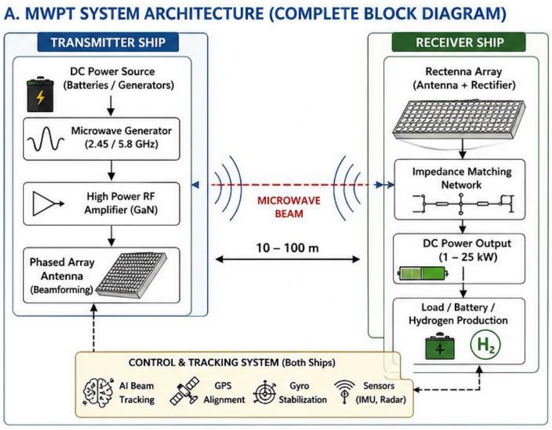


Figure 1: MWPT System Architecture

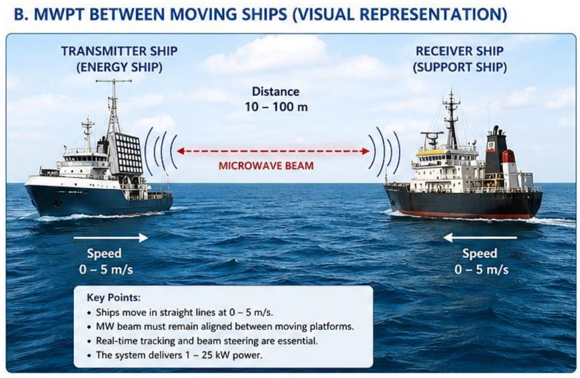
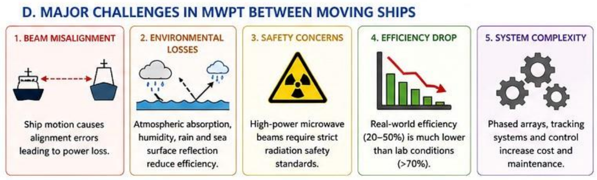


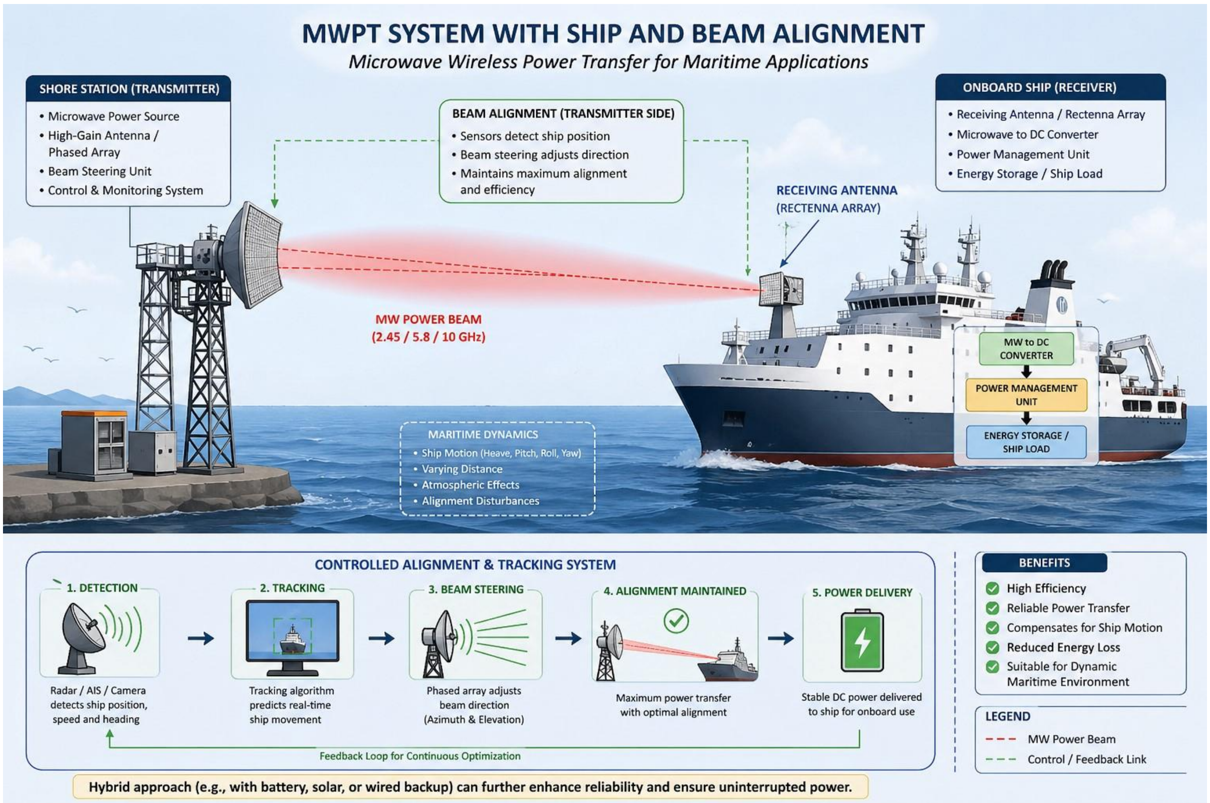
Figure 2: MWPT Application Between Moving Ships

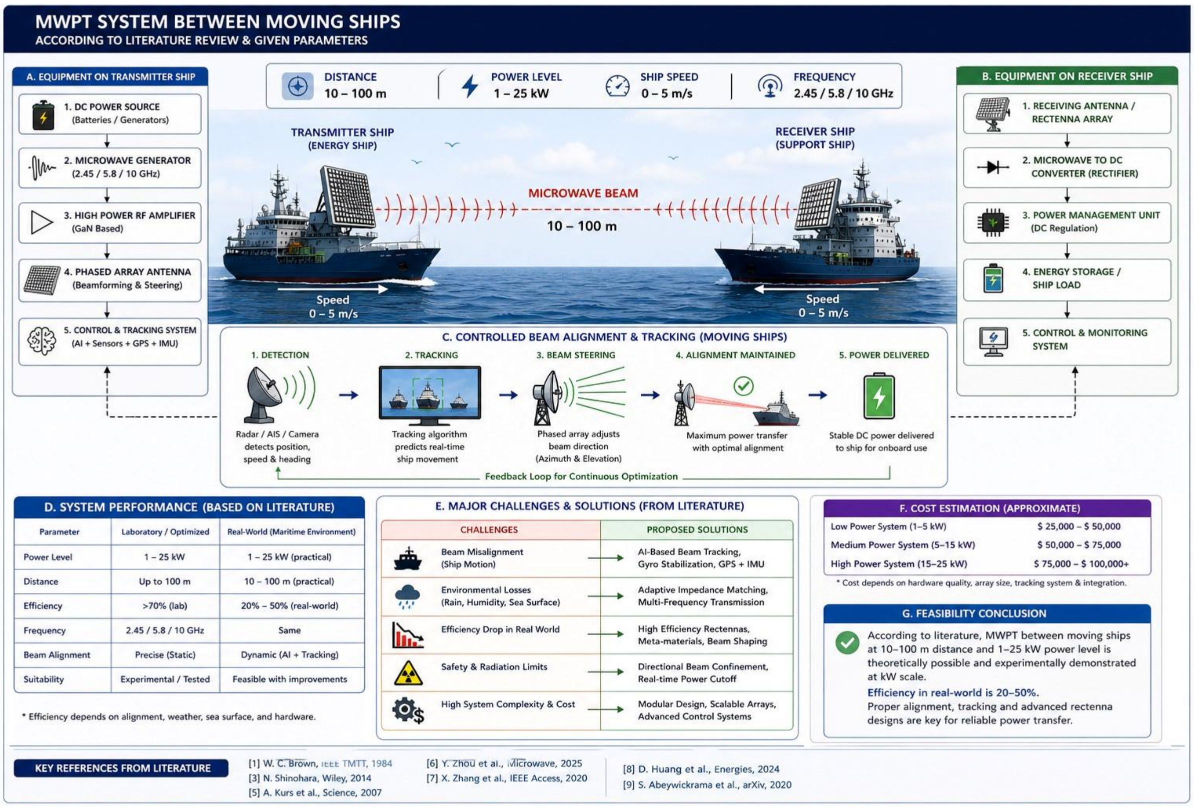
Figure 3: Major Equipment of MWPT System



E. COMPARISON: MWPT vs MREs PROPOSED METHOD

	MWPT (Microwave Wireless Power Transfer)	MREs Proposed Method (Battery/Hydrogen Transfer)
Method	Wireless power via microwave beam	Physical transfer of batteries or hydrogen
Power Level Capability	1 – 25 kW (practical)	Up to MW level (e.g., 2 MW output power)
Efficiency	20 – 50% (real-world)	High efficiency (>90%)
Alignment Need	Very High (Critical)	Not Required
Cost	High ($25,000 – $100,000+)	Moderate (depends on storage system)
Suitability for Moving Ships	Challenging	More Practical and Reliable




MWPT SYSTEM BETWEEN MOVING SHIPS
ACCORDING TO LITERATURE REVIEW & GIVEN PARAMETERS
A. EQUIPMENT ON TRANSMITTER SHIP
1. DC POWER SOURCE (Batteries / Generators)
2. MICROWAVE GENERATOR (2.45 / 5.8 / 10 GHz)
3. HIGH POWER RF AMPLIFIER (GaN Based)
4. PHASED ARRAY ANTENNA (Beamforming & Steering)
5. CONTROL & TRACKING SYSTEM (AI + Sensors + GPS + IMU)
DISTANCE 10 – 100 m
POWER LEVEL 1 – 25 kW
SHIP SPEED 0 – 5 m/s
FREQUENCY 2.45 / 5.8 / 10 GHz
TRANSMITTER SHIP (ENERGY SHIP)
MICROWAVE BEAM
10 – 100 m
RECEIVER SHIP (SUPPORT SHIP)
Speed 0 – 5 m/s
Speed 0 – 5 m/s
B. EQUIPMENT ON RECEIVER SHIP
1. RECEIVING ANTENNA / RECTENNA ARRAY
2. MICROWAVE TO DC CONVERTER (RECTIFIER)
3. POWER MANAGEMENT UNIT (DC Regulation)
4. ENERGY STORAGE / SHIP LOAD
5. CONTROL & MONITORING SYSTEM
C. CONTROLLED BEAM ALIGNMENT & TRACKING (MOVING SHIPS)
1. DETECTION
Radar / AIS / Camera detects position, speed & heading
2. TRACKING
Tracking algorithm predicts real-time ship movement
3. BEAM STEERING
Phased array adjusts beam direction (Azimuth & Elevation)
4. ALIGNMENT MAINTAINED
Maximum power transfer with optimal alignment
5. POWER DELIVERED
Stable DC power delivered to ship for onboard use
Feedback Loop for Continuous Optimization
D. SYSTEM PERFORMANCE (BASED ON LITERATURE)
Parameter | Laboratory / Optimized | Real-World (Maritime Environment)
Power Level | 1 – 25 kW | 1 – 25 kW (practical)
Distance | Up to 100 m | 10 – 100 m (practical)
Efficiency | >70% (lab) | 20% – 50% (real-world)
Frequency | 2.45 / 5.8 / 10 GHz | Same
Beam Alignment | Precise (Static) | Dynamic (AI + Tracking)
Suitability | Experimental / Tested | Feasible with improvements
* Efficiency depends on alignment, weather, sea surface, and hardware.
E. MAJOR CHALLENGES & SOLUTIONS (FROM LITERATURE)
CHALLENGES | PROPOSED SOLUTIONS
Beam Misalignment (Ship Motion) | AI-Based Beam Tracking, Gyro Stabilization, GPS + IMU
Environmental Losses (Rain, Humidity, Sea Surface) | Adaptive Impedance Matching, Multi-Frequency Transmission
Efficiency Drop in Real World | High Efficiency Rectennas, Meta-materials, Beam Shaping
Safety & Radiation Limits | Directional Beam Confinement, Real-time Power Cutoff
High System Complexity & Cost | Modular Design, Scalable Arrays, Advanced Control Systems
F. COST ESTIMATION (APPROXIMATE)
Low Power System (1–5 kW) $ 25,000 – $ 50,000
Medium Power System (5–15 kW) $ 50,000 – $ 75,000
High Power System (15–25 kW) $ 75,000 – $ 100,000+
* Cost depends on hardware quality, array size, tracking system & integration.
G. FEASIBILITY CONCLUSION
According to literature, MWPT between moving ships at 10–100 m distance and 1–25 kW power level is theoretically possible and experimentally demonstrated at kW scale.
Efficiency in real-world is 20–50%.
Proper alignment, tracking and advanced rectenna designs are key for reliable power transfer.
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