附件 2

2025 年黑龙江工程师学院
工程师职称资格申报书

高　　校：哈尔滨工程大学

所在学院：水声工程学院

专业类别：电子信息

黑龙江工程师学院制

2025 年 5 月

填 写 说 明

一、本表仅为黑龙江工程师学院工程师职称资格申报使用，须如实填写;

二、申报书中填写内容原则上不得涉密，如存在涉密技术或数据，须做脱密处理，所在单位须严格审核;

三、申报书涉及签名均须用蓝、黑色墨水笔，亲笔签名;

四、申报书中用宋体小四号字撰写，可另附页或增加页数，A4 纸双面打印。

黑龙江工程师学院工程师职称资格申报书

申报人基本信息			
姓　　名	苗柏露	联系电话	13832070569
出生年月	199502	政治面貌	中共党员
身份证号	130429199502152261	学　　号	S322057012
高　　校	哈尔滨工程大学	所在学院	水声工程学院
所属专项	龙江专项	专业类别	电子信息

联合培养信息			
联合培养（入企实践）单位名称	中国船舶集团有限公司系统工程研究院		
入企实践时间	2023 年 8 月至 2025 年 5 月（共 22 月）		
校内导师	商志刚	职务/职称	教授
企业导师	陈虹宇	职务/职称	高级工程师
项目名称	某通信网关系统		
项目来源	☑ 校企联合攻关项目 □企业揭榜挂帅项目 □企业自研项目 □企业导师自研项目 □其他__________		

<table>
<tr><td colspan="7">课程学习情况</td></tr>
<tr><td colspan="2">课程学习平均成绩</td><td colspan="5">按课程学分核算的平均成绩：85.96 分</td></tr>
<tr><td colspan="7">业绩代表成果（至少选填一项）</td></tr>
<tr><td rowspan="3">校企合作项目</td><td colspan="2">名称</td><td>合同金额</td><td>排名</td><td colspan="2">是否通过验收/校企双导师认可</td></tr>
<tr><td colspan="2">某通信网关系统</td><td>107 万</td><td>4</td><td colspan="2">是</td></tr>
<tr><td colspan="2"></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="2">重点重大项目</td><td colspan="2">名称</td><td>合同金额</td><td>排名</td><td colspan="2">应用成果</td></tr>
<tr><td colspan="2"></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="2">科技成果设计、应用与转化</td><td>名称</td><td colspan="2">类型
（产品或样机设计、科技成果应用转化推广和解决行（企）业技术难题等）</td><td colspan="3">应用成果</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td rowspan="4">理论创新</td><td colspan="2">名称</td><td>类别
（包括论文、专利、软件著作权、著作、标准、规范等）</td><td>发表时间/专利授权时间</td><td>刊物名称/专利授权号</td><td>排名</td></tr>
<tr><td colspan="2">一种跨介质通信定位一体化系统及方法</td><td>专利</td><td>2024.05</td><td>ZL2023 110 80684.6</td><td>2</td></tr>
<tr><td colspan="2">双向全双工空水跨介质无中继通信方法</td><td>专利</td><td>2024.04</td><td>ZL2023 107 73927.8</td><td>2</td></tr>
<tr><td colspan="2">水声/电磁多物理场耦合通信系统 V1.0</td><td>软著</td><td>2025.04</td><td>2025SR06 40980</td><td>2</td></tr>
<tr><td></td><td colspan="2">Full-duplex two-way no-relay cross-media communication method based on acoustic wave conversion</td><td>论文</td><td>2024.11</td><td>IOP Publishing Ltd</td><td>2</td></tr>
<tr><td rowspan="2">获奖</td><td colspan="2">名称</td><td>级别
（包括国家级、省部级）</td><td>类别
（包括科学技术类、工程类、涉及（勘察）类、工程咨询类等）</td><td>获奖时间</td><td>排名</td></tr>
<tr><td colspan="2">深蓝信鸽—全域互联先驱者</td><td>“兆易创新杯”第十九届中国研究生电子设</td><td colspan="2">工程类/2024.08</td><td>3</td></tr>
</table>

		计竞赛全国总决赛团队三等奖		
	空海通信网关系统	“兆易创新杯”第十九届中国研究生电子设计竞赛技术类初赛团队一等奖	工程类/2024.07	2

工程实践总结

一、问题来源与研究现状

线下纸质版可查

二、解决的关键问题（字数300字左右）

线下纸质版可查

三、策略分析及工作量描述 线下纸质版可查
四、实践成果 线下纸质版可查

本人承诺

个人声明：本人上述所填资料均为真实有效，如有虚假，愿承担一切责任，特此声明！

申报人签名：苗柏露

日　　期：2025.5.12

校内导师意见

导师签字：商志刚

日　　期：2025 5.12

企业导师意见

导师签字：陈泓宇

日　　期：2025.5.12

校企评价结果

（由学生就读高校的学籍所在学院以及参与专业实践的企业，联合对申报学生专业实践成绩、业绩代表成果进行评价认定）

学生专业实践考核成绩：95 分

☑优秀　☐良好　☐一般　☐及格　☐不及格

学生满足的业绩代表成果情况：

☑研究生课程学习平均成绩 80 分及以上

☑校企合作项目　☐重点重大项目　☐科技成果设计、应用与转化

☑理论创新　☑获奖

所在学院公章：

副院长（签字）：[illegible]

学生入企期间开展的专业实践情况：

☑学生实践信息属实　☑学生实践内容符合校企实践计划要求

☑学生取得的业绩代表成果与专业实践内

实践单位已签字，已盖章，线下纸质版可查

（专业评议组组长汇总本组组员评审情况，形成对该学生的评议意见，并在评审委员会会议中进行口头汇报） **评议结果：** **☐推荐　　　　☐需答辩　　　　☐不推荐** 、 组长签字： 日　　期：
黑龙江工程师学院意见
单位公章： 日　　期：
黑龙江省人力资源和社会保障厅意见
单位公章： 日　　期：

附件 3

佐证材料清单

姓名	苗柏露	所在高校	哈尔滨工程大学
所属专项	龙江专项	专业类别	电子信息

材 料 目 录

序号	材料名称 （按照审批表填写顺序装订）	份数 （份）
1	课程成绩单（含课程学习情况证明）	1
2	校企合作项目材料	1
3	重点重大项目	
4	科技成果设计、应用与转化	
5	理论创新	4
6	省级及以上获奖	2

注：相应申报材料按照顺序统一装订，此清单粘贴在档案袋上。

申报人签字：苗柏露　　提交时间：2025.5.12

哈尔滨工程大学研究生成绩证明
TRANSCRIPT OF ACADEMIC RECORD

学 号 Student No:	S322057012	姓 名 Name:	苗柏露 Miao Bailu
性 别 Gender:	女 Female	入学年月 Date of Admission:	2022.09
专 业 Major:	电子信息 Electronic information		
学位层次 Degree Level:	硕士 Master	学习形式 Student Status:	全日制 Full-Time

序号 No.	课程编号/课程名称 Course No./Course Name	开课学年/学期 Year/Term	课程类别 Course Category	学时/学分 Hours/Credits	成绩 Grade	备注 Remarks
1	201910510011 声呐电子系统设计 Sonar Electronic System Design	2022-2023/1	必修课 Required Course	48/3.0	90	
2	202010013002 随机过程 Stochastic Process	2022-2023/1	必修课 Required Course	48/3.0	80	
3	202010412201 电子信息领域学科前沿 Academic Frontier in Electronic Information Field	2022-2023/1	必修课 Required Course	16/1.0	85	
4	202010520001 论文写作指导 Thesis/Dissertation Writing	2022-2023/1	必修课 Required Course	16/1.0	92	
5	202032012001 工程伦理 Engineering Ethics	2022-2023/2	必修课 Required Course	18/1.0	95	
6	202032013001 中国特色社会主义理论与实践研究 Study on the Theory and Practice of Socialism with Chinese Charateristics	2022-2023/1	必修课 Required Course	36/2.0	81	
7	202032013002 自然辩证法概论 Introduction to Dialectics of Nature	2022-2023/2	必修课 Required Course	18/1.0	86	
8	202032013003 第一外国语（英语） First Foreign Language (English)	2022-2023/1	必修课 Required Course	60/3.0	87	
9	202032020004 矩阵论 Matrix Theory	2022-2023/1	必修课 Required Course	32/2.0	83	
10	202010013003 信号检测与估计 Signal Detection and Estimation Theory	2022-2023/1	选修课 Optional Course	48/3.0	79	
11	202010513009 通信信号处理 Theory of Modern Communication System	2022-2023/1	选修课 Optional Course	32/2.0	90	
12	202032020013 不朽的艺术：走进大师与经典	2022-2023/2	选修课 Optional Course	35/2.0	优秀 Excellent	
13	202032020016 知识产权法	2022-2023/2	选修课 Optional Course	19/1.0	良好 Good	
14	202010512599 专业实践 Professional Practice	2023-2024/2	必修环节	0/6.0	优秀 Excellent	
15	202010520592 创新竞赛与创业活动 Innovation Competition and Entrepreneurial Activities	2024-2025/1	必修环节	0/1.0	优秀 Excellent	
16	202010520593 文献综述与开题报告 Literature Review and Thesis Proposal	2023-2024/1	必修环节	0/2.0	优秀 Excellent	
17	202010520594 中期检查 Process Assessment	2024-2025/1	必修环节	0/1.0	优秀 Excellent	

总学分Total Credits Earned: 35.0

哈尔滨工程大学研究生院
Graduate School of Harbin Engineering University

哈尔滨工程大学研究生成绩证明 (05) 专用章

日期：2025年5月16日

课程学习情况证明

学籍所在学院（公章）：　　　　　　　　　　2025 年 5 月 12日

专业课程信息 （前沿理论课程、实践类课程、 案例课程、学科交叉课程中至少必修 1 门）					
课程类型	课程名称	课程性质 （必修/选修）	学分	成绩	是否 校企共建
前沿理论课程	电子信息领域学科前沿	必修	1	85	是
实践类课程	声呐电子系统设计	必修	3	90	是
案例课程	随机过程	必修	3	80	是
学科交叉课程	信号检测与估计	选修	3	79	否
	通信信号处理	选修	2	90	否

能力素养类课程信息 （工程伦理、研究方法类、标准与知识产权类必修，工程管理类、职业素养类选修）			
课程名称	课程性质 （必修/选修）	学分	成绩
工程伦理	必修	1	95
知识产权法	选修	1	良好

研究生课程学习平均成绩	
按课程学分核算的平均成绩：85.96 分	专业排名/专业总人数：10/86

合同书

项目名称：系统

项目编号：

委 托 方：中国船舶集团有限公司系统工程研究院

承 研 方：哈尔滨工程大学

起止时间：

中国船舶集团有限公司制

项目验收证明

项目名称：某通信网关系统

承担单位：哈尔滨工程大学（水声工程学院）

合作单位：中国船舶集团有限公司系统工程研究院

项目周期：2024 年 8 月—2025 年 5 月

完成某通信网关系统样机研制，实现双向全双工空水通信指标；

申请 gf 专利 1 项，发明专利 3 项（已授权 2 项）、软件著作权 1 项，发表核心期刊/EI 论文 2 篇；

通过校企联合测试，技术指标达到合同要求（合同编号：KY10500240032）。

校内导师签字：高志刚

2025 年 5 月 12 日

企业导师签字：陈虹宇

2025 年 5 月 12 日

项目贡献证明

兹证明学生苗柏露在"某通信网关系统"项目（2024 年 8 月-2025 年 5 月,哈尔滨工程大学与中国船舶集团有限公司系统工程研究院合作，合作金额 107 万，学生排序第 1）中做出以下重要贡献：

1. 技术创新：主导完成空中水下信号转换算法优化;参与设计的网关结构显著提升设备能力；

2. 成果产出：申请 gf 专利 1 项，发明专利 3 项（已授权 2 项）、软件著作权 1 项，发表核心期刊/EI 论文 2 篇。

经考核，该生在项目中表现突出，在空中水下信号转换算法优化、系统集成测试等关键环节做出重要贡献，其研发成果为海洋监测和水下通信提供了创新性解决方案，项目达到预期目标/成果，得到双方导师高度认可。

校内导师签字：高志刚

2025 年 5 月 12 日

企业导师签字 陈虹宇

2025 年 5 月 12 日

证书号第6972969号

发明专利证书

发 明 名 称：一种跨介质通信定位一体化系统及方法

发 明 人：商志刚;苗柏露;乔钢;孙宗鑫;马璐

专 利 号：ZL 2023 1 1080684.6

专利申请日：2023年08月25日

专 利 权 人：哈尔滨工程大学

地 址：150001 黑龙江省哈尔滨市南岗区南通大街145号

授权公告日：2024年05月07日　　　　授权公告号：CN 117118532 B

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局长
申长雨

申长雨

国家知识产权局
2024年05月07日

其他事项参见续页

证书号第6972969号

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申请日时本专利记载的申请人、发明人信息如下：

申请人：

哈尔滨工程大学

发明人：

商志刚;苗柏露;乔钢;孙宗鑫;马璐

证书号第6943622号

发明专利证书

发 明 名 称：双向全双工空水跨介质无中继通信方法

发　　明　　人：商志刚;苗柏露;乔钢;刘凇佐;青昕

专　　利　　号：ZL 2023 1 0773927.8

专利申请日：2023年06月28日

专 利 权 人：哈尔滨工程大学

地　　　　　址：150001 黑龙江省哈尔滨市南岗区南通大街145号

授权公告日：2024年04月26日　　　　授权公告号：CN 116800352 B

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局长
申长雨

国家知识产权局
2024年04月26日

其他事项参见续页

证书号第6943622号

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申请日时本专利记载的申请人、发明人信息如下：

申请人：

哈尔滨工程大学

发明人：

商志刚;苗柏露;乔钢;刘凇佐;青昕

中华人民共和国国家版权局
计算机软件著作权登记证书

证书号： 软著登字第15297178号

软 件 名 称： 水声/电磁多物理场耦合跨域通信系统
V1.0

著 作 权 人： 商志刚;苗柏露;张晏齐

权利取得方式： 原始取得

权 利 范 围： 全部权利

登 记 号： 2025SR0640980

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2025年04月18日

Journal of Physics:
Conference Series

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Full-duplex two-way no-relay cross-media communication method based on acoustic wave conversion

To cite this article: Zhigang Shang *et al* 2024 *J. Phys.: Conf. Ser.* **2822** 012066

doi:10.1088/1742-6596/2822/1/012066

Full-duplex two-way no-relay cross-media communication method based on acoustic wave conversion

Zhigang Shang [1,2,3,4*] Bailu Miao [1,2,3,4] Xinghao Qu[1,2,3,4] Songzuo Liu[1,2,3,4]

1 National Key Laboratory of Underwater Acoustic Technology, Harbin Engineering University, Harbin 15001,China;
2 Key Laboratory of Marine Information Acquisition and Security (Harbin Engineering University),Ministry of Industry and Information Technology, Harbin 150001,China;
3 College of Underwater Acoustic Engineering, Harbin Engineering University ， Harbin 150001,China;
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Abstract. Due to the difference in acoustic impedance between water and air, the water interface becomes a natural barrier. Underwater sound waves will bounce when they propagate to the water surface. Electromagnetic waves and light waves in the air will rapidly attenuate after passing through the water surface and going underwater, making it difficult to complete air-water cross-media information transmission. In this article, we first analyze the theoretical characteristics and vibration model of the water surface after medium collision, and develop a new full-duplex communication method across the air-ocean medium, which does not rely on relay equipment and only uses three transmission media in the air. Propagate signals in the sea channel physical field to achieve two-way communication, using the mutual conversion between laser, acoustic, and radio frequency signals to fill the gap in cross-media communication technology that can simultaneously achieve two-way, full-duplex and non-relay. It has been verified through experimental installations carried out in laboratory water tanks and large comprehensive anechoic pools that it is able to achieve full-duplex communication links across the air-sea surface, indicating that the combination of laser acousticization and radio frequency-acoustic wave conversion can be used across medium full-duplex wireless communication provides a feasible method for communication that breaks through the water interface.

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1. Introduction

Considering the particularity of the air-water interface, sound waves will encounter rebound when they propagate to the water surface. Electromagnetic waves and light waves in the air will rapidly attenuate after passing through the water surface and going underwater. It is difficult for a single medium to complete air-water cross-media information transmission. In water, sound waves are the main medium for transmitting information. As a kind of mechanical wave, sound waves can transmit thousands of kilometers in water. They are by far the most mature method of signal transmission in water [1]. However, when sound waves propagate to the water surface, they will be affected by the interface Rebound greatly reduces the energy of sound waves crossing the water surface, making it difficult to cross the air-water interface alone. In the air, electromagnetic waves and optical fibers are the main media for transmitting information [2]. The alternating magnetic field and electric field in space excite each other to generate electromagnetic waves to transmit information in the air. Since seawater is conductive, electromagnetic waves will have greater propagation in seawater. attenuation. Autonomous underwater vehicles (AUVs) are usually used for information exchange. AUVs use hydroacoustic communication underwater and transmit information by surfacing at regular intervals. This method not only increases the energy expenditure of AUVs, wastes equipment resources, but also poses great potential safety hazards. Most of today's cross-domain communications still rely on relay equipment. Relay equipment can be divided into dynamic relays and static relays, including surface ships, ships, submarines, and buoys. In order to ensure smooth information exchange in the air and water, it is necessary to continuously deploy a large number of surface repeaters in fixed waters. However, in harsh sea conditions, repeaters can easily spread out or risk being caught, causing information transmission to be interrupted and posing safety risks. In addition, people have begun to try to use light for cross-media information transmission. Wireless light waves are affected by absorption and scattering in water, and can only be transmitted over short distances [3]. The range of activities of wired carrier optical fibers is limited, and the ocean area is vast, making it difficult to comprehensively Coverage, expensive, high cost, not suitable for long-distance communication [4]. Later, someone discovered that when a laser is irradiated into a transparent liquid, when the laser energy exceeds the scope of the liquid, a light breakdown will occur in the water. During the breakdown, the plasma expansion will generate sound waves and then the cavitation bubbles will burst to produce sound waves. This phenomenon Called laser acoustic wave technology [5], the use of laser-excited acoustic wave technology has a small environmental restriction range and strong penetration ability, and is suitable for small attenuation and long-distance transmission. In addition, research has found that underwater sound wave signals hit the water surface and stimulate the water surface to generate microwaves. The echo signals detected using airborne radar or laser equipment contain micro-amplitude wave vibration frequencies. The microwave vibration frequencies are consistent with the vibration frequencies of the underwater sound sources[6], this feature can help achieve air-water cross-media communication and target detection.

With the urgent demand for marine resources and the gradual development of the ocean field, people urgently need to develop more reliable cross-media communication methods. In order to respond to this demand, this paper proposes and experiments a method that can achieve two-way cross-air-sea The new technical means of communication (the combination of laser acoustic and acoustic wave-to-radio frequency conversion) can directly establish a two-way communication link between underwater nodes and air nodes, allowing data to be transmitted in both directions simultaneously.

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This article first analyzes the theoretical characteristics and vibration model of the water surface after medium collision, then studies the echo signal detection method, verifies it in the simulation environment and experimental environment, and finally summarizes it.

2. Basic principles of cross-domain communication

The communication technology used in this article makes use of the existing mature technology-laser acoustic co-operation, so that air network nodes and water network nodes can complete two-way communication without the use of relay equipment. This basic communication principle is to transmit modulated signals underwater and transmit them through the energizer or speaker sends sound waves. Due to the mechanical characteristics of sound waves, the sound waves hit the water surface and cause slight vibrations on the water surface. The microwave amplitude is usually at the micron level. Research shows that the frequency of underwater sound sources is inversely proportional to the amplitude of water surface vibrations [6]. Above the water surface the placed millimetre-wave radar illuminates the slight vibration of the water surface, decodes and analyses the detected echo signals to obtain underwater target transmission information, and completes one-way communication from underwater to air across media [7]. The air node modulates the laser with an external modulator and emits a laser beam containing coded information to the water surface. The laser irradiates the water surface to generate sound waves. After being received by the underwater hydrophone, the signal is analyzed and decoded to obtain the target information, completing the one-way cross-media communication to the water communication.

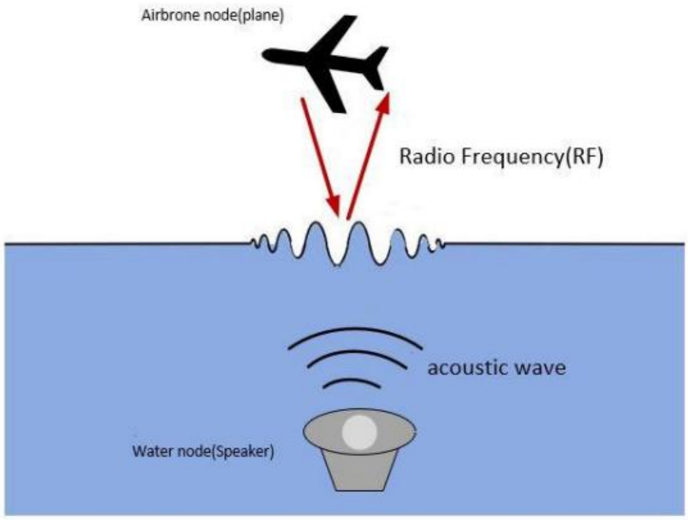

Figure 1. Underwater sound sources impact the water surface to produce vibrations

A variety of principles are used in this communication method, including the propagation of sound waves under water, micro-amplitude perturbation of the air-water soft interface, and electromagnetic wave-radio frequency propagation in the air channel.

2.1 Sound wave propagation attenuation model in water

Compared with light waves and electromagnetic waves, sound waves have the smallest attenuation in the ocean. There are three reasons for the attenuation of sound wave propagation: expansion loss, which refers to the loss caused by the continuous expansion of the wave front during the propagation of sound waves in the medium; absorption loss, which is the sound wave propagation loss. Sound intensity attenuation in a uniform medium; scattering is the scattering and attenuation of sound waves caused by the inhomogeneity of the ocean medium. There is also the scattering of sound waves from the seawater interface, which can also cause sound attenuation [8]. Generally speaking, the density of ocean bubbles is very small, and the impact of scattering losses is negligible. The Transmission loss (TL) of the sound source in water is related to the distance.

$$TL = 10\lg\frac{I_1}{I_r} \qquad (1)$$

In the formula, is the sound intensity 1m away from the centre of the sound source, and is the sound intensity r away from the centre of the sound source.

$$I \propto p_0^2 / r^2 \qquad (2)$$

Is the fixed plane wave sound pressure amplitude, and r is the sound wave propagation distance.
The energy transmitted from the sound source to the water surface satisfies the formula.
In the formula, is the energy transmitted from the sound source to the water surface, is the absorption coefficient, and is the actual transmission distance.
In the above formula, the empirical formula of absorption coefficient α is.

$$\alpha = \frac{0.102 f^2}{1+f^2} + \frac{40.7 f^2}{4100+f^2} dB/km \qquad (3)$$

The value of the absorption coefficient will decrease as the pressure increases. For every 1000m increase in depth, the absorption coefficient decreases by 6.7%.
The sound source level in this experiment is calibrated to 140dB after being monitored by a standard hydrophone. As the water depth decreases, the sound wave attenuation is much less than 1dB, and the sound absorption loss is negligible. The density of ocean bubbles is very small, and the impact of scattering loss can also be ignored.

2.2 Sound wave excited water surface vibration model
Waves are one of the main forms of material motion that widely exist in nature. Water surface waves are one of the most common fluctuations in nature. Wave motion occurs after being disturbed by ships, marine life, wind, snow, and rain. The particles at the water-air interface leave the equilibrium position, showing one after another motion on the water surface; the sound disturbance is caused by the microwave vibration of the water surface caused by the impact of underwater sound sources [9]. The echo signals received by the airborne sensor nodes when illuminating the water surface include water surface waves and acoustic disturbance-microamplitude waves. This section will focus on describing microamplitude waves, microamplitude waves are water surface waves with amplitudes below the micron or submicron level. In this direct cross-domain communication system, the amplitude of particle motion caused by acoustic wave excitation on the water surface is in the nanometre to micron level. The mathematical model of water surface waves can be defined as.

$$A = \frac{2P_i}{w\rho c} e^{-\beta' x} \cos(kx - wt) \tag{4}$$

In the formula, is the amplitude of sound-induced water surface fluctuations, is the energy/sound pressure transmitted to the air-water interface, is the angular frequency of the sound wave, is the density of water, is the sound speed in water, is the wave amplitude attenuation coefficient, is the wave number of water surface fluctuations . In equation (4), the central amplitude of the micro-amplitude wave excited by the incident sound wave on the water surface is proportional to the incident sound pressure and inversely proportional to the vibration frequency. The amplitude of the micro-amplitude wave excited by the point source disturbance on the water surface shows an exponential attenuation law as the lateral propagation distance increases[10]. The figure 2 shows the relationship between the interface particle amplitude, incident sound pressure level and vibration frequency [11].

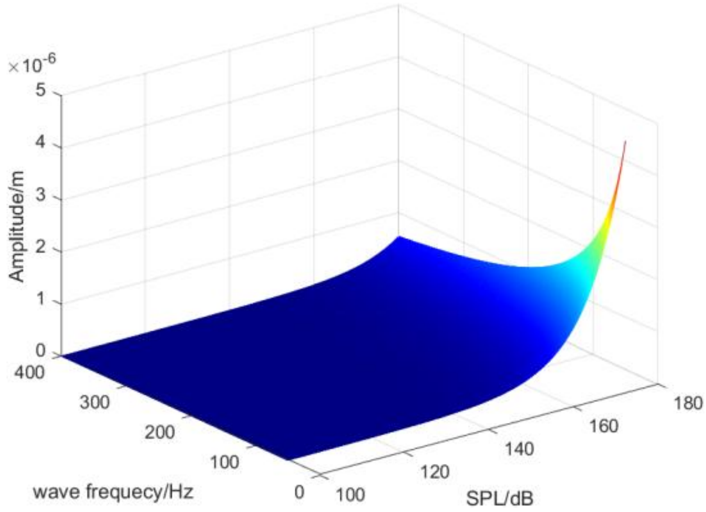

Figure 2. Relationship between interface particle amplitude and incident sound pressure and vibration frequency.

The figure 3 below is a three-dimensional schematic diagram of the micro-amplitude waves on the water surface caused by an underwater sound source of 120Hz[12].

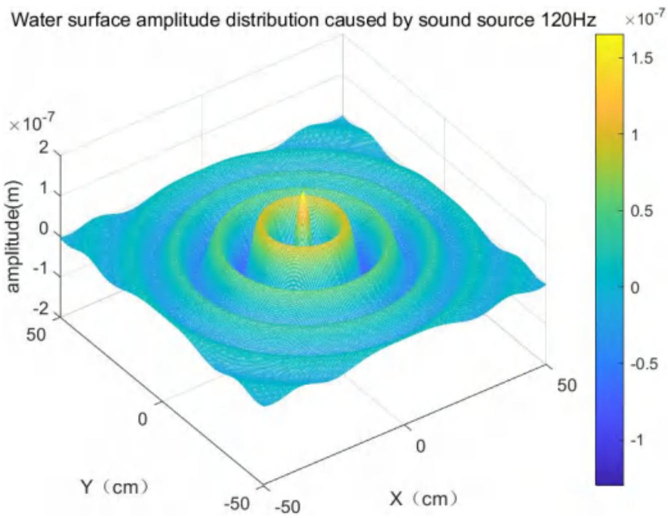

Figure 3. Three-dimensional schematic diagram of microamplitude waves on the water surface

2.3 RF and echo signal analysis

Traveling through the air, a standard radar signal attenuates as is $1/2d_0$. In communication systems, the distance between radar and water surface is usually between 10-150cm, and electromagnetic wave attenuation can be ignored.

The Frequency Modulated Continuous Wave (FMCW) millimetre wave radar has the ability to identify reflective targets at different distances, and the signal whose frequency continuously changes over time within a specific frequency range is called chirp. In fact, when radar transmits signals to measure micro-amplitude waves on the water surface, the target signal can be simply separated from other interference signals in the environment through different 'range gates', specific range gates are extracted respectively, and the range gate correspondence is obtained using Fourier transform Phase. At this time, the phase will be wrapped. Unwind the phase to obtain the phase change of the acoustically disturbed water surface fluctuation [13], finally, Analyse the target frequency information. The following figure is the radar echo signal processing flow chart.

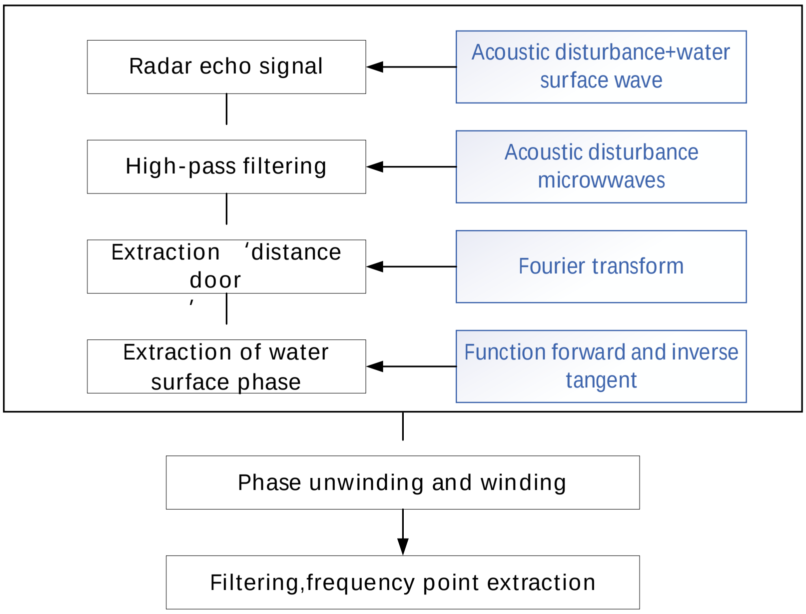

Figure 4. Radar echo signal processing flow chart

Since the microwave amplitude changes on the water surface are at the micron level, direct measurement of the distance changes caused by the change requires terahertz level bandwidth, which is unrealistic for the design requirements of pulse radar. Therefore, this technology uses millimetre-wave radar to illuminate the water surface to obtain the phase changes after mixed filtering of the received signal and the transmitted signal, and estimate the wave height change of the micro-amplitude waves on the water surface.

The phase change φ(t) of the signal can be expressed as.

$$\varphi = 4\pi \frac{A(t)+d}{\lambda} \quad (5)$$

d is the distance between the radar and the water surface when there is no vibration, is the amplitude of the micron-level fluctuation of the acoustic disturbance, and is the wavelength of the radar emitted signal. Equation (5) can explain the reason why the initial phase change extracted from the echo signal is wrapped. In the actual measurement process, the phase is obtained by summing the tangent function of the In-Phase and Quadrature (IQ) two-way signal combination of the millimetre wave radar. The value range is between $(-\pi, \pi)$,When the vibration amplitude of the water surface is greater than half of the wavelength, the actual phase amplitude will exceed it, and the phase will jump, that is, winding occurs, as shown in the figure. To be obtained later the target phase information must undergo an unwinding step.

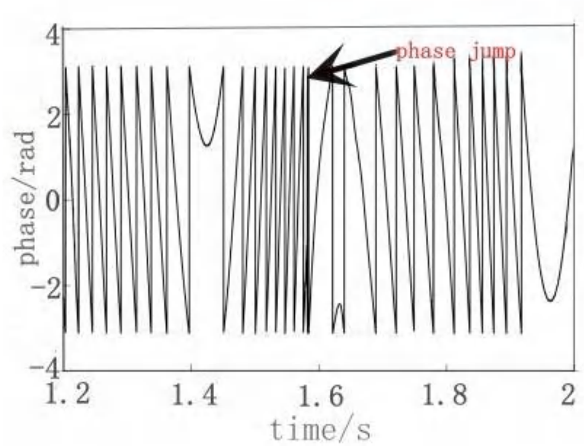

Figure 5. Extracting vibration phase of water surface

3. Experiment

3.1 Experimental verification

Cross-domain communication system construction experiments were conducted in the laboratory and the comprehensive anechoic pool. As shown in the figure, the blue plastic water tank used in the laboratory is 100cm long, 58cm wide, 35cm high, and covers 30cm of water surface. The underwater speaker LT-015 is used as the sound source, the frequency range is 80~20000Hz, the broadcast range is 180°/-180°, placed at the bottom of the water tank, it can achieve full coverage of the water tank. The water tank is as shown below; the anechoic pool is 43m long, 20m wide, and 12m deep. As shown in the picture below, the water surface is completely covered with conical rubber sound-absorbing wedge panels, which are used to absorb various sound waves and form a free sound field environment. The millimetre-wave radar used in this article is supported by a self-made bracket to keep it on the same vertical line as the transducer. The radar irradiation distance is between 0.215m-0.400m on the water surface, and the irradiation range is between 132.5cm^2-170.5cm^2. The sound source used in the anechoic pool is a transducer with a working frequency range of 2KHz-8KHz, which is suspended 40cm underwater through a nylon rope. During the experiment, keep the oscilloscope connected to the standard hydrophone to monitor the signal transmission of the underwater sound source signal, and keep the parameters of the received signal and the transmitted signal highly consistent. During the experiment, the surrounding environment was quiet, no one was moving around, and the test driving lift was not working.

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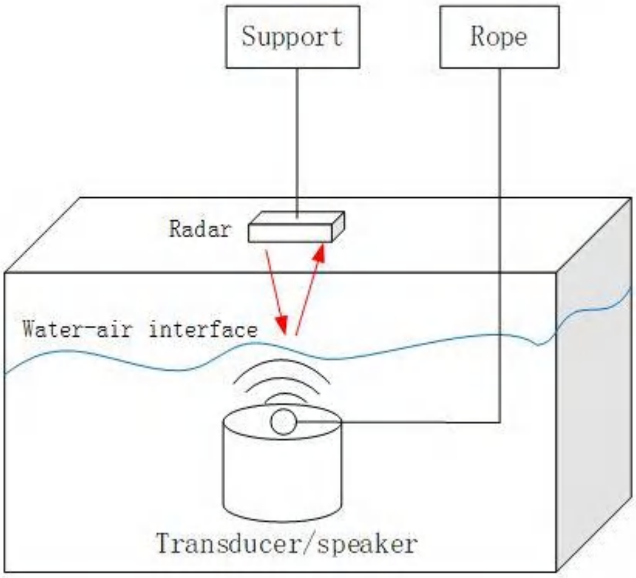
(a) (b)

Figure 6. The experimental site includes (a) water tank and (b) anechoic pool



(a)

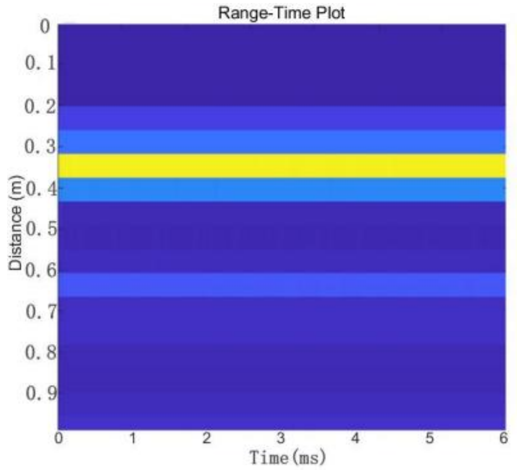
(b) (c)

Figure 7. (a) is the experimental design diagram, Figure (b) is using a speaker as a sound source in a

quiet laboratory environment, Figure (c) is using a transducer with an operating frequency range of 2k-8k in the anechoic pool of Harbin Engineering University sound source

Speakers and transducers are used underwater to emit low-frequency signals and high-frequency signals respectively. In the laboratory water tank, speakers are used to emit several single-frequency signals of different frequencies, including 130Hz and 140Hz. The speakers are placed 28cm underwater, and the radar The sensing device is placed 35cm above the water tank, as shown in Figure 7(b); in the anechoic pool, a transducer is used to emit a single frequency signal of 2kHz, and the transducer is placed 40cm underwater, the millimetre wave radar and data acquisition card are suspended 35cm above the pool through a self-made bracket, and a standard hydrophone is used to collect underwater sound source signals, as shown in Figure 7(c).

The computer is connected to the power amplifier and the transmitting device to send a single-frequency signal. The speaker sends a 130hz single-frequency signal to the calm water surface. At the same time, the radar sensor transmits 25 frames of 400 chirps. Each chirp lasts 400us and has 128 sampling points. The frequency is 4MHz, and the echo signal is obtained. First, judge the distance gate, find the data corresponding to the distance, extract the phase, and perform subsequent processing in Figure 6 to obtain the result in Figure 8. Figure 9 is a 140hz single-frequency signal sent by the speaker to the undulating water surface. The fluctuations are obtained by manually shaking the water tank, trying to simulate the real underwater environment. After the same processing, the target results are obtained. Figure 8(b) shows the phase of the water surface after winding. The range of water surface fluctuations collected by the radar is larger than that of the radar 2 times the wavelength of the emitted wave. The signal with continuous frequency variation over time within a specific frequency range is called chirps. As can be clearly seen from Figure 8, the speaker emits a single frequency signal of 130Hz towards a calm water surface. After processing with this method, the result graph shown in Figure 8 (d) is obtained; The speaker emits a 140Hz single frequency signal towards the fluctuating water surface (with a fluctuation range of approximately 1-3 cm), and after processing with this method, the result graph shown in Figure 9 (d) is obtained.



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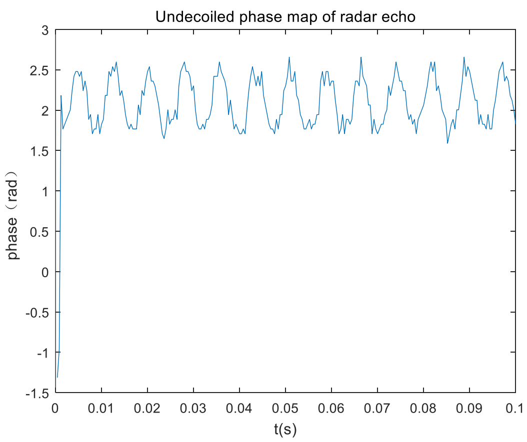

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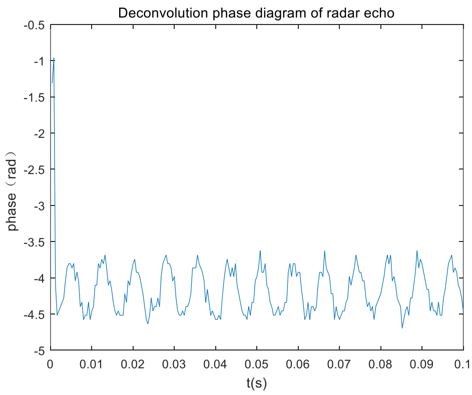

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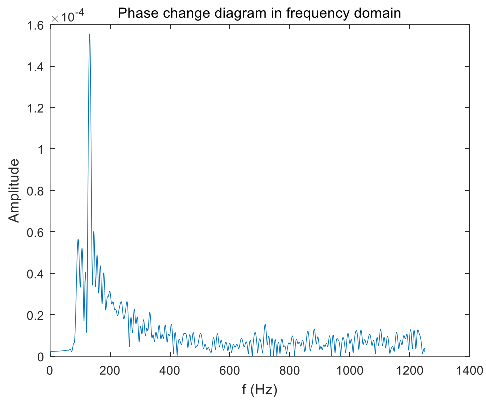
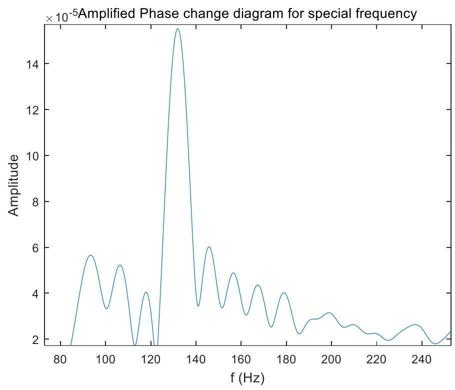
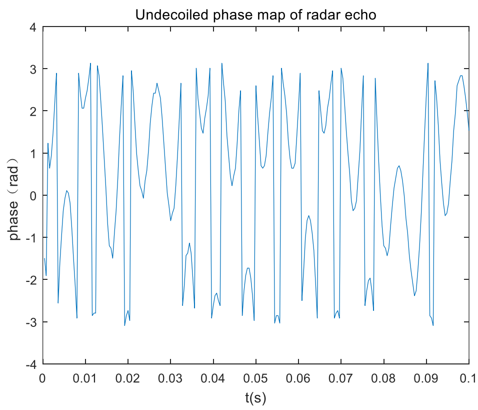


(d)

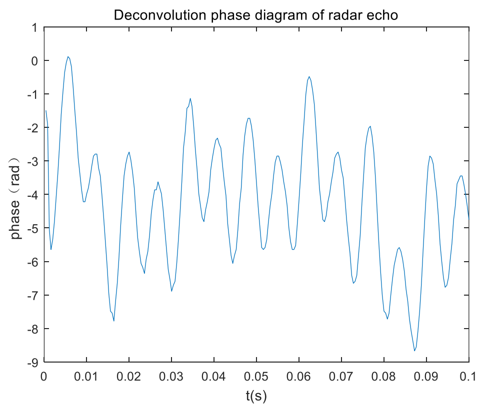


(e)

Figure 8. The echo signal after the radar irradiates the underwater sound source at 130hz to excite the calm water surface. (a) is the 'distance gate' diagram obtained after completing the Fast Fourier Transform (FFT), (b) is the initial phase of the water surface that is solved, (c) is the phase after unwinding, (d) after filtering and Fourier transform, the target frequency is obtained, (e) amplifies the target frequency.



(a)



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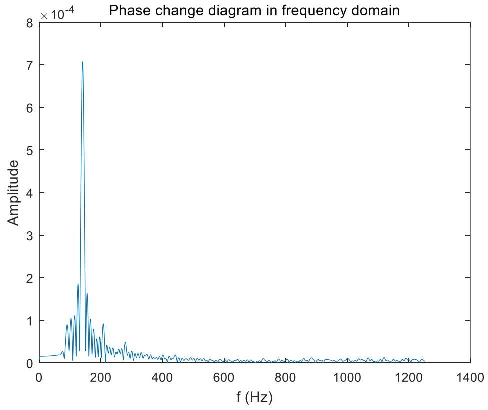

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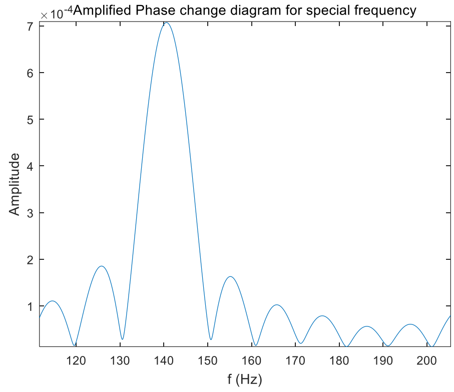

(d)

Figure 9. The echo signal after the radar irradiates the underwater sound source at 140hz to excite the fluctuating water surface (manual fluctuation is 1-3cm). (a) is the initial phase of the water surface that is solved, (b) is the phase after unwinding, (c)is after filtering, the target frequency obtained after completing Fourier transform, (d) amplify the target frequency.

4. Conclusion

This paper theoretically analyses and introduces the principle of one of the communication links of the full duplex communication system, that is, the communication link from underwater to air, and builds a complete communication model in the water tank and pool to carry out experimental verification. Under water, we emit multiple single-frequency signals, which output sound waves through the transducer and speaker respectively. The sound waves hit the water surface to generate fluctuations. The millimetre wave radar on the water surface Measure and decode water surface waves; use existing mature technology to generate laser sound from the air to underwater, and combine the two technologies to achieve relay-free two-way full-duplex cross-media communication [14]. The proposal and description of this system provide theoretical and experimental basis for future cross-media communication between underwater nodes and air nodes.

References

[1] Liu BoSheng,Huang YiWang,et al.Principles of Aquatic Acoustics(Third Edition) [J]. Journal of Acoutics. 2020,45(04):609.DOI:10.15949/j.cnki.0371-0025.2020.04.019.
[2] Luo H, Wang J, Bu F, et al. Recent progress of air/water cross-boundary communications for underwater sensor networks: A review[J]. IEEE Sensors Journal, 2022, 22(9): 8360-8382.
[3] Sangeetha R S, Awasthi R L, Santhanakrishnan T. Design and analysis of a laser communication link between an underwater body and an air platform[C]//2016 International conference on next generation intelligent systems (ICNGIS). IEEE, 2016: 1-5.
[4] Li QiuShi,Zhao XiaoM et al.a new all-fiber laser sound source system for marine hydroacoustic communicatiion. Proceedings of the National Acoustics Academic Conference.2016.
[5] Muzzammil M, Ahmed N, Qiao G, et al. Fundamentals and advancements of magnetic-field communication for underwater wireless sensor networks[J]. IEEE Transactions on Antennas and Propagation, 2020, 68(11): 7555-7570.

[6] ZHANG Xiaolin, MAO Hongjie, LI Kai, et al. Amplitude detection of low frequency water surface acoustic wave based on phase demodulation[J]. Infrared and Laser Engineering, 2019, 48(5): 0506001. doi: 10.3788/ IRLA201948.0506001.

[7] Tonolini F, Adib F. Networking across boundaries: enabling wireless communication through the water-air interface[C]//Proceedings of the 2018 Conference of the ACM Special Interest Group on Data Communication. 2018: 117-131.

[8] MA Dayou. Fundamentals of Modern Acoustic Theory[M].Beijing: Science Press, 2004: 65–68].

[9] Ghadimi P, Feizi Checkab M A, Bolghasi A. Simulation of wind-generated surface waves and effects of bubbles on scattering, transmission, and attenuation of low frequency sound at the sea surface[J]. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2017, 39: 2467-2486.

[10] Ma L , Qiao G , Yang J ,"Underwater Acoustic Communication," acta Acustica, 2020.

[11] Zhang L. Research on optical heterodyne detection technology for acoustically induced water surface capillary waves[J]. Ph. D. Thesis, 2017.

[12] Dai Zhenhong,SUN Jinzuo,et al. The theory of horizontal microwaves on the surface of water caused by underwater sound sources[D],2004.

[13] Zhu D, Liu Y, Li K, et al. Feature extraction for target with micro-motion based on radar phase derived range[J]. J. Astronaut, 2013, 34(4): 574-582.

[14] Z. Shang, M. Li, Y. An, H. Yu, Y. Wang and J. Qin, "Data Splitting Method based on Air-Sea Cross-Domain Gateway Communication Information Transmission," 2022 IEEE International Conference on Unmanned Systems (ICUS), Guangzhou, China, 2022, pp. 1518-1522

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Full-duplex two-way no-relay cross-media communication method based on acoustic wave conversion

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Abstract

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Indexing

Main heading:
Acoustic waves

Controlled terms:

Acoustic surface wave devices   Circular waveguides   Light transmission

Telecommunication repeaters   Underwater acoustics

Uncontrolled terms:

Acoustics waves   Communication method   Cross-media   Full-duplex

Media communications   Two ways   Underwater sound   Water interface

Water surface   Wave conversion

Classification codes:

714.3 Waveguides

716 Telecommunication; Radar, Radio and Television

741.1 Light/Optics

751.1 Acoustic Waves

752.1 Acoustic Devices

Metrics

Scopus

4

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编号：GEDC-02240900946

二〇二四年八月

荣誉证书

参赛单位：哈尔滨工程大学

参赛作品：空海跨域通信网关系统

指导教师：商志刚

参赛队员：邢铭涵 苗柏露 周一文

在“兆易创新杯”第十九届中国研究生电子设计竞赛中，荣获技术类竞赛初赛团队一等奖，特此表彰！

中国学位与研究生教育学会　　中国科协青少年科技中心　　中国电子学会

编号：GEDC-02240100707

二〇二四年七月