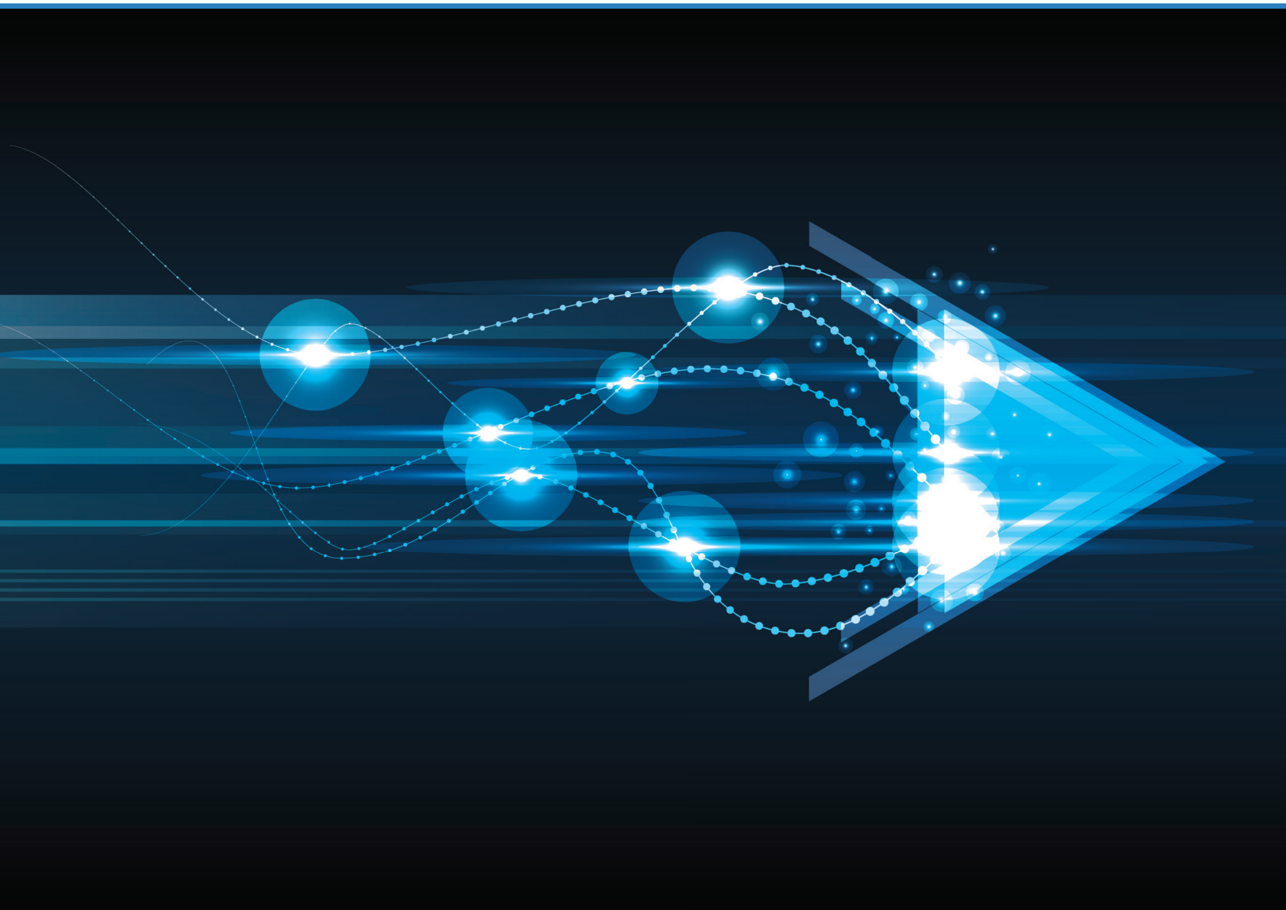
RIGA TECHNICAL UNIVERSITY

Aleksandr Krotov

DEVELOPMENT OF OPTICAL COMMUNICATION SYSTEMS WITH HIGH-RELIABILITY OPTICAL SENSORS

Summary of the Doctoral Thesis



RTU Press
Riga 2024

RIGA TECHNICAL UNIVERSITY
Faculty of Computer Science, Information Technology and Energy
Institute of Photonics, Electronics and Telecommunications

Aleksandr Krotov

Doctoral Student of the Study Programme "Telecommunications"

DEVELOPMENT OF OPTICAL COMMUNICATION SYSTEMS WITH HIGH-RELIABILITY OPTICAL SENSORS

Summary of the Doctoral Thesis

Scientific supervisors

Professor Dr. sc. ing. Vjačeslavs Bobrovs

Ph.D. Svitlana Matsenko

RTU Press

Riga 2024

Krotov, A. Development of Optical Communication Systems with High-Reliability
Optical Sensors. Summary of the Doctoral Thesis.
Riga: RTU Press, 2024. 35 p.

Published in accordance with the decision of the Promotion Council
"P- 08" of 24 May 2024,
Minutes No. 33.

Cover picture from *shutterstock.com*

https://doi.org/10.7250/ 9789934370984
ISBN 978-9934-37-098-4 (pdf)

DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for defence at the open meeting of RTU Promotion Council on 30 August 2024 at the Faculty of Computer Science, Information Technology and Energy (FCSITE) of Riga Technical University (RTU), 12 Azenes Str., Room 201.

OFFICIAL REVIEWERS

Researcher Ph.D. Semen Chervinskii
Tampere University, Finland

Professor Ph.D. Lu Zhang
Zhejiang University, China

Professor Dr.sc.ing. Aleksandrs Ipatovs
Riga Technical University

DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for review to Riga Technical University for promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis has not been submitted to any other university for promotion to a scientific degree.

Aleksandr Krotov …………………………… (signature)

Date: ………………………

The Doctoral Thesis has been prepared as a thematically united collection of scientific publications. It comprises eight scientific articles and publications in conference proceedings proceeding from the author's existing works indexed in SCOPUS, WoS, and IEEE databases. The publications are written in English; their total volume is 62 pages.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my Scientific supervisor, Professor Vjačeslavs Bobrovs, for his invaluable guidance, support, and encouragement throughout the research and writing of this Doctoral Thesis. His expertise and dedication have been instrumental in shaping this work.

I am also grateful to my scientific supervisor, PhD Svitlana Matsenko, for her valuable insights and feedback that have greatly enriched this thesis.

Special thanks to Prof. Igor Nikulsky, Assoc. Prof. Toms Salgals, Professor Aleksandr Shalin, and Professor Pavel Ginzburg, for your valuable input and support throughout this study.

I sincerely thank my colleagues Dmitrii Redka and Aleksei Kuznetsov for their collaboration and assistance in various aspects of this research project.

I am also indebted to all my teachers for their knowledge and guidance, which have shaped my academic journey.

I would like to express my heartfelt appreciation to my parents for their unwavering support, encouragement, and belief in me throughout my academic pursuits.

Last, but not least, I am deeply grateful to my Wife for her patience, understanding, and unwavering support during the challenging times of this research. Her love and encouragement have been my source of strength.

Thank you to all who have contributed to the completion of this thesis!

The most special thanks for this important stage of my life to the entire team of Riga Technical University!

Thank you, dear colleagues!

Aleksandr Krotov

LIST OF ABBREVIATIONS

A
AE – *Aviation Equipment*
ADC – *Analog-to-Digital Converter*
AirDC – *Air Data Computer*
APC – *Angled Physical Contact*
ARINC – *Aircraft Digital Video Interface*
B
BER – *Bit-Error-Rate*
BIC – *Bound States in the Continuum*
BRAS – *Broadband Remote Access Server*
C
CCD – *Charged-Coupled Device*
CDRSP – *Central Device for Switching and Routing Packets*
CPA – *Coherent Perfect Absorption*
CSMA/CD – *Carrier Sense Multiple Access with Collision Detection*
CWDM – *Coarse Wave Division Multiplexing*
D
DNSSN – LZP Project "Dynamics of Non-Scattering States in Nanophotonic"
DSRP – *Device for Switching and Routing Packets*
E
EM – *Electronic Module*
EMC – *Electromagnetic Compatibility*
EMF – *Electromagnetic Fields*
ENC – Exceptional Points of Non-Conservation
ENZ – *Epsilon Near-Zero*
F
FS – *Functional Systems*
FEC – *Forward Error Correction*
FOC – *Fiber-Optic Communication*
FCSITE – *Faculty of Computer Science, Information Technology and Energy*
G
GMI – *Generalized Mutual Information*
GPON – *Gigabit-Capable Passive Optical Network*
GPNS – *Generalized Positional Numeral Systems*
H
HDR – *High Data Rate*
HIRF – *High-Intensity Radiated Field*
I
IEEE – *Institute of Electrical and Electronics Engineers*
IP – *Internet Protocol*
IPTD – *Average Network Transmission Delay*
IPDV – *Average Network Data Variation*
IPTV – *Internet Protocol Television*
IPET – *Institute of Photonics, Electronics and Telecommunications*
K
KTH – *Royal Swedish Technical University*
L
LDPC-IRA – *Low-Density Parity-Check Irregular Repeat Accumulate*
LDPC – *Low-Density Parity Check*
LED – *Light-Emitting Diode*
LZP – *Latvian Council of Science*
M
MUX – Multiplexer
N
NIR – *Near-Infrared*
O
OLT – *Optical Line Terminal*
P
PAM – *Pulse-Amplitude Modulation*
PAM-M – *Multi-level Pulse Amplitude Modulation*
PD – *Photodetector*
PHOTON – LZP Project "Novel complex approach to the optical manipulation of nanoparticles"
PON – Passive Optical Network
PS – *Power Splitter*
Q
QAM – *Quadrature Amplitude Modulation*
QoS – *Quality of Service*
R
RAM – *Random Access Memory*
REE – *Radio Electronic Equipment*
RF – Radio Frequency
RLS – *Radio Location System*
RR – Radio Receivers
RTU – *Riga Technical University*
Rx – Receiver
S
SC – *Subscriber Connector*
SNR – Signal-Noise Ratio
T
TAU – *Tel Aviv University*
Tx – *Transmitter*

U
UAV –*Unmanned Aerial Vehicles*
V
VoIP – *Voice Over Internet Protocol*
W
WDM – *Wavelength Division Multiplexing*
WDM-PON – *Wavelength Division Multiplexed Passive Optical Network*
WoS – *Web of Science*

CONTENTS

CHAPTER 1: OVERVIEW

1.1. Introduction

The development and improvement of modern aircraft onboard radio-electronic equipment (avionics) is associated with the implementation of information and telecommunication technologies. As a result, the requirements for data transmission networks on aircraft are constantly growing [**1**]. On the one hand, every year, the improvement of subscriber devices (traffic generators) of the aircraft on-board network [**2**], [**3**] requires increased performance of aircraft onboard information and telecommunication networks: greater throughput, scalability, ensuring the required level of delays [**4–6**]. On the other hand, the execution of these requirements must be ensured with unconditional compliance with the mass-dimensional characteristics of avionics and the tendency to decrease them.

As a rule, any technical decision taken in relation to aviation equipment (AE) proceeds from a compromise between the weight, size, and characteristics that the AE product must provide while considering the fact that the AE has strict requirements for resistance to external factors, reliability, and electromagnetic compatibility [**7**], [**8**]. According to the complexity of the testing cycle of single products and the increasing complexity of the task, problematic situations often arise during the development or modernization of systems, complexes, and sets of AE. In particular, the solution to the problem of ensuring the proper characteristics of on-board information and telecommunications networks is complex [**9**], [**10**] but does not exclude the requirements imposed on the components of the whole system.

In aviation, the object of electromagnetic compatibility (EMC) research is an aircraft and its onboard equipment capable of generating electromagnetic interference [**11**] or being susceptible to it. A special research object is the external electromagnetic fields on the flight paths. The aircraft's onboard devices are divided into radio-electronic, electronic, and electromechanical; they are divided into potential sources and receptors of unintentional interference [**12**]. The EMC of the aircraft's onboard equipment is determined by the characteristics of three main objects: sources of unintended interference, interference detectors, and the environment in which interference is propagated from the source to the receptor.

Unintentional disturbances are considered sources of interference formed during the operation of aircraft onboard equipment and radiations of radio transmitting devices located outside the aircraft (land-based and sea-based and other aircraft). Onboard radio transmitters are the most powerful sources of unintentional interference on the aircraft [**13**]. They emit continuous and pulsed signals in the frequency range from 2 MHz to 10 GHz. Their capacities are 20... 400 watts for continuous signals and up to several kW for pulsed. The spectrum consists of the main and extra-local radiation, radiation at harmonics of the operating frequency, noise and transit radiation [**14**], [**15**]. Potential sources of interference in the aircraft are pulse power converters, engine ignition systems, pulse de-icing systems, and digital electronic systems [**16**]. The main parameters of the interference sources are the following: the interference power in the radio frequency (RF) range (f) and the width of the spectrum of generated interference ΔFgen(f).

According to the degree of impact of failure on flight safety, aircraft systems are divided into four levels: **A**, **B**, **C** and **D** [**17**]. Level **A** includes systems that perform so-called "critical" functions. Their violation leads to catastrophic consequences [**18**]. Examples are telecommunications systems on board, electrical control, engine control, etc.

Level **B** includes electrical and electronic systems that perform a function, the violation of which leads to an emergency situation.

Level **C** includes electrical and electronic systems that perform functions, the violation of which significantly complicates flight conditions.

Level **D** includes electrical and electronic systems that perform functions, the violation of which does not significantly complicate the conditions of the flight.

Communication systems and aircraft navigation support systems are examples of level B and C systems, which are display systems that provide direction, location, and route data. Failure of a level B or C system is not catastrophic, but it can contribute to other failures.

To date, the greatest danger is expected from the impact of pulsed radiation fields at frequencies from 400 MHz to 10 GHz [**19**], [**20**], which mainly affect electronic circuits.

1.2. Rationale

Analysis of trends in the development of onboard information and telecommunication networks [**21–23**] and sensors [**24**], [**25**] in the conditions of high-intensity electromagnetic fields has allowed us to establish that significant improvements in the resistance of information networks to high-intensity electromagnetic fields are urgently needed today.

As a result of the analysis of the means of increasing durability, network organization and noise-resistant coding methods were identified, and sensors onboard aircraft were considered. System methodological problems and contradictions in the construction of networks, organization of coding, and use of pressure sensors were identified.

The analysis of existing scientific works in this field of research has shown that to build a secure network with guaranteed delivery of messages under increased electromagnetic impact [**26**], [**27**], modernization of the scientific and methodological apparatus is required. For these purposes, the prospects of applying the mainline fault-tolerant coding methods and the application of optical sensors to a new area of research are substantiated. This will allow methodological problems to be solved caused by the influence of electromagnetic fields on the onboard information and telecommunication network [**28**], [**29**].

The disadvantages of existing networks include the use of fiber channel cables with high weight and relatively low throughput, low resistance of transceivers to the effects of fields, as well as high susceptibility of electronic sensors of static and full pressure to the impact of EMV [**30**], [**31**].

1.3. The aim and theses of the Doctoral Thesis

Summarizing the above-mentioned facts about the directions of development of on-board information and telecommunication networks and sensors in the conditions of high-intensity electromagnetic fields, the following **aim of the Doctoral Thesis is proposed:**

Experimentally develop approaches to the construction of information systems based on optical sensors and broadband access facilities that ensure the transmission of traffic from subscribers of the onboard network, meeting the requirements for ensuring the level of delays and requirements for electromagnetic compatibility of onboard equipment providing the possibility of including new devices in the existing network and upgrading existing ones.

To achieve the aim set, the following theses were put forward:

1. A specialized code implementation with irregular repetition and forward error accumulation more than triples the signal transmission efficiency of the aircraft's high-speed digital video interface using 16-QAM (quadrature amplitude modulation) and improves system stability when exposed to high-intensity radiated fields.
2. The use of deformable CuBe2Ni(Co) bronze membranes with a sinusoidal profile and a rigid center, along with light-emitting diodes and charge-coupled device arrays, for measuring membrane deflection allows for increasing the precision of absolute and static pressure sensor measurements by at least 50 %, reducing energy consumption by at least 70 %, decreasing the processing time required for information processing, and reducing the weight of the final sensor by at least 25 %, compared to frequency absolute and static pressure sensors.
3. By introducing asymmetry in the distribution of losses and gains through altering the thickness of the layers, one can transition to the point of generating coherent ideal absorption, characterized by a significant increase in generation intensity and a sharp rise in the quality factor exceeding 10^8.

1.4. The key tasks of the Doctoral Thesis

To achieve the set aim of the Thesis and to prove the proposed theses, it is necessary to perform the following **key tasks:**

1. Develop and implement a fiber optic access network and aircraft onboard network that optimizes channel resource allocation at specific wavelengths, leading to improved quality-of-service (QoS) indicators for traffic within the network that doubles network capacity compared to traditional wave multiplex technologies.
2. Develop a new pressure sensor, showcasing significant enhancements and performance indicators and improved efficiency gains that reduce data transmission, lower supply voltage requirements, and contribute to enhanced energy efficiency and system performance.
3. Explore the potential of non-Hermitian photonics based on insights gained from research, emphasizing the asymmetric characteristics that can be harnessed to achieve desired optical functionalities, therefore, pave the way for further studies in advancing photonics technology and addressing challenges across various domains.
4. Enhance transmission efficiency within the ARINC-818 communication protocol by integrating LDPC-IRA coding, surpassing traditional methods by more than threefold and therefore addressing challenges related to high-intensity radiated fields (HIRF) interference, thereby enhancing system stability and reliability through improved coding efficiency.

1.5. Research methods

To perform the tasks outlined in the Doctoral Thesis and to analyze the problems, mathematical calculations, numerical simulations, and experimental measurements have been used. Numerical simulations were implemented in RSoft OptSim and VPI Design Suite simulation software, which are based on the nonlinear Schrödinger equation using the split-step method, the Fourier transform, and the Monte Carlo method for estimating the bit-error-rate (BER). Mathematical processing was also performed in Matlab, COMSOL, Ansys Lumerical, GPSS World, etc., mathematical modelling software.

The scientific experiments described in the Doctoral Thesis were carried out at the Institute of Photonics, Electronics and Electronic Communications (IPEEC) of Riga Technical University (RTU) and at the Dynamics of Nanostructures' Laboratory at Tel Aviv University (TAU) in Israel.

1.6. Scientific novelty and main results

Novel achievements of the Doctoral Thesis are as follows:

1. The novelty of the Thesis is the developed methods of building high-reliability networks based on fiber optic access means and using optical sensors.
2. A new approach has been developed and tested to ensure traffic transmission from subscribers of the onboard network.
3. The concept of the coherent perfect absorption lasing associated with the quasibound state in the continuum or asymmetric non-Hermitian epsilon-near-zero-containing layered structures was proposed.
4. All new design of full and static pressure sensors with high accuracy in determining the deformation, high speed, and optical interface was developed.

Practical value of the Doctoral Thesis:

1. High-reliability networks: The developed methods for building high-reliability networks based on fiber optic access means and using optical sensors provide a robust and efficient infrastructure for communication systems. This can improve network performance, increase reliability, and enhance data security.
2. At the Institute of Photonics, Electronics and Telecommunications (IPET) of RTU Faculty of Computer Science, Information Technology and Energy, an optical telecommunication onboard system with ARINC-818 interface capable of transmission in HIRF environment and capable of changing FEC on the channel *(proposed for further experimental research)* has been experimentally developed and evaluated in mathematical simulation.
3. Transmission of traffic from subscribers: The new approach developed and tested to ensure the transmission of traffic from subscribers of the onboard network offers a solution for efficient data transfer within networks, especially in scenarios involving

multiple subscribers. This can optimize network resources and improve data transfer speeds.

4. At the Institute of Photonics, Electronics and Telecommunications (IPET) of RTU Faculty of Computer Science, Information Technology and Energy FCSITE, a gigabit-capable passive optical network (GPON)-based high- potential setup with multiple subscribers for guaranteed traffic delivery checks for high-reliability networks has been created *(and is proposed for further experimental research).*
5. Coherent perfect absorption lasing concept: The proposed concept of coherent perfect absorption lasing associated with the quasibound state in the continuum or asymmetric non-Hermitian ENZ-containing layered structures introduces a novel approach to lasing technology. This concept can potentially enhance the efficiency and performance of lasing devices, leading to advancements in laser technology.
6. Full and static pressure sensor design: The new design of a full and static pressure sensor with high accuracy in determining deformation, high speed, and optical interface offers a significant advancement in sensor technology. This sensor can be utilized in various applications, such as industrial monitoring, medical devices, and structural health monitoring, providing precise and reliable measurements.
7. At the Institute of Photonics, Electronics and Telecommunications of RTU Faculty of Computer Science, Information Technology and Energy, a practical setup for verification of the functioning and assessment of the metrological characteristics of the developed design of the static and total pressure sensor according to the criterion of increasing the accuracy and speed has been experimentally developed and evaluated.
8. Overall, the practical value of this Doctoral Thesis lies in its innovative contributions to optical communication systems, sensor technology, and lasing concepts, which can potentially drive advancements in various industries and applications.

The results obtained in the Thesis were used in the following projects:

- LZP project "*Novel complex approach to the optical manipulation of nanoparticles (PHOTON)*" No. lzp-2022/1-0579.
- LZP project "*Dynamics of non-scattering states in nanophotonic (DNSSN)*" No. lzp-2021/1-0048.
- LZP project "*Novel non-Hermitian singularities in all-dielectric nanostructures (NEO-NATE)*" No. lzp-2022/1-0553.

1.7. Structure of the Thesis

The Thesis is prepared as a thematically unified set of publications on the development of optical communication systems with high-reliability optical sensors and optical networks.

*Chapter 1: Overview***.** This chapter describes the scope of the research, formulates the main research hypotheses, and discusses the importance of the novelty of research related to onboard access systems. It also presents a brief description of the Thesis structure and displays the list of publications and presentations at international conferences.

Chapter 2: Methodology. This chapter describes the fundamental factors necessary for successful quality of service improvement and basic approaches for the development contents of high-reliability networks. Three main stages are outlined.

2.1. Data Collection. The procedure is discussed in detail, which could be divided into three sub-stages.

2.2. Data Analysis. This subchapter considers different ways to get high-reliability optical networks according to collected data.

2.3. Methodology development. This subchapter presents the algorithms for forward error correction, methods of coherent perfect absorption and approaches for optical sensors for inclusion in information systems, including fundamental solid principles for robust light enhancement systems

Chapter 3: Main results. This chapter represents publications that reflect the main results obtained during the research and application of fiber optics communications and sensors onboard. The results are published in five cited sources in journals indexed in Scopus.

Chapter 4: Final remarks. This chapter represents the main conclusions and discussion of the challenges and their solutions concerning the practical application of optical communication systems with high-reliability optical sensors and broadband access.

1.8. Publications and approbation of the Thesis

The results of the Doctoral Thesis are presented in eight scientific articles and publications in conference proceedings indexed in SCOPUS, Web of Science (WoS), and Institute of Electrical and Electronics Engineers (IEEE) databases. The author has eight publications altogether. The main results of the Thesis were summarized in three scientific journals. The results of the research were presented at three conferences.

The results of the Doctoral Thesis have been presented at three international scientific conferences.

1. **A. Krotov**, M. Krotov, S. Matsenko, T. Salgals, V. Bobrovs, "*Aircraft Optical Video Transmission Communication based on the Forward Error Correction Codes,*" 2023 Photonics & Electromagnetics Research Symposium (PIERS), Prague, Czech Republic, (**2023**), DOI: 10.1109/PIERS59004.2023.10221478
2. **A. Krotov**, S. Tarasov, A. Lunev, R. Borisov, D. Kushevarova, "*Data Acquisition and Processing Algorithm for Total and Static Pressure Measurement System*," Engineering Proceedings, (**2022)**, 27(1):23, DOI: 10.3390/ecsa-9-13332
3. S. Matsenko, S. Spolitis, O. Borysenko, M. Pudzs, **A. Krotov**, V. Bobrovs, "*LDPC Code with Fractal Decoder Device for 100 Gbps PAM-M Optical Interconnect*," 2021 Photonics & Electromagnetics Research Symposium (PIERS), Hangzhou, China, (**2021**), DOI: 10.1109/PIERS53385.2021.9695128

The results of the author's Doctoral Thesis are presented in eight scientific articles and conference proceedings indexed in SCOPUS, WoS, and IEEE databases:

1. **A. Krotov**, M. Krotov, S. Matsenko, T. Salgals, V. Bobrovs, "*Aircraft Optical Video Transmission Communication based on the Forward Error Correction Codes,*" 2023

Photonics & Electromagnetics Research Symposium (PIERS), Prague, Czech Republic, (**2023**), DOI: 10.1109/PIERS59004.2023.10221478

2. D. Novitsky, A. C. Valero, **A. Krotov**, T. Salgals, A.S. Shalin, A. Novitsky "*CPA-Lasing Associated with the Quasibound States in the Continuum in Asymmetric Non-Hermitian Structures*, " ACS Photonics. 9., (**2022**), DOI: 10.1021/acsphotonics.2c00790
3. **A. Krotov**, S. Tarasov, A. Lunev, R. Borisov, D. Kushevarova, "*Data Acquisition and Processing Algorithm for Total and Static Pressure Measurement System*," Engineering Proceedings, (**2022**), 27(1):23, DOI: 10.3390/ecsa-9-13332
4. R. Borisov, I. Antonec, **A. Krotov**, S. Tarasov, V. Bobrovs, "*Methodology for the Static and Total Pressure Sensor Development Based on Elastic Sensing Elements and Linear CCD Matrices*," International Review of Mechanical Engineering (IREME), (**2022**), Vol. 16, No. 1, DOI: 10.15866/ireme.v16i1.21118
5. S. Matsenko, O. Borysenko, S. Spolitis, A. Udalcovs, L. Gegere, **A. Krotov**, O. Ozolins, V. Bobrovs, "*FPGA-Implemented Fractal Decoder with Forward Error Correction in Short-Reach Optical Interconnects*," Entropy, (**2022)**, 24(1):122, DOI:10.3390/e24010122
6. S. Matsenko, S. Spolitis, O. Borysenko, M. Pudzs, **A. Krotov**, V. Bobrovs, "*LDPC Code with Fractal Decoder Device for 100 Gbps PAM-M Optical Interconnect*," 2021 Photonics & Electromagnetics Research Symposium (PIERS), Hangzhou, China, (**2021**), DOI: 10.1109/PIERS53385.2021.9695128
7. **A. Krotov**, S. Artamonov, K. Kuprenyuk, V. Nikitina, N. Romanov, E. Sosnov, "*Possibilities for Increasing the Signal-To-Noise Ratio in Technical Vision Systems of Robotic Complexes Using Laser Structured Lighting*," International Review of Mechanical Engineering (IREME), (**2018**) 12. 328., DOI: 10.15866/ireme.v12i4.14583
8. **A. Krotov**, D. Volkov, N. Romanov, N. Gryaznov, E. Sosnov, D. Goryachkin, "*Method for measuring distortion in wide-angle video channels*," Journal of Applied Engineering Science, (**2018**), 16. DOI: 10.5937/jaes16-17344

CHAPTER 2: METHODOLOGY

2.1. Development of a mathematical model in the simulation environment of an information and telecommunication network

The main approaches to assessing the quality of service of Internet Protocol (IP) networks are specified in recommendation Y.1541 [**32**], according to which the leading indicators of the quality of service of multimedia traffic are the average network delay of the packet (frame) transmission of IP packet transfer delay (IPTD) and its variation (jitter) IP delay variation (IPDV).

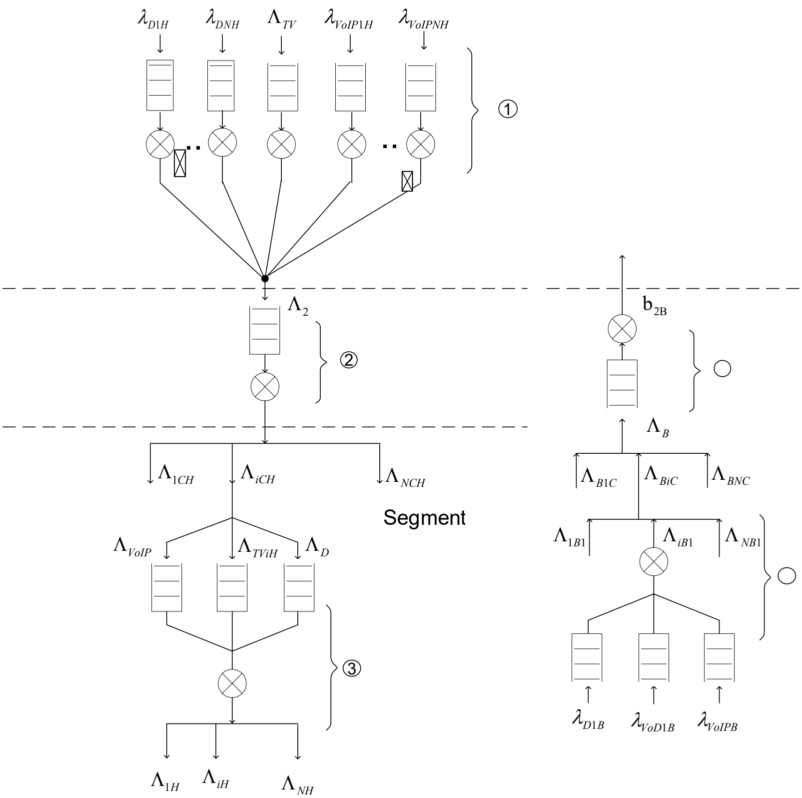


Fig. 2.1. Structure of the analytical model.

There is a GPON-based access network segment that is affected by three classes of subscriber traffic [**33**]:

- In the downstream branch: traffic (highest service priority), with an average intensity λ_{1HI} …λ_{NHI} to all NN subscribers of the considered section of the access network, traffic (average service priority), with an average intensity Λ_{MI}, traffic of data transfer services to NN subscribers (lowest priority), with average intensity λ_{1LI}…λ_{DNI}.

- In the ascending branch: traffic of the highest priority, with an average intensity λ_{EH}, traffic of requests from one subscriber (medium priority) with an average intensity of λ_{1EM}, traffic of data transfer services from one subscriber (lowest priority) with an average intensity of λ_{1EM}. There are Nc segments operating in the broadband segment, each of which has N subscribers. It is required to determine the average IPTD packet (frame) delay for all types of traffic and the IPDV delay deviation [**34**] for traffic in the downstream and upstream branches. VoIP and IPTV.

Available coarse wavelength division multiplexing multiplexers (CWDM-MUX) were used as the network end of the central OLT node (CWDM-MUX 1x4 1550-1610 3.0 LC/APC 1.5 m were used for the four-port laboratory prototype). Devices for dividing propagation directions are connected to each of the divided ports of the multiplexer. These devices are made based on 1×2 planar splitters, which provide significant attenuation of the opposite direction of propagation (up to 30–40 dB) [**35**]. The single-fiber optical line used in the laboratory prototype tested was a 40 km line (4 reels of Fujikura fiber, 10 km each, connected in series).

Since the difference of the proposed network is the application in its segments of the principle of separating transmission directions according to the directions of propagation of the light flux [**36**], [**37**], in such a network, the manifestation of mutual influence (interference) of transmission directions is inevitable, which is an additional source of specific interference and restrictions.

As a prototype, a block of random multiple access to a monochannel using the carrier-sense multiple access with collision detection (CSMA/CD) method [**38**] was chosen, and the random-access method with conflict resolution using the CSMA/CD method was used. There is a multiple access block with asynchronous random access to a monochannel that allows conflicts (collisions) of information frames transmitted over the network.

An obvious disadvantage of existing systems is the possibility of information packet loss when transmitted through the network. Losses occur when frames received with errors are discarded in the receiving part of the access blocks [**39**], [**40**]. This disadvantage persists in modern networks that work with similar access units using Ethernet technology. This circumstance significantly limits the use of networks with access units in real-time data transmission systems that require guaranteed transmission of messages within a given limited time interval [**41**]. In systems using such an access method, data confirmation and auto-request of frames received with errors (discarded at the access level) are carried out by software protocols of the upper levels of the network hierarchy, which requires a period of time depending on the performance of computing devices, and the CSMA/CD access protocol used in the prototype does not provide a guaranteed frame transmission time in the event of errors and conflicts (in heavy load and interference modes). All these shortcomings limit the use of such widespread systems in conditions where strict requirements are imposed on the reliability (absence of losses and errors) of message transmission and the delay in transmitting frames through the network. Such requirements are imposed, for example, when transmitting control commands and other information in distributed real-time control systems [**42**].

Network operation in conditions of high-intensity fields involves the creation of such an optical local network access unit with guaranteed message delivery, which will ensure guaranteed delivery and low latency of information frames transmitted in the local network at the access level over the entire load range, will allow the implementation of a conflict-free access method, and will provide protection from errors that occur when transmitting frames through a common channel [**43**], [**44**], as well as low susceptibility to the effects of electromagnetic interference, interference and complete electrical isolation of the terminals included in the network, which creates additional noise immunity due to the lack of possibility of stray currents flowing [**45**], [**46**], in addition, a network built based on the proposed access devices, assumes passive nodes and an economical single-fiber infrastructure, that is, it should ensure energy saving and resource conservation.

To achieve this goal, it is proposed to supplement the prototype with an optical transmitter, an optical receiver, a separating device, a transmitter and receiver of commands, a reference generator, an address setter, an analyzer, a switch, and an interface unit.

2.2. Development of approaches for optical pressure sensors for the information and telecommunication networks in aircraft

The proposed sensor (Fig. 2.2) for static and total pressure contains a housing (1) with two holes, respectively, for measuring static Pst and total Ptot pressure, and the holes are located above and below the gap formed by membranes (2) and (3).

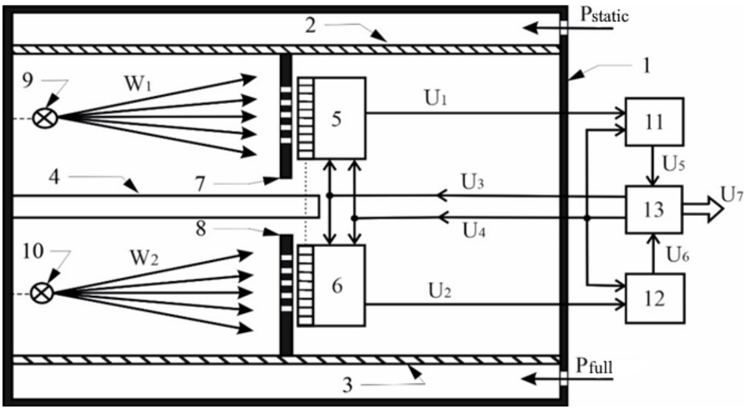


Fig. 2.2. Pressure sensor:
1 – housing with two holes; 2 and 3 – membranes; 4 – stand; 5 and 6 – photodetectors; 7 and 8 – curtains with slits (slots); 9 and 10 – radiation sources; 11 and 12 – analog-to-digital converters (ADCs), 13 – microcontroller.

In the initial state, membrane 2 of the aneroid-sensitive element occupies a certain position. Optical radiation W_1 from source 9 falls on curtain 7 and, passing through n slits, forms n light spots the size of several elements (pixels) of the line on the photosensitive surface of the photodetection line 5. As a result of the operation of the photodetection array, a periodic electrical signal is formed at its output (with a period equal to the time required for sequential interrogation of all pixels of the array), in which the distribution of optical power incident on its surface is reflected in the change in the amplitude of the signal U_1.

The operation of photodetector line 5 is ensured by supplying control signals U_3 and U_4 from the microcontroller. The control signal U_3 determines the beginning (the first pixel) when sequentially polling all pixels of the line. The second signal, U_4, sets the polling period for each individual pixel of the line. The amplitude of the electrical signal U_1 at the output of line 5 at each moment of time is proportional to the optical power incident on the pixel currently being interrogated. As a result, a periodic electrical signal U_1 is generated at the output of the line of photoelectronic receivers (5), in which the spatial distribution of optical power within the photosensitive surface of line 5 is matched with the time distribution of the amplitude of the electrical signal within the period of the signal U_3. Thus, n local maxima will be observed in the output signal of the photodetector array, corresponding to signals from the pixels that receive radiation passing through n slits in curtain 7.

Further processing of the output signal of the photodetector array occurs in digital form. For this, an ADC 11 is used, which converts the signal amplitude from each pixel of the line into a digital code corresponding to the amplitude. To synchronize the sampling moments [**46**] of the ADC with the operation of the photodetector line, signal U4 is supplied to the control input of the ADC. An array of signal amplitude values from the pixels of the line from the output of the ADC 11 in the form of a signal U_5 is supplied to the input of the microcontroller (13). The microcontroller software processes the array of data received during one period of the signal U_3.

To confirm the statistical stability of the measurement results, whether they belong to the normal distribution law was checked. Since the value of $m > 50$, K. Pearson's $\chi 2$ criterion was used for verification [**47**], [**48**]. As a result of analyzing the results obtained, the null hypothesis of normal distribution is accepted for all four experiments.

2.3. Development of a methodology for optimal noise-resistant coding for onboard computer networks in aircraft

Like any linear block code [**49**], a low-density parity check (LDPC) code can be described using a $k \times n$ generator matrix G, where k is the length of the information sequence and n is the length of the code block. Then the code vector $\boldsymbol{C}$ will be obtained by multiplying the information sequence m by the generating matrix G:

$$C = m\ G. \tag{1}$$

For a systematic LDPC code, the generator matrix can be represented as $G = [I, P]$, where I is the unit size matrix $k \times k$ [**50**], [**51**]. Then the code will be described by the check matrix $\mathrm{H} = [P^{\mathrm{T}}, I]$.

The elements of such a matrix are the coefficients of the test equation, from which the test symbols are calculated. For efficient LDPC codes, the check matrix H must be sparse [**52**], [**53**], and the density of units in it, as a rule, is several tens or hundreds of thousands of elements.

Generalized positional numeral systems (GPNS) can have very useful properties, such as noise immunity and ease of creating permutations [**54–56**]. When generating and numbering combinatorial objects, special development methods are used for each individual task, which can be characterized as a fundamental drawback of this approach [**56**], [**57**]. Binomial number systems and the homogeneous binomial numbers generated by them are new results in the field of generalized positional number systems [**58**], [**59**]. The first seminal manuscript that gave rise to binomial systems was a paper published more than 30 years ago.

The binomial number system is finite and efficient [**60**]. A numbering algorithm converts the codeword Ai to its quantitative equivalent QAi after a finite number of steps. The binomial system is well-defined because two different coding combinations cannot be equivalent to the same numerical value.

2.4. Asymmetric non-Hermitian ENZ-containing layered structures for advanced optical devices and systems

Asymmetric non-Hermitian epsilon-near-zero (ENZ)-containing layered structures are a type of composite materials that exhibit unique optical properties due to their specific design and composition. These structures are characterized by having layers with different permittivity values, where at least one layer contains an ENZ material [**61**], [**62**].

One of the key advantages of asymmetric non-Hermitian ENZ-containing layered structures is their ability to control light propagation in unconventional ways. For example, these structures can exhibit unidirectional light propagation, where light waves only travel in one direction while being completely blocked in the opposite direction. This property is particularly [**63–65**] useful for designing optical isolators and circulators, which are essential components in optical communication systems to prevent signal interference and ensure signal integrity [**66–68**].

Moreover, the non-reciprocal nature of these structures enables the realization of topologically protected photonic states, where light waves are immune to backscattering or disorder-induced losses [**69**], [**70**]. This feature is crucial for developing robust photonic devices that are resilient to external perturbations and imperfections.

Asymmetric non-Hermitian ENZ-containing layered structures also offer opportunities for enhancing light-matter interactions and enabling efficient light confinement and manipulation at the nanoscale. These structures can be tailored to support surface plasmon polaritons[**71**], surface waves, or other exotic modes that can be utilized for sensing applications, subwavelength imaging, and energy harvesting [**72–74**].

Furthermore, the tunable optical properties of these structures make them promising candidates for developing reconfigurable and adaptive optical devices. By adjusting the parameters of the layers or introducing external stimuli, such as electric or magnetic fields, the optical response of the structure can be dynamically controlled, opening up possibilities for on-demand modulation of light transmission, reflection, and absorption [**75**], [**76**].

Overall, asymmetric non-Hermitian ENZ-containing layered structures represent a rich platform for exploring novel optical phenomena and designing next-generation photonic devices with enhanced functionalities and performance characteristics.

The asymmetry in the structure refers to the non-reciprocal nature of the material, meaning that its response to light propagation is different depending on the direction of the incident light. This asymmetry can be achieved through various means, such as introducing gain or loss in the structure, breaking time-reversal symmetry, or utilizing nonlinear effects [**77**], [**78**].

These asymmetric non-Hermitian ENZ-containing layered structures have attracted significant interest in the field of photonics and metamaterials due to their potential applications in areas such as waveguiding, sensing, cloaking, and nonlinear optics.

CHAPTER 3: MAIN RESULTS

3.1. High-reliability network

The network can be in three modes:

- o in phasing mode (clock synchronization);
- o in the mode of polling databases in the “P” mode by a unit in the “C” mode and assigning access intervals;
- o in data transfer mode.

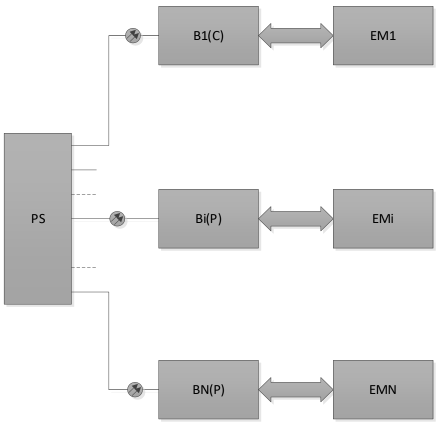


Fig. 3.1. Considered organization of the local network. PS – passive splitter; B, Bi, BN – access devices; EM – electronic module.

Figure 3.1 shows the variant of local network organization based on the proposed protocol 3. In this figure, the access device B1 is in the “C” mode, and the access devices Bi ÷ BN are in the “P” mode. All Bs are connected by optical lines to the passive optical splitter (PS) and are connected through interfaces, each with its electronic module (EM). Thus, the optical signal is branched between all Bs, and a passive bus optical mono channel is created (where all access units “hear” everyone). The network can be in three modes:

1) in phasing mode (clock synchronization);
2) in the polling mode, the T base stations in the “P” mode are polled by the B in the “C” mode and assign access intervals;
3) in data transfer mode.

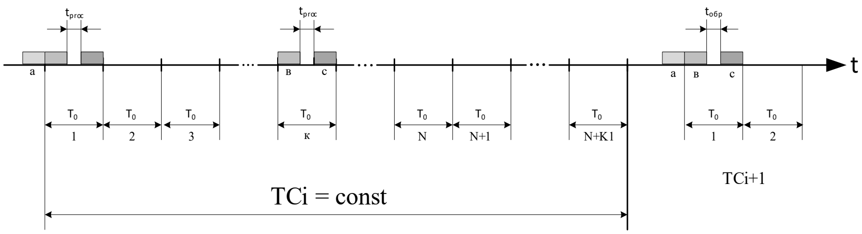


Fig. 3.2. The protocol time chart: a – the phasing interval; b – polling cycle; c – window assignment cycle; t_{proc} – query processing interval by the analyzer; T_0 – the transmission window interval; TCi – i-th transmission cycle; TCi+1 – next i+1 transmission cycle (beginning).

By combining fiber-optic access means with optical sensors, operators can create a smart network that delivers high-speed connectivity and ensures continuous operation, resilience to disruptions, and improved overall system performance. This integrated approach paves the way for the development of advanced applications in diverse fields, including telecommunications, smart cities, industrial automation, and environmental monitoring.

The successful integration of this new approach not only addresses the challenges associated with transmitting traffic from subscribers but also opens up new possibilities for optimizing network operations, improving user experience, and enabling the seamless delivery of services [**79**], [**80**]. Through rigorous testing and validation, the effectiveness and robustness of this approach have been confirmed, paving the way for its adoption in real-world scenarios.

3.2. High-reliability network components

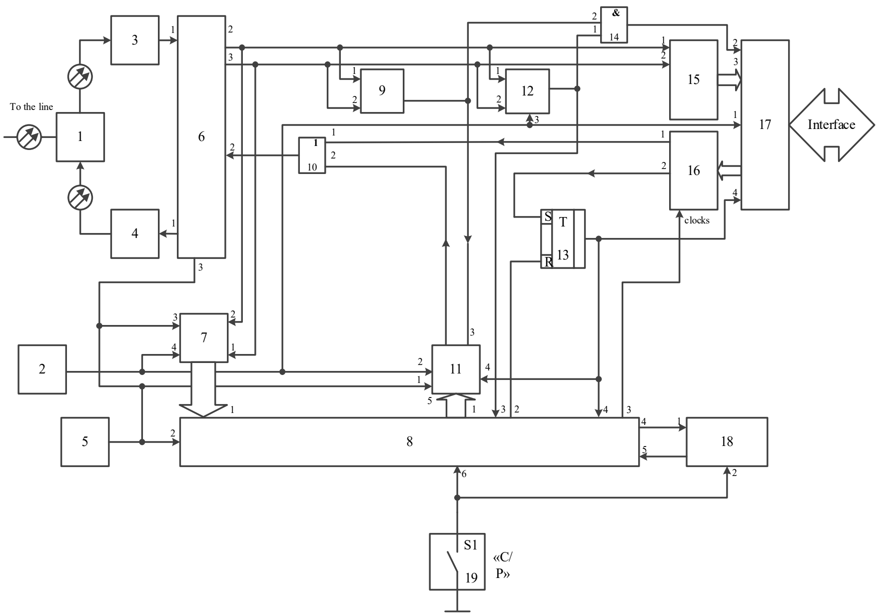


Fig. 3.3. Local network access block with guaranteed message delivery.

Figure 3.3 shows a possible implementation of a local network access block with guaranteed message delivery, where 1 – separating device; 2 – address setter; 3 – optical receiver; 4 – optical transmitter; 5 – reference generator; 6 – linear encoder/decoder; 7 – command receiver; 8 – synchronization and control unit; 9 – error detector; 10 – “OR” circuit; 11 – command transmitter; 12 – frame selector; 13 – “ready” trigger; 14 – “AND” circuit; 15 – receive RAM; 16 – transmission RAM; 17 – interface block; 18 – analyzer; 19 – switch S1 “C/P”.

The development and implementation of a local network access block with guaranteed message delivery for aircraft represents a critical advancement in aviation communication technology. By introducing a robust and reliable solution to manage network access and ensure the transmission of messages, this approach enhances the safety, efficiency, and performance of communication systems on board aircraft.

Through rigorous testing and validation, the effectiveness and reliability of this solution have been demonstrated, providing assurance that critical messages can be delivered promptly and securely within the aircraft's local network. This capability is essential for maintaining seamless communication among crew members, passengers, and ground control, thereby enhancing situational awareness and operational efficiency during flights [**81**].

In summary, the development and use of a local network access block with guaranteed message delivery for aircraft represent a significant milestone in advancing aviation communication technology, paving the way for enhanced communication capabilities and improved operational performance in the skies.

3.3. Optical sensors for aircraft applications

Fig. 3.4. 3D model of the developed pressure sensor.

The proposed design of the pressure sensor is highly accurate in determining the deformation (the value of which is reduced to a minimum) of the elastic sensing element and high speed. The high performance of the measuring system made it possible to use algorithms that consider and compensate for various types of destabilizing factors (interference, vibrations, shock effects, etc.) that arise during the operation of aircraft.

The low power consumption, dimensions, and weight of the proposed design make it possible to use the sensor as part of integrated systems of aircraft backup devices.

Considering the general trend in the development of unmanned aerial vehicles (UAVs) with an electric power plant, the use of pressure sensors based on lines of photoelectronic elements to determine altitude and speed parameters will increase energy survivability and reduce the overall dimensions and weight of the UAV.

The successful development of a pressure sensor based on a deformable CuBe2Ni(Co) bronze membrane of a sinusoidal profile with a rigid center, an LED with a wavelength of 625 nm, a charged coupled device (CCD) matrix with a Photo response non-uniformity of 5 %, and a pixel size of 14 μm represents a significant advancement in sensor technology. This innovative sensor design offers a range of benefits that can significantly enhance pressure measurement systems' accuracy, efficiency, and performance.

One of the key advantages of this pressure sensor is its ability to increase measurement accuracy for both absolute and static pressure sensors by at least 50 %. This improvement in accuracy is crucial for applications where precise pressure measurements are essential for safety, performance, and regulatory compliance.

Moreover, the development of this sensor also leads to a significant reduction in energy consumption by no less than 70 %. This reduction in energy usage contributes to cost savings and promotes sustainability by minimizing the environmental impact of sensor operations.

In addition, the innovative design of this pressure sensor enables a reduction in the time required to maintain order and the weight of the final sensor by no less than 25 % compared to traditional frequency absolute and static pressure sensors. Streamlining of sensor maintenance and weight reduction can positively impact overall system efficiency and performance.

By leveraging this innovative sensor design's unique features and capabilities, industries and applications requiring precise pressure measurements can benefit from enhanced performance, reliability, and cost-effectiveness.

Table 3.1

The Main Characteristics of the Developed Pressure Sensor

Parameter	**Prototype (used in Honeywell AirDC)**	**Prospective pressure sensor**	**Efficiency increase, %**
Data transmission interval, s	0.31	0.25	19
Reduced supply voltage, V	15	3.3	78
Reduced energy consumption, mW	1000	280.708	72
Measurement error, Pa	32	13.14	59
Reception time, s	30	1	96
Weight loss, g	400	213	46.75

3.4. Theory of asymmetric non-Hermitian ENZ-containing layered structures

An example of non-Hermitian asymmetry at various angles is shown in Fig. 3.5. Let us take two angles: the first angle $\theta = 22.7°$ below 0, "bound states in the continuum" (BIC), and the second angle $\theta = 25.0°$ above it. The position of the resonant frequency shifts to the values of $\omega = 0.999\ \omega$ and $\omega = 1.001\ \omega$, respectively. The pole condition $\mathrm{Re}M_{11}\ \theta$ is achieved at $\beta_0 = 1.03263$ (Fig. 3.5 (a)) and $\beta_0 = 1.03$ (Fig. 3.5 (c)), and the zero condition ($\mathrm{Re}M_{12} \ll 1$) at these β_0.

The phenomenon of coherent perfect absorption (CPA) is a fascinating area of study in optics and photonics, where the complete absorption of incident light waves is achieved through interference effects. In the context of the case under consideration, it is noted that the conditions for CPA generation are not fully met, indicating an incomplete state of CPA. Despite this partial fulfilment, an intriguing observation emerges – a notable enhancement of reflection occurs near the critical parameter β_0.

This enhancement in reflection, as depicted in Figs. 3.5 (b) and (d), showcases the significant impact of the incomplete condition of CPA generation on the behavior of light waves interacting with the system. The strong reflection observed near β_0 highlights the intricate interplay between the incident light waves, the material properties, and the specific conditions present in the system.

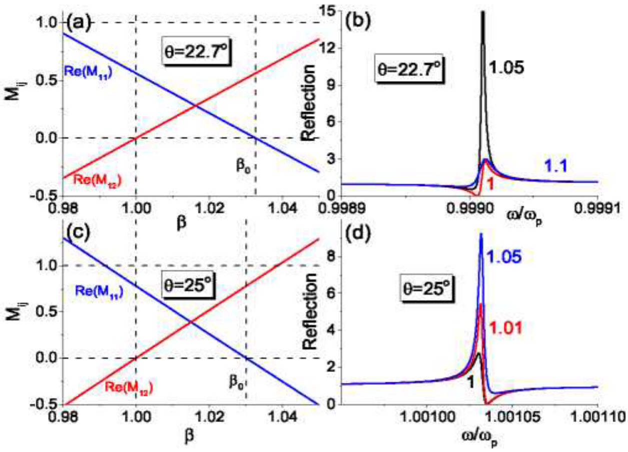


Fig. 3.5. (a), (c) – Dependence of transfer matrix elements on the asymmetry parameter b at angles of incidence θ = 22:7° (at frequency ω = 0.999 ω) and θ = 25.0° (at frequency ω = 1.001 ω); (b), (d) – the corresponding reflection spectra for various parameters of non-Hermitian asymmetry b, marked with numbers next to the curves. The amount of loss γ+= 0.001.

Nevertheless, the case of plasma frequency [**81**] can be distinguished for two reasons. The case of plasma frequency [**82**] stands out for two distinct reasons. Firstly, a notable asymmetry is observed in the profiles of the Fano spectra depicted in Fig. 3.5, setting them apart from the symmetrical profiles seen in Fig. 3.5. This asymmetry indicates a deviation from the expected uniformity or balance in the spectral data, suggesting underlying complexities or unique characteristics in the system under study. The pronounced asymmetry in the plasma frequency case signals a departure from conventional patterns, prompting further investigation into the factors driving this distinctive behavior. This deviation in spectral profiles hints at potentially novel insights or phenomena at play, warranting a closer examination to unravel the underlying mechanisms and implications of this intriguing observation. Secondly, another striking feature of this case is the observation that $\beta_0 > 1$ is both below and above θBIC. This finding contradicts the conventional expectation of $\beta_0 < 1$ at the angle of incidence θ = θBIC. The fact that β_0 exceeds 1 in these instances, contrary to the anticipated behavior at θBIC, highlights a counterintuitive aspect of the plasma frequency case. This unexpected discrepancy raises questions about the underlying mechanisms driving this unusual behavior and underscores the need for further investigation to elucidate the implications and significance of this contradiction. Such counterintuitive results challenge existing assumptions and call for a deeper understanding of the complex dynamics at play in this scenario. These facts confirm the specificity and unusualness of the response close to BIC at the plasma frequency.

3.5. Aircraft optical video transmission communication based on the forward error correction codes

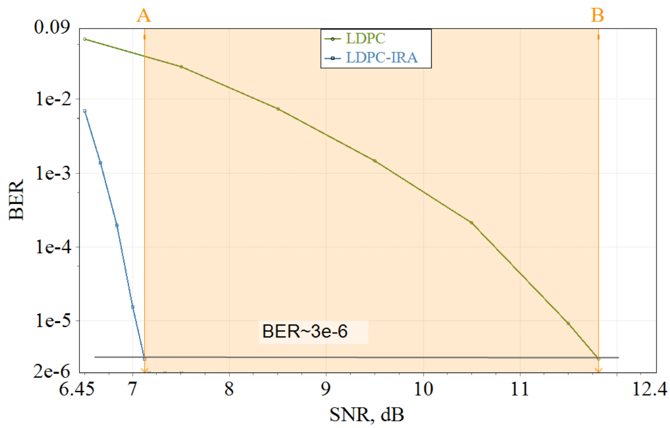


Fig. 3.6. Bit error ratio (BER) versus signal-noise ratio (SNR) for LDPC and LDPC-IRA.

LDPC-IRA's superior performance is attributed to its ability to effectively mitigate errors in the transmission process, especially in the presence of noise and interference. By combining LDPC codes with iterative decoding techniques, LDPC-IRA can achieve remarkable error correction capabilities while maintaining low latency and high throughput.

The simulation results clearly demonstrate that LDPC-IRA outperforms traditional LDPC coding in terms of BER at various SNR levels. This significant improvement in error correction efficiency translates to enhanced reliability and robustness in data transmission, making LDPC-IRA a valuable solution for mission-critical applications such as ARINC-818 communication systems.

Overall, the adoption of LDPC-IRA coding in ARINC-818 systems promises to revolutionize the way data is transmitted and received, offering a more resilient and efficient communication framework that can withstand challenging operating conditions and ensure seamless connectivity in aerospace and defense environments.

According to the simulation results, we obtained a significant advantage of LDPC-IRA over LDPC. Modeling on 16-QPAM modulation shows that LDPC-IRA provides a BER of 2×10^{-6} at SNR 7.2 dB. The addition of LDPC-IRA coding to ARINC-818 improves transmission efficiency more than three times. Within problem-solving, this makes it possible to increase the system's stability under the influence of HIRF.

In practical terms, implementing LDPC-IRA in the system can reduce information dispersion by more than 1.3 times compared to traditional coding methods. This means that even when working with challenging initial data conditions, such as high noise or interference levels, LDPC-IRA can effectively mitigate errors and ensure the accurate and timely delivery of information.

.

CHAPTER 4: FINAL REMARKS

Analysis of trends in the development of onboard information and telecommunication networks and sensors in conditions of high-intensity electromagnetic fields considers that today there is an urgent need for significant improvements in the resistance of onboard networks to high-intensity electromagnetic fields.

As a result of the analysis, increasing resistance, methods for organizing networks, and noise-resistant coding were identified, and sensors onboard aircraft were considered. Systemic methodological problems and contradictions in building networks, organizing coding, and using pressure sensors were identified.

The analysis of existing scientific works in this area of research showed that in order to build a secure network with guaranteed message delivery under conditions of increased electromagnetic load, modernization of the scientific and methodological apparatus used is required. For these purposes, the prospects for the application of mainline noise-resistant coding methods and the application of optical sensors to a new area of research are substantiated. This will allow us to solve methodological problems caused by the impact of electromagnetic fields on the onboard information and telecommunications network.

The disadvantages of existing networks include the use of fiber channel cables, which have high weight and relatively low throughput, low resistance of transceivers to the effects of fields, as well as high susceptibility of electronic static and total pressure sensors to the effects of EMV.

The hypothesis of the research is formulated, according to which the use of fiber optics as the main line for data transmission with hybrid noise-resistant coding, as well as the use of optical sensors for measuring static and total pressure, will significantly increase the resistance of the system to electromagnetic radiation, reduce the weight of transmitting and receiving devices and ensure flight safety.

The Thesis incorporates three interlinked models that are designed to facilitate the research process and assess the validity of the hypothesis. These interconnected models serve as a comprehensive foundation for conducting a thorough and systematic study in accordance with the specified scientific objective.

The developed methodology ensures reliable reproduction of the behavior of a service network using the example of an optical access network based on passive optical networks.

The method of optimal noise-resistant coding for aircraft onboard computer networks based on noise-resistant direct correction LDPC codes increases line resistance to interference.

The methodology for developing optical pressure sensors for the information and telecommunications network of aircraft makes it possible to design a more resistant electromagnetic interference sensor of static and total pressure. A distinctive feature of this technique is the use of optical methods for collecting information.

<u>The mechanism developed in the Thesis allows for further development and application to a new field of research in the construction of fiber optic broadband networks for use on aircraft</u>

4.1. Main conclusions

1. The organization of a fiber optic access network is proposed. Each end node of the proposed network monopolizes the entire channel resource of the bandwidth of the channel

allocated at its wavelength, which significantly improves the quality-of-service (QoS) indicators for traffic in the proposed network. The proposed network achieves doubling the capacity (the number of connected nodes) compared to the use of traditional wave multiplex technologies. The proposed passive network provides complete logical transparency in dedicated channels and does not require any additional headers to be attached to packets (frames) of information, such as in GPON. In addition, there is no dependence on throughput at the node level on the number of nodes included in the network segment or on the variation in the lengths of subscriber lines. An optical network access unit is proposed. The use of the proposed access block makes it possible to organize the guaranteed transmission of information frames at the access network level due to the implementation of a synchronous conflict-free access method with frame acknowledgement at the access level. The use of an access protocol with load polling and assignment of access intervals in the proposed access blocks will ensure, in addition to guaranteed delivery of messages, also a low delay in their transmission, which will increase proportionally as the network load increases, but even at maximum load, the delay at the access level will not exceed the interval time equal to the full cycle of polling and transmission. The use of an access protocol with guaranteed message delivery will allow the proposed access block to be used in real-time networks, which is especially important when building control systems and distributed real-time computing systems. The use of a physical propagation medium based on optical fiber in the network makes it possible to ensure high noise immunity under conditions of exposure to powerful electromagnetic fields and also significantly complicates the interception of information through spurious electromagnetic radiation and interference, which will ensure high noise immunity and protection of information in a local network built on the basis of the proposed access units, and the complete electrical isolation of the terminals created will create additional noise immunity due to the absence of “stray” currents.

These advantages are especially important when building object systems saturated with radio-electronic equipment (REE), such as radio stations, radar stations (RLS) and others, where, in addition, protection of transmitted information is required, as well as the absence of susceptibility of network equipment to lightning discharges.

2. The simulation results highlight a notable advantage of LDPC-IRA (low-density parity-check with irregular repeat-accumulate) coding over traditional LDPC coding schemes. Through modelling using 16-QPAM modulation, it was observed that LDPC-IRA offers a superior bit error rate (BER) performance, achieving a BER of 2×10^{-6} at a signal-to-noise ratio (SNR) of 7.2 dB. This signifies a substantial improvement in error correction capabilities compared to standard LDPC coding techniques.

Furthermore, the integration of LDPC-IRA coding into the ARINC-818 communication protocol demonstrates a significant enhancement in transmission efficiency, surpassing traditional methods by more than threefold. This advancement in coding efficiency plays a crucial role in addressing challenges related to high-intensity radiated fields (HIRF) interference, thereby bolstering the overall stability and reliability of the system.

By leveraging the benefits of LDPC-IRA coding within the context of ARINC-818 communication systems, the solution not only improves data transmission performance but also fortifies the system's resilience against external electromagnetic disturbances.

This breakthrough underscores the potential of LDPC-IRA as a key enabler for enhancing communication systems' robustness and effectiveness in demanding operational environments.

Additionally, the simulation results illustrate that **LDPC-IRA coding offers a more efficient bandwidth utilization than traditional LDPC codes**. This increased spectral efficiency is crucial in aerospace and avionics applications where bandwidth is often limited and costly. By achieving a lower BER at a given SNR, LDPC-IRA coding enables more reliable data transmission with fewer errors, ultimately leading to improved system performance and reduced retransmission rates.

Moreover, the **robust error correction capabilities of LDPC-IRA coding make it well-suited for high-speed data communication systems, such as those used in aircraft avionics and aerospace applications**. The ability of LDPC-IRA to effectively correct errors in noisy and interference-prone environments enhances the overall reliability and integrity of data transmission, ensuring critical information is accurately conveyed without loss or corruption.

Overall, **the integration of LDPC-IRA coding into ARINC-818 communication systems represents a significant advancement in aerospace communication technology**. By leveraging the superior error correction performance and spectral efficiency of LDPC-IRA, aerospace and avionics systems can achieve higher data transmission reliability, improved signal quality, and enhanced resilience to external interference, ultimately enhancing airborne communication systems' safety, efficiency, and performance

3. This research introduces a novel concept of coherent perfect absorber (CPA) generation linked to quasi-bound states in the continuum (BIC) discovered in asymmetric non-Hermitian layered structures containing exceptional points of non-conservation (ENC). The asymmetry present in these structures plays a crucial role in the evolution of quasi-BIC resonance into CPA lasing resonance. Delved into cases involving varying thicknesses of loss and gain layers (geometric asymmetry) as well as unequal levels of losses and gains (non-Hermitian asymmetry), a detailed analysis has been conducted of the effects of asymmetry through the examination of poles and zeros of the scattering matrix, uncovering intriguing characteristics.

Of particular note is the identification of the point at which the pole and zero of CPA generation merge, leading to a significant increase in outgoing intensity and a sharp rise in the quality factor associated with the adjacent quasi-BIC. Two key results have emerged from the study. Firstly, an unusual inverse linear relationship between the quality factor and the asymmetry parameter has been observed. Secondly, in systems exhibiting non-Hermitian asymmetry, a counterintuitive amplification due to losses has been detected at the plasma frequency.

It is believed that the findings presented in this Thesis hold broad significance for the field of non-Hermitian photonics and have the potential for extension to 2D and 3D systems. The anticipated demand for the CPA generation effect linked to quasi-BIC in laser and nonlinear optical applications underscores the practical implications of this research. Further investigation into the interplay between asymmetry, quasi-BIC resonances, and CPA generation in non-Hermitian structures could lead to the d**evelopment of advanced photonic devices with enhanced performance characteristics**. By exploring different configurations and tuning parameters, researchers may uncover novel ways to control light-matter interactions, manipulate wave propagation, and design efficient optical components.

Additionally, the discovery of the counterintuitive amplification effect due to losses at the plasma frequency in systems with non-Hermitian asymmetry opens new avenues for exploring unconventional optical phenomena and harnessing them for practical applications. Understanding and exploiting such unique behaviors could lead to the development of innovative devices for sensing, communication, and signal processing.

Overall, the insights gained from this research have the potential to inspire further studies in non-Hermitian photonics, offering new perspectives on how asymmetry can be leveraged to achieve desired optical functionalities. **By pushing the boundaries of current knowledge and exploring the rich landscape of non-Hermitian systems, researchers may unlock new opportunities for advancing photonics technology and addressing challenges in various domains**

4. The development of a new pressure sensor intended for use in Honeywell AirDC systems has resulted in significant improvements across various key parameters compared to the prototype sensor currently in use. The prospective **pressure sensor demonstrates enhanced performance and efficiency gains in several critical aspects**:

4.1. ***Data transmission interval:*** The new sensor boasts a reduced data transmission interval of 0.25 seconds, representing a notable 19 % increase in efficiency over the existing prototype.

4.2. ***Reduced supply voltage:*** A substantial improvement is seen in the supply voltage requirement, with the prospective sensor operating at just 3.3 V compared to the 15 V needed by the prototype. This reduction of 78 % in supply voltage contributes to enhanced energy efficiency and overall system performance.

4.3. ***Reduced energy consumption:*** The prospective sensor achieves a significant decrease in energy consumption, consuming only 280.708 mW as opposed to the 1000 mW drawn by the prototype. This reduction of 72 % in energy consumption underscores the sensor's improved efficiency and sustainability.

4.4. ***Measurement error:*** The new sensor demonstrates a lower measurement error of 13.14 Pa, representing a 59 % improvement over the 32 Pa error associated with the prototype. This enhanced accuracy ensures more reliable and precise pressure readings.

4.5. ***Reception time:*** A substantial enhancement is observed in the reception time of the prospective sensor, with a swift response time of just one second compared to the 30-second reception time of the prototype. This remarkable 96 % reduction in reception time enhances real-time data processing capabilities and system responsiveness.

4.6. ***Weight loss:*** The prospective sensor also exhibits a reduction in weight, weighing only 213 g as opposed to the 400 g weight of the prototype. This weight loss of 46.75 % contributes to improved portability and ease of installation.

Overall, the **development of the prospective pressure sensor represents a significant advancement in pressure sensing technology. It offers increased efficiency, accuracy, energy savings, and reduced size and weight**. These improvements pave the way for enhanced performance and functionality in air pressure monitoring applications within Honeywell AirDC systems.

BIBLIOGRAPHY

1. Charlo, R. E. R. (2023). On-board radio communication and its development in a historical perspective. *International Journal of Maritime History*, *36*(1), 140–152. https://doi.org/10.1177/08438714231202163
2. Ramanatt, P. R., Natarajan, K., & Shobha, K. (2020). Challenges in implementing a wireless avionics network. Aircraft Engineering and Aerospace Technology, 92(3), 482–494. https://doi.org/10.1108/aeat-07-2019-0144M.
3. Erturk, M. C., Hosseini, N., Jamal, H., Sahin, A., Matolak, D., & Haque, J. (2020). Requirements And Technologies Towards Uam: Communication, Navigation, And Surveillance. Integrated Communications Navigation and Surveillance Conference (ICNS). https://doi.org/10.1109/icns50378.2020.9223003.
4. Liu, D., Cui, J., Zhang, J., Yang, C., & Hanzo, L. (2021). Deep reinforcement learning aided Packet-Routing for aeronautical Ad-Hoc networks formed by passenger planes. IEEE Transactions on Vehicular Technology, 70(5), 5166–5171. https://doi.org/10.1109/TVT.2021.
5. Dashkiiev, V., & Povstenko, Y. (2022). Advanced Architecture of On-Board Multiplex Information Exchange System to Increase Flight Safety. Entropy (Basel, Switzerland), 24(11), 1582. https://doi.org/10.3390/e24111582.
6. Sekera, J., & Novak, A. (2021). The future of data communication in Aviation 4.0 environment. INCAS BULLETIN, 13, 165–178. https://doi.org/10.13111/2066-8201.2021.13.3.14.3074015.
7. Moir, I., Seabridge, A., & Jukes, M. (2013). Civil Avionics Systems (2nd ed). Wiley.
8. Bieber, P., Boniol, F., Boyer, M., Noulard, E., Pagetti, C. (2012). New Challenges for Future Avionic Architectures. Aeropsacelab Journal, 04.
9. He, D., Chan, S., & Guizani, M. (2017). Communication security of unmanned aerial vehicles. IEEE Wireless Communications, 24(4), 134–139. https://doi.org/10.1109/mwc.2016.1600073wc.
10. Jianwei, L., Weiran, L., Qianhong, W., Dawei, L., & Shigang, C. (2016). Survey on key security technologies for space information networks. Journal of Communications and Information Networks, 1(1), 72–85. https://doi.org/10.11959/j.issn.2096-1081.2016.006.
11. Solkin, M. (2021). Electromagnetic interference hazards in flight and the 5G mobile phone: Review of critical issues in aviation security. Transportation Research Procedia, 59, 310–318. https://doi.org/10.1016/j.trpro.2021.11.123.
12. Zatuchny, D. A., Negreskul, G. G., Sauta, O. I., Shatrakov, A. Y., Shatrakov, Y. G. (2022). Methods for Evaluating the Electromagnetic Compatibility of Integrated Ground Systems and On-Board Systems. In: Aerospace Radionavigation Systems. Springer Aerospace Technology. Springer, Singapore. https://doi.org/10.1007/978-981-19-6341-4_1
13. Maouloud, A., Klingler, M., & Besnier, P. (2021). A test setup to assess the impact of EMI produced by On-Board Electronics on the quality of radio reception in vehicles. IEEE Transactions on Electromagnetic Compatibility, 63(6), 1844–1855. https://doi.org/10.1109/temc.2021.3072558
14. Hunt, E. R. Jr., Daughtry, C., Walthall, C., & McMurtrey, J. E., & Dulaney, W. (2003). Agricultural Remote Sensing using Radio-Controlled Model Aircraft. 197–205. 10.2134/asaspecpub66.c15.

15. Kerczewski, B. (2013). Spectrum for UAS control and Non-Payload Communications. 1-21. 10.1109/ICNSurv.2013.6548666.
16. Nicola, M., Falco, G., Ferre, R. M., Lohan, E., De La Fuente, A., & Falletti, E. (2020). Collaborative solutions for interference management in GNSS-Based aircraft navigation. Sensors, 20(15), 4085. https://doi.org/10.3390/s20154085.
17. Borgstrom, E. (2012). An overview of the EMC requirements in RTCA/DO-160G. SAE International Journal of Aerospace, 5(2), 300–310. https://doi.org/10.4271/2012-01-2147
18. Serrano-Mira, L., Maroto, M. P., Ayra, E. S., Pérez-Castán, J. A., Liang-Cheng, S. Z. Y., Arias, V. G., & Pérez-Sanz, L. (2022). Identification and quantification of contributing factors to the criticality of aircraft loss of separation. Aerospace, 9(9), 513. https://doi.org/10.3390/aerospace9090513
19. Osunwusi, A. O. (2020). Occupational Radiation Exposures in Aviation: Air Traffic Safety Systems Considerations. International Journal of Aviation, Aeronautics, and Aerospace, 7(2). DOI: https://doi.org/10.15394/ijaaa.2020.1476
20. Michałowska, J., Pytka, J., Tofil, A., Krupski, P., & Puzio, Ł. (2021). Assessment of training aircraft crew exposure to electromagnetic fields caused by radio navigation devices. Energies, 14(1), 254. https://doi.org/10.3390/en14010254
21. Damaj, I. W., Yousafzai, J. K., & Mouftah, H. T. (2022). Future trends in connected and autonomous vehicles: enabling communications and processing technologies. IEEE Access, 10, 42334–42345. https://doi.org/10.1109/access.2022.3168320.
22. Baltaci, A., Dinc, E., Ozger, M., Alabbasi, A., Cavdar, C., & Schupke, D. (2021). A survey of Wireless Networks for Future Aerial Communications (FACOM). IEEE Communications Surveys & Tutorials, 23(4), 2833–2884. https://doi.org/10.1109/comst.2021.3103044.
23. Saadaoui, H., Bacou, A., Rebiere, Y., Fracasso, B., & Morvan, M. (2022). Broadband optical network design for the future aircraft cabin. Opt. Continuum, 1, 719–737. https://doi.org/10.1364/OPTCON.447053
24. Behbahani, A., Pakmehr, M., & Stange, W. A. (2020). Optical communications and sensing for avionics. https://doi.org/10.1007/978-3-030-16250-4
25. Marques, C., Leal-Júnior, A., & Kumar, S. (2023). Multifunctional integration of optical fibers and nanomaterials for aircraft systems. Materials, 16(4), 1433. https://doi.org/10.3390/ma16041433
26. Hasan, M. Z., Al-Rizzo, H., & Al-Turjman, F. (2017). A survey on multipath routing protocols for QOS assurances in Real-Time Wireless Multimedia Sensor Networks. IEEE Communications Surveys & Tutorials, 19(3), 1424–1456. https://doi.org/10.1109/comst.2017.2661201
27. Wang, X., & Yi, P. (2011). Security Framework for wireless communications in Smart Distribution Grid. IEEE Transactions on Smart Grid, 2(4), 809–818. https://doi.org/10.1109/tsg.2011.2167354
28. Iasechko, Maksym & Gnusov, Yurii. (2019). Determination of Requirements for the Protection of Radio-Electronic Equipment from the Terroristic Influence by Electromagnetic Radiation, International Journal of Emerging Trends in Engineering Research. 7. 772–777. 10.30534/ijeter/2019/077122019.
29. Michałowska, J., Tofil, A., Józwik, J., Pytka, J., Legutko, S., Siemiątkowski, Z., & Łukaszewicz, A. (2019). Monitoring the risk of the electric component imposed on a

pilot during light aircraft operations in a High-Frequency electromagnetic field. Sensors, 19(24), 5537. https://doi.org/10.3390/s19245537

30. Portnov, E. L., Vyacheslav, K., Sergey, I., & Semenov, A. B. (2018). Cupper and fiber-optic cables in moving objects. In Systems of Signals Generating and Processing in the Field of on-Board Communications. https://doi.org/10.1109/sosg.2018.8350626 ,
31. Khatimi, H., Wijaya, E., Baskara, A., Sari, Y. (2019). Performance Comparison Between Copper Cables and Fiber Optic in Data Transfer on Banjarmasin Weather Temperature Conditions. MATEC Web of Conferences. 280. 05022. 10.1051/matecconf/201928005022.
32. ITU-T Recommendation Y.1541 (12/11) Internet protocol aspects – Quality of service and network performance; Network performance objectives for IP-based services.
33. Wang, X., & Yi, P. (2011b). Security Framework for wireless communications in Smart Distribution Grid. IEEE Transactions on Smart Grid, 2(4), 809–818. https://doi.org/10.1109/tsg.2011.2167354.
34. Zouhaira, A., Dieudonne, Y., Aleya, A. (2021). Design, implementation and evaluation of a Fiber to The Home (FTTH) access network based on a Giga Passive Optical Network GPON. Array. 10. 100058. 10.1016/j.array.2021.100058.'
35. Marcon, L., Scarcella, C., Detraz, S., Lalovic, M., Olantera, L., Prousalidi, T., Sandven, U., Sigaud, C., Soós, C., & Troska, J. (2023). High-speed radiation tolerant optical links based on coarse wavelength division multiplexing. Journal of Instrumentation. 18. C02055. 10.1088/1748-0221/18/02/C02055.
36. Dorrah, A. H., Rubin, N. A., Tamagnone, M., Zaidi, A., & Capasso, F. (2021). Structuring total angular momentum of light along the propagation direction with polarization-controlled meta-optics. Nature Communications, 12(1). https://doi.org/10.1038/s41467-021-26253-4.
37. Van Der Schaar, M., Krishnamachari, S., Choi, S., & Xu, X. (2003). Adaptive cross-layer protection strategies for robust scalable video transmission over 802.11 WLANs. IEEE Journal on selected areas in communications, 21(10), 1752–1763.
38. Tobagi, A., & Hunt, V. B. (1980). Performance Analysis of Carrier Sense Multiple Access with Collision Detection. Computer Networks, 4, 245–259.
39. Wu, Chien-Jang, Rau, Yu-Nian, & Han, Wei-Hsieh. (2010). Enhancement of Photonic Band Gap in a Disordered Quarter-Wave Dielectric Photonic Crystal. Progress in Electromagnetics Research. 100. 10.2528/PIER09111610.
40. Yu, N., & Capasso, F. (2014). Flat optics with designer metasurfaces. Nature Materials, 13(2), 139–150. https://doi.org/10.1038/nmat3839
41. Norden, S., Manimaran, G., & Murthy, C. (2002). New protocols for hard real-time communication in the switched LAN environment. https://doi.org/10.1109/lcn.1998.727677
42. Kisner, R., Manges, W., Macintyre, L., Nutaro, J., Munro, Jr, J., Ewing, P., Howlader, M., Kuruganti, T., Wallace, R., & Olama, M. (2010). Cybersecurity through Real-Time Distributed Control Systems. 10.2172/978289.
43. Djordjevic, I. B. (2017). Channel coding for optical transmission systems. In Opto-Electronics and Communications Conference (OECC) and Photonics Global Conference (PGC), Singapore. https://doi.org/10.1109/oecc.2017.8114842.
44. Djordjevic, Ivan & Ryan, William & Vasic, Bane. (2010). Coding for Optical Channels. 10.1007/978-1-4419-5569-2.

45. Mariscotti, A. (2020). Stray Current Protection and Monitoring Systems: characteristic quantities, assessment of performance and verification. Sensors, 20(22), 6610. https://doi.org/10.3390/s20226610
46. Zhang, H., Wu, Q., & Ji, J. (2018). Synchronization of discretely coupled harmonic oscillators using sampled position states only. IEEE Transactions on Automatic Control, 63(11), 3994–3999. https://doi.org/10.1109/tac.2018.2814678
47. Bolboacă, S. D., Jäntschi, L., Sestraş, A. F., Sestraş, R. E., & Pamfil, D. C. (2011). Pearson-Fisher Chi-Square statistic revisited. Information, 2(3), 528–545. https://doi.org/10.3390/info2030528
48. Llopis, Eva & Micheli, Mario. (2014). Implementation of the Centroid Method for the Correction of Turbulence. Image Processing On Line. 4. 187–195. 10.5201/ipol.2014.105.
49. Wolf, J. (1978). Efficient maximum likelihood decoding of linear block codes using a trellis. IEEE Transactions on Information Theory, 24(1), 76–80. https://doi.org/10.1109/TIT.1978.10558
50. Panteleev, Pavel & Kalachev, Gleb. (2021). Degenerate Quantum LDPC Codes with Good Finite Length Performance. Quantum. 5. 585. 10.22331/q-2021-11-22-585.
51. Cai, S., Lin, W., Yao, X., Wei, B., & Ma, X. (2021). Systematic Convolutional Low Density Generator Matrix Code. IEEE Transactions on Information Theory, 67(6), 3752–3764. https://doi.org/10.1109/tit.2021.3064922.
52. Borysenko, O., Kulyk, I., Matsenko, S., Berezhna, O., & Matsenko, O. (2016). Optimal synthesis of digital counters in the Fibonacci codes with the minimal form of representation. Eastern-European Journal of Enterprise Technologies. 4. 4. 10.15587/1729-4061.2016.75596.
53. Cai, Zhaohui, Hao, Jianzhong, Tan, P. H., Sun, Sumei, & Chin, P. S. (2006). Efficient encoding of IEEE 802.11n LDPC codes. Electronics Letters. 42. 1471–1472. 10.1049/el:20063126.
54. Borysenko, O., Matsenko, S., Novhorodtsev, A., Kobiakov, O., Spolitis, S., & Bobrovs, V. (2020). Estimating the Indivisible Error Detecting Codes Based on an Average Probability Method. Eastern-European Journal of Enterprise Technologies. 6/9. 25–33. 10.15587/1729-4061.2020.218076.
55. Matsenko, S., Borysenko, O., Spolitis, S., & Bobrovs, V. (2019). Noise Immunity of the Fibonacci Counter with the Fractal Decoder Device for Telecommunication Systems. Latvian Journal of Physics and Technical Sciences. 56. 12–21. 10.2478/lpts-2019-0027.
56. Ruskey, F. (2003). Combinatorial generation. Preliminary working draft. University of Victoria, Victoria, BC, Canada, 11, 20.
57. Herzog, J., Hibi, T., & Ohsugi, H. (2018). Binomial ideals (Vol. 279). Cham: Springer
58. Vilcane, K., Matsenko, S., Parfjonovs, M., Murnieks, R., Aleksejeva, M., & Spolitis, S. (2020). Implementation of Multi-Wavelength Source for DWDM-PON Fiber Optical Transmission Systems. Latvian Journal of Physics and Technical Sciences. 57, 24–33. 10.2478/lpts-2020-0019.
59. Borysenko, O., Matsenko, S., & Bobrovs, V. (2021). Binomial Number system. Applied Sciences, 11(23), 11110. https://doi.org/10.3390/app112311110
60. Skachek, V., & Immink, K. a. S. (2014b). Constant Weight codes: an approach based on Knuth's balancing method. IEEE Journal on Selected Areas in Communications, 32(5), 909–918. https://doi.org/10.1109/jsac.2014.140511.

61. Thio, T., Pellerin, K., Linke, R., Lezec, H., & Ebbesen, T. (2002). Enhanced light transmission through a single subwavelength aperture. Optics letters. 26. 1972-4. 10.1364/OL.26.001972.
62. Novitsky, D. V., Karabchevsky, A., Lavrinenko, A. V., Shalin, A. S., & Novitsky, A. V. (n.d.). PT symmetry breaking in multilayers with resonant loss and gain locks light propagation direction. Physical Review. B./Physical Review. B, 98(12). https://doi.org/10.1103/physrevb.98.125102.
63. Shamkhi, H. K., Sayanskiy, A., Valero, A. C., Kupriianov, A. S., Kapitanova, P., Kivshar, Y. S., Shalin, A. S., & Tuz, V. R. (2019). Transparency and perfect absorption of all-dielectric resonant metasurfaces governed by the transverse Kerker effect. Physical Review Materials, 3(8). https://doi.org/10.1103/physrevmaterials.3.085201
64. Terekhov, P. D., Baryshnikova, K. V., Greenberg, Y., Fu, Y. H., Evlyukhin, A. B., Shalin, A. S., & Karabchevsky, A. (2019). Enhanced absorption in all-dielectric metasurfaces due to magnetic dipole excitation. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-019-40226-0
65. Valero, A. C., Kislov, D., Gurvitz, E. A., Shamkhi, H. K., Pavlov, A. A., Redka, D., Yankin, S., Zemánek, P., & Shalin, A. S. (2020). Nanovortex-Driven All-Dielectric optical diffusion boosting and sorting concept for Lab-on-a-Chip platforms. Advanced Science, 7(11). https://doi.org/10.1002/advs.201903049
66. Barhom, H., Machnev, A. A., Noskov, R. E., Goncharenko, A., Gurvitz, E. A., Timin, A. S., Shkoldin, V. A., Koniakhin, S. V., Koval, O. Y., Zyuzin, M. V., Shalin, A. S., Shishkin, I. I., & Ginzburg, P. (2019). Biological Kerker effect boosts light collection efficiency in plants. Nano Letters, 19(10), 7062–7071. https://doi.org/10.1021/acs.nanolett.9b02540
67. Terekhov, P. D., Evlyukhin, A. B., Redka, D., Volkov, V. S., Shalin, A. S., & Karabchevsky, A. (2020). Magnetic octupole response of dielectric oligomers. Laser and Photonics Reviews, 14(4). https://doi.org/10.1002/lpor.201900331
68. Kim, S., Taylor, J. M., & Bahl, G. (2019). Dynamic suppression of Rayleigh backscattering in dielectric resonators. Optica, 6(8), 1016. https://doi.org/10.1364/optica.6.001016
69. Liu, C., Gao, W., Yang, B., & Zhang, S. (2017). Disorder-Induced topological state transition in photonic metamaterials. Physical Review Letters, 119(18). https://doi.org/10.1103/physrevlett.119.183901
70. Pitarke, J. M., Silkin, V., Chulkov, E. V., & Echenique, P. M. (2006). Theory of surface plasmons and surface-plasmon polaritons. Reports on Progress in Physics. 70. 10.1088/0034-4885/70/1/R01.
71. Zhang, J., Zhang, L., & Xu, W. (2012). Surface plasmon polaritons: physics and applications. Journal of Physics D: Applied Physics, 45(11), 113001
72. Worthing, P. & Barnes, W. (2001). Efficient coupling of surface plasmon polaritons to radiation using a bi-grating. Applied Physics Letters. 79. 3035–3037. 10.1063/1.1414294.
73. Zhang, Junxi & Zhang, Lide & Xu, Wei. (2012). Surface plasmon polaritons: Physics and applications. Journal of Physics D-applied Physics - J PHYS-D-APPL PHYS. 45. 10.1088/0022-3727/45/11/113001.

74. Han, S., Rybin, M., Pitchappa, P., Srivastava, Y., Kivshar, Y., & Singh, R. (2019). Guided-Mode Resonances in All-Dielectric Terahertz Metasurfaces. Advanced Optical Materials. 8. 10.1002/adom.201900959.
75. Niu, Xinxiang & Hu, Xiaoyong & Chu, Saisai & Gong, Qihuang. (2018). Epsilon-Near-Zero Photonics: A New Platform for Integrated Devices. Advanced Optical Materials. 6. 1701292. 10.1002/adom.201701292.
76. Li, Ying & Argyropoulos, Christos. (2018). Exceptional points and spectral singularities in active epsilon-near-zero plasmonic waveguides.
77. Solís, Diego & Engheta, Nader. (2022). Nonreciprocal Epsilon-Near-Zero-Dielectric Bilayers: Enhancement of Nonreciprocity from a Nonlinear Transparent Conducting Oxide Thin Film at Epsilon-Near-Zero Frequency. Physical Review Applied. 17. 10.1103/PhysRevApplied.17.034053.
78. Schares, L., Lee, B. G., Checconi, F., Budd, R., Rylyakov, A., Dupuis, N., Petrini, F., Schow, C. L., Fuentes, P., Mattes, O., & Minkenberg, C. (2014). A Throughput-Optimized optical network for Data-Intensive computing. IEEE Micro, 34(5), 52–63. https://doi.org/10.1109/mm.2014.77 .
79. Papanikolaou, P., Christodoulopoulos, K., & Varvarigos, E. (2018). Optimization techniques for incremental planning of multilayer elastic optical networks. Journal of Optical Communications and Networking, 10(3), 183. https://doi.org/10.1364/jocn.10.000183
80. Zhao, Y., Yan, B., Liu, D., He, Y., Wang, D., & Zhang, J. (2018). SOON: self-optimizing optical networks with machine learning. Optics Express, 26(22), 28713. https://doi.org/10.1364/oe.26.028713
81. Endsley, M. R. (1999b). Situation Awareness In Aviation Systems. Handbook of Aviation Human Factors.
82. K. S. O'Brien & D. O'Hare (2007) Situational awareness ability and cognitive skills training in a complex real-world task, Ergonomics, 50:7, 1064–1091, DOI: 10.1080/00140130701276640
83. Kim, Jung-Hyung, Seong, Dae-Jin, Lim, Jong, & Chung, Kwang-Hwa. (2004). Plasma frequency measurements for absolute plasma density by means of wave cutoff method. Applied Physics Letters. 83. 4725–4727. 10.1063/1.1632026
84. Taylor & Francis Group. (2015). Optical Fiber Sensors – Advances techniques and applications. CRC Press. https://doi.org/10.1201/b18074.
85. Dandy, G., Daniell, T., Foley, B., & Warner, R. (2017). Planning and design of engineering systems. In CRC Press eBooks. https://doi.org/10.1201/9781351228121.
86. Shtub, A., & Cohen, Y. (2017). Introduction to industrial engineering (2nd ed.). CRC Press. https://doi.org/10.1201/b19091.

Aleksandr Krotov was born in 1989, in Leningrad. He received a Professional Engineering degree from Saint Petersburg State Electrotechnical University (2012). He is currently a researcher at the Institute of Photonics, Electronics and Telecommunications of RTU Faculty of Computer Science, Information Technology and Energy.