

LUT UNIVERSITY  
School of Energy Systems  
Degree Programme in Electrical Engineering

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**UTILIZATION OF DIGITAL DIMMING PROTOCOLS OF LIGHTING IN  
CRUISE VESSELS**

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Supervisor: B.Sc. (Tech.) Seija Hede

## **ABSTRACT**

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### **Utilization of digital dimming protocols of lighting in cruise vessels**

Master's Thesis

2019

83 pages, 7 figures, 8 pictures, 8 tables and 2 appendices

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The purpose of this thesis was to research if digital dimming protocols available in the markets could guarantee to provide a reliable lighting controlling system entity to be implemented to cruise vessel's public venues. The objective was to investigate DALI technology in detail and the benefits it could provide to cruise vessels' dimming systems. The purpose of this thesis was also to find out how thoroughly the electrical specialists in marine industry were familiar with this new, strictly regulated and constantly developed digital DALI2 control protocol. The objective was also to bring forward the benefits of digital dimming methods compared to the most commonly used dimming methods.

The investigation of alternative DALI based dimming technologies to control lighting in marine industry was executed as the previously commonly used technology available in the markets kept decreasing while the share of digital replacing dimming protocols kept increasing. The research was carried out by forms of interviews, questionnaires collected information and discussion about the topic with the field of the area specialists. The research executed about the topic from the reliability of marine industry point of view is unique. The knowledge about the topic was acquired by getting familiar with related standards and requirements, enquiring experiences from the field of area professionals, comparing the protocols and studying the DALI protocol from a technical-scientific perspective.

As a result, DALI as a light controlling protocol was found out to be considerable alternative for lighting's control protocol but the improved DALI2 protocol is more trustworthy due to its stricter supervision and more developed device interoperability. The research made it possible for most of the specialists working in the field of the area to get themselves more familiarized to the DALI protocol. As a result, the addressable DALI was to be implemented to a limited area in a cruise vessel, which is to be delivered during the year 2020.

## TIIVISTELMÄ

LUT-Yliopisto  
School of Energy Systems  
Sähkötekniikan koulutusohjelma

Mikko Ruostemaa

### **Valaistuksen digitaalisten himmennyskäytäntöjen hyödyntäminen risteilyaluksissa**

Diplomityö

2019

83 sivua, 7 kaaviota, 8 kuvaa, 8 taulukkoa ja 2 liitettä

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Hakusanat: Digitaalinen himmennysprotokolla, valaistuksen ohjaus, ohjausjärjestelmä, DALI, DALI2

Tämän diplomityön tarkoituksena oli tutkia markkinoilla saatavilla olevien digitaalisten himmennysprotokollien tarjontaa luotettavan valaistusohjausjärjestelmäkokonaisuuden takaamiseksi risteilyaluksen yleisiin tiloihin. Tavoitteena oli tutkia yksityiskohtaisesti DALI-teknologiaa ja sen käytön tarjoamia mahdollisuuksia risteilyalusten valaistusohjausten kehittämiseksi. Työn tarkoituksena oli myös selvittää kuinka perusteellisesti meriteollisuuden sähkötekniikan asiantuntijat ovat tutustuneet uuteen, tiukasti säänneltyyn ja jatkuvasti kehittyvään digitaaliseen DALI2-ohjausprotokollaan. Tavoitteena oli myös tuoda esille digitaalisten himmennysmenetelmien tuomat hyödyt verrattuna tavallisimmin käytettyihin himmennysmenetelmiin.

Työssä tutkittiin vaihtoehtoisia DALI-pohjaisia himmennystekniikoita meriteollisuuden valaistuksen ohjaukseen, sillä tavanomaisimmin aiemmin käytetty valaistusohjaustekniikka on väistymässä markkinoilta digitaalisten korvaavien himmennystekniikoiden tieltä. Tutkimustyö toteutettiin haastatteluihin, kyselylomakkeilla kerättyyn tietoon sekä alan ammattilaisten kanssa käytyihin keskusteluihin pohjautuen. Aiheen luotettavuudesta tehty tutkimus on meriteollisuuden näkökulmasta ainut laatuaan. Tietoa aiheesta saatiin tutustumalla aiheen standardeihin ja säännöksiin, tiedustelemalla käyttäjäkokemuksia alan ammattilaisilta, vertailemalla protokollia ja tutkimalla DALI-protokollaa teknillistieteellisestä näkökulmasta.

Tutkimuksiin perustuen DALI:n todettiin olevan varteenotettava valaistuksen ohjausprotokolla, mutta paranneltu DALI2-protokolla on luotettavampi tiukemman valvontansa ja kehittyneemmän laiteyhteensopivuutensa vuoksi. Tutkimus mahdollisti useiden alalla toimivien asiantuntijoiden paremman tutustumisen yleisesti DALI-protokollaan. Tutkimuksen tuloksena ohjelmoitava DALI tulee toteutettavaksi rajatulle alueelle risteilyalukseen, joka luovutetaan asiakkaalle vuonna 2020.

## **FOREWORDS**

With interest in shipbuilding and developing the lighting technology used in marine business, I decided to focus on studying about the newest available lighting technology as my master's thesis. The idea for the topic of the thesis originated from the need to increase the usage of digital lighting control protocols in cruise vessels and therefore the digital addressable lighting interface protocol, DALI, was decided to be put into research.

By learning to understand that the ship-owning companies preferred to utilize only reliable and well-experienced functioning dimming protocols in new building ships, even if the used technology was decades old, I decided to study how field of the area specialists would adopt to usage of newer DALI protocol. It was soon revealed to me that the specialists and the decision-makers in the field of the area have not had the chance to get familiar enough with the new existing and strictly regulated protocol, which is capable of replacing most of the commonly used dimming protocols, but also to bring benefits to the ship-owning company's operations. I most sincerely hope I have succeeded on introducing the available technology to the marine industry and have managed to point the ship-owning companies to a right direction, in which they could always select the most reliable and the most developed dimming protocol to be utilized on their state-of-the-art cruise vessels.

At this point I want to express my compliments to the lighting related companies working in the marine industry, and especially to their specialists who supported me gathering relevant information, shared their knowledge and experiences with me, participated the interviews and questionnaire, but the most important, found the time to guide and promote me in this significant project. From all the companies, I want to give special thanks to the lighting specialists in Audico Oy, Hella Lighting Finland Oy, Loisto Pro Oy and Osram Oy who were able to support and provide valuable experience-based information to me during my project.

I want to thank my colleagues in Meyer Turku, but also in Meyer Werft, Papenburg for your support that you have given me during the project. I also want to thank my examiner Pertti Silventoinen from LUT University for his support and guidance during my project. Finally, I want to give my gratitude to my family and especially to my fiancée whose support, flexibility and understanding has meant the most to me during these study years.

In Raisio, Finland

19.6.2019

Mikko Ruostemaa

## **TABLE OF CONTENTS**

<b>LIST OF ABBREVIATIONS</b>	<b>7</b>
<b>1 INTRODUCTION</b>	<b>8</b>
1.1 Background of the thesis	8
1.2 Goals of the research	9
1.3 Limitations	9
1.4 Scientific perspective	10
1.5 Outline of the thesis	11
<b>2 LIGHTING IN A CRUISE VESSEL</b>	<b>12</b>
2.1 Background	12
2.1.1 Significance	13
2.1.2 Interference/problems	13
2.2 Theory	16
2.2.1 Lighting Requirements on board	19
2.2.2 Dimming methods	24
2.2.3 Comparison of dimming methods	39
2.2.4 EMC in a cruise vessel	41
2.2.5 IoT in lighting technology	47
2.2.6 Classification society requirements	48
<b>3 UTILIZATION OF DIMMING METHODS</b>	<b>50</b>
3.1 Dimming type test in test environment	50
3.1.1 Test rack introduction	50
3.1.2 Components used	51
3.1.3 Execution of test	53
3.2 Importance of programming	56
3.3 Comparison of 1-10V and DALI implementations	58
3.3.1 System differences	58
3.3.2 Cost effect and efficiency study	61
<b>4 CONCLUSIONS</b>	<b>63</b>
4.1 Analyzation of practical research results	63
4.2 Analyzation of specialists' questionnaire replies and interviews	65
4.2.1 Introduction	65

4.2.2 Analyzation	66
<b>5 SUMMARY</b>	<b>77</b>
5.1 General	77
5.2 Findings	77
5.3 Recommendations	79
5.4 Final words	79
<b>REFERENCES</b>	<b>81</b>
<b>APPENDIX 1. Emission requirements standardized by EN 61000-3-2.</b>	
<b>APPENDIX 2. Questionnaire form with answers</b>	

## LIST OF ABBREVIATIONS

A	Ampere, unit of current
AC	Alternating current
CRI	Colour rendering index
DC	Direct current
DiiA	Digital Illumination Interface Alliance
DALI	Digital addressable lighting interface
DALI2	Digital addressable lighting interface (2 <sup>nd</sup> generation, strictly regulated)
DMX	Digital multiplex, digital communication standard for entertainment lighting
ECG	Electronic Control Gear
EMC	Electromagnetic compatibility
EMF	Electromagnetic field
IEC	International electrotechnical commission, global organization preparing and publishing international standards for all electrical and electronic related technologies
IGBT	Insulated Gate Bipolar Transistor, used as phase-cut dimmer method
IMO	International Maritime Organization
IP	International protection rating, IP code
LCP	Local control panel
LED	Light-emitting diode
PC	Personal computer
PWM	Pulse Width Modulation
RF	Radio frequency signal
RFI	Radio-frequency interference
RGBW	Red-Green-Blue-White colour based light source
SCR	Silicon controlled rectifier, used as phase-cut dimmer method
TRIAC	Triode for AC, used as phase-cut dimmer method
USPH	United States Public Health
SOLAS	Safety of life at sea
V	Volt, unit of voltage

## 1 INTRODUCTION

Artificial lighting on cruise vessels have evolved remarkably during the past decade. The light source types have typically been incandescent bulbs, halogens and fluorescent tubes before the year 2010 when the light-emitting diodes (LEDs) started to get developed in a way that no one could have dreamed of in lighting business. LEDs took over the artificial lighting sources quickly after this and today it is the most used light source type there is on board. Since the lighting has evolved quickly, so must have their control methods. There are multiple options how to control the various types of LEDs, such as electrical phase-cutting of trailing or leading edge but also analogic 1-10V and digital controls exists. Depending on the type of the LED light fixture the controlling method can variate. The LED based lights can provide high illuminance levels and accordingly their utilization possibilities have increased remarkably. Today the question lies on the dimming side of the high intensity containing light sources. The lights need to be dimmed properly for them to perform as per the event requires them to. Analogical and phase-cut dimming methods have been existing for several decades already, but the digital dimming methods are being developed constantly and their further utilization in near future is going to be the inevitable.

### 1.1 Background of the thesis

Light sources are being developed to a direction in which they are controlled by digital dimming methods. Entertainment technology, such as DMX was developed to be used as a digital lighting control method since late 1980s and it has been used on cruise vessels from early 2000s. It is still a method used in show and entertainment lighting, practically in any venue which requires a strong performance from the lighting. Therefore, it is also feasible for general lighting control in such a venue. Because of its high quality of technology, it comes with a cost and its own requirements. These values are not necessary for all the lighting on board and therefore alternative solutions were looked for. As a reasonable alternative, a digital addressable lighting interface, DALI, was developed and it has been developed already from early 1990s until today. In late 2010s markets, it appears to be one of the most common dimming methods available. Most major lighting fixture manufacturers are developing their lighting to be seamlessly suitable for DALI control. Until now the new-building cruise vessels barely have had DALI installed in them. Since the LED-driver manufacturers are dramatically reducing their development, but also production for 1-10V

control method that has been commonly used on cruise vessels, the industry is under a revolution of getting to use digital alternative dimming methods soon. As markets are basically trying to force the industry to adopt to DALI, it was decided to be further studied to find out how it performs in the demanding environment such as a cruise vessel.

### 1.2 Goals of the research

The purpose of this thesis is to find out whether the digital dimming methods available in the markets can provide a fail-safe lighting controlling system in cruise vessel's public venues. The purpose is also to find out the benefits of digital dimming methods compared to the commonly used analogic dimming methods.

From a technical point of view the digital dimming research target, i.e. DALI, functions well on controlling the lighting but since it has not been used on a new building business nor in the marine business in an extensive scale, it was now taken under closer observation as a new potential dimming method alternative. The objective is to investigate DALI in a cruise vessels' environment and reveal its potential as a dimming method.

The cruise vessel industry is extremely careful on adapting to new technologies on board, especially if the used existing technology has been working reliably enough. The purpose of this thesis is also to provide reliable information to the industry's administrators about the new strictly regulated DALI 2 dimming method. One of the researches objectives is to help analysing if the new technology is worth adopting into the demanding business.

### 1.3 Limitations

The research is chosen to handle only the house lighting dimming system related light fixtures that are being dimmed instead of the entire house lighting system with local dimmers, excluding entertainment lighting. Some of the light fixtures may not be dimmed in a reasonable way with DALI but these are included in the investigation to point out that one dimming method cannot operate the ship wide lighting alone, such a light source is being phase-cut dimmed or non-dimmed with on- and off-switched by relays. This arrangement is done to concentrate on the topic in a more realistic and dedicated way.

The focus is on improving the dimming system and adopting of modern developed digital lighting control technology into the design of house lighting dimming system on a cruise

vessel. The focus is put to the DALI based solutions as it is currently the newest control method and rarely used on a cruise vessel.

#### 1.4 Scientific perspective

##### Hypothesis

The author of the thesis is excited on the research topic and trusts that new important knowledge and information can be achieved during the research. The author is confident that the research results out that the studied digital dimming methods are well reliable and therefore the technology is ready to be utilized on a cruise vessel. The author expects no problems related to the latest version of DALI (i.e. DALI2) as lighting control method if it is operated mainly as broadcast and partly as addressable, it is well designed on board, the electricians installing it on board and the crew maintaining it after are well trained to the new used technology.

##### Research problem

The research was done for a need of renewing and updating the technology used on marine businesses' lighting control systems. The technology was not widely used on board in earlier projects; therefore, the study problem was defined to be about finding trustworthy information about the reliable utilization of digital dimming methods on a cruise vessel.

The industry was not utilizing digital dimming methods too widely before year 2019 and the question was if the industry was ready to adopt to a change of changing the well-experienced functioning dimming methods to a new one from which not all working in the industry had longer nor trustworthy experience of. The target was set to study the technology's reliability and implement it on board, built in future, more widely if the experienced study results supported the author's expectations.

##### Literature review and research methods

Dimming method of digital addressable lighting interface as a topic is not a recent invention but it has not been dedicatedly marketed to be used in a marine industry and therefore there does not exist a 100 per cent suitable literature related to the topic in the markets while the thesis is in work. The research is implemented by keeping this in mind.

The research for this thesis is done in multiple forms and it is analysed together with specialists of the field of area. The produced information about the topic is a result of many interviews, familiarization to the system, questionnaires kept to specialists, interpretation of drawings and documentation, visual dimming tests done in test environments and familiarization to standards.

The author of this thesis has also interviewed third party representatives with their neutral opinions on the topic, e.g. hired lighting consultants from different companies and ship owning companies' electrical superintendents.

### 1.5 Outline of the thesis

Chapter two contains information about the lighting technology in principle utilized in a cruise vessel. It includes a brief review to the background of the lighting, to the significance of lighting, availability, theory, requirements, dimming methods and light's features. This chapter bases on facts about lights and their controllability.

Chapter three deals with the topic from more practical aspect. It includes description about the executed dimming tests done in a test environment, but also compares the dimming systems differences while used lights base on 1-10V, DALI broadcast and DALI addressable or combination of these.

Chapter four consists of the description of the visual tests executed in test environment and dimming systems comparison of different versions but also the analyzation of them and analyzation of questionnaire study results received from the respondents.

Chapter five contains the summary of results of the thesis and the author's proposal for the next steps to be taken.

## **2 LIGHTING IN A CRUISE VESSEL**

Artificial lighting, comprising of various type of light fixtures, is one of the most visible subjects to the passengers on board. It enables the operation of the whole ship, which is in principle surrounded by massive steel structures, but it can offer also pleasure to the passengers as a smooth ambient lighting for plenty different situations and as correctly designed it can be enjoyed by everyone on board. The key for creating a successful lighting to the venues, along with good designing, is the lighting's adjustability by dimming.

The cruise vessels are equipped with generators, which transforms the main engine generated kinetic energy to electrical energy, and with transformers, which transforms the produced electricity to be suitable for all the consumers installed on a vessel. Lighting fixtures and the house lighting dimming system on board are commonly connected to 400V, 3-phase / 230V, 1-phase alternating current (AC) power grid with 60 Hz of frequency. Since most of the light sources installed on board are nowadays based on LED technology, the light fixtures are typically equipped with either integrated or separately located transformers or ballasts to convert the primary side providing alternating current to secondary side used low voltage direct current (DC), which is then connected to the LED light source, i.e. LED chips.

Since there exists various types of LEDs in the markets, it is very essential for the area designing lighting designer to make sure which type of a ballast is required to be used with each type of a light source, since not all the products are compatible with each other. This creates some challenge to the design phase but the result of accurate designing rewards at the end with fancy lighting effects finishing the décor and architecture utilized in the built space.

### **2.1 Background**

Marine industry has utilized fluorescent tube lights, compact fluorescent tube lights, halogen and incandescent bulb lights and metal-halide lamps for decades. The new light source in the industry is LED which has developed from indication lamp purpose to general illumination and decorative illumination purposes during the past decade. Cruise vessels can now fully be built by utilizing only different types of LED light source based light fixtures.

The existing dimming methods, such as 1-10V and phase-cut, have been the basis for LED lights controls' development. The electronic LED-drivers, suitable for modern LED-chips,

were produced to support these existing dimming methods so the industry could use the well-experienced functioning dimming technology. These methods were based on electrical phase-cut, transistor and thyristor controlling and on analogic 1-10V control voltage controlling method.

These controlling methods have been enough to control the lighting so far but now the technology is developing further, and the light sources should be controllable even separately by called addresses or by called groups of lights. It was not feasible to utilize the existing technology for this purpose and therefore digital addressable dimming methods justifies their position for these applications.

### 2.1.1 Significance

Light is essential for human life. Without proper lighting built on board the vessel is not operable. The modern lighting systems, light fixtures and technology can provide suitable lighting for each operations and tasks that are in a cruise vessel. Wheelhouse as an example requires gentle lighting with reliable control to dim it to lower and higher intensities. The purpose of the lighting is also to be glare-free so the reflection of light fixtures from the monitors does not disturb the operators controlling the ship operations. In the workshop areas and especially on working tables a suitably high intensity illumination is required for the crew to perform their work properly. For the public spaces the illumination implemented on board must be flexible to be able to adapt to each of the themes, scenes and events that are arranged in the area. Generally, the lighting should be available in the location which is wanted to be highlighted at a time and the rest of the venue should be illuminated with relaxing ambient lighting. A proper event illumination in the area is the key to highlight also the best sides of the venue's architecture.

### 2.1.2 Interference/problems

As the lighting technology is developing and changing rapidly, all the participants working around implementing the lighting and dimming systems on board must be aware of the used technology and their requirements. System requiring instructions are essential to be followed at all phases in the implementation process, starting from the lighting designer's work of grouping the light fittings to the electricians' work doing the installation and connections on board.

Malfunctions and unintended events might start occurring as one of the participants working in the command chain has made an error which has been implemented to the system. Dimming system supplier is the responsible of designing the dimming system topology and related equipment. In this process the required components are to be positioned to the ship's different spaces according to the need. Master PC is to be located to a centralized location from which the whole system can be operated and configured in case of a need. Dimming boards are to be located to different technical lockers or similar ship wide with suitable network built between the dimming boards to keep the connections of the system complete. Programming point, local control panels, light sensors and other related equipment are designed to be connected to the dimming system.

Electrical designer designing the venue area lighting drawings is to have the information of what type of a light fixture are to be used in the area. The information of which type of a light and what is the required control method are essential to be known as this affects the cabling of the light fixtures. The most commonly used cable types pulled for the light fittings are 3G1,5 and 5G1,5. The 3G1,5 is utilized if relay controlled, on/off-switchable, or phase-cut dimming light fixtures are supplied. 5G1,5 is used if 1-10V or DALI broadcast dimmable light fittings are to be supplied as these dimming methods requires the two control wires in addition to the power supply wiring. A common issue is that the light fixtures are changed during the process and sometimes this would require a changing of cabling and reserved dimming controller component in the dimming boards, but they are not always up to date to match the most recent design. This causes problems to the electricians and to the commissioning team working on board while the dimming modules and light fixtures have been configured and it is realised that this light fixture cannot be dimmed with the setup that is available from the dimming board to dim the fixture in case. Some of the electrical contractors working on board have made the decision to pull a cable with 5-cores for all the decorative light fixtures in the venue if there is a risk the light fixture might be changed during the design or building process. This allows the change of dimming method at the dimming board end but does not require new cabling to be pulled after the venue's surfaces, such as ceilings and walls have been closed with the finished cover materials. Even with these precautions taken, such an issue with the cabling types might occur on board.

DMX based light fittings are most commonly cabled with two separate cables as the control cable might be wanted to be looped for the next fixtures, but the power line is preferred to

be divided to multiple different circuits. DMX based lights are commonly cabled with 3G1,5, for power, and a CAT6, for data, or a simple pair twisted and shielded cable such as 2x1x0,75. DMX line has strict rules how the cabling is to be done and these rules might be hard to be followed sometimes if area working electrician is not fully aware how these light fittings are to be cabled. Not over 500mm branches from main data line is to be divided and a daisy chain cabling style should always be preferred. Also, the terminator of 120  $\Omega$  is to be connected at the end of the DMX data line in order to make the line working. In case of an XLR connectors are used, this end-plug could be for example a male plug, the one with pins, and it is connected at the end of the data line. [1]

Locating of cables on board might be essential for the systems functioning reliably. Pulling the dimmable lighting group cables to the same cable tray as the main propulsion cables or similar high load cables should be avoided. This is mainly to avoid the risk of getting any interferences or voltage fluctuations induced to the cabling that are controlling lights.

Problems have been experienced also with the LED-drivers, which electricians working on board have not been fully familiar with. For example, such a connection mistakes might have happened in which the 230 V mains supply was connected to the control line of 1-10V, this had caused the LED driver to break. Similar issues have experienced to be faced with DMX drivers which require separate transformer before the DMX controller is connected to the line. Another issue with DMX is the drivers which does not have the daisy chain connection possibility, which is typical in a ceiling installed recessed spotlights. As the DMX line should not separate more than 500mm from the main line to the light source driver, a utilization of junction box or line distributing T-shape quick connector are required to be used.

For the builder of the ship, it is essential to always use only components that are EMC tested and approved. This is one of the main approaches if one is to build a venue on board as there is multiple different electrical and electronic systems which might cause electromagnetic interference to other equipment around them. One of the worst EMI sources are the LED-drivers with their high frequency working electronics. Locating these on board is a matter of consideration before installing them close to communication devices, satellite antennas or similar to avoid the possible interference issues.

## 2.2 Theory

The lighting technology and features of light generally are the same in marine industry as in anywhere else. Most commonly the difference in lighting becomes in a form of the light fixtures structure, which might have to be made sturdier for the light fixture to withstand the harsh environment on a cruise vessel.

Most common enforcements that are done to the light fixture are adding extra sealants to the light fixtures seams to increase the international protection rating (IP rating), changing of pendant lights' mounting support wires to tougher rods to prevent the pendants from swinging while ship moves, rewiring of light fixtures' inbuilt wires to match the requirements of marine light fixtures internal wiring, adding extra earthing connections to the light fixtures body, changing light sources or the socket for the light bulbs to be more suitable for the fixture, adding a proper fixing point to the light fixture, changing of light source powered driver for dimmable version, changing light sources to match the electrical grid providing electrical characteristics and reconsider of using different materials for the light fixtures structure to avoid using of material which adds fire load on board.

IP rating is one of the most important matter to observe when considering placing a light fixture on board, especially on outdoor areas in which IP44 or IP55 for example would be sufficient to be used if only the environment conditions were thought of, but ship operations might be using pressurized water to clean the deck surfaces so the IP ratings have to be increased in some cases. "IEC 60529 Degrees of protection provided by enclosures (IP Code)" standard classifies the protection degrees provided against the intrusion of solid objects, unintended contact, dust and water in electrical enclosures. The standard targets to provide users detailed information instead of marketing vague terms such as waterproof. The first digit for solid object levels and the second digit for liquid levels are described in detail in tables 1 and 2. [2]

Table 1. IP rating's first digit's definition of levels for solid materials. [2]

Level	Object size protected against	Effective against
0	Not protected	No protection against contact and ingress of objects
1	>50mm	Any large surface of the body, such as the back of the hand, but no protection against deliberate contact with a body part.
2	>12.5mm	Fingers or similar objects.
3	>2.5mm	Tools, thick wires, etc.
4	>1mm	Most wires, screws, etc.
5	Dust Protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment; complete protection against contact.
6	Dust Tight	No ingress of dust; complete protection against contact.

Table 2. IP rating's second digit's definition of levels for liquids. [2]

Level	Object size protected against	Effective against
0	Not protected	-
1	Dripping water	Dripping water (vertically falling drops) shall have no harmful effect.
2	Dripping water when tilted up to 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15° from its normal position.
3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect.
4	Splashing water	Water splashing against the enclosure from any direction shall have no harmful effect.
5	Water jets	Water projected by a nozzle (6.3mm) against enclosure from any direction shall have no harmful effects.
6	Powerful water jets	Water projected in powerful jets (12.5mm nozzle) against the enclosure from any direction shall have no harmful effects.
7	Immersion up to 1m	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).
8	Immersion beyond 1m	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects.

Most of the decorative pendant lights are mounted with wires which allows the pendant to hang and move at the end of the support wires. These are changed to solid pipes or equivalent

before the product is brought on board. The procedure is required in order to make the pendants or chandeliers marine proof as they are not allowed to move while ship operates. This is also considered as a safety issue for passengers as the light fixtures cannot move and cause a risk of damaging anyone's head on the light fixtures. Preventing these moving parts from swinging also minimizes the risk of getting to feel nauseous.

Internal wiring might be differently regulated by classification societies. The internal wiring of light fixture is to be executed by using stranded halogen free wiring. Some of the classification societies might regulate also the cross section of the used wires. The instruction might be for example that minimum of 0,75 mm<sup>2</sup> cross section wires are to be used or the internal wiring is to be one standard cross-section size smaller than the light fitting supplying cable.

The mounting method and the fixing points of the light fixtures must be carefully considered. Heavy pendants and chandeliers require robust connections to be executed and properly fixed to the ceiling structural steel parts. Also, part of the decorative floor lights might have to be bolted or otherwise fixed to the deck to make sure any bigger light feature elements do not fall during the ship operations.

### 2.2.1 Lighting Requirements on board

Requirements exist regarding lighting on board. These requirements mainly consider the safety matter side of lighting, such as emergency lighting generally, guiding low location lighting and in certain cases the battery backed-up lights requirements. The rules are regulated by the International Maritime Organization (IMO) with the International Convention for the Safety of Life at Sea (SOLAS) in principle, but additional requirements are regulated by Classification Societies. The Classification society involved in the ship construction is agreed on during the ship contract phase project by project and the agreed classification society's rules are to be followed throughout the project.

The ship specification defines further instructions to the lighting that is to be considered while lighting is designed and implemented on board. Most commonly it defines certain average illuminance levels to be met in different types of venues on board, such as working areas, technical rooms, open decks and staircases. The purpose of this is to ensure a reasonable working environment lighting for the crew working on board, but it can also be

considered as safety matter in certain level for example to prevent passengers on board from falling down the stairs or slipping on a wet outdoor deck. The specification may additionally provide requirements on for example for colour temperatures, locating some specific light sources, lighting control systems, lighting system's operating electrical parameters, amount of light fixtures to be connected to a single lighting circuit, mainly used light sources type, lighting of different cabins, emergency lighting and additional requirements to be followed, e.g. United States Public Health (USPH).

#### Common light source, LED

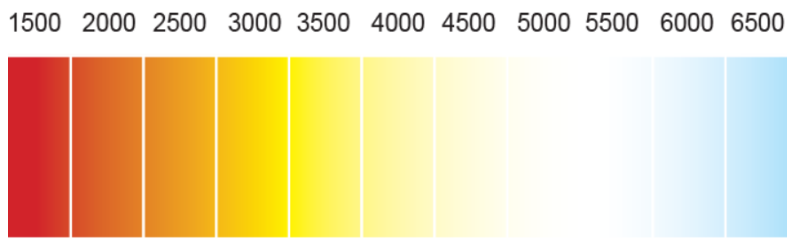
Light-emitting diodes (LEDs) in a lighting technology has provided plenty of variables and options to be utilized in the lighting design. It provides great amount of choices from which the optimal lighting can be chosen from for each application.

If the area is wanted to be able to perform at its best, it requires a final touch which can be provided with a proper lighting design. In this design process the one designing the lighting to the area should be aware of the basics of lighting technology. Not all lighting features and characteristics can be controlled after installation and therefore it is important to take these matters in to account before the implementation of the area. Part of the possibilities and things to consider in lighting design are shortly described in the following sub-chapters.

#### Colour Temperature

Colour temperature is one of the characteristics of visible lights in LED based lighting. It is commonly expressed in kelvins (shortened as K), which is the unit of measure of absolute temperature. Colour temperatures can be divided to cool and warm colours, in which the cool colours are normally valued to be over 5000K, while the warmer colours are below the 5000K, typical warm colour temperature is in a range of 2700K to 3000K.

Colour temperatures can be utilized in different operations and in purposes, while it is still a matter of personal opinions, which is the best tone for which purpose. As an example, the working light on top of an office table could be about 4000K and the table light in the living room could be about 2700K to keep the ambient feeling in comfortable levels. Colour temperature, that is the tone of the light output of light fixture affects the illuminated room's atmosphere. The illustration of colour temperatures is shown in picture 1.



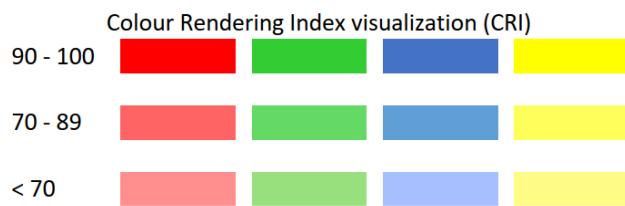
Picture 1. Illustrative colour temperature chart in Kelvins (K).

Modern lighting fixture can be a colour changing version, called for example as tuneable white light. Commonly the tuneable white light fixtures can be adjusted e.g. in range from 2200K to 6500K and the preferred level can be selected for each situation for example by the time of the day. Changing colour temperature during the times of the day is the basic idea also for the Human Centric Lighting (HCL) technology. In this technology the purpose is to make sure the light colour is always the optimal for each event and time of the day. The light could be warmer in the morning when a person is supposed to wake up but turns colder to activate the person during the day. Warmer tones could be utilized while relaxation and comfort are wanted during the evening time before going to sleep. The warmer the colour the more it could illustrate e.g. the tones of a sunset.

Most of the light sources that are meant to be changing colour temperature are normally operated with two different channels, one for cool white LED-chip and another for warm white LED-chip. These light sources are commonly controlled by DALI or DMX, but for example the control of “dim-tone” light source, which turns the warmer the dimmer it gets, can be controlled for example by 1-10V.

#### Colour Rendering Index (CRI)

Colour rendering index describes the light’s characteristic of how accurately the light appears on an object to human eyes. The scale of colour rendering index is from 0 to 100 per cent. The higher the value is, the better is the colour rendering ability. Light source with  $R_a = 100$  can reproduce all colours perfectly. One of the most commonly used light source, incandescent bulb has the colour rendering ability close to 100, almost the same as the sun, which is the reference point with the CRI value of 100. The modern-day LED light source has lower CRI values. Common CRI value for modern light fixture is around 90, but even 97 starts to be more and more available. The colour rendering principle is visualized in picture 2.



Picture 2. Principle of Colour Rendering Index visualized.

CRI is the feature of the light source itself and it is not separately controllable by any common lighting control method.

### Luminous flux

Luminous flux describes the amount of visible light emitted by the light source. The unit of luminous flux is called lumen. Modern light sources are not anymore selected in a traditional way of observing the wattage of the light source. Selection of light source has become lumen based but it is common for example for LED bulb supplier to inform the wattage and lumens in the product's package. Often the manufacturer instructs the customer with an informative chart which explains how the lumens are comparable to traditional incandescent bulbs. For example, 60 W incandescent bulb produced approximately 800 lumens of light output. With a modern light source, the same amount of light output can be produced from a LED-bulb with about 7-8 W with the today's technology which has developed remarkably during the past decade.

The light source's luminous flux can be controlled by utilizing any suitable dimming method meant for the light source. Sometimes the venue can even be designed to be a bit over-illuminated with an intention to keep the venue's lighting always a little dimmed while operation. This allows to increase the light levels of the venue to higher total illuminance levels in case of an operation which requires more accurate working, such as cleaning. This affects also the lifetime of the light source.

### Flicker

Flickering is a light's characteristic in which the light source's visible brightness continuously fluctuates. It is a possible result of unsteady voltage source, high frequencies (PWM) supplying the light source or incompatible control or dimming device.

Flickering is an attribute of the light fixture as well and it might become clearly visible while the light fixture is dimmed close to zero level. In the current LED technique, it has been noticed that the most commonly flickering light fixture is a direct 230 V AC LED light source which is supplied directly from the ships power grid with 60 Hz frequency and not through an individual light fixture dedicated LED-driver. Tests have resulted for example that the ceiling installed downlight/spotlight may possess over 90 % of flicker meanwhile the similar product can be made with a LED-driver and low voltage chip on board (COB) LED possessing the same other light features, such as light intensities and colour temperatures, but has closer to only 5 % of flicker. The light fixtures may be visually flickering also due to the PWM control high frequencies.

Flickering can be avoided by utilizing suitable combination of dimmer, LED-driver and LED light source and mostly the non-flickering light fixtures have been preferred to be installed to a cruise vessel. This is due of making the vessels as comfortable as possible to the customers, reducing possibility of sickness but it also guarantees that the taken photos and video clips are successful as there exists no horizontal reflection stripes in the taken shots caused by the flickering effect.

#### Beam angles

Beam angle describes the measurement of how the light effect is distributed from the light source. Beam angles are dependent on the LED chip's characteristics but also the diffusors, optics and lenses used in the light fixtures. This feature is not normally controllable by the control devices, but some pioneers in the field of the area are developing the beam angles to be slightly adjustable also for the architectural lighting.

#### Lifetime

Lifetime describes the time in which the light source can provide certain illumination level over a certain amount of time. Light sources' light output decreases over time and all different light sources dims out in different rates. LEDs have the benefit of having a long lifetime, if compared to most of the conventional light sources. This is mainly because LEDs does not consist of movable or easily consumable parts.

According to the LED and lifetime article of Glamox LED Education Centre, "The lifetime of a LED module is defined as the time it takes until its light output, or lumen maintenance,

reaches 70% of the initial output. This is also called L70. In other words, the module does not die instantly as many conventional light sources do, it slowly dims down”. LED lifetime has been standardised by the luminaire industry to be in values of L70 after minimum of 50000 hours of operating time. The lifetime of a LED is standardized in the international standards IEC 62717 LED-modules for general lighting – Performance requirements, and in IEC 62722-2-1 Particular requirements for LED luminaires. [3]

Normally the LED light source lasts longer than the LED driver feeding the LED chip and therefore the lifetime of the LED light source and the driver should both be declared separately.

The lifetime of a LED chip depends on the temperature and the current it is controlled with. If the LED chip is required to produce slightly more illuminance output per consumed wattage (lm/W), it can be driven with a slight over-current. Normally this procedure decreases the lifetime of the LED chip remarkably. If the light fitting is designed to have certain lumen output, the light source can be operated in its optimal electrical values. Typical LED chips produce roughly 120 to 200 lm/W, depending on light fitting application.

### 2.2.2 Dimming methods

The oldest common dimming methods such as electrical phase-cut and analogic 1-10V controls are acting a huge part in built cruise vessels. This technology is well-known in the industry and thus they are not observed in such a detailed level in the following chapters. The newer, more unknown technology, as DALI therefore is observed more in detail.

### LED drivers

Multiple different types of LED drivers exist in the markets. These types and terms of architecture can broadly be divided into two-stage types and single-stage types, see figure 1.

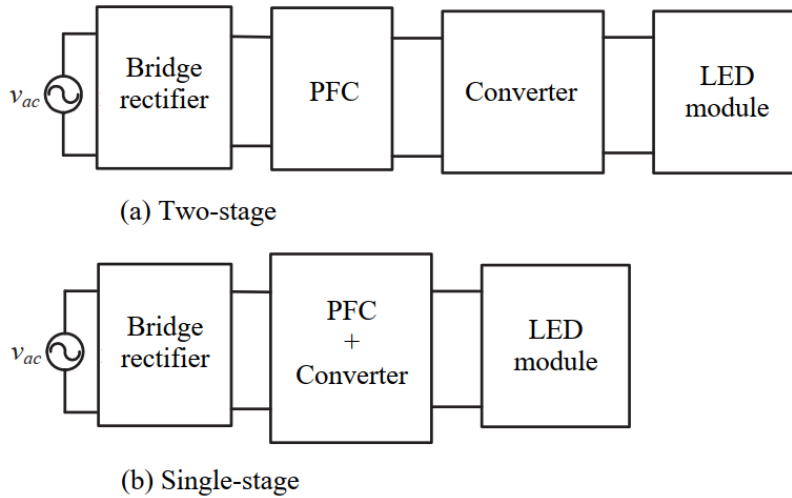


Figure 1. LED driver structure with supply and LED light source [4]

The first stage of two-stage circuit is the correction circuit of power factor. Second stage is the current control circuit. Two-stage circuit can control front stage and rear stage circuits separately, due to these it is more stable for the system operation and the protection circuit design is relatively easy. Because the circuit requires many components, the size and cost of the components are larger. In single-stage type power factor correction and current control functions are integrated. Circuit has less components and thus is small sized and costs less. Disadvantages of the single-stage circuit LED driver is that the system's stability and reliability are poor, while the protection circuit is more complicated, feedback network design becomes more difficult, circuit operation under universal input voltage and specific components have higher stress. [4]

The common LED dimming methods have two different types, as shown in figure 2. In amplitude modulation (a) method it changes the current values flowing through LED to change brightness, but this method causes changes of the peak wavelength of LED, which causes light colour floating. In Pulse Width Modulation (b) (PWM) method most of the series switch conduction will cut-off to change the current flows, through the LED's duty cycle to change the LED's average current value, which can achieve the purpose of dimming. The conduction current during the peak of the pulse width modulation modes are maintained at a rating of the LED, so amplitude modulation and colour floating problems does not exist. Due to these the PWM mode is suitable for dimming of LED. [4]

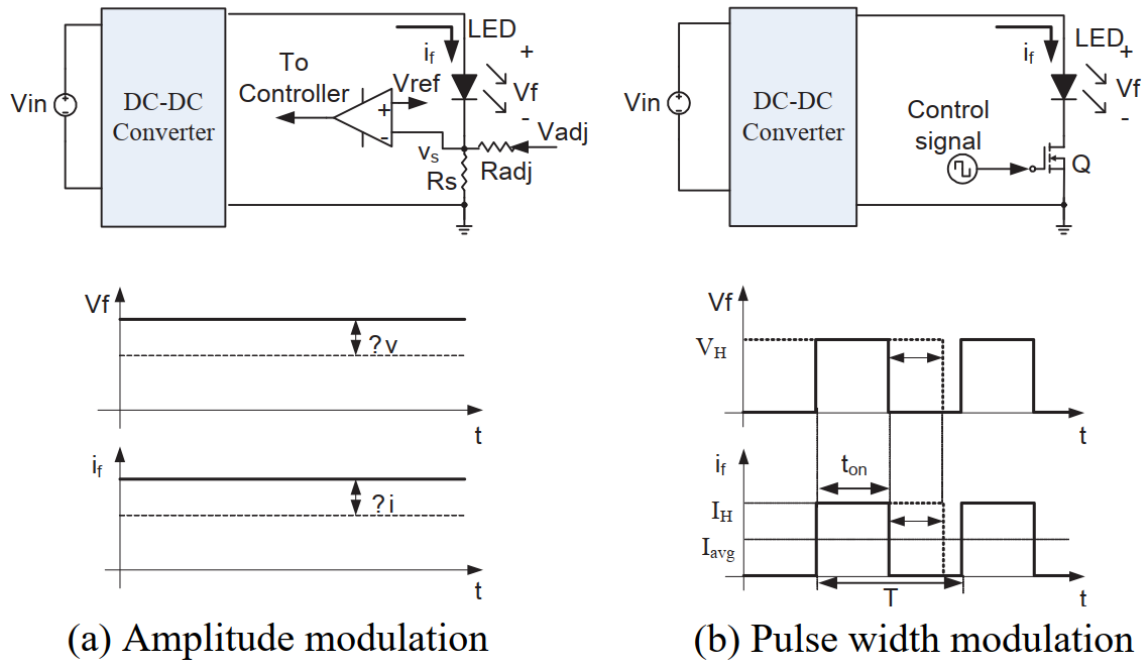


Figure 2. Common dimming methods. Amplitude modulation and Pulse width modulation [4]

#### Availability of LED drivers

LED drivers are constantly developed for the modern dimming methods. This includes mostly the wide variations of DALI drivers. According to the feedback from well-known manufacturers, such as Osram, the demand for 1-10V LED drivers has decreased remarkably while the demand for DALI has increased. This direction in the markets limits the availability of 1-10V LED drivers.

Also, DMX drivers demand has decreased lately as lighting technology can utilize DALI, instead of more complex DMX 512. As DMX protocols demand decreases, the costly known products price rises even higher as they are not sold in a rate as they used to be before the DALI started to get widely utilized during the last decade.

The DALI drivers are the products that most of the manufacturers want to develop and improve to keep up in the markets, therefore the costs of the DALI drivers are decreasing slightly over time, and they start to reach the level that 1-10V used to be. Availability of DALI and DALI 2 drivers is getting constantly better.

## 1-10V

One of the most commonly used dimming type that has been used on boards during the past couple of decades is 1-10V dimming method. The general way of adjusting the luminance is done analogically adjusting the DC value between 1 V to 10 V. 0-10V dimming method functions the same but the lowest value is 0 V instead of 1 V. Analog dimming requires more components than phase-cut TRIAC dimmers and has complex circuit architecture. The system is quite large for management and their functions are limited, which is the reason not all the ship-owning company's needs cannot be met. [4]

The 1-10V dimming method is a low voltage lighting control system that utilizes the analogic dimming ballasts that are connected in parallel and are controlled simultaneously by changing the DC voltage between 1 V up to 10 V with a dimming control unit. The ballasts cannot be addressed separately so they are not individually controllable. Hard wiring of the ballasts determines which units are controlled as a group. [5]

One of the most commonly used 1-10V controllers are Helvar 474 module, that is 4-channel ballast controller capable of controlling 4 pcs of 16 A output channels. The outputs are configurable to match common ballast control loads including 0/1-10V, DSI, DALI broadcast and PWM. The outputs can be set to be independent of, or paired with, relay channels. [6]

1-10V LED drivers have lately been used to control recess-mounted spotlights and LED strips on board. These light sources may have formed 80 per cent of the space illumination and therefore this dimming method has been one of the most favoured dimming methods in cruise vessels for a while. Marine industry adopted to 1-10V dimming method by controlling the fluorescent tubes and compact fluorescent tubes, but later also with LED light sources.

## Phase-cut

Joel Spira invented the silicon-controlled rectifier (SCR) controlled dimmer in 1959 and Eugene Alessio announced TRIAC (Triode for AC) controlled dimmer a year later. These thyristor-based controls are mainstay of dimmer technology today, even the insulated gate bipolar transistor (IGBT) is utilized in some of the newest dimmer designs due to its easiness of driving and controlling. [7]

All these devices functions by cutting off part of each half cycle of the AC line waveform. The amount of which is cut off is measured by phase angle. The complete sine wave is 360 degrees in length and half wave is 180 degrees. If 90 degrees of each half cycle is cut off by dimmer, the effective voltage applied to the light source is reduced to half. Phase-cut dimmers are operating the waveforms by cutting the leading edge (forward phase-cut) or trailing edge (reverse phase-cut) of sine wave. Leading edge phase-cut was developed from the thyristor behaviour. The SCR or TRIAC is triggered to turn it on and it turns off when zero voltage of waveform is crossed. Trailing edge phase-cut was developed to improve the performance of low voltage halogen light sources that operates on an electronic transformer. [7]

Controlling of LED lamps with traditional phase-cut dimmers might be challenging as the dimmer technology has dominated the market for decades and there is wide number of these dimmers installed worldwide. A simple phase-cut dimmer is connected in series with an incandescent lamp with its two wires and it requires the voltage to be across the dimmer if operated. More developed dimmers require more power for their electronics and that is why there is an added wire (third wire) provided to power the electronics. Dimmable LED fixture has the two wires from the dimmer to provide power, without the benefit of full line voltage being present during the cut off part of the phase. Dimmers that bases on thyristors, requires a minimum load current for their proper operation. The dimmed LED fixture must provide this load current also at low line voltage, which is contrary to the improved efficiency of LED if compared to incandescent lamp.

Generally, because of these limitations dimming of LED light sources with existing phase-cut systems were unsatisfactory. Dimming below certain level, such as 30 per cent illumination, was unreliable. Due to the problems faced while trying to dim LED bulbs with phase-cut, the field of the area engineers started to investigate digital alternatives for dimming this type of light sources. [7]

Technology has developed and phase-cut as dimming method has been utilized in cruise vessels for 40-50 years, lately the transistor dimmers, such as Helvar 454 with its four-channel transistor dimmer, has been used on board. The dimmability of LED bulbs is highly depending on the LED bulb itself. Some of the bulbs dim lower than others and some of the LED bulbs may start flickering if they are tried to be dimmed to the lowest illuminance

levels. Due to these differences between the behaviour of the LED bulbs, testing of the light source in advance with the dimming system components intended to be used on board is highly preferred.

The Helvar 454 dimmer module supports both Trailing-edge and leading-edge dimming. The module has seven different output settings possibilities. These settings have the following possibilities to be used to dim phase-cut light sources: [8]

- Non-dim, which switches light sources on and off only
- Linear, Square and S-law, which are optimised for incandescent loads
- DALI logarithmic and linear, for basing on IEC62386-205 standard's dimming
- LED curve, which is optimised for LED, but is also the default output type for this module

This transistor dimmer module can be connected to digital bus also with DALI terminals, in which case the unit consumes 2 mA from the 250 mA that DALI line has as default.

The transistor dimmer modules are widely used to mostly control the E27 and E14 based LED bulbs installed in the decorative light fixtures on board.

## DMX

DMX is a digital communication standard which is most commonly used in entertainment equipment's controlling, such as stage lighting. The DMX512 protocol was established late 1980s and it has been used on board for decades by now to control mainly entertainment and performance lighting but for almost two decades also for architectural lighting. The original standard for DM512 protocol was developed and published by USITT in 1990. The standard is now an ESTA publication and it is under the following title Entertainment Technology – USITT DMX512-A – Asynchronous Serial Digital Data Transmission Standard for Controlling Lighting Equipment and Accessories. [9]

A pure DMX system is commonly built with using DMX512 standard connectors. There exists couple different types of XLR connectors with different number of pinouts. The standard connector for the protocol is the five pin XLR connector, which female version is fit to a transmitter, e.g. console, and a male is fit to the receiver, e.g. a dimmer. The typical pin & connection order of XLR5 connectors is shown in table 3. The body of the connectors

is not to be connected to the screen as if two different earth potentials exists in connectors that are picked up, there is a risk of getting a shock. [9]

Table 3. Typical pin order with colours and usage for XLR5 connector. [9]

Pin	Usual colour	Usage	Notes
1	Screen	Interference screen, and ground reference	[Note 2]
2	Black	DMX512 Data -ve	
3	White	DMX512 Date +ve	
4	Green	Spare data -ve	[Note 3]
5	Red	Spare data +ve	[Note 3]

As the DMX512 data rate signal is 250,000 bits per second, it can be categorized to radio frequency (RF) signals. RF signals may behave unintendedly in a cable without end terminator, because of the signal reflections which would bounce the signal back down the wire. To avoid the effect the two data lines of DMX512 line should be terminated to about 120 ohms terminator. This terminator is to be added at each end of DMX circuit. Light fixtures utilizing DMX512 protocol commonly has the XLR5 sockets integrated in the light fixture's body and the fixtures can be daisy chained from a light fixture to another. If the final light fixture in the circuit does have only one socket connection point in it, it may have integrated end terminator. This is to be confirmed by measuring the devices resistance with a device that does not cause voltage peaks to the light fixture while measurement is executed. [9]

## DALI

At the end of 1990 the first research had been started on a universal applicable, a powerful and reasonably priced digital interface for controlling of Electronic Control Gears (ECG) for fluorescent tube lights. According to the study of P.F. Hein's, Tridonic-Bauelemente GmbH, from October 2001, the major targets of the investigation from the beginning were: [10]

1. to improve analogous interfaces' features,
2. to standardize the interface within IEC 60929 AC-supplied electronic ballasts for tubular fluorescent lamps – Performance requirements,
3. to minimize the amount of the controllable ballasts' different families for various types of lighting bus systems
4. to assure maximum interoperability between different suppliers' digital ECGs

A working group was formed, and the outcome was accepted in 1997 by IEC/COMEX as New Work Item Proposal. The COMEX nominated a so-called Digital Panel of representatives from various countries that wanted to contribute the activity. Digital Panel consisted of experts from e.g. Helvar, Philips, Siemens-Osram and Tridonic who drafted Annexes for IEC 60929 Control interface for controllable ballasts. An abbreviation DALI, Digital Addressable Lighting Interface, was created for marketing purposes. [10]

The digital controlled ballasts were to be used in simple stand-alone system solutions as so-called intelligent luminaires but also as a sub-system in building management systems. The automatic control of one light fixture by means of passive infrared detector or such were an improved feature compared to 1-10 V analogical control systems. The major advantages are: [10]

- individual controlling of light fittings (control by individual addresses)
- multi-channelling (controlling of several groups)
- mains switching was not needed to switch off
- back-channelling, i.e. information feedback e.g. for present light level, indication if light is switched on or off, ballast conditions and lamp conditions
- system's easy re-configuration, i.e. changing light fitting groupings and scenes
- adding new components easily

Transmission capacity needed, the longest distances of transmission, requirements for RFI-suppression and flexibility of configuring advantageous arrangements are a good compromise respect to the electrical requirements. The process functions with low information rate of 1200 bits per second. The distance of transmission highly depends on the used wires, which should not exceed 300 meters. Cable voltage drop can be 2 volts while the nominal voltage of the system is 16 volts. [10]

To avoid unnecessary high frequencies which could create radio-frequency interference (RFI) problems a 100% redundancy is added to information transmitting the signal pulses. The tolerances of transmission pulses are described in Figure 3. [10]

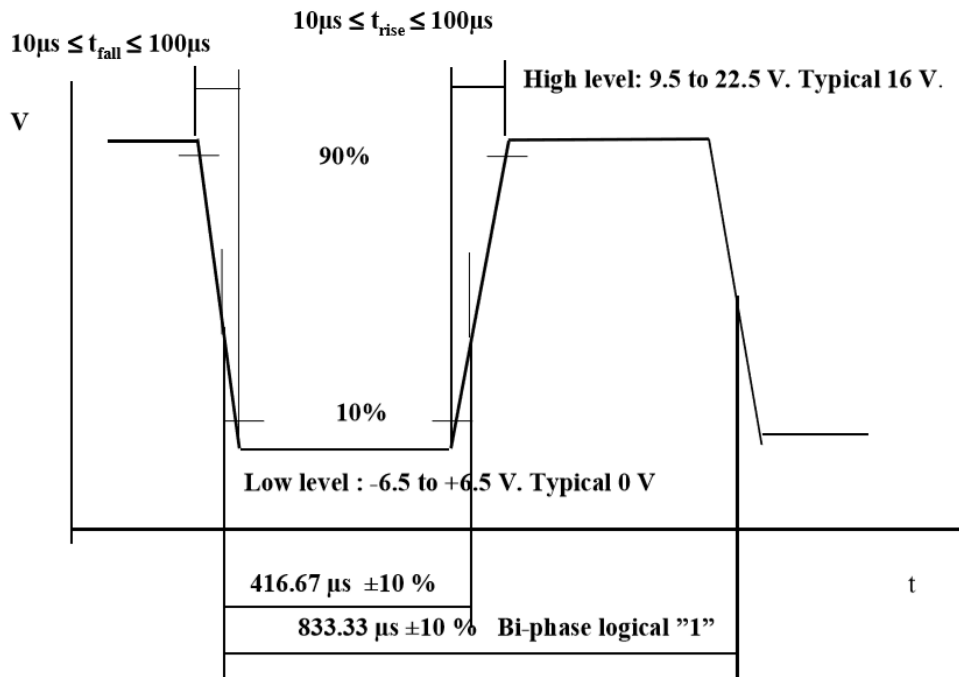


Figure 3. DALI transmission pulse tolerances [10]

The up to date transmission pulse tolerances can be confirmed from the most recent DALI standard from IEC62386-101, under chapter “Signal voltage rating”. The low-level voltage has been increased from -6,5 V to 0 V on year 2018. The valid time frame for checking a logical bit, starting at an edge at the beginning of the bit for a valid half bit is minimum 400,0 μs to 433,3 μs. About 40 μs around this time frame are considered as grey area and bigger deviation from these values are considered as destroy area for the bit. [11]

The following parameters offers freedom of configuring the system and to protect the ECSs against miswiring [10].

- Voltage controlled operation is used to enable spatial separation of the interface supply unit and of the control unit
- Asynchronous start-stop transmission protocol
- Bi-directional transmission; from ECG on request 1 byte-frame, to ECG 2 byte-frame
- Polarity insensitive interface input (optional)
- Over voltage protection for accidental mains voltage between the control wires (optional)

From operational requirement point of view the following addressing capabilities are specified [10]:

- Each ECG has its own individual short address, 16 group addresses and capability of reacting to broadcast commands.
- A maximum of 64 individual short addresses, and
  - I. Multiple ballast groups

The following features shall be implemented if the arc power level is to be changed [10]:

- Each ECG stores 16 scene levels, a fade time, a fade rate, the MAX-, MIN-, POWER-ON and SYSTEM FAILURE levels
  - I. 255 absolute light levels including “Off”, range 0.1% to 100%, logarithmic dimming curve, the lower level depends from the ECGs performance.

The above-mentioned logarithmic relationship enables that each pair of neighbored digital expressed absolute values of the arc power  $P(x)$  and  $P(x+1)$  differs by a constant percentage of 2,8%.

$$\left| \frac{P(x)-P(x+1)}{P(x)} \right| = constant = 2,8\% \quad (1)$$

This feature corresponds with the physiological behaviour of human eye [10].

The central control unit controlling group of ballasts shall react the following way:

- Master-slave operation
  - I. the ECG reacts on request only
  - II. no multi-master algorithm implemented
  - III. no collision detection and collision avoidance algorithm implemented
- The ballast cannot function as a master controller
- ECG ignores the command or aborts the unfinished sequence if a code violation or time limit failure is detected
- Within the physical performance of the ECG a minimum and a maximum light levels can be programmed
- Each ECG informing of its status and its version number on a request
- If the interface supply voltage is not detected, the ECG goes to its “System Failure Level”, i.e. either no change or a specific emergency light level

During the installation phase of a system where light fittings are installed the latter feature is important. In this phase the mains power supply is connected but the system control is either not installed or initialized yet. In this situation the default value of the “System Failure Level” guarantees 100% light level [10].

While using DALI, the user can send an instruction to ECG by control unit and the addressed ECGs would react. The structure of the DALI system is shown in figure 4.

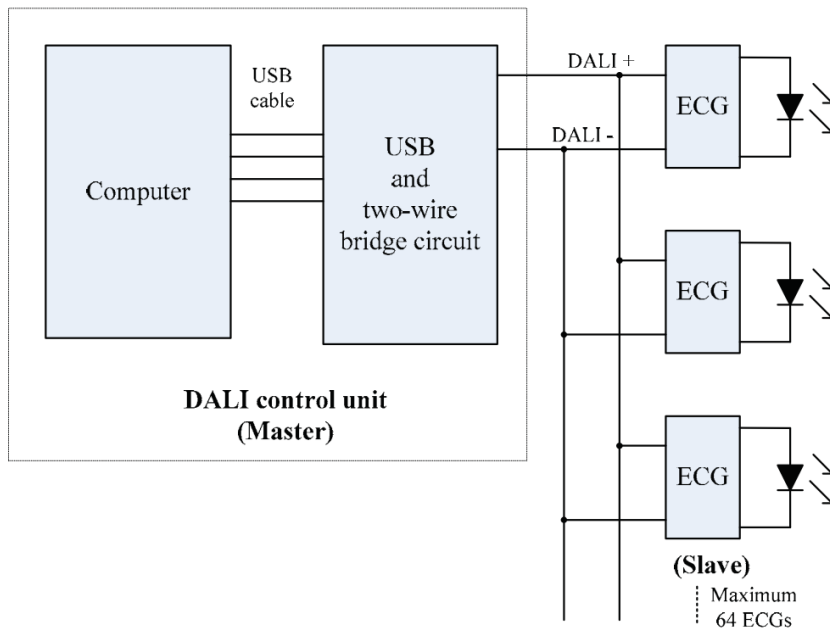


Figure 4. DALI system structure with Electronic Control Gears and light sources. [4]

A computer or similar with user interface to convert computer signals and DALI signal to a bridge circuit are needed. Computer Universal Serial Bus (USB) interface allows communication between external peripheral device and computer. Computer can automatically recognize the peripheral devices and configure the appropriate driver. The ECG can be divided to several parts, which are optical isolation circuit, micro-controller circuit, dimming circuit, and LED driver circuit, the structure is shown in figure 5. [4]

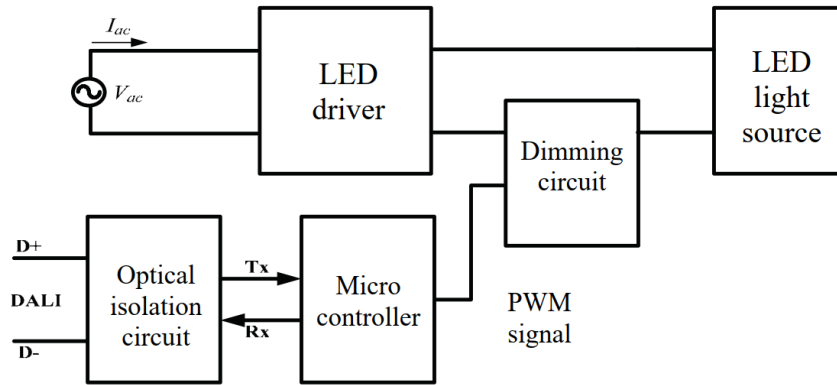


Figure 5. Principle of DALI electronic control gear structure. [4]

User can give command signal, which is delivered through computer. The signal contains addresses and commands are sent by the bridge circuit. This signal is transmitted through DALI transmission line into each ECG. ECG receive data from opto-coupler and is decoded by the micro-chip. The micro-chip then determines whether it has been addressed or not, which gives proper response for the command content if it is addressed. Non-addressed control gears are not to react. [4]

A 2-wire bus is utilized for communication but also to power some devices. The bus signal is typically around 16 V if there is no active communication, but it can be significantly above and below this. [12]

DALI commands allow controlling, configuration and querying of the products. Control commands are for example the command to start a fade to a defined light output level, recall scenes or turn the lights off. Configuration allows for example to change the fade times or change the light level stored in a scene. Query commands are utilized to ask the current light output levels or if there is a lamp failure. Commands can be addressed to an individual device, to a group of devices or as broadcast to all the devices. These different commanding methods makes the communication efficient. [12]

DALI broadcast subnets can be created to the dimming system for example by utilizing Helvar 478 controller module, which is a module providing 8 pcs of subnets for DALI broadcast control method. The device can control the DALI standard instructing 64 devices via one of these subnet channels, but with a limitation of 128 mA can be loaded to a single channel. It is a controlling device which can be used if ballasts and drivers are not given device addresses. While commissioning and maintenance are considered, the utilization of

DALI 478 can reduce the costs and time related to them since the load devices can be replaced and re-configuration is not separately required, but the system configures them automatically. The flexible control inputs support multiple protocols by routing an input address or group to the corresponding subnet output. The 478-controller device can report a lamp failure for each subnet. The device can be operated with the mains supply that is between 100 V AC – 240 V AC, as nominal value. Absolute values for mains supply voltage are 85 V AC – 264 V AC, while 45 Hz – 65 Hz is as frequency range.

Helvar DALI controller modules have been developed according to DALI standard as per EN 62386:2009, edition 1, and EMC emissions and immunity are following EN 55015 and EN 61547. [13]

The DALI system requires a bus power which is powered with typically 16 V, with connected bus power supplies providing up to 250 mA. It is used for DALI communication, but can also be used by bus-powered devices, such as sensors, small relay devices or pushbuttons. The bus power supplies can be integrated within the control devices or control gear but can also be a separate product. The bus wiring consisting of the two-wires, which are recommended to be 1,5mm<sup>2</sup> of cross section and the allowed maximum distance is 300 meters between the farthest two devices on the bus, when using the maximum rated bus power supply of 250 mA. The two-wires are instructed to be adjacent. [12]

LED drivers that typically converts the mains providing AC supply to a low voltage regulated DC output are described as control gears according to the standard. More commonly, the power to the lamps, and therefore control of light output is provided by control gear. All control gears are to comply with IEC 62386, part 102 and to the specific device type's standards which are specified in 200-series parts.

A single DALI bus allows a total of 64 addresses for control gear, as well as 64 addresses for control devices. There are 16 groups for control gear, in which each control gear can be a member of any combination of the 16 groups. 32 groups for control devices are available, in which each control device can be a member of any combination of the 32 groups. There are also 32 groups for instance of input devices, such as individual buttons within a panel, each of these instances can be a member of up to 3 of these groups. [11]

The functioning in a pre-set scene is described in the DiiA's published DALI quick start guide as follows: "Scenes in control gear contain a light level or can be set to "ignore". When

the scene is recalled, the output will fade to the stored light level, or will have no effect if an “ignore” is stored. Each item of control gear has 16 scenes. A single GO TO SCENE command instructs all the lights, or any combination of the lights, to go to individually pre-defined levels.”. [12]

DALI controlled lighting systems have been implemented on big projects worldwide. According to the DiiA websites providing information, a couple of huge lighting technology manufacturer companies have implemented the lighting renovations to churches, museums, warehouses, airports and so on with DALI based technology. The projects have provided energy savings but also flexibility on changing scenes with the intelligent systems. [14]

## DALI2

DALI 2 is the updated, more strictly regulated and new version of the IEC 62386 standard. The main differences to previous DALI are mostly directed to two different areas, those are control gears and control devices.

IEC 62386 standard has been re-written for control gears. This re-writing makes the standard much clearer and more strictly specified which results significant improvement in product interoperability. The amount of testing has been largely increased and as an example of this, it takes about three times longer to test the new DALI 2 standard’s devices than it took to test DALI version 1 LED drivers. The thorough testing results out also the increased interoperability between the devices and electricians installing the equipment should expect clearly less problems to be faced. Control gears’ features have also been updated and one of the most significant improvement could be defined to be the extended fade times, which allows fading from 0.1 seconds up to 16 minutes. If a DALI2 control gears is not available with required properties, they can be replaced by a DALI version 1 control gear. This mixing of different DALI protocols is very unlikely to give a problem, but the DALI2 control gear providing new features are then disabled for these drivers. DALI2 devices are designed to be backward compatible. [12]

DALI 2 LED drivers, control gear, implement the DALI requirements from DALI standard’s parts 101, 102 and 207 currently, but in future they will be implementing the parts 101, 102 and a selection of different features from parts 216 and upwards. The need for the previously utilized device types defined in parts 201-209 are to be removed. [12]

Control devices are new to DALI 2 standard, which are handled in IEC 62386, part 103. This part of standard was not specified for DALI version 1. Those that connected to the DALI version 1 bus were proprietary solutions, which meant that all the control devices implemented in same system had to be from same manufacturer to ensure they would work together. DALI 2 standard gives requirements for the input devices and application controllers, which allows of utilizing different manufacturers' devices connected to a same DALI bus line.

Control devices include input devices and application controllers, which have two different purposes but are occasionally combined into a same product. Application controller can be thought as the “brains” of the system. They utilize the information from any source, makes the decisions and sends the commands to control, configure or query the lights (control gear) or other bus connected devices. Input devices provides information for use of application controllers. The information could be originated from light sensors, sliders, occupancy sensors, pushbuttons, rotary controls or other devices. [12]

In addition, DiiA has prepared and launched the DALI 2 certification program. DALI 2 products are to be fully certified by DiiA before getting the permission to use DALI 2 logo. Each of the DALI 2 certified product can be found from the list from DiiA websites. [12]

The dimming curve of DALI is standardized to be logarithmic, which is based on the response of the human eye. The maximum and minimum light levels are configurable, and each dimming step is only 2.8 % greater than the previous step, as an example if started at 5 % light level, the next step would be 5.14 %. The tests are always done for the light output curves, if half of the light is requested, the half of the light is to be available on command, and it is also tested to be within an allowed tolerance. The DALI logarithmic dimming curve with allowed tolerances is shown on figure 6. [15]

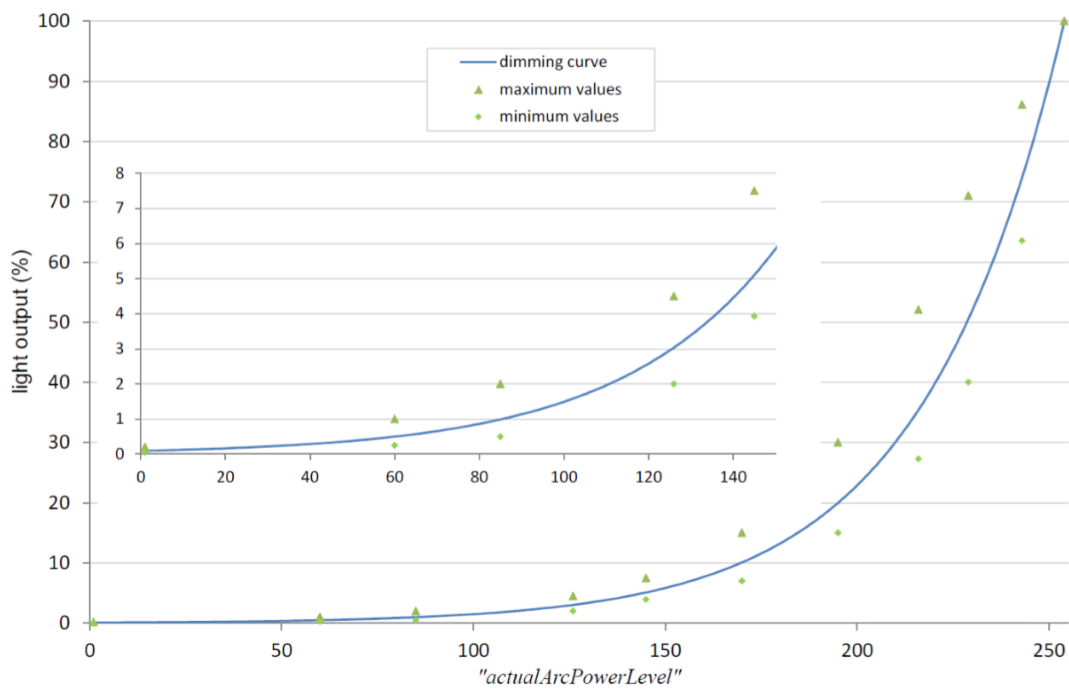


Figure 6. DALI logarithmic dimming curve with minimum and maximum values. [15]

### 2.2.3 Comparison of dimming methods

The marine industry commonly utilized 1-10V dimming method is compared to different variations of DALI protocol's dimming methods in this chapter. As the DALI protocol is developed to be controlling lights digitally, it can provide some benefits that analogic 1-10V protocol does not support. DALI is also compared to DMX512 protocol in this chapter as this protocol has commonly been used to control RGBW (Red-Green-Blue-White colour) based light sources in venues that does not require performance lighting's quick responsiveness.

DALI bus is a digital, bi-directional and polarity-free communication line which supports commands for controlling, configuring and querying with control devices and has quite free wiring topology. 1-10V dimming method's analogic control signal wiring must be connected the right way for the dimming effect to function as intended and it is not capable of querying the status of the control gear unlike as DALI is. The DALI protocol's commands can be utilized to monitor the status of the control gear, which also helps the end user in their maintenance work during the ship operations. Lamp failures can be detected but also other statistics following functions are constantly developed for the DALI 2 protocol, such as light output compensation, thermal lamp protection and power measurement. [12]

DALI broadcast and 1-10V control gear can operate with similar type of wiring as both support 5G1,5 cables to be used from which two of the cores are dedicated for the control signal. As the same cable can be used for both dimming methods in principle, the guidelines regarding the cabling lengths and thicknesses are still to be honoured. 1-10V are to be cabled separately for each group that is wanted to be controlled individually, but DALI addressable devices can be connected to bigger groups and the grouping of lights can be done by programming afterwards. In DALI, the groups can even overlap with each other to different control groups.

Addressable DALI is flexible as changes to the system configuration can easily be done via software by re-programming, while no cabling is required to be changed. Broadcast DALI and 1-10V behave similarly from this point of view as both require re-wiring to be done if groups are wanted to be changed. [15]

DALI is often thought to be more complicated if compared to 1-10V, but they are told to be even simpler as they are operable immediately after installation, without any configuration as they are programmed as default to respond to broadcast commands, like 1-10V operation. DALI control gear requires only the mains to be connected, without controls yet programmed as they turn on to 100 % of light level by default. This gives the electricians an indicative information in the field to evaluate if the light fixtures installed are intact.

DALI standardizes the dimming curve to match certain light outputs, which minimum and maximum levels are configurable via software. A protocol such 1-10V does not specify the dimming curve's light outputs similarly and therefore the light sources may behave differently if powered by different manufacturer's control gear, i.e. LED driver. [15]

DALI is not intended to be replacing the entertainment lighting controls as they require fast changes and diverse load types often to be used. Synchronized changes across all connected lights can be done with predefined scenes with DALI GO TO SCENE command. This command functions in shorter time than it takes to DMX protocol to send 512 DMX channels. This type of a controlling is acceptable in wide spaces with a lot of light sources with multiple channels, such as RGBW or tuneable white light fittings.

DMX requires a strict utilization of daisy-chain (series) connection of the bus and in addition, an end terminator to be used at each end of a bus. DALI bus wiring is more freely choose able which gives more flexibility to the area installation and designing, but both

protocols still have their recommendations for the maximum cabling distances between the farthest-apart devices. DALI also allows more than one master device to control the bus, to send light fixtures commands.

Colour control in DALI is done differently compared to DMX protocol that sends individual levels to each separate channels (addresses), the DALI utilizes the usage of a specific colour device type which supports four methods to be used. The methods are described to be “Tc (colour temperature), xy chromaticity (for precise and repeatable selection of colour), RGBWAF (simpler colour control) and primary N (individual control of each lamp, or primary)” according to S. Wade, from DiiA. [15]

#### 2.2.4 EMC in a cruise vessel

Cruise vessels are developing among with the available technology, which increasingly turns to be based on electronics that constantly increases the possible electromagnetic interference sources on board. Light fixtures, a decade ago, included less electronics as their control equipment, but two decades ago they barely had any electronics by the light source which meant a simpler, close to EMC free environment. In modern ship, the EMC is considered as a daily reality as the systems are developing and have remarkably more electronics involved in them. The same applies to lighting technology.

#### EMC

The EMC is strongly involved in LED based lighting technology as even the light source consists of semiconductors and its controlling electronic circuitry. The LED driver controlling the light source is responsible for all the problems in the light fitting. The other related parts, such as LEDs, heat sinks, cables and enclosure act as antennas and reference ground planes and can increase the emissions radiated and conducted. [16]

The LED drivers available in the market should be tagged with logos of CE, FCC or other to prove they have been certified and tested. The LED drivers are normally tested by utilizing the same standards as LED lamps or LED luminaires, e.g. [16]

- EN 55015 - Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment

- EN 61547 – Equipment for general lighting purposes – EMC immunity requirements (IEC 61547)
- EN 6100-3-2 – Electromagnetic compatibility (EMC) – Part 3 – 2: Limits – Limits for harmonic current emissions (equipment input current  $\leq 16$  A per phase)

The international standard EN 61000-3-2:2006+A1+A2 is applicable for electrical equipment which is supplied from at least 220 V mains network with current up to 16 A to limit the harmonic component emission. This standard's scope is excluding for example independent dimmers for incandescent luminaires with less than 1kW. This standard covers the following classification equipment classes: [17]

- Class A: Household appliances, except equipment of class D, 3-phase equipment, Stationary and fixed tools, dimming equipment that are meant to be combined with incandescent lamps, audio equipment and other equipment which is not classified as class B, C or D.
- Class B: Non-professional arc welding equipment and portable tools
- Class C: Lighting equipment
- Class D: PCs and similar and television receivers with power less than 600W.

The class C relates mostly to the modern lighting as it includes items such as LED lighting, LED street lighting and other equipment related to lighting. The standard covers the first 40 harmonics which allowed current limits are described in Appendix 1. Emission requirements standardized by EN 61000-3-2. [17]

The light fixture manufacturer buying a ready EMC tested LED driver have to make sure the whole light fitting as whole is following EMC rules. Sometimes problems might occur even the components have the EMC tests done, or so is told. Firstly, LED driver manufacturer's product may have changed partly after the official EMC tests are done and after the product is revised it is not re-tested with the new upgraded components. Secondly, the drivers might have also been tested separately from LEDs as load, without the proper enclosure and real wiring as they should in case of a real light fixture. The tests of LED drivers are typically tested with 1,5m of primary side AC power cable and some tens of centimetres long secondary DC cable with a resistive load or a resistive load with a parallel connected 0,1  $\mu$ F and 10  $\mu$ F capacitors. The possibly used setup is different than the real LED light fixture would be and therefore the test results may differ. Thirdly, the LED fixture manufacturer is

not following the LED driver manufacturers installation instructions and thus the driver might emit excessive amount of emissions. The common weak points that are not considered are grounding of primary – AC side of driver, grounding of the secondary – DC side of the grounding – heat sink of LEDs. Companies, such as RF EMC Development, have tested hundreds of LED drivers and have found LED driver manufacturers whose products do always comply with the EMC requirements and no problems in configuration have been faced, but there also exists companies with cheaper products with lower quality that do not comply to the EMC standards. [16]

Some of the dimming protocols withstands interferences, for example the benefits of using DALI digital protocol is that it is a robust system against possible interferences. [15]

The LED driver products mainly used on a new-building cruise vessel are preferred to be from a well-known company that has a reliable reputation. This decreases the risk of anything un-expected to happen on board while the areas are built and the commissioning of the lighting and dimming system is executed.

A LED driver that is covered by EMC directive 2004/108/EC includes multiple harmonized standards for LED lighting equipment, see Table 4. The EMC and interference standard may differ from the standards of households and industry. The most essential requirement for LED driver is the EMI emission EN 55015 and the harmonic current standard EN 61000-3-2. If both standards are met, then the Voltage flicker EN 61000-3-3 and EMS EN 61547 are to be followed the next. [18]

Table 4. List of harmonized standards in EMC directive for lighting equipment. [18]

<b>Electromagnetic compatibility(EMC)</b>		
	<b>Standard</b>	<b>Scope</b>
<b>Electro-Magnetic Interference (EMI)</b>	EN55015	Conducted emission / Radiated emission
	EN61000-3-2	Harmonic current
	EN61000-3-3	Voltage flicker
<b>Electro-Magnetic Susceptibility (EMS)</b>	EN61547	
	EN61000-4-2	ESD air/contact
	EN61000-4-3	RF field susceptibility
	EN61000-4-4	Electrical fast transient/burst immunity
	EN61000-4-5	Surge susceptibility
	EN61000-4-6	Conducted susceptibility
	EN61000-4-8	Magnetic field immunity
	EN61000-4-11	Voltage dip, interruption

The EU EMC compliance of lighting products defines that all electronic and electrical devices when brought to the market and/or are taken into service in the EU they need to meet the EMC requirements as defined by the new EMC Directive 2014/30/EU. The manufacturers are required to consult the following standards to determine the primary EMC compliance requirements for lighting based on LED: [19]

- EN 55015: 2013 defining emission requirements
- EN 61547: 2009 determining immunity requirements
- EN 61000-3-2 dealing with the harmonics emitted by electric equipment
- EN 61000-3-3 outlining the flicker requirements
- EN 62493: 2010 stating the Electromagnetic Field (EMF) requirements

The light fixture and LED driver manufacturers must be carefully following the EN requirements and be aware that as the lighting industry increases rapidly, the need to update the requirements is occasionally necessary and they must follow the latest instructions while new products are developed and brought to the market.

While the manufacturer's follow the EMC related requirements, also the performance standard EN 62384 should be honoured which defines the optimal operation of LED drivers driven LEDs, ensuring the LEDs to be operated only within their specified operating parameters. By following this standard, best performance and maximum lifetime of suitable LED modules is guaranteed. [20]

### CE marking

To get LED light fitting CE marked, there is several requirements including electromagnetic compatibility, safety, RoHS and Ecodesign involved. Safety, EMC and RoHS have been topics of discussion for the past few years as these requirements are to be followed if the company seeks to get CE marking for their product. [18]

The LED driver is essential part of the LED light fixture's components and it determines the above stated major requirements. Therefore, it is the LED driver that has a great impact on the luminaires overall performance and the approval acquiring during the process of certification. Commonly the luminaire manufacturer favours of choosing a LED driver product which has full reports and certificates available. The figure 7 illustrates the composition of CE marking of control gear or LED driver. [18]



Figure 7. CE requirement for a LED driver or control gear. [18]

Ecodesign requirements has been followed since December 2012 and it regulates the light emitting diode lamps, directional lamps and related equipment. It does not address only specific products but also the related equipment between the mains supply and the light source, for example the LED driver. The important parameters relevant to a LED driver are the power factor, standby power and starting time. [18]

The power factor related requirements for directional and non-directional LED lamps with an integrated LED driver are shown in table 5.

Table 5. Power factor values as per Ecodesign requirements. [18]

Effective input power P	Power factor requirement
$P \leq 2 \text{ W}$	No requirement
$2 \text{ W} < P \leq 5 \text{ W}$	>0.4
$5 \text{ W} < P \leq 25 \text{ W}$	>0.5
$P > 25 \text{ W}$	>0.9

The standby power is the lowest average consumption of the LED driver that is connected at the mains supply, but the connected light sources are not emitting light. This requirement applies to the dimmable and controllable control gears. If the control gear has further advanced functions integrated to the driver, such as sensors or network connections, their standby power consumption is not to follow the requirements. The standby power consumption limits are shown in table 6.

Table 6. Standby power consumption limits as per Ecodesign requirements. [18]

Date	Standby power limit	
	output power $P \leq 250$ W	output power $P > 250$ W
<b>From September 2014</b>	<1W	$0.5W \times P/250$
<b>From September 2016</b>	<0.5W	$0.5W \times P/250$

The requirement for starting time of directional LED lamps and non-directional lamps is less than 0.5 seconds. Average starting time of the light fittings should not be higher as the requirement's stating value plus 10 per cent. [18]

#### Sources and victims of EMI

The LED drivers are the most remarkable EMI source in lighting technology. They should always follow the latest available EMC standards and their positioning on board should be carefully considered. EMI sensitive devices should be separated from the LED drivers as practicable. In case of malfunction in close by installed electrical product, the LED drivers could be totally unpowered from the mains to make the fault indication in the venue. Cables running near by the LED driver could be changed to screened or pair twisted versions to reduce the possibility of electromagnetic disturbances to generate to them. Issues with the EMC has been experienced for example in placing a dimming board next to an entertainment rack. In such a case the dimming board may have generated interferences to the entertainment rack's components and caused the area installed entertainment devices behave unpredictably. The risk for this is minimal but nevertheless existing.

To reduce the EMC risks and complications on board the builder, and the operator after the delivery, should always make sure that high quality products are used that has proper tests done and the product is certified suitably by CE marking and by other requirements and standards which might be available upon a separate request from the manufacturer.

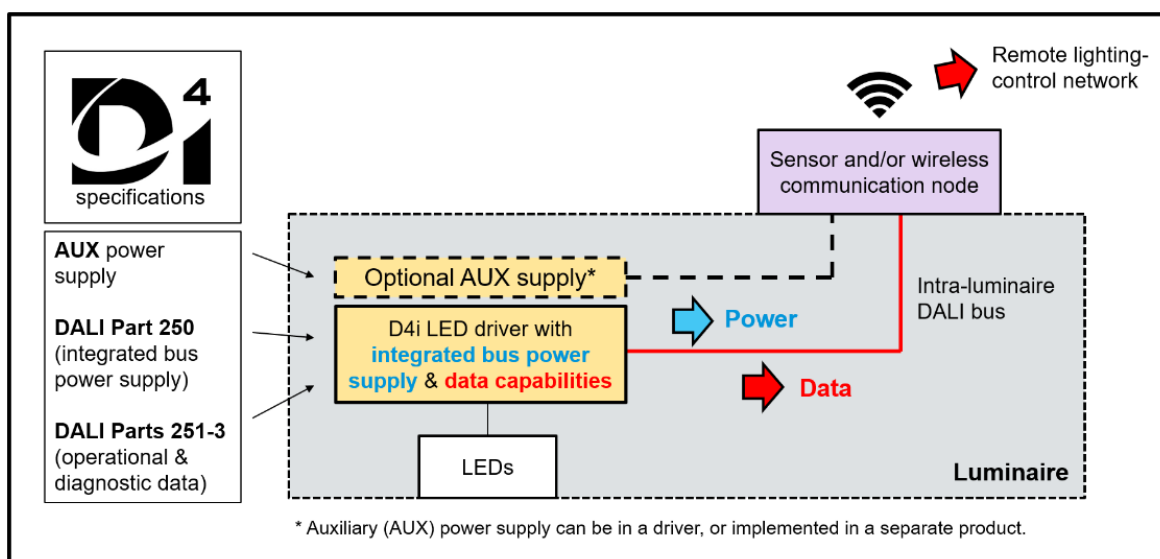
If a product that is wanted to be used on board is not fully tested and certified, but it has proven to work reliably on previous projects, a separate emission and immunity tests can be carried out by a local test laboratory that has the rights for it. An accredited EMC test laboratory such as Espotel Oy, part of Etteplan Group, with accreditation code T298 in accordance with requirement SFS-EN ISO/IEC 17025:2005 services can be utilized to make sure the product is meeting the requirements. This service can be provided by a handful of accredited commercial EMC test laboratories in Finland. [21]

### 2.2.5 IoT in lighting technology

As the Internet of Things (IoT) keeps expanding in the market, the lighting protocols are adopting to this and therefore new DALI protocols are developed. The new DALI certification program is expected to be available on third quarter of 2019 and the program carries name “Intra-luminaire DALI, D4i”.

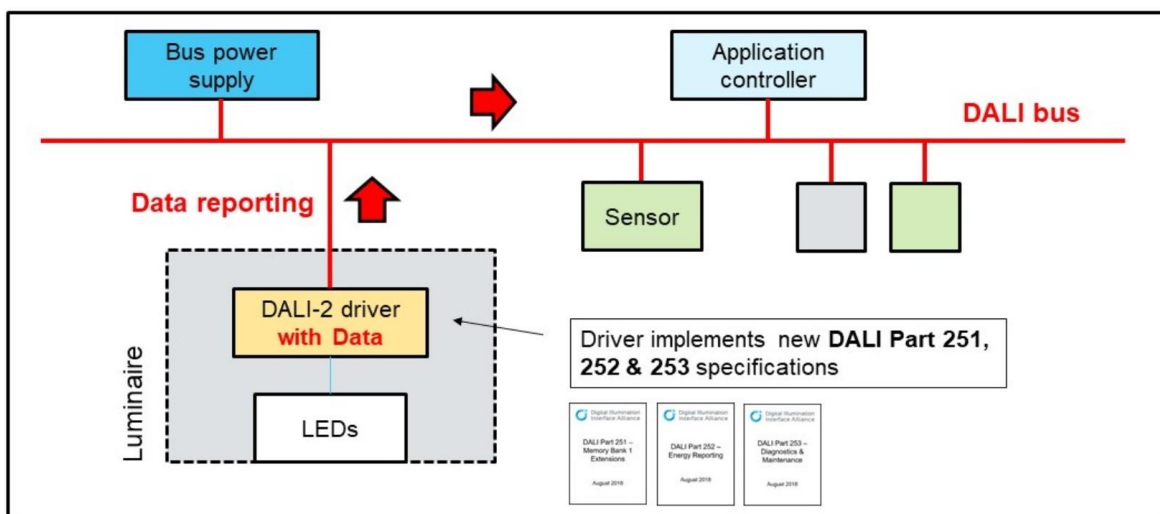
The name intra-luminaire DALI refers to a DALI bus integrated within a luminaire, which connects the LED driver with any DALI-2 control devices. D4i is an extension of DALI2, which are DALI 2 products that have specific set of features. The features are related to power, energy metering and diagnostics. All the products certified and marked with D4i are to be also DALI 2 certified. LED drivers will have to be built according to the part 207 and parts 250 to 253 from IEC 62386 to achieve D4i tag. These means that the driver has the following abilities to be read out from its data: “Data related to asset management, energy usage, diagnostics and maintenance can be stored in and retrieved from the driver”. [22]

D4i standardizes the intra-luminaire DALI in two keyways. In the first of these, the way in which data is stored and accessed in DALI 2 drivers is standardized. This enables smart luminaires to participate in the IoT. DALI standards parts 251 to 253 are defining which covers the storage and retrieval of data related to asset management, to the energy usage and to diagnostics and maintenance. In the second, it is defined how a bus power supply is integrated to DALI driver and how it can provide power to a connected DALI device on the bus. This simplifies the incorporation of DALI control devices or sensors, that are powered from DALI bus, to a single luminaire. If a control device requires higher power, an auxiliary 24 V power supply may be used to power for example wireless communication devices. The principle of D4i specifications for intra-luminaire DALI in standalone use is shown in picture 3. [22]



Picture 3. Principle of D4i specifications for intra-luminaire DALI. [22]

The drivers are capable of reporting operational, diagnostic and inventorial data to the data line as shown in principle in picture 4.



Picture 4. Principle of D4i smart connection luminaires connected in DALI bus. [23]

## 2.2.6 Classification society requirements

Classification societies regulate the electrical installations to some extent in marine business. Normally the lighting as an electrical consuming equipment are not widely regulated by the classification societies, except supplemental lighting and emergency lighting, such as light fixtures with battery back-ups used in car ferries and similar. The cabling installation for light fixture are regulated by some of the classification societies but so far, no classification

society has seen the need to regulate the dimming methods controlling the light fixtures. As DALI standard is expanding increasingly also to emergency lighting applications, it is foreseen that classification societies might have to notify this in their requirements in near future.

### **3 UTILIZATION OF DIMMING METHODS**

Cruise vessels consists of multiple decks that have very different types of venues to entertain or serve the passengers on board. These venues are called passenger public spaces, which main principle is that all the passengers taking the cruise can enter these areas. These types of areas must have advanced lighting features available to be able to provide a suitable ambiance for all circumstances and therefore the venue lighting is controlled by utilizing house lighting dimming system's programmed pre-set scenes.

This thesis focuses on the utilization of Helvar's lighting controlling system. As the cruise vessels requires well-controllable and comprehensive lighting system to be implemented on board, the Helvar Imagine router-based system is utilized, that is intelligent, advanced and energy saving lighting controlling system. The imagine series routers are the most advanced Helvar routers available in the markets and the system is flexible as it suites single rooms but also bigger spaces because of its re-configuration possibilities, connecting possibilities and robustness.

#### **3.1 Dimming type test in test environment**

##### **3.1.1 Test rack introduction**

The Helvar dimming system was tested in miniature size as part of the thesis' practical research process. The dimming board used was an actual size rack, that is used on board as part of setting up the whole house lighting dimming system. The rack included the main system components to be able to control the test light fixtures. The test board was connected to a 3-phase 400V AC, 50Hz power grid. The test environment differed from a cruise vessel installation as the frequency of the available power grid on board is typically 60 Hz and the test grid were based on shipyard's electrical network with cranes, welding machines and similar heavy load equipment. This may have affected the dimming of light fixtures and component behaviour slightly as an exact replica of ship grid was not achieved. Test installations, dimming function and programming rehearsals were executed with the test rack, but as the rack strongly based on an actual dimming board used on a cruise vessel, no pictures, drawings or other material is distributed among with this thesis.

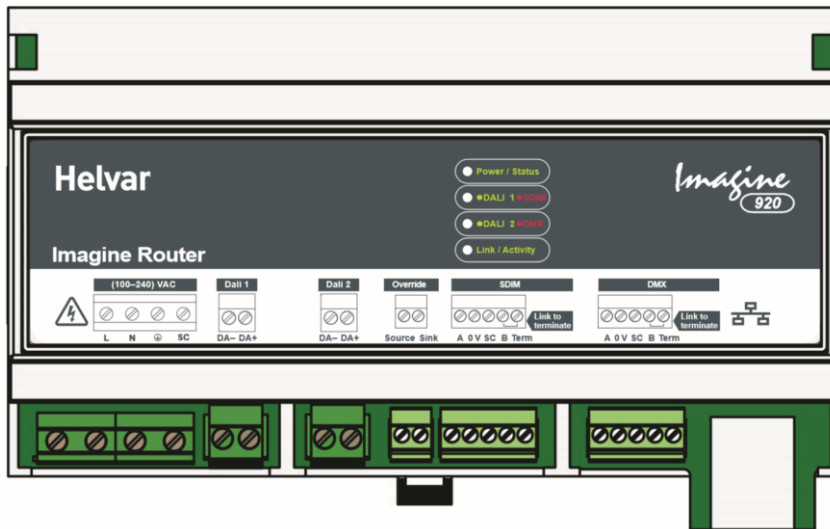
### 3.1.2 Components used

The test dimming board included the following DIN rail mounted light controlling components at the time of the tests were executed:

- Helvar 920 Imagine Router
- Helvar 454, 4 x 2.2 A Transistor Dimmer
- Helvar 474, 4 x 16 A Ballast Controller
- Helvar 498, 8 x 16 A Relay Unit
- Related protection hardware, distribution board's internal wiring, etc.

Additionally, a separate wireless commissioning tool, tablet, to test the light fixtures dimming abilities and check the functioning of dimming channels was utilized during these tests.

The 920 router utilizes Ethernet connection as a backbone for the network to combine DALI/DIGIDIM, DMX and SDIM networks. A personal computer (PC) can be connected to the system for diagnostics and logging purpose if required, but computer is not required for daily operation as all the data programmed to the system is stored within the system itself. Eliminating the central controller, a single failure in system cannot cause the whole system shutdown. The router supports total of 64 DALI devices on its each subnet, of which there exists two. The DALI addressable network can be implemented by using these subnets which are current limited according to DALI standard to 250 mA. The router tolerates supply voltage changes decently as the nominal values are 100 V AC to 240 V AC and absolute values are from 85 V AC to 264 V AC with a frequency kept between 45 Hz and 65 Hz. The product follows EMC emission EN 55022 Class A and EMC immunity EN 55024 standards so the device can be considered as reliable product to be used on a cruise vessel. The router functions as the system brains and can be linked to other routers to create a wider, extendable system. An illustrative picture of the device in case is shown in picture 5. [24] The router Ethernet connection at the lower corner of device can be used to connect a computer for programming of router and light fixtures connected to the system.



Picture 5. Illustration of Helvar 920 Imagine Router. [24, p. 2]

Transistor dimmer, the Helvar 454 module, provides the possibility to control four individual 2,2 A output channels capable of handling capacitive and resistive loads. The device compensates voltage and frequency and each of its channel has temperature and overcurrent protections included. The device can be used in trailing edge and in leading edge mode. While one of these is selected, the all four channels operate in the same selected mode. The device's channels can be set to seven different output types, which are marked from t0 to t6. The types are non-dim, linear, square, S-law, DALI logarithmic, LED curve, DALI linear respectively. [25] The device is commonly used to power up Edison based LED bulbs those are commonly utilized in decorative light fixtures, such as pendants and table lights. The transistor module's default output type is therefore the t5 mode for LED curve, which is optimised for LED.

The ballast controller, Helvar 474, is a four-channel controlling module which has high-inrush relays rated at 16 A for each output channel. The relays can handle short-lived high current peaks during the switching on of the loads. The outputs are configurable to 0/1-10V, DALI broadcast, DSI and PWM which match the commonly used LED drivers. The dimming styles can be set to be paired with, or independent of the relay channels. [26] The ballast controller is one of the most commonly used controllers that is used to connect 1-10V operated light fixtures to the dimming system in modern cruise vessel. The device is flexible as it can be configured to include also DALI broadcast channels, which helps solving

problems on board if light fixtures that are meant to be used on board are only available in DALI.

The Helvar 498, relay unit, can control eight high-inrush output channels. The high inrush limit in this device is 800 A at 200  $\mu$ s. The relays are type NO (normally open) with a single pole and the contacts can tolerate 16 A incandescent/resistive load and 10 A HID load with a power factor of 0,6. Not the extra-low voltage operated devices can be connected to this relay unit as these are power relays for higher voltage operation. The relay unit can be operated in three different modes, as: [27]

- 8 individual channels (8 x 1)
- 4 sets of 2 channels (4 x 2), or
- 2 sets of 4 channels (2 x 4)

All the above mentioned four different Helvar products can tolerate the voltage difference from 85 V AC to 264 V AC in frequency between 45 Hz to 65 Hz. [24][25][26][27]

### 3.1.3 Execution of test

After the test rack's internal wiring between the added controllers, circuit breakers and router were connected, the power supply of 3-phase, 400V AC at 50 Hz was prepared to be connected to the rack. The supply voltage was tested and measured to be within the nominal values and the supply's tolerance of voltage was about 0.5 percent from the nominal 400 V while the measurements were done between phases, i.e. line-to-line voltage. Also, the line-to-neutral voltages were measured for certainty of everything to work as intended. As the dimmer rack was required to be kept transportable, the power supply was executed by using suitable 5G2,5 extension cord which was to be connected to 3-phase power socket when the test setup was operated. In this setup also the secondary side of the dimmer module channels were protected by B10 type circuit breakers. The test rack was built with an idea kept in mind that changing of light fixtures was to be possible by using quick connectors and therefore the dimmer module and controller output channels were prewired from the rack by utilizing a marine cable type 5G1,5 and for transistor dimmer's output channels 3G1,5. The ready connected cables were equipped with Wago Winsta Midi 770 series socket type quick connectors with strain relief housings. The single phase, 3-pin quick connector socket type in case is shown in picture 6.



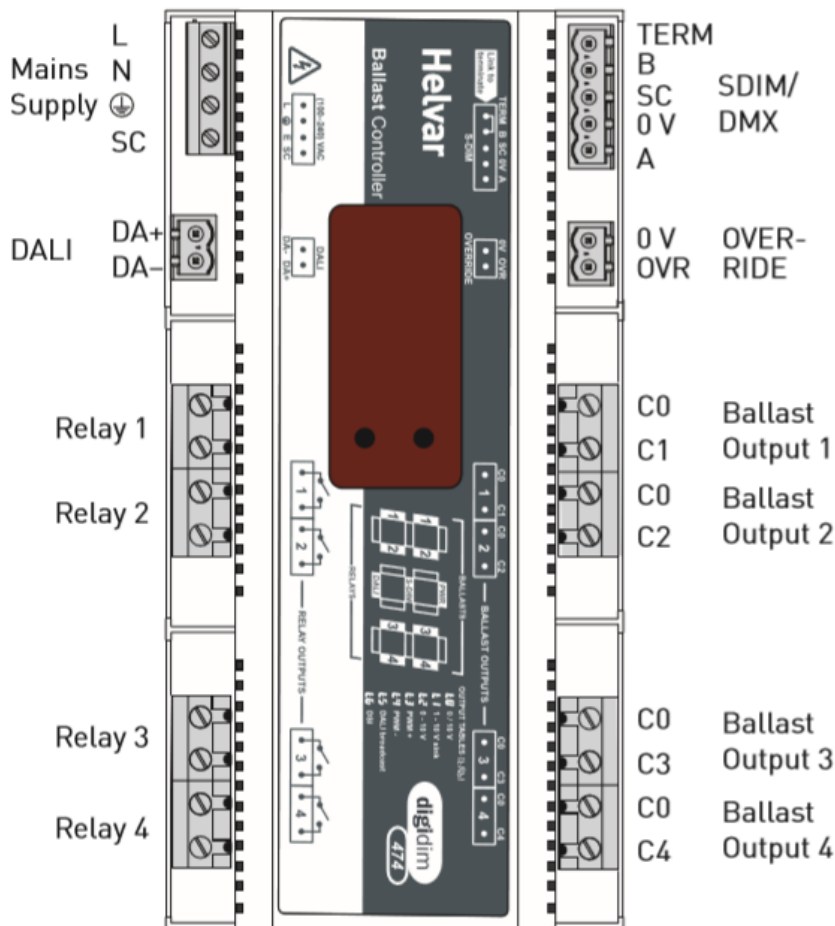
Picture 6. Wago single phase, 3-pin quick connector, socket -type. [28]

Also, ready-connected cables with 5-pin socket type quick connectors from same product series was prepared as they were to be used in the 1-10V and DALI device supplying cables to enable connection of dimmable light fittings to the dimming board.

The light fixtures such as downlights were prepared with the same principle that they have the plug side of the quick connector installed on them for quick swapping to another fixture type. Also, four different 1-10V LED drivers with 24 V DC secondary voltage level were prewired and equipped with quick connector to power up different types of LED stripes and modules to them for test purposes.

The E27 and E14 based LED-bulbs were connected to a test bench which consisted of three E27, one E14 and one GU10 base connected in row with spacing of about 150 mm. The test bench was connected to transistor dimmer and the LED bulbs were tested how they operate while dimmed by phase cutting. It was noted that different manufacturers' LED bulbs behave very differently as some manufacturer's product might be dimming to low levels without flickering while the other supplier's product might start flickering or does not dim even near as close as the competitor's product.

The 474-ballast controller's all four output channels were prepared for test purposes with ready made cables with quick connectors attached. The ballast controller's two output channels were set to t1, i.e. 1-10V, and two remaining channels were set to t5, i.e. DALI broadcast, types. The setting up of the ballast controller was done manually by utilizing the two buttons at the right side of the module's LCD screen. This configuration of channel types could have been done via computer using Helvar Designer software as well. The manual set up by using buttons is well instructed in the manual of the controller module. In this rehearsal the relay and the ballast output functions were utilized. The ballast controller's connection points are shown in picture 7.



Picture 7. Helvar 474, 4-Channel Ballast controller connections. [26, p.1]

To compare the dimming levels of 1-10V driver and DALI driver, two similar power level marine grade spotlights from Hella Lighting Finland was connected to each circuit. As the light fittings were connected to two different circuits and Designer software was not utilized in this rehearsal, a commissioning tablet to test the dimming function of both fixtures one by one was used. Visually the DALI controlled spotlight seemed to reach slightly lower intensity levels if compared to similar test with 1-10V driven spotlight's behaviour. The spotlights were both equipped with Helvar LED drivers and the fixtures dimmed evenly to very low levels but after reaching the percentage of five and below set values from the commissioning tool the light stopped dimming any lower and did not react to this low dimming levels.

The Helvar relay unit was not further tested in this test procedure as the target was to find out how well the light fixtures and LED stripes can be dimmed and controlled by a dimming

system and how would the lights behave at lowest dimming levels. A relay controlled on/off switched light fittings were not found essential to be studied in this practical test for this thesis.

### 3.2 Importance of programming

The Helvar based dimming system is configured by utilizing Helvar Designer software that is a Microsoft compatible software providing intuitive tool for engineers to design, commission and program the Helvar 920 router systems. Designer includes the basic software and optional software modules. The Designer program's utilization requires either participation to the official Designer programming course offered by Helvar trainers or by buying the Helvar dimming system from an authorized system supplier. Helvar's ongoing hardware and software development ensures the reliable performing and compatibility of components configured to the system.

Basic functionality of 920 router are available out of the box without programming, but Helvar Designer software allows the advanced configuration of router. The router acts as a gateway to configure the system connected to it by using a computer. The utilized port is normally the standard RJ-45 Ethernet connection which can be found from the bottom right corner of the router module. A logical way of starting the configuration of house lighting dimming system connected light fittings is to connect a computer which is equipped with Designer software to the system and find the light fixtures after which their configuring can be started. If 1-10V or DALI broadcast dimming is intended to be used, the cabling should be carried out and circuited for the fixtures that are meant to be controlled as a group. After the groups are defined to the system, they can be configured to be part of the pre-set scenes that are called by a local control panel (LCP). The scenes, that can be set from LCP, are designed to cover the illuminated area's need during different times of a day or certain moods which are wanted to be quickly available to illuminate the space in a required manner. As the area may consist of multiple different type of controllable light sources, the configuration must be done by setting the wanted illumination levels for each group of light.

Before the specialists can start configuring the pre-set scenes to the area lighting, all the light fittings must be connected to the required dimmer or controller module. The Ballast controllers and transistor dimmers for instance requires the type of the connected load to be defined to the module so the lights can be controlled with a right method. For ballast

controller module the most used output types to be configured are t1 for 1-10V and t5 for DALI broadcast functions. The transistor dimmer's one of the most used output types is the t5, for LED curve, optimised for LED load such as E27 base LED bulb. All the light fitting types must be recognised and considered while configuring the load types to dimmers and controllers, or if the types are not exactly known, the best operation type is to be tested by changing output types per channel to find the best suitable one.

Normally the system on board is initially set up by the system supplier, but the ship-owning company may have a lighting consultant, or similar specialist, setting the final scenes to the system. At this point the importance of configuration skills are valued as some of the light groups may start behaving in an unexpected manner if the user is not certain how the system works. The Designer software teaching events are provided by system supplier, or an authorized Helvar product supplier, to support the users that mainly deals with making the settings to the system.

The system can be configured to be controllable by using manual pre-set scenes, motion detectors, constant light controls with light sensors, time programs, colour and colour temperature controls and combinations of these. The desired light effects might be configured to be basing on the requirements of the lit architectural articles, such as seating areas, a furniture or art which is wanted to be highlighted. The control of lights might also base on energy savings, for example if area has large windows with a lot of natural light coming in, then the artificial lights might be dimmed to low levels or be even turned off. The main functions to be programmed are the scenes and their fade times, links, sequences and conditional logic, multisensory intelligence and room partition functionality.

To get started with the new Helvar Designer 5 and programming of the system, the initial programming is to be done for the system. The different phases to go through are “Before going online”, “Go online”, “Subnets and workgroup settings”, “Identify, name and group devices”, “Scene table and event log”, “schedules and conditions”, “Sensor control (occupancy detection and constant light)” and “Exercises: Classroom” according to the “Helvar Designer 5 Foundation Course: Initial programming” Edition 1, from May 10<sup>th</sup> 2018. [29]

### 3.3 Comparison of 1-10V and DALI implementations

The implementations of 1-10V and DALI variations are compared in this chapter. DALI can be used as broadcast, addressable or as a combination of both. The purpose of this chapter is to find out which implementation method is the most efficient and beneficial, but also to find out the effects of using these all from a space reservation, cabling, expense, installation and commissioning point of view.

The research area was a three-deck high venue with comparable light fitting quantity to a real implementation on a cruise vessel. Each deck had a dimming board controlling the areas, but the dimming boards were also connected to each other to enable the whole area's lighting control in case of a need. The research area consisted of light fixtures mounted to ceiling and walls. For straight forward comparison, only one type of each main light fitting types was considered in this research. The whole area consisted of 1,478 pcs of spotlights, 397 meters of single colour LED strip, 108 meters of RGBW strip, 27 pcs of chandeliers and 48 pcs of wall sconces. The lighting material was divided on different decks according to table 7. [30]

Table 7. Division of light fitting quantity from observed area. [30]

Area	<u>Light source quantity per type in [pcs] or [m]</u>				
	Spotlight	LED linear	Linear RGBW	Chandelier	Wall light
Deck 6, Bar	285	0	108	4	13
Deck 5, Café	618	94	0	10	15
Deck 4, Restaurant	575	303	0	13	20
Total	1478	397	108	27	48

Average cabling length from dimming board to the circuit's first light fitting was 15 meters. The average cable length between ceiling mounted spotlights is 2,5m. Drivers for LED-linear light sources were centralized behind ceiling in-built service hatches, which are approximately 5 pcs per deck.

#### 3.3.1 System differences

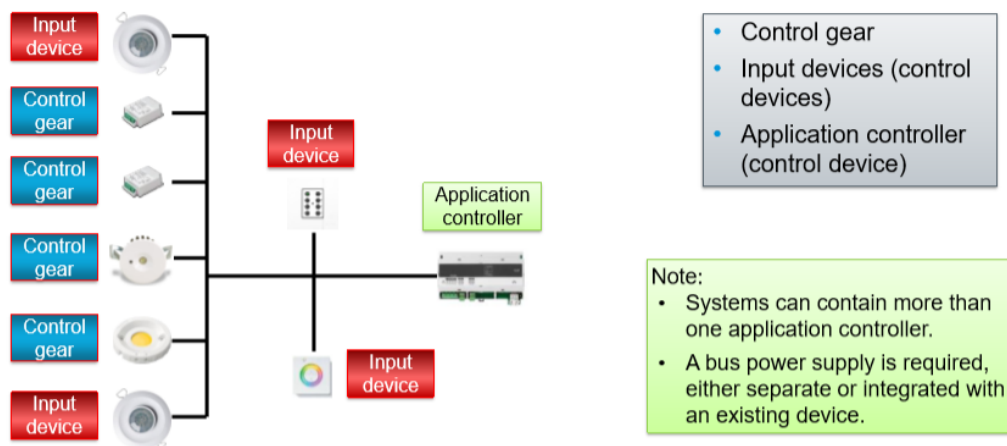
First observed implementation methods compared the commonly used analogic 1-10V and digital DALI in broadcast mode. 1-10V and DALI broadcast-based cabling in the field would be equal in the observed area. Neither of these dimming methods can control the whole area's lighting completely as the chandeliers and wall lights are illuminated by E27 based LED bulbs, which are preferably controlled by transistor dimmer for guaranteed smooth

dimming. Also, the RGBW control requiring linear light causes of changing the dimming method as 1-10V is not capable of controlling it, while DALI could control it but only in addressable version as the four colours are fully controllable only by specific addresses. If DALI addressable is not to be used, another way to control the RGBW strips is DMX protocol, which also requires channels to be addressed individually. The field implementation for the light fittings appear to be almost similar if 1-10V and DALI broadcast are compared, but with the LED driver inrush currents kept in mind, which are typically lower in DALI than in 1-10V drivers, there might be a need to change the cabling to get the load distributed evenly for each implementation style. This reduces the cabling slightly in the field as more load can be connected behind a same circuit breaker, to a same lighting group if this is acceptable from the lighting grouping designing point of view. Full change of spotlights to DALI broadcast in the area reduces also the space needed in dimming board. This is because 474 Ballast Controller can control only 4 pcs of 1-10V output channels while the newer 478, 8-subnet DALI broadcast controller can control double amount of output channels. In the dimming board, the controller quantity would reduce to half from the hardware need that 1-10V output modules would require. The circuit breakers are not affected by this change as the group of lights would still need the group dedicated protection devices, but approximately one DIN-rail would be possible to be removed from the dimming board due to this simplification. This would allow the height of the dimming board to be reduced as well, but also bring cost savings at the dimming board as less components are needed.

In the second implementation version 1-10V was compared to addressable DALI. In this large area it seems not to be beneficial to change all the 1-10V lights to addressable DALI as this would increase the commissioning work and the complexity of maintaining the area after the ship delivery. Replacing a broken DALI light fitting should pick-up an address automatically from the system, at least if the replacement light fitting had not been addressed previously. The DALI addressable version comes also with benefits, as it is a good alternative to replace the RGBW lights control method, which has most commonly been DMX based during the last decade. The DMX controlled light fittings are controlled by utilizing first a transformer to lower the voltage level for example from 230 V AC to 12/24 V DC and connecting the lower voltage to power up the DMX driver. If replaced by DALI, there would be saving in installation work and the risk to make errors in connection phase

would decrease. The chance to change DMX to DALI is possible especially in areas which does not require the acting speed of performance lights, that are normally used for entertainment. The DALI addressed devices can change their status to another set level in a blink of an eye, but they respond slowly if the lights are controlled by DJ booth's slider dimmers or similar. The performing area's lights could be implemented also by utilizing a show effect player device which can be triggered to play a predefined scene from the dimming system. Both control methods, DMX and DALI, for this application requires addressing of LED drivers, but DMX requires more knowledge from the installing electrician as the DMX line is to be terminated with resistor at the end of data line. This is additional cost as component but also as installation expense, depending in the way how the end terminator is connected to the DMX line. Another valid light fixture to be changed to addressable DALI in the observed area could be the art lights. The fixtures that are adjusted to point towards the art on the wall or ceiling, would be beneficial to have them be re-programmable during the ship operation if the art was to be illuminated differently during the ship's operation. The broadcast version's re-programming would be depending on the cabling behind the light fittings. This issue would not exist with addressable DALI as the controls of all art illuminating lights can be changed digitally. This art light change in approach would also save cabling and dimming channel outputs as normally the art is located so far apart from each other that they must consume multiple dimming channels in the area's dimming board.

The utilization of addressable DALI would free up space from dimming board as the intelligence is in the DALI drivers in the field. A single 920 router can control 128 pcs of DALI addresses and in near future this quantity might increase slightly if a new router is brought to the markets. It is worth to be noted that if DALI bus limits are wanted to be utilized, a separate cable forming the DALI bus could be utilized. The additional cabling causes some extra work and connections to be done. This DALI bus is described at its simplest in picture 8. Circuit breakers are still to be connected to light fixtures according to the rules and the ship technical contract, but the size of the dimming board could be reduced with this change.



Picture 8. Example of DALI bus connection at its simplest. [15, p.7]

In third designed implementation version the whole area's spotlights and LED strips were utilizing either DALI in broadcast version or in addressable version. In this version all the previously mentioned benefits were utilized. This style allowed the smallest dimming boards to be designed and executed as part of the intelligence is spread to the field, to the LED drivers, no DMX splitters or similar components, nor space consuming ballast controller modules were needed in the dimming board. This style provided the best monitoring of the light fittings as DALI broadcast is capable of informing about broken light fitting connected to the channel and the addressable DALI allows monitoring of each addressed light fitting individually. Also, as the DALI2 keeps improving, it is possible to start the monitoring of light fittings' lifetime, colour tone change, power consumption of single light fitting and other relevant information which would help in maintaining the area's lighting if gathered and processed. This information could be used as a guideline to monitor the other light fittings installed to the area, as most likely the area's lights would be used quite similarly area-wide so the light fitting's wearing off would be comparable between the light fixtures.

### 3.3.2 Cost effect and efficiency study

The 1-10V and DALI broadcast systems were compared in previous chapter from technical point of view. It was mentioned that dimming board height could be reduced, cabling could be slightly reduced but there is also a cost effect in this modification. The DALI broadcast module 478 can be approximately 20-30 % more costly than Ballast Controller 474 but has double the output channels, which would allow of using the dimming board rack inside space more efficiently. If the change was done in the whole studied area, cost savings from the

dimming board perspective would be available, but at the same time the DALI driver attached to the light source are more costly by about 5-10% per unit (depending on light fixture this value varied slightly). This would compensate the savings from dimming board. As the 478 module supports only broadcast channels, the addresses are not to be individually programmed which would save some commissioning time as the process would be quite like 1-10V with ballast controllers commissioning.

If part of the light fittings is changed to DALI addressable, also the RGBW powered fixtures could be changed to be controlled by this method. The DMX based technology is rarer in architectural lighting controlling and thus it is also more costly than addressable DALI with 4-channels. The DMX protocol also requires separate transformer to be attached to the DMX driver to power up and control the RGBW LED strips, so replacing the dimming type to addressable DALI would save the cost of driver requiring transformer and simplify the installation process. Savings could also be done in area installation work which comes simpler and quicker. It would also decrease the chance of the electricians making errors in connections work.

## 4 CONCLUSIONS

### 4.1 Analyzation of practical research results

The lighting controlling tests executed with the test dimming board in test environment was carried out as planned. The whole setup fulfilled its purpose and functioned well. Unfortunately, the available test environment's electrical grid differed from the power grid on board, which might have affected the test results. The dimming tests were carried out 5-10 times with each dimming type with a light fitting load connected to it and the test results stayed the same throughout the event, while it was monitored, measured and evaluated with the available equipment, but also visually. The purpose was to find out if all the tested lights would function as expected, especially as the whole test system was set up for the first time for these tests. All the components worked as they should and setting up of the dimming module parameters were successfully done.

The test rack provided optimum test environment to execute the rehearsals for light controls as the rack was assembled mostly by one of the local house lighting dimming system suppliers. Only some dimming module additions and changes were done to the dimming board by the author of the thesis, so the system can be interpreted to be following the latest available rules, guidelines and requirements. The system was experienced to work properly.

The light fittings were noticed to dim slightly differently in the set dimming levels, which might be a result of using different manufacturer's control equipment, i.e. LED driver, which are following the same standards and requirements. All the test equipment was brand new so the difference in controlling behaviour is interpreted to be basing on the different functioning of the electronics in light fittings. The most visible difference was found in the E27 based LED bulbs which should have had the same technical specifications to dim down to 1% illuminance level. The LED bulb from Philips did dim to very low level but it was still the brightest from lowest levels in the comparison. Although this light bulb was not showing any signs of flickering at its lowest dim levels. Meanwhile a competitive product from Osram dimmed visually clearly to lower illumination level without occurring any visual flickering. The flickering problem in the LED bulbs have mainly been experienced on board and such a result could not be repeated with the test setup in test environment.

Spotlights controlled to the lowest dimming levels did not change the light fitting's light intensity after reaching 5% and below. The 5% and 1% appeared to be the same while visual observation was utilized. The test mentioned percentage values might not be accurate as the commissioning tool was not tested nor calibrated before starting of the dimming tests. The LED driver from Helvar had labelled information in it which stated it should dim to 1%, but this was not possible to be fully confirmed during tests. This might be a result of the LED COB and LED drivers not performing seamlessly together. The available 5% dimmed down to decently low level and the light fixture barely provided light at this mode, but there might be such a venue on board where the spotlights should dim even lower. For these cases, the tests should be repeated in a dark room, to make sure the illumination levels are acceptable for their intended location.

The dimming system comparison was mainly focusing on the cabling, installation, commissioning time, dimming board size and cost effects. The comparison and findings were mostly done by observation of drawings that were partly produced by the author but also by interviewing the field of the area specialists about their experiences of similar applications executed with equivalent dimming system. The observation and findings could have been more informative and realistic if the system supplier had produced the material fully with all the details considered. The cross-check of minor errors in drawings were done only by the author, which enabled the possibility for a certain amount of minor errors be left unnoticed to the used material.

The all compared dimming system implementation versions had their pros and cons. The 1-10V has a long experience of reliable working on board but it requires more space at the dimming board for ballast controllers, the availability of 1-10V drivers is reducing in the markets, the system is not capable of providing any maintenance information for end-user and the lighting grouping cannot be changed without re-cabling in the field. DALI broadcast is increasingly used dimming method which has not yet gained much of experience from the cruise vessel implementations in extensive scale. It is capable of saving some space from the dimming board as the DALI broadcast controller provides 8 output channels for lighting grouping, it is capable of informing about lamp failure in the subnet and suitable LED drivers are increasingly available in the markets, but the cabling also has to be changed if re-grouping of light fittings is required. Addressable DALI is reprogrammable as the LED drivers and light fittings are configured with their own addresses. No re-wiring is required

in this version, but the commissioning of the system requires more work as the addresses must be given to the drivers and the fixtures are to be programmed to the house lighting dimming system. The system can give different type of information to the system as in earlier applications as the DALI protocol is constantly developed. It also reduces the size of a dimming board because no separate dimming modules are required, just the DALI bus and the bus power are required to start the implementation of DALI addressable network. This network can also include input units such as switches, pushbuttons, motion detectors and similar.

According to the study, the combination of DALI broadcast and DALI addressable seem to able to provide the most flexible, monitorable, space saving and re-configurable implementation method to this type of a 3-deck high space in a cruise vessel. The technology to follow this principle has existed for a good decade and it is just a matter of a time when this technology is more widely utilized on board a massive cruise vessel.

#### 4.2 Analyzation of specialists' questionnaire replies and interviews

In this chapter the executed questionnaire's results are summarized and analysed for the part of the most important topics. Not all the questions are further handled in this analyzation process but the main points from findings are picked up for closer observation. In addition to the executed questionnaires, also interviews with the questionnaire answered specialists were held with the key persons to discuss the main points in more detail.

##### 4.2.1 Introduction

A questionnaire about digital dimming methods, which concentrated on digital addressable lighting interface, was send to 27 specialists who work with the lighting and dimming technology in new-building cruise vessel business. The author of the thesis received 13 replies to the sent questionnaires and interprets the take to be reasonably good and it is capable of providing reliable and valuable information on the requested questions but also to survey how well the specialists in the field of area are aware of the digital dimming methods, systems and their providing possibilities.

The group of specialists that answered to the questionnaire consisted of ship-building companies' lighting and dimming system responsible persons, ship-owning companies' senior electrical superintendents and senior electrical engineers, lighting consultants, house

lighting dimming system suppliers and light fitting suppliers. The questionnaire was also sent for attention of electrical designing companies, but no replies related to the questionnaire were received from them in the given schedule.

The utilized questionnaire is available at the end of the thesis, see Appendix 2. Questionnaire form with answers. The appendix includes the questions presented to the specialists but also the author's interpretation about correct answers which are either based on literature, valid standards, learned facts or questionnaire replies from the respondents. The questionnaire included questions of which setting up were not specific enough for part of the questions and therefore those questions were understood differently by different repliers and that caused part of the variation to the received answers. It is also to be noted that the respondents of the questionnaire are coming from different technical backgrounds, cultures, continents and habits so not everyone could answer to all the presented questions. The instruction given to the questionnaire recipients was to answer the questions with the current knowledge and understanding of the question's topic. With this principle kept in mind, the author of the questionnaire could investigate how well the most recent technology for digital dimming methods were in the respondents' knowledge. [31]

#### 4.2.2 Analyzation

The first question in the held questionnaire was meant to be surveying on who the questionnaires repliers are. Were they competent enough to participate the questionnaire and to survey how familiar they were with the dimming methods utilized on new-building cruise vessel business. The objective of the question was fulfilled as all the respondents answered with a short and confident answer of "yes". This reflected also to the reliability of the replies received. The author was very pleased on the take of respondents as all appeared to be aware of the topic.

The purpose of the second and third question was to find out how commonly each dimming method was used and for how long they have existed. The study result pointed out unambiguously that the phase-cut dimming was the oldest dimming method that has been used on a marine industry already from early 1980s. It was developed to dim down incandescent bulbs in the first place but had been since utilized to dim 230V AC supplied LED bulbs as well. The second oldest dimming type was 1-10V which was developed first to dim down the fluorescent tube-based lights. This dimming method was found out to be

used on board already since late 1990s. The thirdly most used dimming method, DMX, was taken in to use at about the same time as 1-10V, but it has been used to control entertainment related lighting already before this. 24 V PWM based controlled lighting had been used after this but not so widely. DALI based dimming method had been first tested on board already during the early 2000's, but the first bigger and more successful implementation had taken place on year 2018, if only new building vessels were considered. For refurbishment ship projects it has been used already roughly 5-10 years before this. Most of the respondents shared the same understanding of which dimming type is the most used but as all the cruise ships have at least partly different lighting types installed, there is no single answer which would apply to all cases. In some projects, the 1-10V is the most used dimming method, while in another ship the phase-cut may have been the most used dimmer type. The study results from these questions had shown that the respondents of the questionnaire had high competence regarding the cruise vessel lighting dimming systems. This also supports the reliability of the study material and the results.

In the questions four, five and six the most reliable experienced dimming method was looked for and the study result proves that phase-cut dimming had been the most reliable dimming method back in the days when incandescent bulbs were used for illumination of the areas. After the breakthrough of LED technology, the phase-cut dimming had become a bit more unreliable as there have occurred incompatibilities with the dimmers and LED light source electronics. The phase-cut dimming has also been the most vulnerable and the most sensitive for any interferences included in the ship's power grid. 1-10V method has been considered as a better dimming method to phase-cut as it has not been as sensitive for harmonic distortion or such, as phase-cut method had. DALI has been considered to be functioning well during the last tests done on board, but for this dimming method the cruise industry does not have any longer data available and the couple of next years are to be important for the industry's development to find out if the technology is reliable or not. So far, the results have been positive, and problems have not been faced, unless if it is related to installation or configuring errors. The house lighting dimming system suppliers had also experienced the 1-10V analogic dimming method to be more sensitive for harmonic distortion but had not faced similar problems with digitally operated DALI protocol.

The shipbuilders, ship-owning company representatives, system suppliers and light fitting suppliers have all experienced partly both positive and negative feedback from using DALI.

Most of the experienced problems have been partly due to mistakes done in the designing of the lighting system in the area or during the installation and wiring of the drivers. Addressable DALI has had the most problems with giving the individual addresses to the LED drivers, while the maintenance of these fixtures had also been experienced quite challenging by the crew on board while the ship was in operation. Part of the problems would have been possible to prevent by careful training of electricians doing the installation work on board of the ship. For the broadcast DALI the feedback has been clearly better and even a feedback of easy installation and easy putting into operation had been received by the shipbuilder designers. Another possible problem in utilizing the first version of DALI equipment have been based on the small additions done to the products by the device manufacturers. The protocol has been standardized but as it has not been strictly regulated and controlled if all the devices fulfil the requirements, there has been problems on the interoperability of the devices between different manufacturers if used in same system. For DALI 2 this type of an issues has been fixed and these “DALI 2” tagged products are for sure interoperable with another product with the same logo marked on it. In overall, broadcast version of DALI has built the better reputation from DALI versions so far on cruise vessel business.

The question nine processed the availability of different dimming control methods used in LED-drivers. According to the query results it can be noted that the 1-10V dimming devices were fading out from the markets currently and especially shipbuilders and light fixture manufacturers did suffer from this as the method had been experienced working fine enough on cruise vessel environment. DMX products were pointed out to be hard to get as it is not available as an option for most of the light fittings sold worldwide. To quote one of the dimming system supplier’s words: “DALI is commonly used these days and will be the most used protocol in the future. 1-10V will die away in (near) future. DMX is marginal, though used in cruisers, in some occasions.” supports the fact that DALI is to have its breakthrough in marine industry as the other previously used dimming methods are not as easily available in the market anymore. Some of the major LED-driver manufacturers have even informed that they have cancelled producing and developing of 1-10V and DMX LED-drivers. Taking this fact in to account, the DALI protocol’s utilization appeared to be inevitable. The received announcements from the manufacturers might be increasingly causing trouble to the shipbuilders if the agreed lighting was meant to be implemented mainly by utilizing 1-

10V dimming. Ship-owning companies might also have to adopt to the market's situation during the coming years. Meanwhile the state-of-the-art shipyards had already been studying the DALI providing possibilities for a couple of years, done tests and are already ready to provide the most recent technology available to the cruise vessel business and to the ship-owning companies.

The question number ten revealed one of the most remarkable findings of this thesis. It was found out that approximately 70 per cent of the respondents had not either heard of the Digital Illumination Interface Alliance (DiiA) organization or was stating that they were not familiar with this organizations goals or who they were. On the other hand, only one of the shipbuilders, one from lighting consultant offices representatives and one of the dimming system suppliers were clearly familiar with this organization and were aware what they do. Digital Illumination Interface Alliance (DiiA) is an open, global consortium of the lighting companies which target is to grow the market for lighting-control solutions based on DALI technology. This consortium develops DALI protocol and the standards related to it constantly and implements new features and functions to it with a fast rate. As most of the persons working in the cruise vessel lighting industry were not familiar to this consortium's work, DALI as a protocol and as a dimming method had not reached to the knowledge of the right participants working in the field of area. This information explained also part of the suspicious comments related to DALI that had been faced during the thesis project's interviews and discussions. This also explained part of the fact of why DALI had not been used already in previous projects, as no one preferred to rely on technology that is not well known before it was implemented on board ship wide. At the same time about half of the respondents were not familiar with the IEC 62386 – the international standard for DALI technology, which consists of several different parts for the system components, control gears, control devices and their sub-parts that are shown in detail on table 8. The red text in the table describes if the standard has been revised and published for DALI-2 version.

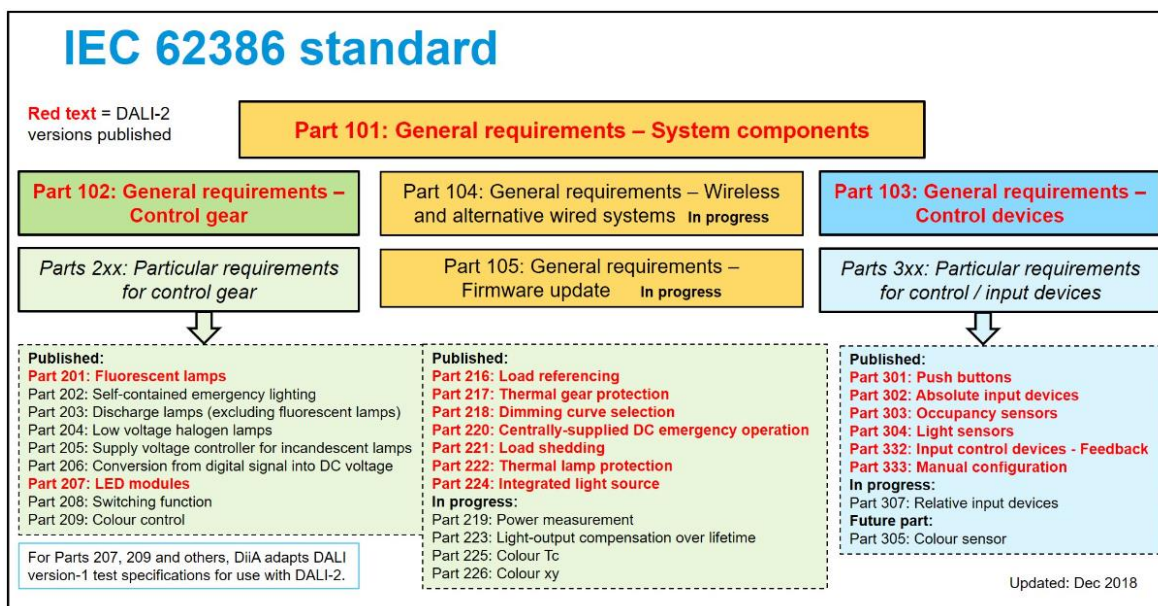


Table 8. IEC 62386 – the international standard for DALI technology. [32]

According to the query results DALI 2 was preferred over the original DALI version 1. The reasoning behind the statement was that the DALI 2 is an updated version of DALI and it is now including more command possibilities, getting feedback from the device and the hardware were considered to be more flexible as it was tested to be fully interoperable with other DALI 2 devices. The DALI 2 protocol was also noted to be supporting 24-bit commands which DALI version 1 did not, and the DALI 2 could dim with 0,1% steps, DALI busses connections DA+ and DA- could be connected either way around and it did not matter which way they were connected. DALI 2 had a reputation of being a remarkable improvement over DALI protocol. With the received replies, the conclusion can be formed according to which the DALI 2 is a developed version of original DALI which had started to grow more and more famous with its good reputation and therefore the author sees this as a positive event to the industry, to protocol and to its usage in the near future. DALI 2 was widely trusted to be reliable enough to be used on a cruise vessel and it got the support of about 83 per cent of the respondents.

The questionnaire's question number fourteen revealed the fact that only one shipbuilder, two dimming system suppliers and a single lighting fixture manufacturer felt they had enough of knowledge and experience over DALI or DALI 2. The rest of the respondents were either unconfident of their knowledge level about the topic or had barely experienced DALI in practice. This fact seemed reasonable as not many of the field of the area's

specialists had had time to study the topic any further and in more detailed way. One of the respondents also notified that DALI is not too widely used protocol in the United States of America, unlike in Europe, so they had not gained experience with this protocol, but they announced to be up for testing it.

According to the questions fifteen and sixteen providing query results there was only one person, from ship-builder side, who was confident enough to say that he had no concerns about replacing 1-10V entirely with DALI or DALI 2 protocols on board. Rest of the builders and ship-owning company representatives were slightly concerned about the required extra training of different participants working on the ship project, especially the crew who would be maintaining the operating ship. Also, a concern about added setting up time of the system was pointed out in case addressable DALI was used. Configuration challenges, DALI bus speed and the delays of the system, but also lack of knowledge about the system were mentioned to be topics of concerns. One of the dimming system suppliers highlighted also that the protocol's requiring guidelines were to be brought to everyone's knowledge and stressed the importance to make sure the guidelines were followed by all participants in the project. Another dimming system supplier also mentioned that if addressable DALI was fully utilized, the commissioning and especially maintenance by the ship operations would require to face changes as the system would be more complex to operate than with the traditional control methods. Lack of general understanding of the system could lead to unexpected problems during the commissioning of the house lighting dimming system. Therefore, the simpler version, broadcast, was preferred to be used ship wide at the beginning of adopting to DALI control methods. Yet, the question number seventeen pointed out that the whole variety of respondents would consider of using DALI as an addressable version in some certain applications on board, e.g. in cases such as art lighting, public spaces, suites, cabins and treatment rooms. The author of the thesis considered this as positive as it was found out how open the field of the area working specialists were to start implementing also the addressable version of DALI on board.

The question eighteen was formed in a bit too general level, which affected the received query replies. If addressable DALI was to be used, the size of dimmer racks would decrease significantly as the intelligence would move from racks to ballasts in the field, but at the same time more of a cost would have transferred to the commissioning and setting the system up as an extra addressing work. Also, the first installations and commissioning would take

clearly more time than to what was used to as there were new things to be done compared to the current common implementation. According to the query results, if utilizing DALI broadcast instead ship wide, the commissioning time would stay approximately the same as with currently used methods but with this system the dimming racks would not reduce in size so significantly as the broadcast dimming modules, such as Helvar 478 would still be needed to be located in dimmer racks.

Removing of the separately used emergency lighting's switch-over unit boxes could technically be removed from the construction of a ship, but regulations of classification society would still need to be honoured while the system was designed. This statement referred to the DALI LED-drivers basic function called "System Failure Level", in which the driver commands the secondary side to go to a specific emergency light level, i.e. maximum level if the bus interfaces supply voltage is not detected. According to the query results not all had understood the question the same way or were not aware of this function in the DALI drivers. One declined this, while stating that classification society would not allow this, four respondents would allow this under certain conditions and rest could not comment on the set question.

The question twenty had gathered multiple benefits of exchanging 1-10V to DALI on board. To summarize the most remarkable ones, those would be the robustness against interferences, bi-directional communication which would enable the system status monitoring and more intelligent systems to be used, cabling amount to be reduced and re-configuring possibilities of the system without having to re-wire the field's light fixtures. It was also pointed out that as the 1-10V dimming components were getting harder to be found from the markets, it was beneficial to adopt to latest technology as fast as possible. Part of the above-mentioned benefits were supported by the addressable DALI version connected to the dimming system and the benefits cannot be utilized in this extent with the broadcast version. Most of the respondents, 11 out of 13, saw a benefit of utilizing DALI protocol instead of 1-10V. The numbers described the fact that DALI had developed in a way that no other dimming control method could perform so widely as DALI could in such a cost-effective and reliable way.

According to the query replies for question twenty-two, the specialists suggested to use the 5-core cable to form DALI broadcast lines. There appeared to be no technical reason to keep

DALI as a separate line in all cases, but it is seen beneficial if addressable DALI is to be used. This was mainly because then the DALI line could be filled closer to the given limits than by using 5-core cable with the DALI bus included. According to the feedback from specialists, the system must work with either cabling style utilized, so this question had no just one and only proper answer, but the cabling depends also on the infrastructure and version of DALI that is used.

The questionnaire's question number twenty-three was one of the questions in which all the respondents, that replied, shared the same opinion that the DALI line cabling does not have to be screened or pair twisted. Standard does not require this either. In some cases, in which the cabling is close to the maximum of 300 m and the line included only e.g. Local Control Panels, for calling pre-set light scenes, the screened or pair twisted cable could be utilized, if wanted.

In the questions twenty-four and twenty-five, the reliability of using 5G1,5 to form DALI broadcast lines was questioned. Most of the respondents replied that they would allow of using this cabling format and it has been already used in a cruise vessel by four of the respondents. None of the specialists had experienced any interferences which could affect the light fixtures' controllability if this type of cabling topology was utilized. As this has been the common way of cabling DALI broadcast, it was not expected to cause problems to the control of lights either.

The query results of question twenty-six pointed out that not all the field of the area specialists were aware of the possible connection methods that DALI supports. Some of the respondents would have preferred to create guideline, to use e.g. serial connection, that is to be followed ship wide to ensure the easier maintenance of the crew later during the ship operation. From technical and DALI standard point of view, all the possible combinations were available for use. According to the IEC 62386-101, chapter 4.8.1 the wiring of the bus should be connected in a linear topology, star topology or a mixture of both. The only forbidden connection method was stated to be a ring structure.

According to the query results DALI broadcast was kept quite like 1-10V if maintaining of LED-drivers was considered. The DALI broadcast protocol can monitor the status of the LED-drivers connected to the circuit and can give a "lamp error" messages to the controller, which 1-10V analogic protocol could not do. Addressable version of DALI can utilize well

the bi-directional messages and therefore it can inform controller if a DALI driver had stopped functioning. Addressable DALI also allowed the monitoring of the LED-drivers lifetime and these functions were constantly being developed and improved in DALI 2 protocol. According to the received replies, it was found out that specialists in the field of the area were not too familiar of the DALI providing possibilities and functions. Most of the query respondents were aware or assumed that DALI would be dimming lower than 1-10V lights would, as it was basing on newer technology if compared to 1-10V. The achievable dimming level depended on the type of the control gear, but DALI 2 could be dimmed even in almost a step of 0.1 per cent.

The query results for question twenty-nine pointed out that both compared dimming methods, the 1-10V and DALI were experienced to be equally sensitive for Electromagnetic Compatibility (EMC) related emissions. None of the respondents justified their experiences any further, but both dimming methods were thought to be tolerating EMC well. According to the study results and behaviour of the different dimming methods, there should have been quite remarkable interferences and electromagnetic emissions around the LED-drivers if they were forwarding the disturbances to the light source and make visual changes to light levels. Basically, the DALI command required strictly regulated pulses to be received, with a certain voltage level and for certain time before it acted according to received command. While DALI was utilizing strictly regulated commands to change and control lights, 1-10V method instead kept the adjusted analogic voltage signal active all the time in the fixture. If bigger voltage leakages or emissions would occur, basing on the technology, 1-10V should have been more sensitive to the visual changes in light levels. EMC should be considered when designing dimming system on board. Especially locations of dimmer racks and LED-drivers should be carefully designed in a way that they are not too close to EMC sensitive devices. Usage of EMC tested, and CE marked system components is a must, when building a system of this extent.

The secondary cabling lengths from LED-driver to LED light source were questioned in questionnaire's questions numbers thirty-one and thirty-two. This was experienced to strongly base on the instructions given by the LED-driver manufacturers. The common distances from driver to a LED-strip as an example was mentioned to be between 2-20 meters, but utilization of even 50 meters had been tested to work, even against manufacturer's instructions and recommendations. Normally the driver manufacturers were

experienced to promise 2-5 meters of secondary cable lengths while following the EMC requirements. One of the LED-driver suppliers had also been studying the topic more carefully and were providing a possibility to use even 100 meters secondary cables with constant current application.

The question number thirty-three in questionnaire was studying the vessels which were mostly utilizing DALI as a lighting controlling system. It turned out that the dimming system suppliers, who had the most experience, could not reveal the project names as the information was confidential, but it was found out that there was no new-building cruise vessel yet implemented which was mainly utilizing DALI for light controls. Smaller vessels, such as ferries and yachts therefore existed which public areas were fully utilizing DALI. DALI had also been implemented on a new building vessel built in Meyer Werft, Papenburg, but also in Meyer Turku shipyards. The areas utilizing this digital control method on these projects were kept limited. Refurbishment projects instead had more DALI installed in them, but in these projects the system was being applied to limited venues such as restaurants or similar, not to the whole ship. To summarize the received replies, the DALI protocol as broadcast or addressable version had been utilized on over 10 different vessels in different extents. Therefore, it seemed that the reputation of the digital dimming method had started to increase in a positive way.

In the question thirty-four, it was asked how full the DALI lines should be as maximum according to the questionnaire recipients. The received feedback was diverse as the topic had been interpreted from different points of views. According to the builder's and ship-owning company's representatives' point of view the lines should not be filled over the ship contract limits, which might be only one third from allowed 64 devices. According to the dimming system suppliers the maximum of allowed amount should not be met, but the line was to be filled to 50-80 per cent of the recommended amount. This was justified with the fact that it would be easier to add light fixtures to the existing lines in case light illumination levels would not be satisfactory to the ship-owner.

Inrush currents of DALI LED-drivers were not experienced as a problem by the questionnaire respondents. The feedback from them was that they had not experienced problems at all if the topic was kept in mind while designing of the system. DALI drivers were experienced to have remarkably smaller inrush currents if compared to older

technology of 1-10V drivers for example. One of the light fixture suppliers encouraged to always check the data sheets of the LED drivers for this information; this was due to make sure they can be connected behind the intended circuit breaker.

In the final question of the questionnaire the dimming system component manufacturer alternatives were looked after. The respondents managed to define a long list of different suppliers, such as Lutron, Beckhoff, Wago, ETC, Eaton and so on. So far, the best experience had been made with Helvar products, as it was one of the most known lighting and dimming system component suppliers having longest experience in the business. They have developed the system to be robust for marine use and therefore it has been used in several cruise vessels.

## 5 SUMMARY

### 5.1 General

The purpose of this thesis was to find out whether the digital dimming protocols available in the markets can offer a fail-safe lighting controlling system to be used in cruise vessels. The objective was to investigate DALI protocol and technology to find out the benefits it could provide to the dimming system. The purpose was also to find out how well the field of the area specialists were aware of this alternative light control method, but also to compare it to the currently used dimming methods and find the differences and advantages that could be achieved if DALI was more widely utilized on board. The received questionnaire replies and the held interviews with the field of the area specialists made it possible to find out what the industry's current status with the digital dimming protocols was and especially how DALI was seen by different participants. The research based on the held questionnaires, interviews, discussion about the topic, getting familiar to standards, comparing protocols, studying the related literature, drawings and documentation.

### 5.2 Findings

Firstly, it was found out that DALI as protocol was not too well known by the field of the area specialists. Part of the industry's knowledge relating to this protocol was strongly basing on the DALI version 1, which was not strictly enough monitored by the DALI standardization association. In this procedure the manufacturers could test their products themselves, make minor software additions to them and finally inform the association that they are about to start offering their DALI product to the markets. From interoperability point of view between different manufacturer's products this did not work out, even the launched DALI protocol was all right and followed correctly. This bad-experienced information had spread to the industry and therefore the protocol had been avoided ever since. Now at the beginning of year 2019, the DALI standard IEC 62386 clearly defines how the protocol utilizes DALI commands and as the DALI command must be strictly in certain electrical values for a certain amount of time to be a proper command that the devices reacts to, the DALI protocol has gained back its positive reputation. DALI 2 requirements have been partly re-written and it has been directed to a way in which it is made to be well interoperable with other DALI 2 devices, which interoperability is regularly tested, and as

this improvement has taken place to DALI standards, the reputation of DALI was being purified.

Questionnaire replies pointed out that the specialists working in the field of area had not yet had the chance of getting familiar to DALI providing technical aspects. The author of this thesis highly recommends the field of area specialists to get familiar to the DALI standard, to find out what is possible in controlling of light fixtures if DALI was utilized in addressable version. More advanced functions are constantly being developed and implemented to DALI 2 standards and utilization of these could help the ship-owning company to maintain the areas' light fixtures. For example, the change of light fixtures could be predicted by monitoring the used hours of light fitting and comparing this information to the manufacturers' given lifetimes. Also LED lights' problems regarding slight changes in colour temperature and illuminance level changes could be monitored and spare parts could be adjusted to match the area other lights before replacing of products.

A lot of trustworthy and beneficial information regarding DALI protocol and its applications were found during the done research. The main benefits of using DALI would be its robustness against different types of interferences, bi-directional communication allowing monitoring and more intelligent systems to be utilized, re-configuration possibilities without re-wiring in addressable DALI version, devices good increasing availability and the system flexibility.

As DALI pulse must be certain length long in certain voltage level. The information transmitting the signal pulse is 100% sure. The LED driver ignores the command or aborts the unfinished sequence if a code violation or time limit failure is detected. The GO TO SCENE command can be used in the area lighting and the speed of this function is comparable to DMX control as the called pre-set light levels are stored to the DALI drivers. As the DALI 2 protocol is flexible and the combination of addressable and broadcast DALI can control most of the area light fittings with precise dimming curves it seems that the utilization of DALI in the studied area would be the best choice to go for. Nevertheless, it is not to be used in the area as the only dimming control method, but it can be supported by using of transistor dimmers for more traditional lights' control.

A positive finding was made in the research project, since most of the field of area specialists expressed their willingness to give DALI controls a try in their next built vessels.

### 5.3 Recommendations

The dimming tests executed in the test environment will be continued and the found information is to be utilized in the future built cruise vessels. The testing of products in controlled environment gives the possibility to test the product's interoperability with the dimming control equipment used on board before actual installation on board.

The visual dimming tests were executed with decent results, but if more accurate tests results were needed, utilization of advanced measuring devices could be used to check if the manufacturer's instructed values and limits are met. The author of the thesis would propose cross-checking of manufacturer's guidelines with the test system to find out if the electrical values are the ones that have been informed to the consumer.

Harmonic distortion in the cruise vessel's power grid could be further studied to find out the real quality of certain time frame. The topic has not been too widely studied from the lighting control view of point in the past, but it would be beneficial so the information could be used to prevent possible problems relating to this matter.

The author of the thesis recommends the field of the area specialists to investigate the possibilities of utilizing the DALI LED-drivers basic function about the "System Failure Level" behaviour in which the LED-driver would go to emergency level turning the light to 100 per cent. If this topic was further studied and it was found approvable for all the participants working on a project, this could save space of approximately 150 pcs of small electrical distribution boxes and their installation time on board. The freed-up space could be utilized for some other purposes and area lighting cabling would be simplified slightly.

Previously used dimming methods availability is reducing in the markets, which forces the industry to adopt to other available dimming methods. The sooner the adaptation to DALI is done, the smoother the transaction era is passed. The author of the thesis recommends of starting this transaction era already in the cruise vessels that are currently being under construction.

### 5.4 Final words

DALI as lighting control protocol was found out to be reliable and robust system which is suitable to be used in cruise vessels. DALI 2 protocol is strictly regulated, monitored and tested constantly and the interoperability of DALI components has improved remarkably.

The research for the thesis made it also possible for multiple key persons and administrators in the field of the area to get involved on the topic and the author believes that most of the questionnaire respondents and the interviewed persons will further consider adopting to DALI in near future.

The author of this thesis highly recommends all the specialists working in the cruise vessel's lighting field of area to get to know with DiiA consortium's work and get familiar with the information available in their webpages. The author believes that after the knowledge and understanding of DALI protocol has spread to all the participants working in the industry, it grows to be more acceptable in the everyone's minds in the business and more of DALI broadcast and addressable variations are going to be implemented on board on the next built cruise vessels.

A good approach to make this change would be for all the ship-owning companies to consider in which areas they would like to have the flexible lighting control system implemented to. The author proposes to start the test implementations on some limited area, such as at a lounge, bar, multipurpose functioning areas or similar. Also, part of cabins and suites are good test places and the target should be to take the addressable DALI to use in some of these venues during the next built vessels.

It took approximately five months for the author to finish this thesis. The schedule was tight as the topic barely had proper marine based literature available or studying done and documented; however, the author of this thesis concentrated on the topic from the beginning and had some preliminary experience and understanding about the industry's situation and beliefs. He found the project's topic very interesting and was confident he could help the industry to get the familiarization process to the topic started. The discussions about the topic were very productive and a lot of new aspects were developed to different parties during the project. The basic level details about DALI protocol is gathered to this thesis and the author of the thesis trusts that by doing this work and openly introducing the topic to the industry, it shall have a long-term influence to the lighting control methods used in cruise vessels in the future.

## REFERENCES

- [1] DMX512. 2019. DMX512 Termination. [Online document]. [Accessed 25.5.2019]. Available at <http://www.dmx512.com/web/light/dmx512/term.htm>
- [2] DSMT. 2019. IP Rating Chart – Learn what IP means and what rating is best for your application. [Online document]. [Accessed 25.5.2019]. Available at <http://www.dsm.com/resources/ip-rating-chart/>
- [3] GlamoX LED Education Centre, LED and Lifetime. [Online document]. [Accessed 4.5.2019]. Available at <https://glamoX.com/gsx/led-lifetime-and-the-factors-that-affect-it>
- [4] T.J.Liang, J.F.Huang, P.K.Yadav (June 2017). Design and implementation of dimmable LED control circuit with DALI protocol. [Online document]. [Accessed 4.5.2019]. Available at <https://ieeexplore.ieee.org/document/7951545>
- [5] Ribarich, T. & Contenti, C. 2002. Analog and Digital Fluorescent Lighting Dimming Systems. [Online document]. [Accessed 19.5.2019]. Available at <https://pdfs.semanticscholar.org/0d4d/fbf15d93f2b7d814b950c45439bda5ce56f1.pdf>
- [6] Helvar. 2019. 474 4 x 16 A Ballast Controller [Online document]. [Accessed 19.5.2019]. Available at <https://www.helvar.com/en/products/474/>
- [7] Sharp, C. & Trzyna, B. 2015. Solving the Phase-Cut Dimming Challenge. [Online magazine]. [Accessed 19.5.2019]. Available at <https://www.led-professional.com/resources-1/articles/solving-the-phase-cut-dimming-challenge>
- [8] Helvar. 2019. 454 4x2.2 A Transistor Dimmer [Online document]. [Accessed 19.5.2019]. Available at <https://www.helvar.com/en/products/454/>
- [9] DMX512. 2019. DMX512 Index – The Protocol. [Online document]. [Accessed 25.5.2019]. Available at <http://www.dmx512.com/web/light/dmx512/index.htm>
- [10] P.F. Hein. “DALI – A digital addressable lighting interface for lighting electronics”. August 2002. [Online document]. [Accessed 5.5.2019]. Available at <https://ieeexplore.ieee.org/document/955559/>
- [11] IEC 62386-101:2014/AMD1:2018 CSV Consolidated version. Digital addressable lighting interface – Part 101: General requirements – System components. Available for purchasing at <https://webstore.iec.ch/publication/63236>
- [12] Digital Illumination Interface Alliance. April 2018. DALI Quick Start Guide. [Online document]. [Accessed 25.5.2019]. Available at [https://www.digitalilluminationinterface.org/data/downloadables/6/4/dali-quick-start-guide\\_public-v1\\_april-2018.pdf](https://www.digitalilluminationinterface.org/data/downloadables/6/4/dali-quick-start-guide_public-v1_april-2018.pdf)
- [13] Helvar. 2019. 478 8-Subnet DALI Controller [Online document]. [Accessed 19.5.2019]. Available at <https://www.helvar.com/en/products/478/>

- [14] Digital Illumination Interface Alliance. 2019. Projects and case studies. [Online document]. [Accessed 26.5.2019]. Available at <https://www.digitalilluminationinterface.org/projects/>
- [15] S. Wade, DiiA. – “DALI-2: Smart lighting control and interoperability”. October 2018. [Online publication]. [Accessed 26.5.2019]. Available at [https://www.digitalilluminationinterface.org/data/downloadables/9/4/1810\\_lux-webcast-diiA-presentation-oct-2018.pdf](https://www.digitalilluminationinterface.org/data/downloadables/9/4/1810_lux-webcast-diiA-presentation-oct-2018.pdf)
- [16] RF EMC Development. 2019. LED driver EMC [Online document]. [Accessed 30.5.2019]. Available at <http://www.rfemcdevelopment.eu/en/emc-basics/led-drivers-emc>
- [17] RF EMC Development. 2019. Electromagnetic compatibility testing in EMC lab, EN 61000-3-2:2006+A1+A2 Elec-tro-mag-netic com-pat-i-bil-ity (EMC) — Part 3 – 2: Lim-its — Lim-its for har-monic cur-rent emis-sions (equip-ment input cur-rent  $\leq 16$  A per phase). [Online document]. [Accessed 30.5.2019]. Available at <http://www.rfemcdevelopment.eu/en/emc-emi-standards/en-61000-3-2-2006-a1-a2>
- [18] Mean Well Europe. April 2015. A guide to select driver for LED luminaire to meet CE marking. [Online document]. [Accessed 30.5.2019]. Available at <http://www.meanwell.eu/ExclusivePDF/LEDAPPROVALS-NOTE.pdf>
- [19] TÜV Rheinland. 2019. Electromagnetic Compatibility Requirements for LED Lighting Products. [Online: White Paper]. [Accessed 2.6.2019]. Available at [https://www.tuv.com/media/india/informationcenter\\_1/products/documents\\_4/light/EMC\\_LED\\_Whitepaper.pdf](https://www.tuv.com/media/india/informationcenter_1/products/documents_4/light/EMC_LED_Whitepaper.pdf)
- [20] Osram Digital Systems. 2019. Technical application guide. Standards for LED drivers, LED modules and LED luminaires. [Online document]. [Accessed 2.6.2019]. Available at [https://www.osram.com/ds/app-guides/14\\_standards.jsp](https://www.osram.com/ds/app-guides/14_standards.jsp)
- [21] Etteplan. 2019. EMC test laboratory. [Online document]. [Accessed 2.6.2019]. Available at [https://www.etteplan.com/expertise/software-and-embedded-solutions/test-laboratory?gclid=CjwKCAjwv6blBRBzEiwAihbM-VcQgz\\_fm0vKBALewToVt1jRGL106ai4wmpMJ1VbI2CJ\\_Vy\\_fRgjkhoCiX0QAvD\\_BwE](https://www.etteplan.com/expertise/software-and-embedded-solutions/test-laboratory?gclid=CjwKCAjwv6blBRBzEiwAihbM-VcQgz_fm0vKBALewToVt1jRGL106ai4wmpMJ1VbI2CJ_Vy_fRgjkhoCiX0QAvD_BwE)
- [22] Digital Illumination Interface Alliance. May 2019. D4i – A new logo and certification program for intra-luminaire DALI. [Online document]. [Accessed 26.5.2019]. Available at <https://www.digitalilluminationinterface.org/d4i/>
- [23] Digital Illumination Interface Alliance. 2019. DiiA specifications – Data and Power-Supply specifications. [Online document]. [Accessed 5.5.2019]. Available at <https://www.digitalilluminationinterface.org/specifications/>
- [24] Helvar. October 2016. Helvar, Imagine Router (920). [Online datasheet]. [Accessed 5.6.2019]. Available at [https://www.helvar.com/media/pd/2017/20170120/920\\_DATASHEET\\_EN.pdf](https://www.helvar.com/media/pd/2017/20170120/920_DATASHEET_EN.pdf)

- [25] Helvar. July 2018. Helvar, Transistor Dimmer (454). [Online datasheet]. [Accessed 8.6.2019]. Available at [https://www.helvar.com/media/pd/2018/20180706/454\\_DATASHEET\\_EN.pdf](https://www.helvar.com/media/pd/2018/20180706/454_DATASHEET_EN.pdf)
- [26] Helvar. November 2018. Helvar, 4-Channel Ballast Controller (474). [Online datasheet]. [Accessed 8.6.2019]. Available at [https://www.helvar.com/media/pd/2018/20181211/474\\_DATASHEET\\_EN.pdf](https://www.helvar.com/media/pd/2018/20181211/474_DATASHEET_EN.pdf)
- [27] Helvar. August 2016. Helvar, 8-Channel Relay Unit (498). [Online datasheet]. [Accessed 8.6.2019]. Available at [https://www.helvar.com/media/pd/2017/20170224/498\\_DATASHEET\\_EN.pdf](https://www.helvar.com/media/pd/2017/20170224/498_DATASHEET_EN.pdf)
- [28] WAGO. WAGO WINSTA – The Pluggable Connection System, Full Line Catalog, Volume 5 – Edition 2017/2018, p. 127. [Online catalogue]. [Accessed 9.6.2019]. Available at <https://www.wago.com/infomaterial/pdf/60321952.pdf>
- [29] Vanpee. May 2018. Helvar Designer 5 Foundation Course: Initial programming. Edition 1. [Online document]. [Accessed 9.6.2019]. Available at [https://www.vanpee.dk/media/76098/20180510\\_designer-5-foundation-course.pdf](https://www.vanpee.dk/media/76098/20180510_designer-5-foundation-course.pdf)
- [30] Ruostemaa, M. 9<sup>th</sup> of June 2019. Dimming system implementation material created for the Thesis study purposes. [Created exercise material].
- [31] Ruostemaa, M. 11<sup>th</sup> of May 2019. Interviews and questionnaire held to the field of the area specialists. [Created research material with replies from specialists].
- [32] DiiA web pages, DALI standard IEC 62386, “IEC 62386 – the international standard for DALI technology”. December 2018. [Online document]. [Accessed 14.5.2019]. Available at <https://www.digitalilluminationinterface.org/dali/standards.html>

**APPENDIX 1. Emission requirements standardized by EN 61000-3-2.**

Harmonic	Current limit				
	Class A	Class B	Class C	Class D	
n	[A]	[A]	Expressed as percentage of the input current at the fundamental frequency	Permissible current per watt	Permissible harmonic current
			[%]	[mA/W]	[A]
2	1.08	1,62	2	–	–
3	2.3	3,45	3*λ	3.4	2.3
4	0.43	0,64	–	–	–
5	1.14	1,71	10	1.9	1.14
6	0.3	0,45	–	–	–
7	0.77	1,15	7	1	0.77
8	0.23	0,34	–	–	–
9	0.4	0,60	5	0.5	0.4
10	0.18	0,27	–	–	–
11	0.33	0,49	3	0.35	0.33
12	0.15	0,22	–	–	–
13	0.21	0,31	3	0,29	0.21
14	0,13	0,19	–	–	–
15	0.15	0,22	3	0.25	0.15
16	0.11	0,16	–	–	–
17	0.13	0,19	3	0.22	0.13
18	0.1	0,15	–	–	–
19	0.11	0,16	3	0.2	0.11
20	0.09	0,13	–	–	–
21	0.1	0,15	3	0.18	0.1
22	0.08	0,12	–	–	–
23	0.09	0,13	3	0.16	0.09
24	0.07	0,10	–	–	–
25	0.09	0,13	3	0.15	0.09
26	0.07	0,10	–	–	–
27	0.08	0,12	3	0.14	0.08
28	0.06	0,09	–	–	–
29	0.07	0,10	3	0.13	0.07
30	0.06	0,09	–	–	–
31	0.07	0,10	3	0.12	0.07
32	0.05	0,07	–	–	–
33	0.06	0,09	3	0.11	0.06
34	0.05	0,07	–	–	–
35	0.06	0,09	3	0.11	0.06
36	0.05	0,07	–	–	–
37	0.06	0,09	3	0.1	0.06
38	0.04	0,06	–	–	–
39	0.05	0,07	3	0.09	0.05
40	0.04	0,06	–	–	–

## **APPENDIX 2. Questionnaire form with answers**

Date & Location: 11.5.2019, Raisio, Finland

Name: The Author's interpretation of Questionnaire's correct answers

Department: Electrical Design Department

Position: Lighting System Responsible in Meyer Turku Oy

### Questionnaire about Digital dimming methods

1. Are You familiar with dimming methods used on a cruise vessel?
  - Yes, a person working with marine business-related lighting should be aware of the basics of dimming methods used on a cruise vessel.
  
2. Describe the commonly used dimming methods on a cruise vessel. Name the most used the first and the rest in the most used order.
  - Questionnaire results from the received replies from the field of area specialists and experience from designing cruise vessels in Meyer Turku for past three years results up with the following order:
    - 1-10V (0-10V)
    - Phase-cut (with leading and trailing edge)
    - DMX 512
    - 24V/PWM
    - DALI
    - DALI2
  
3. Describe for how long each of these dimming methods has been used on a cruise vessel.
  - Questionnaire results from the received replies from the field of area specialists and experience from designing cruise vessels in Meyer Turku for past three years results up with the following order:
    - 1-10V (0-10V) – Used since 1990s (about 25 years)
    - Phase-cut (with leading and trailing edge) – Used since the beginning of dimmable lighting
    - DMX 512 – Used since early 2000s (about 15-20 years). Even earlier in entertainment lighting.
    - 24V/PWM – Used since about year 2005. As a combined solution.
    - DALI – Used for about 5-10 years.
    - DALI2 – Used from 2018 (first versions also known as DT8, utilization increasing)
  
4. Which dimming method has had the least problems related to it and to its instalment? Was the problem located in the dimmer itself or in components which should be dimmed?
  - Phase-cut has had the least problems if conventional loads, such as incandescent bulbs and halogen lights were used.
  - 1-10V has had the least problems after the LED technology has come to the markets. This is mainly because the drivers have been matching well with the light sources.

- It is to be noted that connection, wiring, designing mistakes affect the results remarkably. If all the dimming methods and components are installed according to the requirements, all the dimming methods work without any major issues. With the LED technology-based lighting systems, the controller's, driver's and light source's compatibility should always be tested before usage. DALI 2 standard is the first worldwide standard that regulates and supports the improved interoperability of lighting components.
5. Have You experienced the ship's power grid causing any problems to the dimming system?
    - It can be noted out that phase-cut dimmed light fixtures may suffer from the unsteady power grid. This is especially if the power grid supplying the dimming boards are not well protected with THD filters. Also, bigger power peaks, such as starting of the main propulsion may cause peaks to the power grid which might cause visible flickering to phase-cut lights.
    - Most commonly this kind of issues are not affecting the digitally controlled light fixtures unless the supplying voltage levels are dramatically fluctuating.
  6. Is the harmonic distortion affecting analogic (e.g. 1-10V) or digital (e.g. DALI) dimming methods?
    - The dimming system supplier companies have experienced that the 1-10V analogic dimming method would be more sensitive for the harmonic distortion than the digitally operated dimming methods.
    - Neither of these is clearly affectable by harmonic distortion but if the THD appears, it is possible that the fixtures pick up the THD peaks and the fixtures might get flicker.
  7. What kind of an experiences You have from using DALI as dimming method on board?
    - DALI broadcast has been experienced to function well. Also, a feedback of easy installation and putting into operation has been received. A successful installation can be compared to 1-10V installation so the electricians on board have not had to learn too much new and the physical connection work does not differ from the accustomed connection work. The designers are required to make sure of the compliance of used drivers and dimming equipment. DALI broadcast supports its place for large public venues which consists of lighting that does not have to perform quickly. It can be considered to operate too slow e.g. in theatre type of areas where lights might be part of the show's effects.
    - Addressable DALI has been more challenging according the results received. It requires well design but even if the lighting design drawings are faultless but the electricians on board are not aware of how the system works, there might start to be problems in the commissioning of the areas. The addressing of the drivers can also be considered as time consuming process and it is preferably done by a professional in this specific field of area.
  8. Has there been any functioning problems in using DALI? Describe.
    - Problems are always present if careful design and implementation is not followed. This applies to all dimming methods and lighting controlling styles.

- The incompatibility of driver and control gear have caused unexpected issues. For DALI this was a common issue if for example two different manufacturer's control device and drivers were mixed up in the same circuits. This has been the result of how the manufacturers got the permission to use DALI in the first place. The manufacturers were free to use DALI sign on their products if they had followed up to the standards and regulations given by DiiA, but the final testing was on the manufacturer's responsibility. If the product was constructed and programmed as the standard required, the product's manufacturer got the permission to start production of the new DALI device. With manufacturers producing lighting components with this method, the end-user or the device installing electrician should have always tested the interoperability of the used components before starting the final installation and commissioning work on site.
  - DALI broadcast has had clearly the least problems, but still it is a matter of well designing which products are to be included in the same DALI lines or lighting circuitry groups.
  - DALI 2 has a new way of approach and now it is DiiA making the test results approval for the product manufacturers. If the products pass the tests, the DALI2 sign is granted to be used on that tested product. Each product type is tested separately before DALI2 sign is given.
9. Describe the current availability of 1-10V, DALI and DMX LED-drivers.
- 1-10V LED drivers are fading out from the markets. The biggest driver suppliers such as Osram has started to limit the product range that is kept available from this control method. The 1-10V dimming components are barely developed by any manufacturer anymore as the 1-10V utilizing technology gets out-dated and replaced by other dimming methods. There is clearly less decent 1-10V driver manufacturers available in the markets than about a decade ago.
  - DALI drivers are increasingly manufactured and used worldwide. Also, the DALI2 protocol's ensuring good interoperability between control devices has increased the reputation of DALI protocol drivers and therefore these products are increasingly utilized and tested worldwide. Out of experience, the DALI versions of light fixtures are nowadays even more easily available in the markets than 1-10V versions of same light fixture.
  - DMX has started to get limited in the markets and finding these products gets a bit rarer nowadays. The main reason is told to be the cost and the demand for these products that affects the availability. DALI, as an alternative to DMX, can control all the required lighting types in the architectural lighting, but not with the same instant responsiveness as DMX is. Most commonly it is enough if the light fixtures operate reliably and if the products are connected to house lighting dimming system which calls for pre-set scenes from the light fixtures installed to the venue, there is no DMX necessarily needed. DMX is preferably used in performance areas, such as theatres or discos, so they are needed on board but if such a performance is not required, simpler to design/install/operate methods could be preferred. One of the limiting matters of using DMX is the cost of the drivers. Drivers are roughly 3 times more costly than commonly used DALI drivers. One reason behind the current cost level is the reduced demand for DMX drivers in the markets.

10. Are You familiar with DiiA (Digital Illumination Interface Alliance) organization? Describe their goals shortly. Why do this organization exist?
- Persons working in the lighting industry should have heard of DiiA if they have investigated the newest available lighting controlling methods, DALI and DALI2.
  - To describe the organization and their goals, a straight quote from the DiiA organization's web pages helps to describe them in a nutshell: "The Digital Illumination Interface Alliance (DiiA) is an open, global consortium of lighting companies that aims to grow the market for lighting-control solutions based on Digital Addressable Lighting Interface (DALI) technology." Target is to enhance the interoperability and additional functions of DALI systems.
  - According to the IEC 62386-101 General requirements – System components the purpose of the updated DALI standard is "the standardization of the digital addressable lighting interface is intended to achieve interoperable multi-vendor operation below the level of building management systems".
  - To find out more and to further familiarization to the organization, visit DiiA's web sites at <https://www.digitalilluminationinterface.org/>
11. Are You familiar with IEC 62386 – the international standard for DALI technology?
- Yes, as a ship-builder's representative, system supplier or light fixture/driver manufacturer, as having strong expertise in the utilized technology, the ships can be designed and built in a way that the lighting systems works reliably while utilizing modern technology.
  - Yes, in principle level, as a ship-owning company's electrical representative, as understanding the technology utilized on board is important while ship's lighting control systems are being selected and new technology is implemented.
  - No, as a lighting consultant, as the job description does not include of understanding all the details of the used system.
12. Describe the difference between DALI and DALI 2. Which You prefer?
- According to DiiA, the "DALI2 adds new features, and introduces standardisation of control devices including the recent additions of input devices, while maintaining backwards compatibility.
  - DALI 2 is the new and enhanced version of DALI, with many additions, from which the most remarkable are the backwards compatibility, fade times updates, addressing quantity increased to 128pcs (divided to 64 addresses for control devices and 64 addresses for control gears), more precise specification of electrical tolerances, 24-bit commands and the devices are required to be either polarity insensitive or the power supplies are to be able to withstand reverse voltages.
  - To find out more about the differences of DALI and DALI 2, visit DiiA's web sites at <https://www.digitalilluminationinterface.org/dali/comparison.html> & [https://www.digitalilluminationinterface.org/data/downloadables/5/4/1711\\_tech\\_nical-note-dali-2-the-new-standard.pdf](https://www.digitalilluminationinterface.org/data/downloadables/5/4/1711_tech_nical-note-dali-2-the-new-standard.pdf)
  - DALI2 should be preferred over original DALI. This is because of the new more strictly regulated standards and approval process of the products.

13. Would You be willing to use DALI 2 as lighting control method on a cruise vessel?
- Yes, due to its increased interoperability of components.
  - Broadcast could be utilized in the venues where lights may remain in the originally designed circuits over the whole operation period of the vessel.
  - Addressable DALI could be utilized in venues which usage purpose is required to be changed occasionally (such as meeting rooms, art illumination, suites, embarkation areas and similar)
14. Do You feel that You have enough of knowledge and experience of DALI or DALI 2? Justify Your statement shortly.
- DALI is unused lighting control protocol in marine industry, so the specialists in this field of area are not all aware about the possibilities of DALI.
  - Target is to increase the basic knowledge of the cruise vessel industry's specialists about the DALI protocol and implement this modern and quickly developing latest light controlling invention on board.
15. What are Your biggest concerns if 1-10V was entirely replaced with DALI/DALI2 in Your next designed cruise vessel?
- The question was formed poorly, and it ended up being in too general level as there is different issues to be faced if DALI is used as addressable or as broadcast version. The broadcast is about like 1-10V, so in this version any bigger problems cannot be expected. In case of utilizing addressable DALI in bigger venues, there exists multiple issues that must be carefully implemented on board for the system to work as intended.
  - According to the query results, the biggest concerns about changing 1-10V devices to DALI (in general, with broadcast and addressable) based devices are the following:
    - o Lack of knowledge and understanding the DALI requirements
    - o Missing experience
    - o New design guidelines to be followed → quality of design work
    - o Ability of builder to commission system properly → configuration issues
    - o Ability of maintaining the system by ship-owning company's crew working on board
    - o System supplier's and DALI requiring guidelines are to be followed
    - o To find out if the control gear is high quality
    - o Cabling requirements to be taught to the electricians working on board
    - o Setup time
    - o Training of the whole supply chains persons (Owner, shipyard, designers, electrical foremen, electricians, crew on board)
    - o Doubts about dimming speeds and delays of DALI system in general
16. Which version of DALI is the better for operability after the ship delivery, broadcast or addressable version of DALI? Which one would You predict the ship owning company favouring?
- According to the query results, majority of repliers supports the broadcast version to be used as a main lighting controlling system on board. Acceptance of using DALI addressable version in limited sized areas is considered acceptable, such a venue could be suites, training rooms, dividable meeting

rooms, multipurpose venues and similar. Even art lighting is considered that it could be utilizing addressable DALI in public venues side by side to the broadcast lights in the same venue. This allows the looping of all art related lights to single “group” which utilization and effects can later be modified just by simple programming.

- Addressable DALI ship wide would be acceptable only if full flexibility would be the goal to achieve. This requires proper training to be held for the crew working on board and a faultless documentation of the area’s lighting.

17. Would You consider of using addressable DALI at some lighting control purposes (in which?) and utilize the broadcast version more commonly ship wide?

- According to the query results, there was a lot of different points of view to this question
- A builder’s representative would propose to use addressable version especially in restaurants to keep the simple reprogramming as an option if the pre-set scenes are wanted to be changed during the ship’s operation. In principle in all venues which requires different moods to be programmed every now and then. The broadcast could be utilized in places in which the lighting groupings are not needed to be changed during the ship’s operation, for example in public toilets and in staircases. Even some of the lighting consultant representatives agrees to this principle.
- Owner’s representatives seem to be open for suggestions but in principle agree that both versions should be utilized side by side.

18. Would there be a cost impact for the used dimmer racks if DALI was utilized as the main lighting control method on board? Increasing or decreasing impact?

- According to the query results, there are benefits and disbenefits of utilizing DALI from a cost perspective.
- DALI based LED drivers appear to be quite in similar cost level as now currently used 1-10V drivers. In case of Helvar dimming components there is a slight (approximately 10-15%) cost saving if broadcast DALI is used instead of 1-10V. This is because Helvar 474 Ballast controller contains 4 dimmable channels while Helvar 478 DALI broadcast module has 8 channels to be utilized. If addressable DALI is utilized, the cost savings from material is spent on the setting up the system and addressing all the fixtures.
- As a summary, this topic should be studied ship wide in a whole project to find out the reality. Currently it seems that there could be a slight decrease in cost of the system in whole if DALI was utilized but the real benefit comes from the improved controllability, re-addressability, utilization of digital control method and monitoring of the status of the light fixtures.

19. Could You think of removing the separately used switch-over unit boxes from emergency power feeder on board if DALI was used ship wide?

- In case of a lack of interface supply voltage, the DALI driver goes to its “System Failure Level” that corresponds to the light value that DALI devices adopt while fault in bus occurs. In such a situation the default value assures 100% light output from the light fixture.

- If the DALI equipped drivers were connected to the emergency power supply, the above-mentioned function could be in principle utilized on board without using the switch-over unit emergency supplies.
- The technology should work in principle, but regulations of Classification Societies are to be honoured. This would also require that DALI was used ship wide.
- NOTE: If the above-mentioned idea is considered as interesting topic, it should be further studied separately before instalment on board. Functionalities to be tested and system to be approved by required authority.
- The IEC 62386-202 Self-contained emergency lighting and IEC 62386-220 Centrally-supplied DC emergency operation describes these functions more in detail.

20. Is there a benefit of using DALI on board instead of 1-10V? Justify.

- According to the query results the system supplier considers the digital control method in principle to be very robust against interferences faced on board.
- DALI broadcast type of light controller is capable of reporting on a lamp failure in a subnet. DALI broadcast is easy to configure and maintain as the LED drivers are not needed to be separately addressed.
- Addressable DALI offers the benefit of flexibility as it can control individual lights, groups and lines as programmed. Regrouping of lights possible without rewiring. Addressable DALI is capable of reporting about a malfunction of a LED driver connected to the DALI bus by name. In principle DALI as protocol is a two-way bus which enables the system status monitoring and more intelligent lighting control system's implementation.

21. Have You experienced that DALI has become more reliable during the last few years? How?

- According to the query results, the reliability of DALI has not been bad at any point. The problem has not been in the protocol but in some of the drivers that have been constructed differently as instructed by standards. Since the launch of DALI 2 and the new standards the compatibility issues therefore have reduced significantly in past years. While keeping this in mind, in the bigger picture it seems that DALI has become more reliable.
- DALI as a protocol is strictly regulated by a range of international standards in IEC 62386 containing several parts. Also, a certification process must be applied to a product which carries DALI 2 logo.
- The key steps of DALI-2 certification process, that is available in DiiA's web sites, describes the process for the product to become DALI2 approved:
  1. DiiA creates and maintains DALI-2 Test Specifications, which bases on IEC 62386 or on new DiiA specifications
  2. DiiA develops software Test Sequences for use on approved test equipment. The members of DiiA can download these Test Sequences from the member web sites
  3. Member companies execute the required tests for each product or utilize the services of accredited DALI test houses
  4. If all tests pass, the member company submits the results via the DiiA website. Certification credits (one per product) must be pre-purchased before products are submitted

5. DiiA verifies the results. If all data is acceptable, then DALI-2 certification is granted. The member company may use the DALI-2 logo on the certified product after this.
  6. Relevant data is displayed in the online DiiA Product database. Visibility of a product in the database confirms that the product is certified. If a product is not listed, it is not certified.
22. Would You recommend of keeping the DALI line as a separate cable and form full DALI lines on the area?
- IEC 62386-101, chapter 4.8.1 Wiring structure states that the two leads serving as the buss shall be in same cable conduit or in the same cable. The two leads shall be next to each other in order to prevent unintended coupling to other signals.
  - The standard does not require a separate DALI bus line to be formed but in some venues it could be beneficial. For larger venues it might not be the first choice to make as it requires more careful maintenance.
  - There is no technical reason to form the separate DALI line, 5-core cable functions just as fine. But if distances grow close to the acceptable 300 meters, the cable cross-sections size should be considered in the design phase. Also, the voltage drop should be kept below the 2,0 V as it is the maximum allowed voltage drop in a single line.
23. Does the DALI line cabling have to be screened and/or pair twisted?
- No, as it is not a regulation from the DALI standards.
  - In certain cases, it might be beneficial to have the cable either screened or pair twisted, this kind of situations could be for example the cabling for Local Control Panels (the pre-set panels) if the distances of the cabling grow up to the 300m. The system does not require this, but it can be done as precautions.
24. Could You consider of using DALI broadcast with 5G1,5 equipped cabling for the light fixtures?
- IEC 62386 does not instruct not to use 5G1,5 cables in DALI broadcast case. In fact, the 1,5 mm<sup>2</sup> cross-section copper wire is capable of providing the maximum of 300m allowed cabling distance for the DALI system, so in principle this cable is the most suitable for broadcast functions.
  - According to the query results, this has been exactly the method used on cruise vessels that has been lately built which has had DALI broadcast as lighting controlling method.

25. Can this method interfere with the light fixtures' controllability?
- According to the query results, none of the repliers have experienced such a case.
  - The IEC 62386 regulates the bus signal rise and fall times and voltage levels that must be kept in certain limits during the command signal is given, so the possibility of interference affecting to the controllability of system is extremely low. If such a case was found, one of the corrective actions would be to replace the cable to a screened version.
26. Which single circuit connection method would be most suitable for DALI use on cruise vessel: Serial connection, Star connection or combination of these both?
- According to the IEC 62386-101, chapter 4.8.1 Wiring structure, the bus wiring is to be connected in a star topology, a linear topology or a mixture of both. Wiring is not to be implemented in a ring structure.
  - In case if DALI broadcast is used on board, the actual limitation for cabling of DALI light fittings is the ship contract's instructing maximum allowed light fixtures connected to one circuit. This allowed quantity is usually less than 25 light fixtures per one circuit. In case of a high-quality DALI drivers, even more could be connected to the same circuit if LED drivers' in-rush currents, DALI line max length (which is extendable up to 600m) and current consuming (as mA) per device is considered.
27. Does DALI help in maintaining the light fixture related drivers? Explain shortly how, in case of a broadcast and addressable versions.
- IEC 62386-101, chapter 4.5 Command types, defines that the system uses event messages, instructions and queries in the commands while communicating.
  - DALI broadcast type of light controller is capable of reporting on a lamp failure in a subnet. DALI broadcast is easy to configure and maintain.
  - Addressable DALI is capable of reporting about a malfunction of a LED driver connected to the DALI bus by name. In principle DALI as protocol is a two-way bus which enables the system status monitoring and more intelligent lighting control system's implementation.
28. Which dimming method can dim visually to the lower levels, DALI or 1-10V?
- The answer to this question depends highly on the drivers used to compare which dims to the lowest
  - According to the query results, the light fixture manufacturers, dimming system suppliers and part of the shipbuilders have experienced that DALI dims to the lower levels if compared to 1-10V dimming method.
29. Which dimming method You consider more sensitive for EMC, the DALI utilizing digital signal or 1-10V utilizing voltage signal?
- According to the query results, the field of area specialists have replied the answer to be about 50:50 between DALI and 1-10V. None of the repliers have explained their reply any further so it is not possible to make accurate conclusions.
  - LED drivers should have been built according to the valid EMC standards, such as IEC 61547 Equipment for general lighting purposes – EMC immunity requirements, EN 55015 Limits and methods of measurement of radio

disturbance characteristics of electrical lighting and similar equipment, IEC/EN 61000-3-2 Harmonic currents, etc.

30. Do You have to take EMC in to account while designing dimming system?
- The question was formed to be in quite general level. The mostly correct answer is yes, as the whole dimming system consists of electronics in control equipment located in dimming boards, LED drivers in the field and light sources but also other related equipment. The LED drivers for example may produce EMI around itself while the cabling and such may function as antennas. All these should be considered while designing the system. Even positioning of the devices should be considered.
  - On the other hand, all the used components in the dimming system should have been EMC tested and approved as per required standards, so there should not be a reason to worry about the EMC issues on board if only dimming system is considered, but the cruise vessel includes large variety of other systems installed on board as well.
31. What is the longest cabling distance that can be supplying a LED light source from the LED-driver's secondary side? If the installation works as intended.
- The answer is dependent on the used LED-driver and manufacturer, but according to the query results, the longest used cabling on board have been in range of 5-20 meters. Even 50 meters of cable have been used without any problems. Currently on the constant voltage range even 100 meters secondary cable lengths are being tested.
  - LED-driver manufacturers give their guidelines for their own products' secondary cable installations.
32. What is the maximum secondary cable length that the LED-driver manufacturer instructs to use? While the EMC is considered. Name a supplier with long secondary cabling if possible.
- According to the query results, the secondary cable length recommendations vary widely between the different manufacturers.
  - ETC, constant current LED-drivers were given as example in the query replies which promises even 100m secondary cabling length.
  - Common variation for secondary cabling length is announced to be between 2-10 meters, depending on the manufacturer of the LED-driver. These lengths have announced to be passed the EMC tests.
33. Name an existing (if any) reference vessel for a cruise vessel which is utilizing mostly DALI as a lighting controlling system.
- New cruise ships have not been built so far which utilizes mostly the DALI lighting control system. The DALI based system has lately been used on part of the ship's venues in AIDA Nova (2018) and Costa Smeralda (2019) projects, that are built in Meyer Werft shipyards.
  - Smaller projects such as car ferries, super yachts and comparable have been built in Finland and in rest of the Europe. These projects' public spaces have been utilizing DALI lighting control systems.

- Refurbishment projects implemented with DALI systems do exist, but the system is extended to maximum of couple of public venues.
34. It is possible to connect 64 devices to 250mA DALI line. How big of a portion from this would You harness to be used on a cruise vessel environment?
- DALI line with 64 addressed devices can be formed but if area is possibly going to need additions done, it would be recommendable to leave the group size to about 80-90% from the allowed maximum. The maximum length is to be considered among with the consumed current of the connected devices.
  - According to the ship contract the installation of fixtures in same circuit might be limited to be less than 25 units.
  - The system built on board is always a result of good designing, considering the construction, commissioning and maintenance phases over the ships operation life cycle. Electrical requirements of drivers are to be considered, for example a limiting factor is the inrush currents of the drivers, cabling lengths and similar.
35. Have You experienced problems with DALI drivers' inrush currents? Which performs typically with lower inrush currents, 1-10V or DALI driver?
- According to the query results, the DALI drivers have had least problems with the inrush currents as they contain newer technology and the inrush currents have reduced dramatically while the technology has developed. As of the technology currently, the inrush currents are still a matter to consider while designing the whole system.
36. Helvar is one of the commonly used house lighting dimming system component manufacturers. Whose products could you consider of using as an alternative for the same purpose? Justify.
- According to the query results, there exists multiple different dimming system suppliers from which some is here below listed:
    - o Helvar
    - o Lutron
    - o ETC
    - o Beckhoff Automation
    - o WAGO
    - o RVE
    - o Eaton
  - The products and manufacturers mentioned above are most likely capable of providing the needed hardware for a cruise vessel sized project but the integration of the whole system on board requires expertise working on ship environment. Helvar for example has a long and successful history as a product range for this purpose but also that requires an integrator.