BACHELOR THESIS

To acquire the academic degree B.Sc.

Topic:
Development of a mobile audiovisual hardware-based system for training purposes

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Abstract

Nowadays staff trainings in the media technology sector have a prime importance as the technologies are evolving more frequently than ever.
This thesis shows how a training environment can be designed which allows training participants to get in touch with new media technologies during a training course. Therefore the criteria for the selection of the right hardware which is serving the purpose of such trainings are depicted. On the basis of a training concept for engineers on private superyachts a mobile training unit was developed which is used for the implementation of hands-on exercises during the courses.

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List of abbreviations

AV: Audiovisual

ETO: Electro-Technical Officer

RF: Radio Frequency

IP: Internet Protocol

IR: Infrared

HDMI: High Definition Multimedia Interface

TPS: Twisted Pair Shielded

CAT: Category

Coax: Coaxial cable

FO: Fiber optic cable

MEC: Main Equipment Center

BEC: Branch Equipment Center

LEC: Local Equipment Center

LOA: Length Overall

RX. Receiver

TX: Transmitter

LAN: Local Area Network

OLED: Organic Light Emitting Diode

VoD: Video on Demand

AVoD: Audio/Video on Demand

DtO: Download to Own

HD: High Definition

GUI: Graphical User Interface

TVRO: Television Receive Only

BYOD: Bring Your Own Device

RU: Rack Unit

DMR: Digital Media Renderer

PYA: Professional Yachting Association

1. Introduction

“Not having heard is not as good as having heard, having heard is not as good as having seen, having seen is not as good as mentally knowing, mentally knowing is not as good as putting into action; true learning is complete only when action has been put forth.”[1]

This quotation of a Chinese philosopher that lived from 312-230 BC shows that practical training was already an axiom centuries ago. The way how we learn has not changed since but it is often forgotten that only with practice the process of learning is successful.

This applies in particular at technical trainings where complex systems and functionalities are mediated. Those course contents need to be taught with the support of practical examples where the training participants can apply the theoretical knowledge.

This thesis handles the conception of such a technical training course with the subject of AV systems on superyachts. In particular a training unit, based on AV hardware, shall be built to allow the participants to gain hands-on experience at the training course.

As complex AV systems on superyachts are a relatively new branch of the yachting industry it is always a subject to change. This is due in part to the fact that generally AV systems are also a fast moving area. This makes it even more important to provide training courses for yacht crew members who are involved in the AV system on board. Although larger yachts (> 100 m) often got a skilled Electro Technical Officer (ETO) who is responsible for the AV system, often an engineer who is not trained needs to maintain those systems.

Certainly a lot of technical trainings for yacht crew members are offered but none of them occupies the AV part on board. To fill this gap the company Bond Technology Management (in the following stated as Bond) has decided to create a training course which shall mediate the basics of AV technologies on superyachts.

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[1] Liu Xiang, Xunzi - Ruxiao, chapter 11.

A main requirement on the training was that the trainees can gain real hands-on experience during the course. For that reason the development of a mobile training unit was demanded.

1.1. Bond TM

Bond Technology Management is a project management company specialized in AV, IT, communications, security and navigation systems on superyachts. From the first concept to the commissioning of completed yachts, Bond is supporting the whole procedure of the integration of the respective systems and is helping to save time and budgetary targets during the build of yachts. The same services are also offered for residential projects although it is a secondary branch of business.
Bond was founded in 2007 and is actually represented in six countries with about 40 employees.

1.2. Target and structure of the thesis

The target of this thesis is the development of a mobile training unit that will be used at basic AV technology training courses. The development comprises the conception, construction and the documentation of the hardware based unit.
Chapter 2 of this thesis is transferring the basic knowledge of the signal distribution on superyachts as a foundation for the construction of the training unit. Chapter 3 procures an overview and an evaluation of the significance of typical AV hardware that is used on private superyachts.
These sections help to understand why particular decisions were made during the construction phase of the training unit. Also because there is barely any specialised literature about AV systems on yachts, these sections are giving an insight about the usage of AV hardware on those special vessels.

In chapter 4 the actual conception and construction of the training rack is described as well as the first application in an actual training course. Chapter 5 is summarizing the result of the thesis and gives and outlook.
The development of the specific training content is not a part of this paper as it would exceed the extent and topic of the thesis.

2. Signal distribution on superyachts

This chapter describes the different kinds of distributing audio and video signals on superyachts.
The possibilities to distribute a signal from a source to a sink especially in the digital signal process are immense and can quickly become a complex task to overcome on a large vessel. Therefore it is mandatory to distinguish and understand the different ways a signal can be distributed.

A basic requirement of the AV system on a yacht is that the user experience of the entertainment system does not differ from the one at real estates. This entails that most of the end user devices that are used at a yacht are common consumer devices without any optimized connections for the infrastructure cabling of a vessel. In addition, there is a large number of different consumer devices that needs to be integrated because of the high standards and custom requirements of the entertainment system on board. Although a HDMI interface is almost available at every consumer device, those connections are very limited regarding their maximum cable length and reliability.[2] Since most of the AV sources are not located in the same area as the displays and speakers, long cable runs need to be overcome and cannot be realized through a HDMI connection. Also the HDMI specification does not state a maximum cable length, experience shows that distances above 20 meter are the critical point where the signal starts to drop.[3] This approx. value depends on various attributes like the quality of the cable and the connector itself, the data rate of the signal, the source of the signal and the sink. As a consequence of those uncertain factors a point to point signal distribution via HDMI should be avoided if source and sink are not serried. The implementation of both distribution variants weather the source is located nearby or remote from the sink is described in detail in chapter 2.2 and 2.3.

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[2] Cf. Somers, Steve: DVI and HDMI, 2015.

[3] Cf. n.u.: Running Long Cable Lengths, 2015.

2.1. Infrastructure cable

The basis of the signal distribution on a yacht consist of at least one signal distribution channel that is capable of transferring the high bandwidth signals from multiple AV sources to the different locations from the vessel. Therefore an infrastructure cable must be pulled through the entire vessel as a backbone for the AV system. Nowadays this infrastructure cable is a multicore hybrid cable with a variety of different signal types that can be distributed over long distances.
Typical cables that are integrated in those multicores are coaxial (Coax), twisted pair shielded (TPS), and fiber optic (FO) cables (cf. Figure 1) which are described in detail in the next chapters. The inner layer is covered with a cable sheath for protection against cuts and kinks.

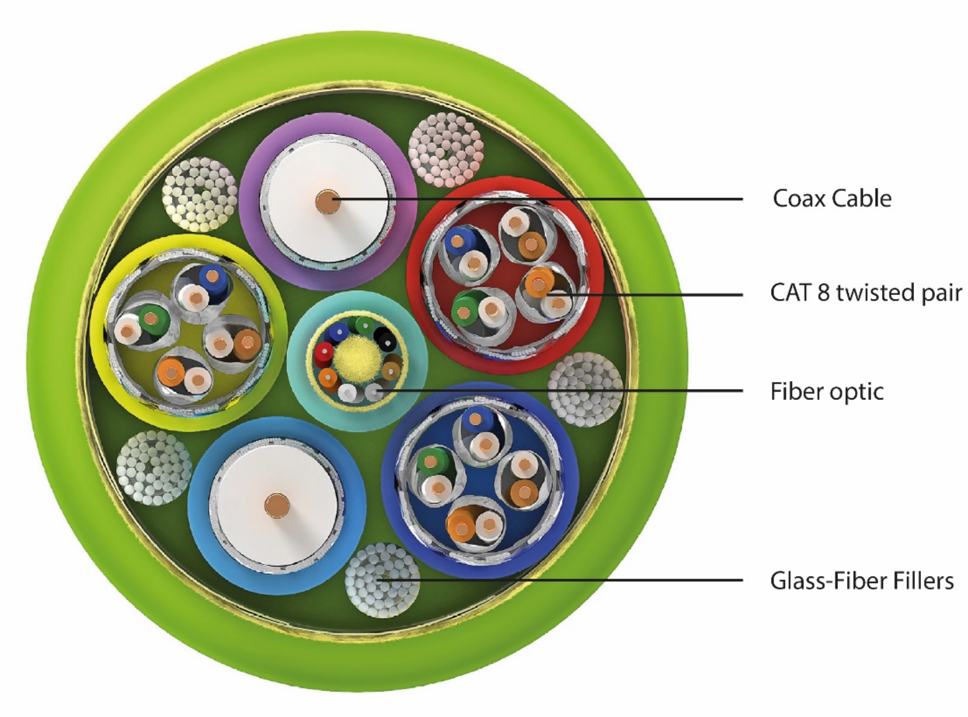

Figure 1: Cross section of a multicore cable showing the coax, twisted pair and fiber optic cables[4]

Once the arrangement of the AV devices in all areas of the yacht is defined a wiring schematic will be designed. On the basis of this plan the infrastructure cables can be pulled through the vessel. The infrastructure cable is routed from an equipment centre to the respective rooms. Since the single interfaces in a multicore cable are

[4] N.u.: INTERCORE®, 2015.

not assembled, the termination needs to be done at the respective technical spaces and at the locations the AV sinks are based. Therefore a distribution box is mounted at every equipment centre and sink location where the infrastructure cable can be terminated. For spaces who only require a central distribution feed and network connectivity, a pure FO cable run is sufficient.

All central distributed sources are consolidated in one or more main equipment centres (MEC) or branch equipment centres (BEC). The MECs are usually based at the lower decks of a vessel because of the lack of space for technical equipment at the areas where guests or the owner is staying. Therefore the MECs are the largest locations for AV equipment where most of the hardware is stored. The BECs are branches of the MECs and are located nearer to the areas where the actual signals are routed to. BECs are usually just to be found at yachts with a complex AV system with a large amount of components. Through the BECs the AV/IT system can be subdivided in smaller affiliations, like the allocation of one deck or area to one equipment centre.

The local equipment centres (LEC) are based close to the spaces where the signal is routed to. Typical locations where LECs are used are guest or owner cabins with a great number of local AV equipment for which it is likely that they need to be accessed often or a signal extension from a remote location is not desired. Typical devices that are stores in LECs are disc players, AV receivers or processors.

Figure 2 shows the different possibilities of distributing the AV sources through central locations like MECs and BECs, local distribution through LECs and the combination of those three kinds of equipment centres.

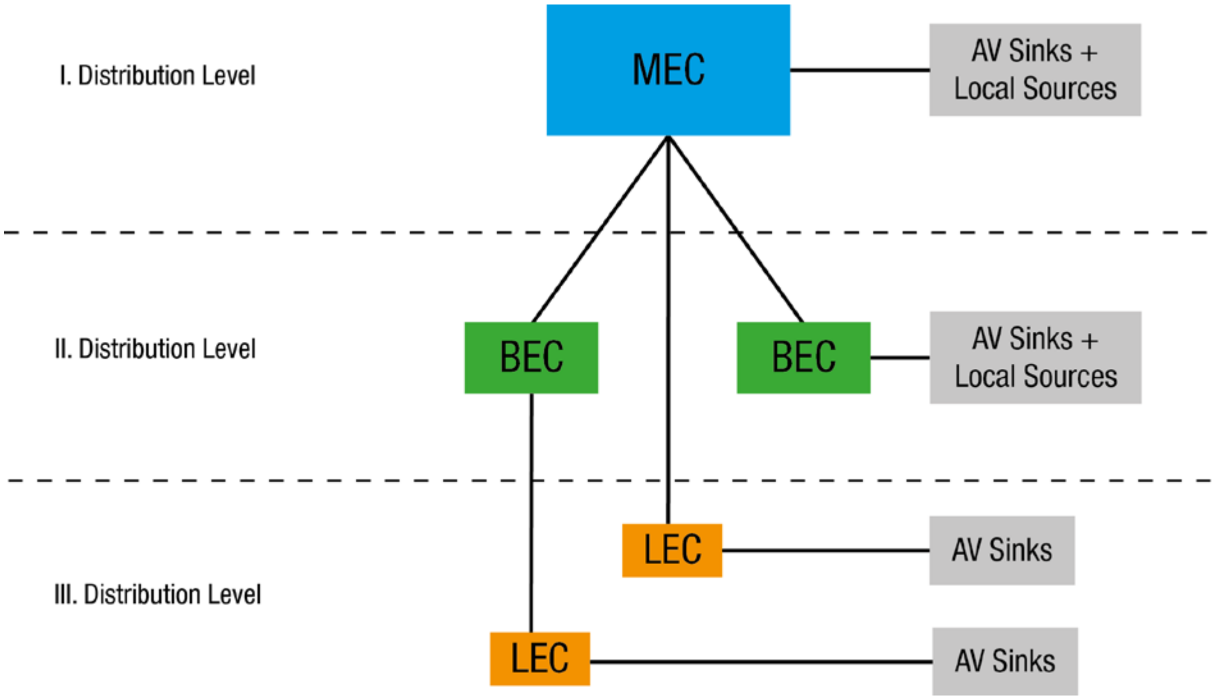

Figure 2: Hardware distribution levels based on three different kinds of equipment centres

On most private luxury yachts the combination of the first and third distribution level with one central MEC and small LECs in guest and owner cabins are most common however, locations with a huge amount of AV hardware like cinemas and event areas will still have their own technical spaces. The second distribution level provides a better subdivision between different AV zones all over the vessel. The sources and the distribution for each deck or area with special AV requirements can be handled separately by moving them to BECs. In most cases those zones got their own sub matrix but are still connected to the MEC where the main control process is handled. The advantages of a second distribution level alongside the shorter cable runs to the respective areas are a better maintainability through the segmentation of the AV system into logic units for different areas.

2.1.1.Coaxial cable

Coaxial cables are built for high frequency signal transmission and are based on a coaxial conductor construction. They are characterized by their length and attenuation as the performance of the signal transmission decreases with the distance and improves with a thicker conductor. Although the attenuation depends on the frequency of the transmitted signal.

A coaxial cable consist of an inner conductor with a specific diameter $\boldsymbol{d_i}$, an overlying dielectric insulator with a dielectric constant ε and a relative permittivity μ, a concentric outer cable with the diameter d_o, a shield out of metallic braid or tape and the cable jacket (cf. Figure 3).
The main attribute of a coaxial cable is the characteristic impedance Z_0 and a specific attenuation α. It is crucial that the impedance at the end of the cable matches the characteristic impedance Z_0, otherwise reflections can occur which are returning on the cable and distorting the signal.

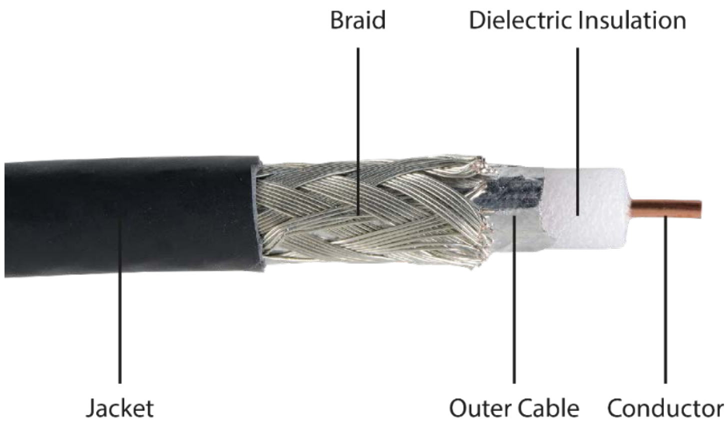

Figure 3: Coaxial Cable Structure[5]

Typical applications for coax cables are broadband and baseband radio frequency (RF) signal transmission where the signals needs to be protected against outside interferences on long cable runs. The nominal impedance at electric circuits for low voltage RF signal transmission is 75 Ω since it results in the lowest attenuation through impedance matching when the isolator is air. In addition there are coax cables with 30 Ω for a maximum power transmission and 50 Ω for communication applications.[6]

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5 N.u.: Typ-1-RG59-Kabel, 2015.
6 Cf. Schmidt, Ulrich: Professionelle Videotechnik, 2013, p. 63.

2.1.2. Twisted pair cable

A twisted pair (TP) cable is a cable type where a pair of wires are helical twisted. In most cases a TP cable consists of four pairs of copper wires with a diameter of approx. 1 mm. The twisting of the wires is necessary as a parallel cable run of two wires is building an antenna that would cause crosstalk at the signal transmission by sending out electromagnetically waves. Due to the twisting of the wires the waves are getting refracted and cancelling each other out. For the same reason, the twisting is protecting the signal against external interference like alternating magnetic fields. In addition, TP cables have got a conductive shielding out of metallic braid or tape against external electromagnetic influences (cf. Figure 4).

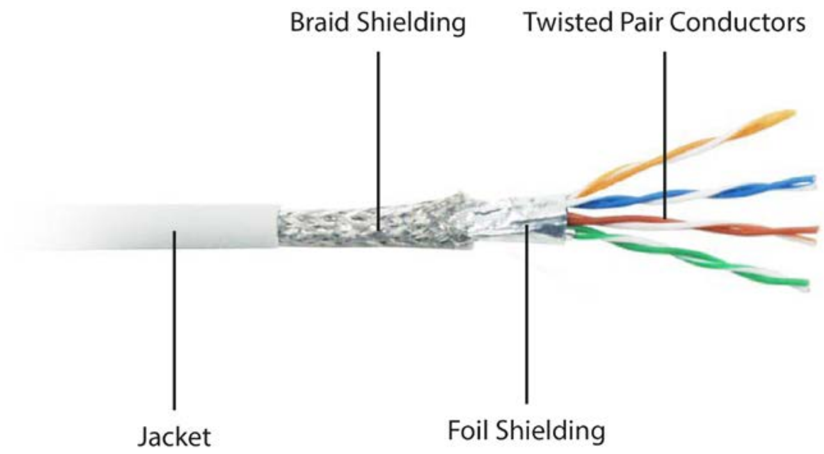

Figure 4: Twisted Pair Cable Structure (S/UTP)[7]

TP cables are used both at digital and analog signal distribution. The signal transmission on TP cables is symmetrical, with the result that the original signal on the receiving end gets reconstructed by generation and subtraction of the difference between both signals.

Basically a distinction is made between the two following types of twisted pair cables who are standardized according to ISO/IEC-11801:[8]

[7] N.u.: Twisted Pair, 2015.

[8] Cf. n.u.: Internation Standard ISO/IEC 11801, 2002, p. 105.

- **Unscreened Twisted Pair (UTP)**
  Cable type with unshielded twisted pairs and without an overall shield. Compared with shielded TP cables the maximum bandwidth and cable length is far smaller. However, UTP cables can be used for Gigabit networks with bandwidths up to 1 Ghz. The advantage over shielded cable types is the smaller outer diameter that makes UTP cables easier to install. Although UTP cables are less expensive as the shielded TP cables.

- **Foil Screened Twisted Pair (FTP)**
  Cable type with a foil shield around each twisted pair but without an overall screen. Due to the shielding the FTP cable have got a larger outer diameter and the bending radius is a bit bigger, therefore FTP cables are more difficult to install. However, the shielding provides a better protection against external electromagnetic influences and crosstalk can be reduced.

In addition to the element screen around each twisted pair, two types of an overall screen is defined in ISO/IEC-11801.[9] The overall screen is either made of foil (F/XXX), braid (S/XXX) or both materials (SF/XXX).
In the following table (cf. Table 1) the different cable types are listed.

Name	Overall screen	Element screen
U/UTP	-	-
U/FTP	-	Foil
S/UTP	Braid	-
S/FTP	Braid	Foil
F/UTP	Foil	-
F/FTP	Foil	Foil
SF/UTP	Foil/Braid	-
SF/FTP	Foil/Braid	Braid

Table 1: Cable types according to ISO/IEC-11801

[9] Cf. n.u.: Internation Standard ISO/IEC 11801, 2002 p. 106.

Furthermore TP cables are divided into seven cable categories (CAT) according to their performance. Since the categories one to four are outdated due to their lack of performance, the following explanations are related to the relevant TP categories five to seven. However,

Table 2 shows the attributes of all specified TP categories. The most common connector for TP cables is the RJ45 connector.[10]

- **Category 5 (CAT5)**
  CAT5 cable are used for both voice and data transmissions with frequencies up to 100 MHz. CAT5 cables are suitable for bitrates up to 100 Mbit/s (100BASE-T). Of the four wire pairs only two pairs are used.

- **Category 5e (CAT5e)**
  CAT5e (enhanced) cables are providing a better transmission characteristic compared to CAT5 cables. By using all four wire pairs the bitrate can reach up to 1000 Mbit/s (1000Base-T).

- **Category 6 (CAT6)**
  With CAT6 cables the bandwidth increased from 100 MHz to 250 MHz. However, the absolute bitrate of 1000 Mbit/s has not increased but as the diameter of the conductors is bigger compared to CAT5e cables, the noise immunity is higher and the attenuation lower. This leads to an extended maximum cable length and a higher temperature range the cable can be used.

- **Category 6a (CAT6a)**
  CAT6a cables are increasing the maximum operating frequency up to 500 Mhz which results in a maximum bandwidth of 10 Gbp/s using all 4 wire pairs. The greater frequency can be achieved through shielding (STP) and thicker wire diameters, resulting reduced noise and crosstalk effects.

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[10] Cf. n.u.: RJ45-Stecker, 2015.

- **Category 7 / a (CAT7 / a)**
  CAT7 cables are specified by a maximum frequency of 600 Mhz and is realized through four individually shielded pairs and an overall shield (at least S/FTP or F/FTP). Because of the high operating frequencies, a CAT7 infrastructure requires a new type of connector. The wires in a RJ45 connector are too close which leads to crosstalk at frequencies above 500 Mhz.[11] Therefore the GG45 connector was developed and standardised in 2001 (IEC-60603-7-7). The GG45 connector adds four wires at the bottom of the RJ45 layout whereby the distance between the conductors is increased which leads to less crosstalk at high frequencies up to 1000 MHz (CAT7a). The GG45 socket is backward compatible to RJ45 connectors by detecting if the connector contains the four additional conductors. Because of the different layout, the GG45 connector is not compatible to RJ45 sockets.

Table 2 shows the different performance characteristic of all released CAT cables in the form of their maximum operating frequency and bandwidth.

Category	Operating frequency	Maximum bandwidth*
CAT1	1 kHz	400 kbp/s
CAT2	1 MHz	4 Mbp/s
CAT3	16 Mhz	10 Mbp/s
CAT4	20 Mhz	16 Mbp/s
CAT5	100 MHz	100 Mbp/s
CAT5e	100 MHz	1 Gbp/s
CAT6	250 MHz	1 Gbp/s
CAT6a	500 MHz	10 Gbp/s
CAT7	600 MHz	10 Gbp/s
CAT7a	1000 MHz	10 Gbp/s - 100 Gbp/s (Up to 15 m.)

* For cable length < 100 m.

Table 2: Categories of twisted pair cables [12]

[11] Cf. n.u.: Twisted-Pair-Kabel, 2015.
[12] Cf. K., Rajesh: Network Cables, 2010.

2.1.3. Fiber Optic

A fiber optic cable consists of a light-transmitting core made out of fused silica or polymeric optical fiber (POF). Around the core a cladding with a lower refraction index than the core, which leads to a total reflection at the boundary layer between the jacket and the core. Due to the total reflection the light is guided through the conductor. The cladding is surround by a coating and the outer jacket (cf. Figure 5). [13]

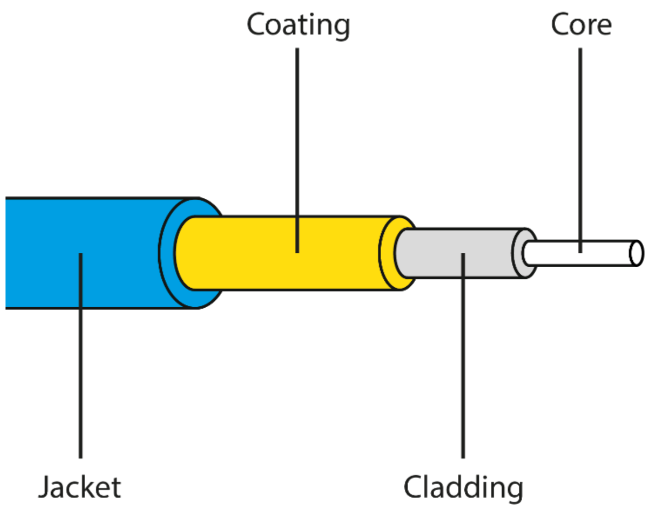

Figure 5: Fiber optic cable structure

The advantages of FO conductors over coper based conductors are the high data rates combined with a high maximum cable length and smaller cable diameters. [14] Depending on the core diameter and the refraction index the light travels either in the basic mode or in several higher modes. This distinction leads to two different FO cable types, singlemode and multimode cables. Both types are explained in the following.

[13] Cf. Baun, Christian.: Computernetze kompakt, 2015, p. 64.

[14] Cf. Löffler-Mang, Martin: Optische Sensorik, 2012, p. 142.

- **Singlemode step index fiber**

  The core of a singlemode step index fiber is relatively small (9 µm) compared to the wavelength (1310 – 1550 nm). Therefore only one mode can propagate in the fiber core. A singlemode fiber is characterized by a very low signal attenuation and wide bandwidth. Because of the constant transit time, no pulse expansion occurs.

- **Multimode step index fiber**

  Multimode fibers have got a thick core diameter (>100 µm) relative to the wavelength (850 – 1300 nm). Dependent on the angle of incidence multiple modes with different transit time are propagating through the fiber. The high modal dispersion is leading to a pulse expansion and a high signal attenuation (cf. Figure 6). Because of limited bandwidth and cable length, step index fiber cables are hardly used nowadays.[15]

- **Multimode graded index fiber**

  In a multimode graded index fiber cable, the refractive index is changes gradually from the core to the cladding. Such fibers are characterized by low transit time differences, low pulse expansion and low signal attenuation (cf. Figure 6).

[15] Cf. Reisch, Michael: Elektronische Bauelemente 2007, p. 1226.

Fiber Type	Diameter (Core/Cladding)	Bandwidth (1 km)	Typical Application
Multimode step index	100 - 400 µm / 200 - 500 µm	100 MHz	Simple industrial installations
Multimode graded index	50 µm / 125 µm	1 GHz	LAN Backbone, ATM (655 MHz) in Europe
	62.5 µm / 125 µm	1 GHz	LAN Backbone, ATM (655 MHz) in USA
Singlemode step index	9 µm / 125 µm	100 GHz	Long-distance network operations

Table 3: Fibre optic cable types

Table 3 shows the three different fiber cable types, their bandwidth and typical applications.

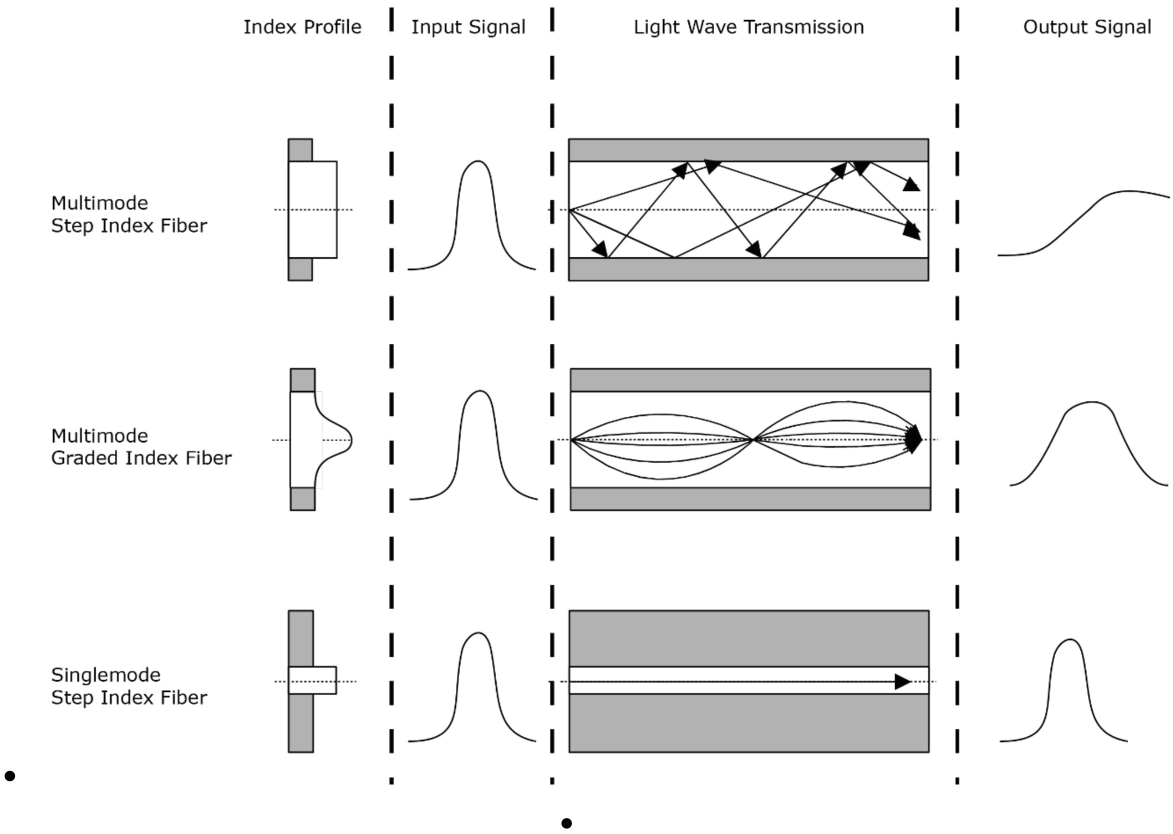

Figure 6: Multimode and singlemode fiber index types

Figure 6 is showing how the different signals are passing through the FO cables and how the input signal gets modulated because of the different wave transmission characteristics.

2.2. Local distribution

A first distinction of the different distribution systems on superyachts is drawn between a local and a central distribution form. The local distribution is the simplest way to allocate AV sources to different locations but although the least flexible way. In a strict local distribution system every sink (e.g. display or speaker) is connected directly to the respective sources and are located in the same area. Therefore the devices can be connected directly via HDMI without the need of signal extenders. This reduces costs and possible sources of error since every additional device between the sink and the source can be damaged or drop out. A local distribution although circumvents long cable runs through the ship through Equipment that needs user interaction like connection panels, touch panels, disc players and gaming consoles needs to be integrated locally to ensure accessibility. Equipment in guest spaces that does not need to be accessed by the guests is usually stored in a LEC (cf. chapter 2.1) in or near the room with adequate service access. In an environment with just a few AV sources and sinks a local distribution in most cases is cheaper and easier to realize than a central distribution. As the AV system on luxury yachts are getting more and more complex nowadays with a large number of different sources, a pure local distribution is rarely applicable on recent luxury yachts. Only on small vessels without sufficient space for a MEC to store AV devices centrally, a strict local distribution would be applicable. Figure 7 shows the schematic of a local distribution system, based on an exemplary guest cabin.

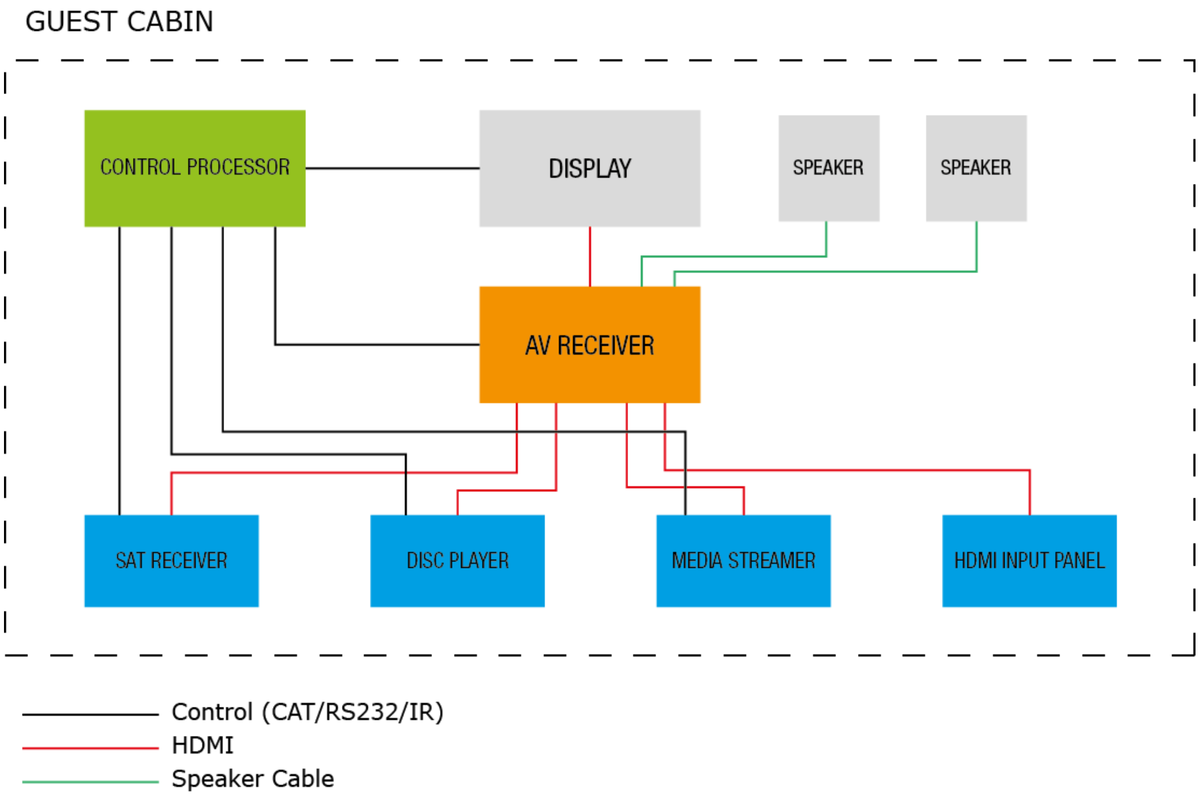

Figure 7: Local distribution schematic of an exemplary guest cabin

All sources (blue) are located in the cabin and are directly connected via HDMI to the AV receiver which primary function is the switching of the different sources to the display and secondary to amplify the speakers. The control processor takes over the centralisation of the control of all sources so they can be controlled through one control device instead of using one remote control for each source. The control protocol depends on the sources connectivity but most of the current AV sources can be controlled through the IP protocol. Further possible control connections are RS232 and infrared (IR). An in-depth look to the functions of the different AV devices on a yacht are given at chapter 3.

2.3. Central distribution

The second approach to distribute AV signals on a large scale yacht is through a centralized system. This method is based on a central based core system which joins all signals from the respective sources and distributes them to the single locations. Those systems have got in common that they rely on one core device for the signal distribution which is therefore the most critical device in the AV system. It must be ensured that this device is working reliable without drop outs to maintain the signal distribution of the AV system. There are three different solutions for realizing a central distribution system: Matrix switching, Radio Frequency (RF) and through the Internet Protocol (IP).

Figure 8 shows the different functional principles of those distribution systems.

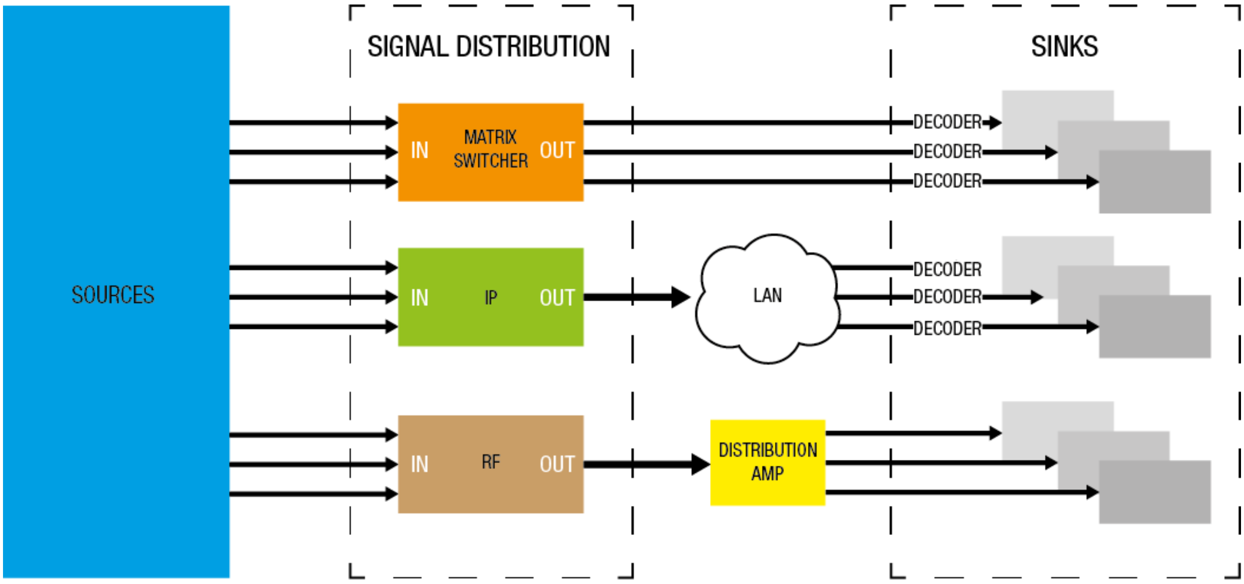

Figure 8: Central distribution systems

In chapter 3.3 the different central distribution systems are described in detail, based on the utilized hardware.

2.4. Hybrid systems

A hybrid distribution system combines a central and a local distribution typology by dividing all AV sources into local and central installations based on their functionality and available space. The distribution on most modern private superyachts is based on a hybrid distribution system as there is always a vast amount of sources that need to be located in a central space (e.g. SAT receiver, media server) and although devices that need to be accessed by the user (e.g. disc player, gaming consoles). Although the space for AV devices in the central AV store can be insufficient, so parts of the sources need to be located in the respective cabins or areas. Another reason for a hybrid distribution system can be the insufficient amount of inputs on the central AV matrix. Especially on AV refits where new sources are added to the AV system but the AV matrix does not get upgraded, the devices need to be integrated locally.

3. AV hardware on superyachts

As described in chapter 2 there are a lot of different AV devices used on modern superyachts. On the one hand there is a vast number of different typical consumer devices like TVs and media sources to measure up to the guest's expectations of a luxury accommodation. On the other hand the needed infrastructure for the interconnection, distribution and control of those devices is based on professional hardware. Therefore the challenge at the development and integration of an AV system on superyachts is to design an environment where the user does not notice the complex linkage of the single hardware modules and to create an infrastructure that can be maintained by an ETO or a another crew member that is trained in AV systems. In general the hardware can be divided in sinks, sources, distribution and control. Depending on the approach of the distribution system those devices besides the sinks can be placed central or local (cf. Figure 9).

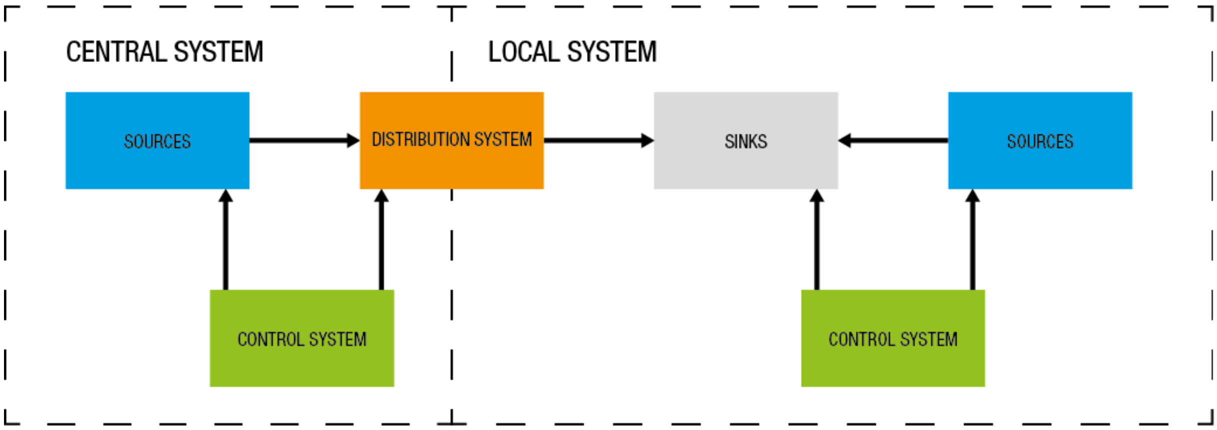

Figure 9: Overview of AV hardware and their interconnection on a yacht

In a hybrid system (cf. chapter 2.4) there are two kinds of control systems. The central control system takes over the control of the switching interface and the central sources. The local controller is used for the remote controlling of the local sources and sinks. The next chapters are outlining the different types of hardware components that are typically used on private superyachts and pointing out the challenges at the integration on a vessel. This roundup is also the basis for all further considerations for the choice of hardware that have been installed in the mobile training rack.

3.1. Sinks

The devices that are acting as a sink on a private superyacht can be divided in two different classes, consumer and professional devices. Typical consumer devices are flat screen displays, in-ceiling and in-wall loudspeakers, AV receivers and AV processors and HiFi amplifiers. Those devices are mostly found in guest, owner and crew cabins and although in lounge areas and representing the largest amount of AV sink devices on a yacht. AV hardware that is built for the professional market is mainly used in areas where special functionalities are required. Those locations are for example external areas because of their weather exposure or locations where a special audio and video experience is mandatory, like in private cinemas and party areas.

The main reason behind utilising mainly consumer hardware is that the user on a private yacht is demanding the same functionality of an AV entertainment system as he is used to in residential buildings. Due to the short-lived media technology nowadays it is although a question of costs and adaption of new features. Especially display technologies are evolving fast since flat panel displays entered the market and replaced cathode ray tube displays. Besides the continuously increasing display resolutions (The ITU approved the 4k and 8k UHDTV resolutions in 2012)[16] the display panel technologies are evolving just as quickly. It is therefore that alongside the increasing average display sizes new display technologies like OLED[17] and Quantum Dots[18] are attracting the consumers'

[16] Cf. n.u.: Recommendation ITU-R BT.2020-1, 2014, p. 2.

[17] Cf. n.u.: OLED TVs, 2015.

[18] Cf. Peach, Matthew: Quantum dots, 2015.

attention. As luxury yacht owners and guests are a target group who is demanding the latest and greatest entertainment technology, displays are getting replaced faster than most of the other AV sinks (e.g. loudspeakers and amplifiers). However, professional devices are built to last longer than comparable consumer devices and very often do not have the same features a user expects of an up-to-date consumer device. Also professional AV devices are often much more expensive than their consumer counterparts and the design more conservative which does not fit often in extraordinary interior and exterior designs.

3.2. Sources

As described in chapter 2 the sources are basically divided in central and local devices. Furthermore there is also a distinction between consumer and professional hardware. Typical consumer sources that are used on private superyachts are satellite receivers, media player and disc player which significance is decreasing since the focus of media consumption is shifting to on demand services. [19] Beyond that there are some AV sources that are specially tailored to the yachting industry. Among them there is the Kaleidescape entertainment system which offers a huge online video and audio on demand library and although the possibility to read in DVD and Blu-Ray Discs to a personal storage server on a legal basis.[20]

Besides Kaleidescape there are further more services who are providing audio and video media libraries like iTunes, google play movies or amazon prime instant video. With this services you have access to an audio and video on demand (AVoD) library and also the possibility to buy movies and music and store them locally (download to own). To get access to those online libraries the user needs a set-top-box with internet access like the Apple TV, roku player, google nexus player or amazon fire TV.

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[19] Cf. von Leszczynski, Ulrike/ Hoenig, Andreas: Videoverleih versus Streaming, 2014.

[20] Cf. n.u: Experience, 2015.

Besides a local media library which can be used without an internet connection, the access to satellite TV channels is a central requirement on the AV system on a yacht as the users are used to those services on shore. However, satellite TV services are not always available on a yacht because of different barriers like the footprint of the actual satellites and the amount of simultaneous satellite services. The footprint describes the reception area of a satellite signal on the global map and depends on the orbit and size of the respective satellite.[21]
As each satellite service requires at least separate satellite dish, the amount of simultaneous reception of different satellite services depends on the amount of dedicated TVRO (Television receive online) satellite dishes.

Because of those reasons another niche technology evolved at the yacht industry. Instead of receiving the satellite TV signals directly through the satellite decoders on the yacht, the video signal of a decoder can be transmitted via an internet stream. This technology is called IP TV and only requires a stable broadband internet connection. As internet access on yachts is globally available through the Ku, Ka and C band frequencies a stable internet connection can be achieved on a yacht everywhere on the globe. [22] [23] There are two relevant IP TV systems that are used on private superyachts: Slingbox and Jetstream. Both services pursue the approach to transmit the video signal of a sat decoder via an IP stream. The Slingbox solution only offers the infrastructure for the IP stream, the decoder and the streaming encoder needs to be provided by the user itself. Jetstream on the other hand provides subscriptions which are including different satellite services through data centres around the world which can be accessed through a proprietary decoder box (Jetset) or via a web application. Those IP TV solutions are providing TV reception independent from footprints, TVRO satellites and the range of satellite decoders which are available on the yacht. Those services can although be used as a fall-back solution if the regular satellite reception is not available or to provide additional TV channels.

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[21] Cf. Wolff, Christian: Ausleuchtungszone, n.d..

[22] Cf. n.u.: C-Band, 2015.

[23] Cf. n.u.: Fleet and coverage, 2015.)

The currently most demanded AV sources on vessels are providing access to AVoD services and allow the integration of personal end user devices through local streaming. The access to AVoD services like Netflix, Spotify, Youtube is increasing since the last five years rapidly and will be the fastest growing sales market for audio and video media.[24] [25] Therefore universal media player like the Apple TV and the Roku Media Player have a high significance as local and central AV sources on superyachts. Besides the access to AVoD services those devices are providing the possibility for local streaming, the transmission of media from personal devices to the central or local AV network through network services like Apple Airplay and Miracast. The integration of those personal devices into an AV system is called Bring Your Own Device (BYOD) and is facilitated through the mentioned media players as a physical connection is not necessary.

When using online streaming services on yachts the internet connection is the main limitation as on most vessels the available bandwidth is much lower as on shore.[26] This is because of the much higher costs for an internet connection through satellite reception as the costs for the satellite infrastructure is just financed by a few users compared to land based internet infrastructure where the costs are divided across millions. Therefore a simultaneous access to online HD video streams is only possible if the vessel has a great internet bandwidth (>10 Mbps) where monthly subscription costs can reach hundreds of thousands euro. Because of the high costs for a great internet connection the bandwidth management, which is regulating the available bandwidth for different network devices, is an important task for the IT site on a yacht. Without a functioning bandwidth management the AV devices with online services would exploit the whole bandwidth as most of the consumer devices do not have a data limitation. Because of the limited internet bandwidth, offline media libraries are still mandatory on private superyachts.

[24] Cf. n.u.: Musikstreaming-Abonnementdiensten, 2015.

[25] Cf. Brandt, Mathias: Netflix, 2015.

[26] Cf. Trask, Lulu: Connecting the dots, 2014.

The change of the media consumption, away from static (e.g. discs) and time-dependent media (TV, radio) to on-demand services, affects the yachting industry in the same manner as it does on the rest of the media landscape. The expectations on the AV system in this luxury sector are high but they cannot always be fulfilled as the internet connection is not as elaborated as onshore. Therefore a trade-off between online and offline media sources needs to be found.

3.3. Distribution System

As described in chapter 2 there are a lot of different AV sources that need to be distributed through the vessel. If the source and the sink are not located nearby and are not connected through a point-to-point connection an infrastructure for the distribution of the signals is needed. The main function of the distribution system is to route the AV signals of the central sources to the respective remote locations. As a basis for those distribution a communication channel based on RF, TPS or FO (see chapter 2.3) needs to be provided.

Using RF for the signal distribution on superyachts is the longest-standing technic and is based on the RF distribution in hotels. Here the output signals of the sources are getting modulated on a RF carrier frequency. This is done on the basis of the VHF frequency bands. Sources which do not provide RF signals as an output signal (e.g. disc- and media player) the baseband signal needs to be modulated on the RF carrier frequency. This is done by RF modulators which are adding the modulated signals to the existing coax distribution system. This is done by RF multiplexers which are combining different RF signals to one RF channel which is based on DVB-C or DVB-T standard nowadays.
Figure 10 is showing a HDMI to RF QAM modulator with four HDMI inputs and digital and analog audio inputs.

Figure 10: HDMI to RF modulator[27]

On the receiving end the signal gets decoded through the DVB-C or DVB-T tuner of the TV. As most TVs got an integrated tuner this distribution variant takes no additional distribution hardware (glue) at the location of the sink which safes money and integration effort. The downside of a RF distribution is the limited bandwidth so 4k cannot be distributed through RF and the determination on fixed channels at the receiving end. Therefore a RF distribution is just being used for the crew AV distribution as at those areas a cost efficient AV system is desired. This is because the crew areas are representing a large part of the whole AV sinks, so every saving on the hardware is multiplied quiet often.

Because of the limited bandwidth and the bounded modularity regarding the integration and switching of new AV sources in a RF distribution, the usage of AV matrix switcher have been established in the yacht AV sector.
An AV matrix switcher got the essential advantage of the free assignment of every input to every output. Therefore it is possible to route all or just a selection of sources to every sink on the vessel. Another advantage of an AV matrix is the modular design of the switchers. The inputs and outputs (I/O) are implemented through so called I/O-boards which are mounted in a matrix frame (cf.
Figure 11) and partitioned in one half inputs and one half output boards.

[27] N.u.: HDb2840, 2015.

Figure 11: 32x32 Lightware matrix frame with various I/O boards[28]

The typical notation for the size of AV matrices is 32x32 for a matrix with 32 inputs and 32 outputs. The common amount of inputs and outputs per board is 8 as this segmentation can be found at all matrices from the leading manufactures like Crestron, AMX, Lightware and PureLink.
The maximum amount of I/O boards depends on the frame, whereby matrices also can be cascaded to one large-scaled logical matrix (cf. Figure 12).

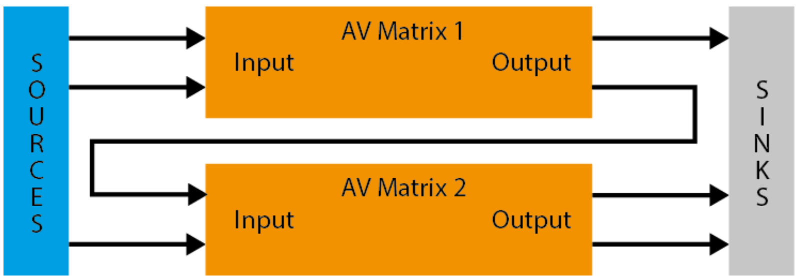

Figure 12: Schematic of cascading AV matrices

I/O boards are available in big variety of interfaces. Typical input boards are: HDMI, DVI, VGA, SDI, HDBaseT over TPS, FO, analog video over BNC, analog audio over RCA. Output boards are available with HDMI, FO and TPS.

[28] N.u.: 2015.

The most important input cards on private superyachts are HDMI because of the great number of AV sources from the consumer market where HDMI is established as the common AV interface (cf. chapter 3.2). On the output side FO and TPS are the predominantly used cards as those interfaces are capable of distributing high data rates over long distances (cf. chapter 2.1). The decision whether using TPS or FO depends on the infrastructure cable that is installed on the vessel. On large yachts (>100 m) where long distance cable runs are necessary, FO is the prevailing distribution channel. On smaller yachts (<100 m) a TPS distribution is sufficient in most cases as the maximum cable length for a 10 Gbps bandwidth over CAT6/7 is not exceeded.

The advantage of a TPS infrastructure are the lower costs, the easier termination and the more robust cable. A FO cable run on the other side is insensitive against electromagnetic influences and the possible bandwidth is higher.
As opposed to a RF distribution an additional receiver needs to be inserted between the matrix output and the AV source when using FO or TPS as the output interface. At a FO distribution the electrical TMDS signal from the HDMI source gets converted to an optical TMDS signal and needs to be reconverted for the HDMI input at the sink. As the AV distribution over TPS uses in most cases the HDBaseT standard this signal also needs to be reconverted to the TMDS signal because there are just a few AV sinks that have got an HDBaseT receiver build in yet.
Although the electrical TMDS signal could also be distributed directly through a CAT cable, the achievable cable length is not sufficient for long cable runs.[29] Therefore HDBaseT is an alternative possibility for distributing UHD video, audio signals and further more data over CAT cables. Those features are summarized as “5Play” which describes the simultaneous transmission of UHD digital video, audio, 100BaseT Ethernet, USB 2.0, control signals and up to 100 W of power over one CAT cable. [30] Because of the possible long cable runs of up to 100 m and the integration of the different data signals and power, the distribution with the HDBaseT standard is to be preferable to the direct TMDS transmission over TPS.

[29] Cf. Bock, Stefan/ Helga Rouyer-Lüdecke: CAT-Kabel, 2015.

[30] Cf. n.u.: HDBaseT 5 Play, 2015.

Therefore the matrix based distribution systems on superyachts are almost entirely equipped with HDMI input cards and FO or HDBaseT over TPS output cards.
The amount of the I/O cards depends on two criteria. At first the amount of independent AV locations which are requiring access to the central AV distribution. The second criterion is the amount of central AV sources which in most cases is determining the matrix size. Especially on vessels where no local AV sources shall be used, the amount of central sources are scaling up the required inputs. That is why on some superyachts matrices with 128 inputs and outputs are not uncommon. The largest AV matrix available is made by PureLink with a size of 256x256. [31]

Besides a signal distribution over an AV matrix which requires a separate cable run for the AV infrastructure, HDMI over IP streaming solutions are gaining relevance. The advantage over a RF or Matrix distribution is the simultaneous use of the CAT infrastructure for IT and AV. But since the quality loss and the time delay through compression is still adverse for a high quality AV distribution on yachts, the technology needs to be further developed to be an actual alternative to the matrix distribution.

3.4. Control Systems

Besides the advantages of the centralisation of AV sources through a central distribution, like the saving of local space and the better maintenance, the direct control of the sources at the sink is lost. With a local distribution the sources can be controlled through a remote, but with the sources located in a MEC or BEC a distinctive interface which enables a remote control over long distances is necessary. Besides the control of the sources the distribution matrix also needs to be controlled to switch the inputs to the corresponding outputs.
Therefore a control system is used on almost every modern superyacht which has different interfaces to control all kinds of AV devices. The most widespread manufacturers of control systems are Crestron and AMX. Both provide an integrated hard- and software solution for remote controlling. The central device

[31] Cf. n.u.: AV Matrix, 2015.

for a control system is a processor which provides the different control interfaces like IR, RS-232, relays, analog and digital I/O ports and ethernet control shown in Figure 13.

Figure 13: Rear view of a Crestron CP3 control processor with different control interfaces[32]

Most AV devices are providing different possibilities for remote control. The decision which interface shall be used depends on the reliability and integration of the interface. The preferred option, especially if the device is part of the local network, is the control of ethernet, as no separate cable from the control processor to the AV device is necessary. The next best solution is the control connection over RS-232 as this is a physical end-to-end connection with simple serial command set which is very resistant against errors. Whereas IR is the least preferable control interface, although the control set is the same as RS-232, because of the optical transmission through the atmosphere. The biggest problem with the IR connection is the possible interference of the infrared signal through natural or artificial light. Although the positioning and attachment of the IR diode to the respective device can cause problems. The IR diodes may fall off or do not reach the IR receiver of the device through wrong placement.

Besides the control processor as the back-end of the control system which handles the command processing a front-end is necessary for the command input of the user. There are different devices that can be used for the command prompt. At the one side there are remote controls and keypads with free assignable hardware buttons and on the other hand touchpads with a customized graphical user interface (GUI). Some devices are shown in Figure 14.

[32] N.u.: Crestron, 2015.

Figure 14: Control Devices: Crestron remote, keypad and Apple iPad with a Crestron GUI

In most cases the control through a touchpad is preferred as you can adjust the interface to the needs and taste of the user.
A basic setup for controlling a hybrid AV system with central and local sources consists of at least three different components:

1. A central processor to control the central sources and the matrix switcher.
2. A local processor to control the local sources and sinks as well as for the linking of the control device.
3. A control device for the command prompt through the use.

The operation of a complex yacht AV system on a yacht is inconceivable without such integrated control systems nowadays. In addition to the AV control the system can also be used for controlling the lighting and HVAC (heating, ventilation, air condition) of a yacht.

4. Conception and implementation of the training rack

In this chapter the development of the mobile training unit, which will be used for the AV training, is described. The training concept, which was elaborated in collaboration with the employees of Bond TM, serves as the basis for the design of the training unit. As a first step the requirements on the hardware that will be used are getting elaborated. The next step will be the device compilation and assembling with a detailed review of the mounting and connection of the hardware. Finally, the integration of the training unit at the first training course will be described.

4.1. Training Concept

The aim of the mobile training system was the content-related support of the AV training course from Bond, by allowing the trainees to practice on a realistic yacht AV system.

The AV training was developed because of the lack of trainings for AV technicians on yachts. The target group of the training are engineers from yachts which do not have an ETO so the engineers have to take over the tasks of an ETO. The training is not qualifying ETOs but shall enable yacht crew members to perform basic troubleshooting and a fundamental grasp for AV technology on board. For a deeper insight to yacht AV system a second AV course shall be developed by Bond.

Precedent to the AV course an IT training was developed by Bond two years ago. The IT training is being offered in two levels and is carried out two to three times a year. At those trainings the trainees recurrently asked for the same training for AV system so the idea for this training was born.

The IT training takes place at two days and on each day there is a theoretical and a practical part where the trainees are practicing basic troubleshooting on IT systems. Because of the positive feedback from the IT training the AV course shall have a comparative concept. Therefore the requirements on the practical part of the AV course was also the development of troubleshooting scenarios on actual AV hardware.

The first day of the course comprises the AV basics audio, video and system design, on the second day the control systems on yachts are handled. The AV learning content is lectured by an employee of the Bond TM AV department, the second day is led by A-Knowledge, subcontractor of Bond who have specialized in project planning and programming of Crestron control systems. As the second day shall also have a practical hands-on section the mobile training system needed to have also complex control system hardware. The complete AV training concept is shown in the appendix A.

Before the training concept was developed in detail the training unit was developed to provide the right hardware for most of the topics that are covered at the training. This procedure helped to create the content of the training around the training unit, so that the hardware could be utilized in the most effective way.

4.2. Design of the training unit

The central function of the training unit is the demonstration of the theoretical content as well as the implementation of troubleshooting tasks as the practical part of the training. In addition the trainees shall get an insight into the latest AV technologies which they might not have on the yachts where they work but might be confronted with in the future on other yachts or at a refit.
As the training courses from Bond TM are taking place at the offices in Amsterdam and Barcelona a crucial requirement was the transportability of the training unit. The aim was to ensure that the training unit can be moved by two persons and is fitting on a euro-pallet to easily transport the unit by a shipping company. Also the unit needs to fit into the company car of Bond. Beside the size limitations another requirement was the simple and quick build-up of the unit. The system should be as much preconfigured as possible to reduce the installation time at the training. This demand leads to the case that most of the hardware needed to fit in one coherent unit.

As the mounting of professional AV and IT hardware is normally realised through 19-inch racks (cf. Figure 15) and this mounting type is secure and established, as many hardware as possible had to be integrated in a 19-inch rack. The selection of the rack is describe in chapter 4.2.2 in detail.

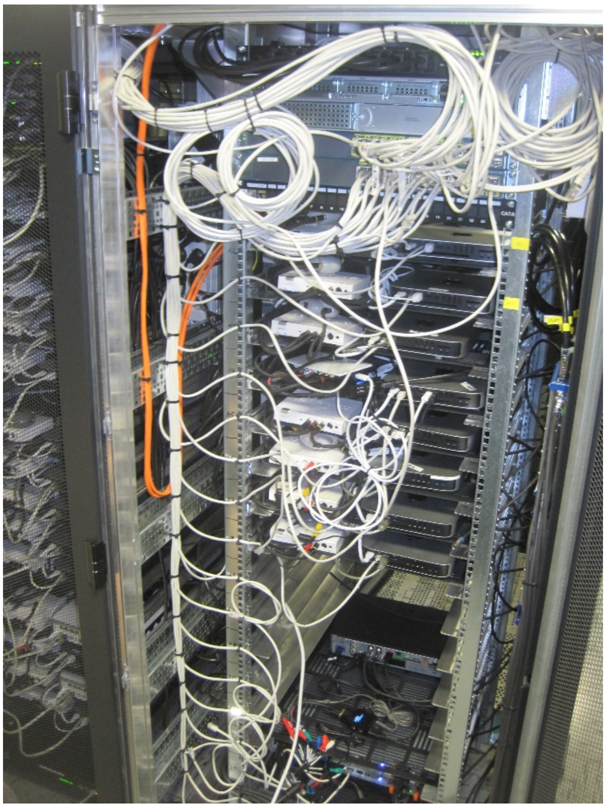

Figure 15: 19-Inch rack at the Jetstream datacenter

4.2.1. Choice of AV hardware

While choosing the hardware for the training unit different factors needed to be considered to create a realistic model of an AV system on a superyacht. Thereby the matrix distribution system is in the centre of attention and shall provide at least 8 HDMI inputs and HDMI and FO outputs for integrating current AV devices and showing the most commonly used distribution channels. As the matrix is the most important device regarding the functions and although because of the size and costs the choice had to be made carefully. Since Bond is well networked with different AV matrix manufactures a permanent loan was given by Lightware in form of a 17x17 fully equipped AV matrix with the required I/O boards and also a TPS transmitter and a FO receiver.

Figure 16 is showing the matrix with the HDMI and FO output boards on the top and the HDMI and TPS input boards at the bottom. At the front of the matrix are the hardware buttons to route the inputs manually.

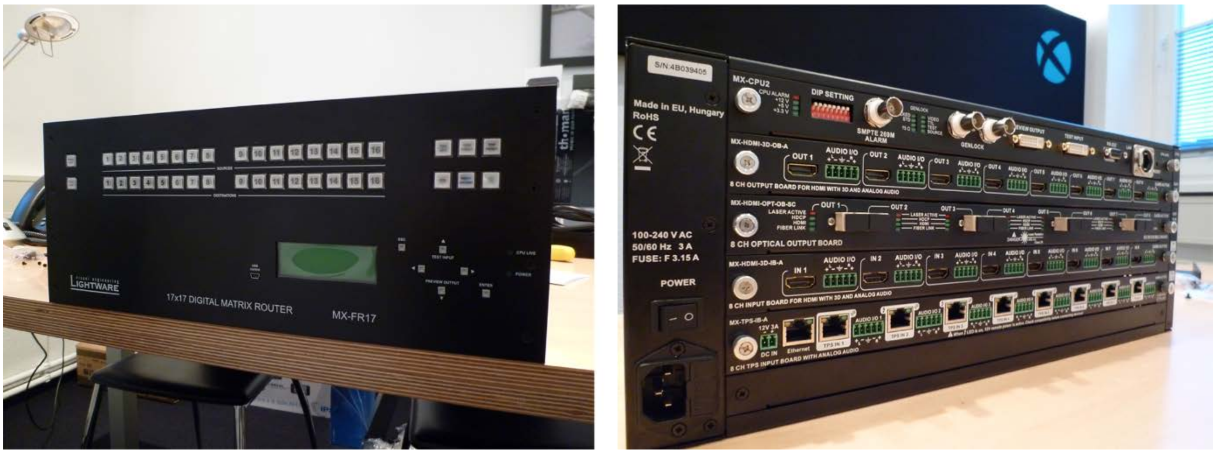

Figure 16: Front and rear view of the 17x17 Lightware matrix

On the basis of this matrix the choice of the additional hardware could be made. As the matrix takes up the space of five rack units (RU) the next step was the determination of the maximum available rack space. As described in section 4.2 as much of the devices should be mounted in the 19-inch rack and the overall size of the rack should not exceed the dimensions of a euro-pallet (1200 mm x 800 mm).[33] The detailed determination of the rack size is described in detail in chapter 4.2.2 which led to a maximum of 23 RU.
The chosen devices for the training unit are described in the following tables.

[33] Cf. Voges, Jonas: Paletten, 2015.

In-Rack hardware		
Picture	**Device**	**Description**
	Oppo BDP-103D	High-end Blu-Ray-Disc (BD) player with additional darbee chip for enhanced upscaling and conversion. Besides the playback of discs the player is also able to operate as a digital media renderer (DMR), the ability to play-back diverse media from network storage. Additional features: 4k upscaling and 2D to 3D conversion.
	Apple TV	Set-Top-Box for play-back of AV media which is provided through the LAN or internet like music, podcasts, videos and movies. Futhermore the Apple TV gives access to a collection of online services like Youtube and diverse AV streaming services. Also the Apple TV can be used as a receiver for Airplay, Apples distinct interface for wireless media transfer.
	Lightware MX-FR17	17x17 AV Matrix with 2 input and 2 free assignable I/O cards. Backplane with 12.8 Gbit bandwidth for 4k and 3D video signals. I/O boards: MX-HDMI-3D-OBA: HDMI input board 4k, 3D and deep colour compatible with analog audio stereo I/O. MX-TPS-IB-A: TPS input board for HDMI extension over HDBaseT MX-HDMI-3D-OBA: HDMI output board 4k, 3D and deep colour compatible with analog audio stereo I/O. MX-HDMI-OPT-OB-SC: HDMI 1.3 compatible FO output board with SC/SC connectors
	Sony Playstation 4	Gaming console as an example for a typical local source because of the required local connection between concole and controller. The Playstation is also providing CD, DVD and BD playback and also access to a variety of streaming services.
	Jetstream Jetset	Set-Top-Box for receiving the TV over IP stream, invented by bond. The Jetstream service and device is designed to be easily integrated into an AV system on yachts. The device is based on a small form factor PC with a proprietary operating system for the access and control of the Jetstream TV over IP service.
	Marantz NR1605	Low profile 7.1 AV receiver with 8 HDMI inputs, 4k compatibility, WiFi, Bluetooth and Airplay streaming
	Crestron CP3	Rack mountable control processor of the latest generation. Main control unit for the central sources and the matrix. Requested by A-Knowledge.
	Crestron MC3	Small variant of the CP3 for use as a control unit for the local devices. Requested by A-Knowledge.
	Cisco Catalyst 2950	24 port network switch for the IT infrastructure. Connects all network devices to the LAN and enables the control over ethernet by the crestron processor.
	Apple AirPort Extreme	Wireless LAN router to share the internet access over WLAN or LAN.

Table 4: In-Rack hardware description

External hardware

Picture	Device	Description
	JBL Control One	Two small sized monitoring speaker with a tough casing.
	Samsung UE22H5670	Two 22 inch full HD TV with smart functionality. The TV model was chosen because of the small size and the full HD resolution.
	Philips 224E5QDAB/00	Simple 22 inch monitor with full HD resolution, integrated speaker and a DVI input as the AV matrix provides a DVI output for the preview monitor.
	Apple iPad Air 2	10 inch touchpad for use a crestron control device. Most common control touchpad on yachts.
	Crestron C2NI-CB	Hardware button keypad for demonstrating the Cresnet connection. Requested by A-Knowledge.
	Lightware HDMI-3D-OPT-RX150RA	HDMI, analog and digital audio signal extender over a single FO cable. 3D and 4k compatible with audio deembedder for demonstrating a HDMI extension from the central matrix to a remote location over FO.
	Lightware UMX-TPS-TX140	Universal,four input (DVI, HDMI, VGA, Displaypot) HDbaseT CAT transmitter for demonstrating the feedback of a local source to the central matrix.

Table 5: External hardware description

Miscellaneous hardware

Picture	Device	Description
	Power distribution	Two 230V switchable power distribution strips for 19" mounting with 8 power sockets each. One power strip for external devices with 8 power sockets.
	Rack shelves	Four rack shelves for all in-rack devices with a lack of 19-inch mounting solution. Those devices shall be screwed or sticked to the shelves to fit in the rack. Those shelves are available in different RUs and depths.
	Rack panel	For a distinct look of the rack front through covering unused rackspace.
	Cable	Diverse cables. See chapter 4.3.2 for a detailed description of the utilized cables.
	Cable management	Cable ties, velcro tape and cable organizer rings to straighten up the in rack wiring.

Table 6: Miscellaneous hardware description

All devices except the switch, WAP, Lightware and Crestron hardware was purchased through a central wholesaler Bond is using for hardware purchases. The Crestron hardware was directly ordered at Crestron as they are a direct distributer. Before the hardware was ordered the costs for the whole training unit was agreed with the management of Bond. As the training courses are carried out without a view to gain profit it was necessary to pay attention to the costs of the hardware and sometimes making compromises between functionality and exclusivity of the devices.

For the calculation of the overall rack units, for the devices which have been mounted in the rack, the diagramming application Microsoft Visio was used. With the aid of the software the hardware and rack could be drafted by their actual measurements. In this way the positionig of the devices in the rack could be tested virtually to consider how the devices will be arranged and to include free rack units for heat dissapation and maintenance.

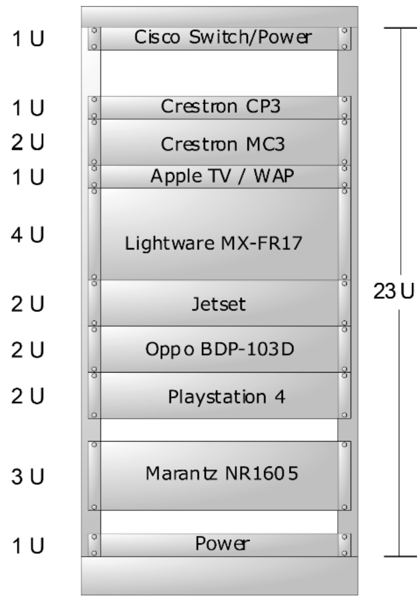

Figure 17: AV rack allocation schematic

Figure 17 is showing the final rack allocation with the actual needed RU for the hardware and free RU for heat dissapation and maintenance. The overall rack height was estimated by this point as the exact model of the rack was not defined yet.
The specification and choice of the mobile rack is described in the following chapter.

4.2.2. Mobile rack

A central requirement on the training unit was the mobility of the whole hardware setup (cf. chapter 4.2). This implies that all the devices are housed in portable casings and still fitting on a euro-palett for easy shipping. Therefore the optimal housing for the AV devices are 19-inch rack frames which typically are used at datacenters and for event technology. The 19 inch are refering thereby to the standardized width of the frame. The height of the 19-inch racks are indicated as rack units (RU). One RU measures 1.75 inch.The hardware is getting mounted through vertically aligned perforated rail for screw fastening with a gap of 1.25 inch in between (cf. Figure 18).

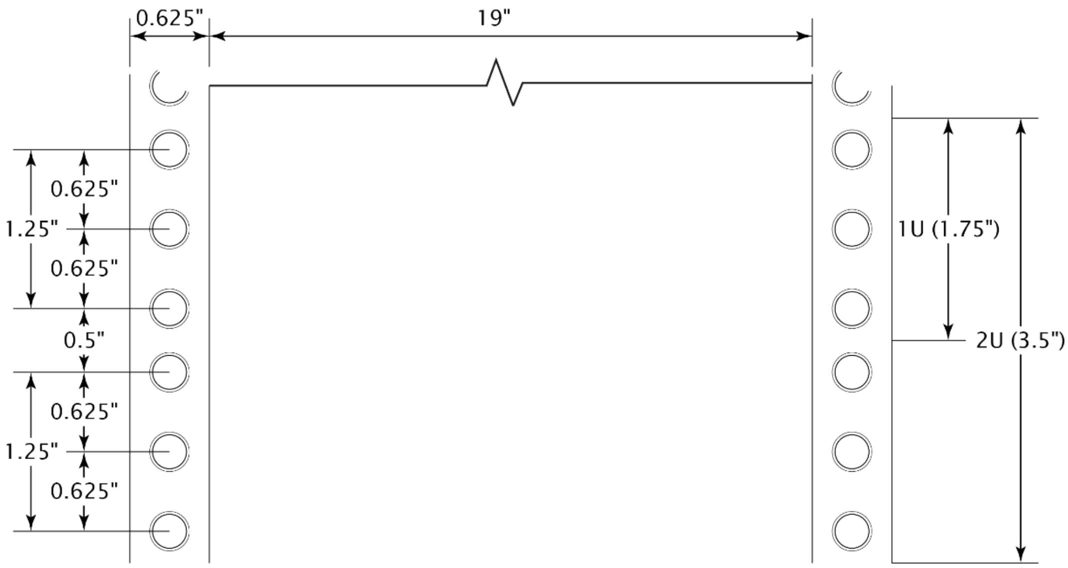

Figure 18: Rack frame dimensions

Besides the height the depth of rack frames are varying to fit the frame to the depth of the devices that will be mounted in the rack. Common rack sizes are 42 RU (full height) and 18-22 RU (half height) with depths between 600 and 1000 mm.[34]

The rack for the mobile training unit should be equipped with the maximum RU possible that still fits on the euro-pallet (1200 mm x 900 mm). In a length of 1200 mm 26 RU (approx. 1160 mm) would fit, but it needed to be considered that the framework and casing of the rack itself will take away some space.

For transportable 19-inch racks the installation in a flightcase is a well tried and tested option that protects the hardware from damage. Flightcases are shipping

[34] Cf. n.u.: Define: EIA-310, 2007.

containers constructed out of 5 -20 mm thick plywood which is joined with aluminium profiles and protected through rounded case corners. For the mobile use those cases are fitted with 100 mm swivel castors and carrying handles. Those parts of the superstructure of the case will reduce the available height for the actual rack units.

After consultation of employees from Bond regarding a manufacturer for custom made flightcases the company Amptown Cases were recommended because of their well build and robust products.

For the integration of 19-inch racks into a flightcase Amptown provides different types of cases which are available in a wide range of heights and widths.

The preferable variants for the rack enclosure are double-door and case-in-case constructions as shown in Figure 19.

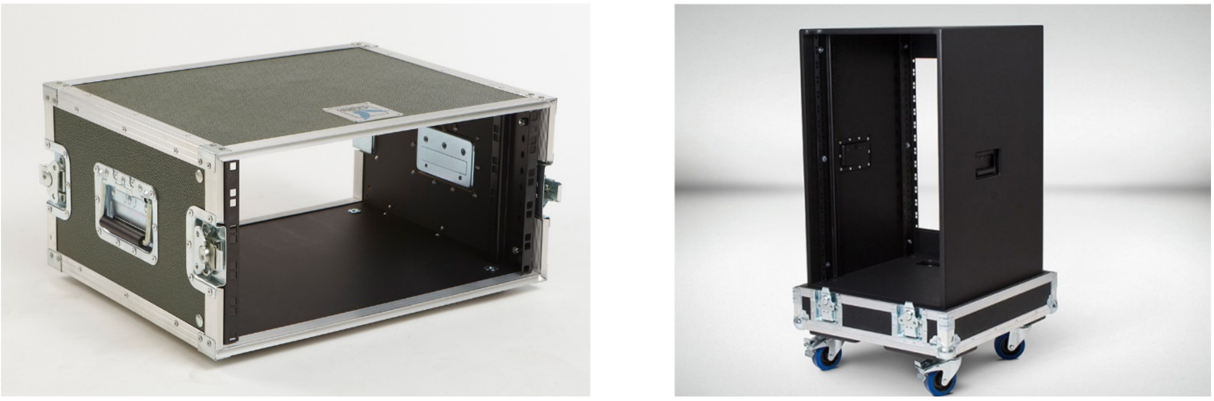

Figure 19: Double-door and case-in-case flightcases from Amptown

In both variants 19-inch hardware can be integrated from both sides through rack rails and although swivel castors are optionally available. As on the case-in-case model two RU are not accessible because of the foundation and the removing of the lid might be impractical because of the height, the double-door case was chosen for the training rack. [35]

Figure 20 shows the actual flightcase that was ordered after consultation with Amptown.

[35] Cf. n.u.: Case in case, 2011.

- Double-door rack
- 23 RU
- 444 mm mounting depth
- Heavy duty blue wheels with brakes
- 1220 mm overall height

Figure 20: Custom double-door rack from Amptown

Additionally rack shelves, panels and flightcases for the TVs and supplies were ordered. The additional flightcases were ordered at Thomann as they are offering ready-made cases that fitted the purpose and were cheaper than custom made solutions.

4.3. Assembling the training rack

Besides the hardware selection the integration of the single devices into a coherent unit was a challenge at the creation of the AV training course.
Before the devices were assembled and configured a functional schematic was drawn to illustrate the distribution concept of the rack. On the basis of this schematic the logical organization and wiring of the single components could be carried out. The schematic although shows the division of local and central devices. The assembling of the rack is divided in three sections:

1. Device mounting
2. Wiring
3. Configuration and commissioning

The complete assembling of the rack was executed at the office of Bond TM in Hamburg.

4.3.1. Device mounting

Before the hardware was mounted in rack the exact positioning of the devices in the rack needed to be elaborated. The first factor that had to be considered was the access to all devices and their connectors in the assembled rack. This is necessary as in the training all cables might be interchanged by the trainees and to give an overview of the wiring concept. Because of the different widths of the devices (100 – 400 mm) it might occur that a large device covers a smaller device that is mounted below. To prevent this incident the larger device needed to be mounted below the smaller devices or some free rack units needed to be assigned above the small devices.

A second consideration should be made regarding the weight of the devices. To prevent the rack from falling over easily the heavy devices should be mounted in the lower sections of the rack. If the center of gravity is located on the lower half of the rack, the rack will not fall over when moved careless.

Finally the devices should be mounted in order to keep the cable runs as short as possible. For example by putting the AV matrix in the middle of the rack as this is the device with the most cable connections. By keeping the cable runs short less space is needed for the cable management and leads to a cleaner look of the rack. Considering this three factors the rack allocation shown in Figure 17 has been chosen.

The mounting of the hardware in the rack can be done in two ways. At first all devices with an existing fastening possibility for 19-inch racks can be mounted directly into the rack. Those devices providing drill holes in the front plate and the width corresponds with the 19 inch of the rack. The following devices are having actually 19-inch mounting possibilities:

- Switch: Cisco Catalyst 2950
- Control Processor: Crestron CP3
- AV matrix: Lightware MX-FR17
- Set-Top-Box: Jetstream Jetset
- Disc Player: Oppo BDP-103D

For the rest of the devices a different mounting solution for the secure integration to the rack needed to be found. Therefore rack shelves are a flexible solution to fit incompatible hardware into a 19 inch rack. Those shelves are frameworks with 19 inch rack dimensions where smaller devices can be fixed through screws, cable ties or Velcro tape. Those shelves are available in different depths, rack units and mounting possibilities. The following devices were mounted through shelves:

- Control processor: Crestron MC3
- Set-Top-Box: Apple TV
- Wireless access point: Apple Airport Extreme
- Game console: Sony Playstation 4
- AV receiver: Marantz NR1605

Admittedly a rack mount kit for the AV receiver is available but just for the American market. Therefore a custom rack mount on the basis of a rack shelf was constructed (cf. Figure 21).

Figure 21: Custom made rack mount for the AV receiver

The attachment of the 19 inch compatible hardware and shelves was realized through cage nuts and M6 thread screws. For the mounting of the devices the rack was laid on the backside so that the devices could be easily adjusted at the rack without additional assistance.

After finishing the mounting of the hardware the wiring of the devices could be attempted.

4.3.2. Wiring

The cabling of the devices can be divided in two categories. At first the power cable distribution was carried out and afterwards the AV, IT and control wiring.
The power distribution is distinguishing from the rest of the cabling as those cables will not be discussed or modified at the training. Therefore the connections can be fitted inaccessible and hidden which is providing a cleaner look of the rack. As shown in chapter 4.2.1 the power distribution is based on two power strips with eight power sockets each on the top and bottom of the rack. The sockets are facing into the rack to provide a clean look. Before the final cable management was approached all devices were tested with loose cabling to test if a device is damaged (cf. Figure 22).

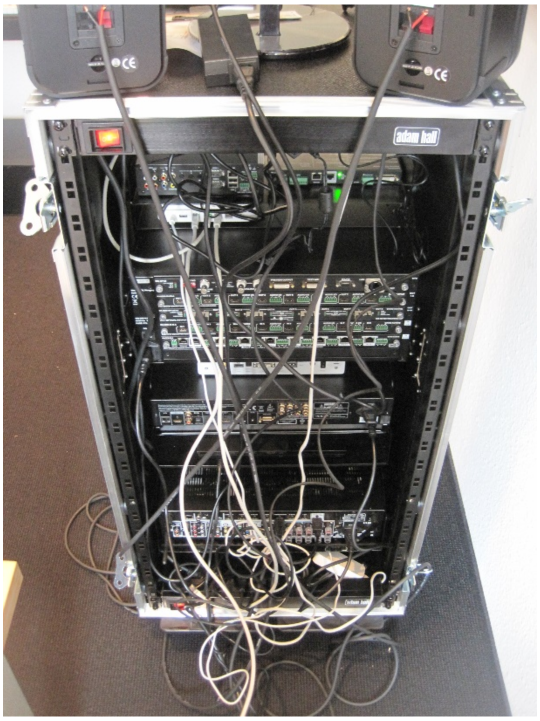

Figure 22: Testing the hardware with lose cabling

The challenge with the wiring of the power cables was the tidied up placement as the three-pole cables are thick (approx. 6 mm) and inflexible.
To keep the cables as short as possible to allow a hidden installation the cables needed to be shortened to the ideal length. Therefore the cables were cut and equipped with new connectors. In addition the external power supplies were fixed

discreet at the inside of the rack. Figure 23 is showing a shortened power cable and with Velcro tape attached power supplies.

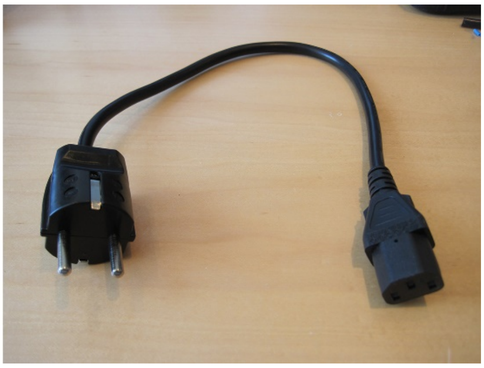

Figure 23: Attached power supplies and shortened power cords

After finishing the power cabling the connections for the AV, IT and control devices were implemented. As a first step a cable plan was created which points out all required connections. Based on this and the distances between the single devices in the rack the different cable types were ordered. For every cable type at least one spare was ordered to demonstrate faulty cables at the training and for providing spares. The HDMI cable where provided complimentary from the company PureLink.

To achieve a well structured wiring and a better distinction the AV and IT cables were assigned to the left (IT) and right (AV) side of the rack. The cables were conducted through rack organizer rings and bundled with Velcro cable ties. Those measures are leading to a clean and well-structured cable management as shown in Figure 24.

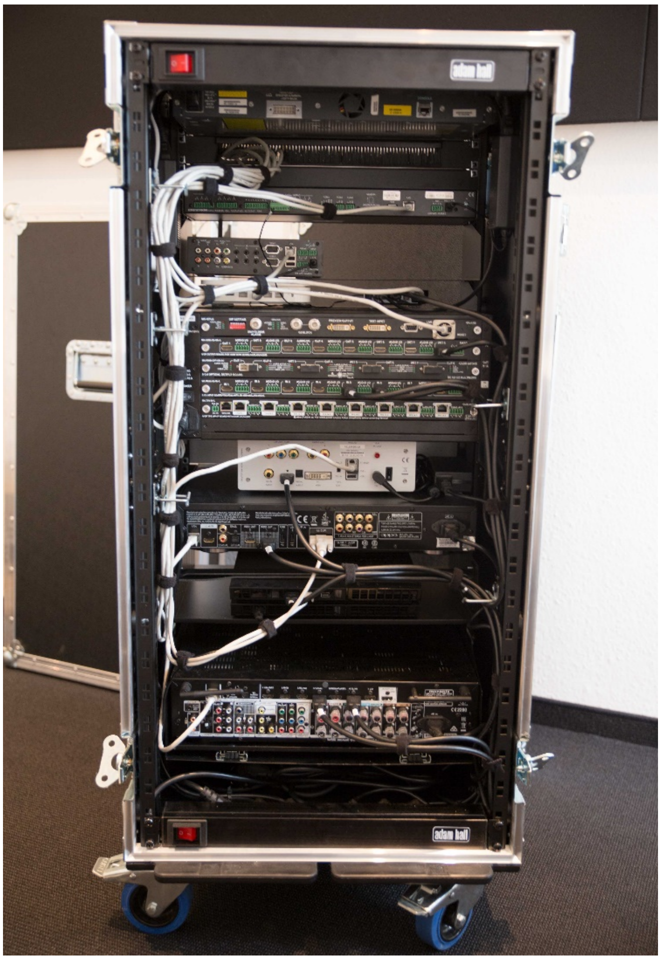

Figure 24: Final internal rack cabling

As the CAT cables which are connected to the network switch needed to be routed to the front of the rack an additional brush panel was attached below the switch. This panel provides a cleaner look of the rack front and although prevents dust from entering through the front (cf. Figure 25).

Figure 25: Front view of the final training rack

Besides the internal rack cabling all external devices like the TVs, preview monitor, transmitter, receiver, loudspeaker and keypad were connected according to the wiring schematic (Appendix B) and although bundled through Velcro tape. After all devices were connected the whole training setup was checked for connection faults.

Alongside the cable management, the labelling and documentation of the connection is a crucial part of the rack build. For labelling the cables typically self-laminating labels were used which containing at least the following information: Continuous cable number, cable type, start and end device on the opposite end of the cable. In this way it is ensured that also third parties can track the cable-routing.

After finishing the labelling a cable plan was created which is written in the same way as the cables are labelled. The cable plan is shown in the appendix C. By the use of the wiring schematic, cable list and cable labels the trainees can reconstruct the cable routing which is a basis for the troubleshooting part on the training (cf. chapter 4.4).

4.3.3.Configuration and functional overview

After finishing the hardware related work on the rack the single devices of the training unit needed to be configured. This includes the IP address assignment, AV device settings and the programming of the Crestron controller.
Starting with the IP address assignment it needed to be decided whether a static or dynamic allocation through DHCP is chosen. An automated assignment through DHCP makes the most sense in networks with many network devices as the IP addresses do not have to be assigned manually. Because the training setup has just a few and consistent devices, a static IP assignment should be preferred. This allows an easier access to the device since the IP address is not changing.[36]
For the documentation the following logic for the IP assignment was chosen:

- 10.0.70.x: Network backbone
- 10.0.70.15x: Control devices
- 10.0.70.16x: Distribution system
- 10.0.70.17x: Central AV devices
- 10.0.70.18x: Local AV devices

The complete IP table is shown in appendix D.
At the configuration of the AV matrix the input and outputs where configured through the Lightware device control software.
Apart from that, the matrix was configured in a way that the signal transmission is realised transparent, means that the sinks are receiving the unbiased signal from the source.
At all other AV devices only a few configurations had to be made as through the EDID exchange the right settings are getting automatically negotiated by the devices.[37] However, the following configurations have been made:

---

[36] Cf. n.u.: IP Adresses, 2015.

[37] Cf. n.u.: Understanding EDID, 2009.

- IP assignment based on the IP table
- User setup for the Apple TV, Jetset and Playstation 4
- Loudspeaker configuration at the AV receiver

After finishing the device configurations, employees of A-Knowledge took over the programming of the Crestron hardware. The demanded functions of the control system were agreed with Bond in advance.

4.4. Development of troubleshooting scenarios

The primary function of the rack at the AV training should be the provision of an environment where the trainees can gain hands-on experience (cf. Chapter 4.1). Therefore different errors should be integrated into the training unit which the trainees shall fix during the training course. Hereby the requirements on those errors are:

- A fast implementation of the failure in the training unit in under five minutes
- Realistic errors that could occur on yachts
- Not too complex and solvable in under 15 minutes
- Integration of all devices of the training unit

At the development of the troubleshooting cases a lot of scenarios failed after testing their practicability with some employees from Bond because they were either too complicated or too simple to solve. After picking out the inconvenient scenarios the tasks were classified in to three different difficulty levels to adjust those to the individual skills of the trainees during the training course. Although the trainees were allowed to use the following tools to fix the failure: Spare cables, factory remotes, documentation of the training rack.
Table 7 shows the troubleshooting scenarios that were developed for the first training course.

Scenario	Error	Cause	Level
After a refit that included an upgrade of the AV system you are in charge of performing a pre-charter check one day before the first guest trip will take place.	Instead of the Blu-ray disc player we see Apple TV when trying to watch a Blu-ray disc	Input 6 and 7 are switched	1
The yacht owner is upset because he cannot watch a Blu-ray disc at the main salon	Blu-ray player is not working at the main Salon	FO cable between matrix and FO receiver is broken/not connected	1
A guest is complaining that he cannot stream movies from his iPad to the TV. He mentions that he just can hear the sound of the movie.	When streaming a video to the Apple TV the video is not displayed at the TV but audio is working	Broken HDMI cable between AVR and TV	1
The owner wants to watch a football game at the main salon. The game starts in 10 minutes and he dont get a picture.	Jetset input is not working at the main salon	Powerconnector from the Jetset PSU is not plugged in correctly	2
A movie night is planned at the main salon. Check if everything is working correctly	Instead of a widescreen picture the movie is played with a 4:3 aspect ratio	The aspect ratio from the TV is set up wrong	2
A guest wants to stream music from his iPad to his cabin but did not get any sound	No sound at the guest cabin	The speaker connection at the AVR is loose	2
A guest is complaining that he did not get any sound from the game console	No sound from the Playstation	The audio format of the Playstation is not matching with the input configuration of the AVR	3
A guest is complaining that the sound is lousy while watching a Blu-ray disc	Dialogs are missing when playing a Blu-ray disc	EDID mismatch on the matrix. The Blu-ray player gets the EDID from the AVR and sends out multi channel audio	3

Table 7: Troubleshooting scenarios for the AV training

4.5. The final training course

After the finalization of the training unit and the content of the training a week before the first training course a test setup was built at the office from Bond in Amsterdam were the final training course also took place. At this stage the functionality of the rack was tested and the cabling and configuration optimized.

The actual training took place on 3 and 4 June 2015 and was attended by six trainees. Figure 26 shows the setup of the training unit at the first AV course in Amsterdam.

Figure 26: Setup at the first training course at the Bond office in Amsterdam

During the lecture of the theoretical basics the trainer could always refer to the single rack components and their functionalities to enhance the content with practical examples. In the afternoon of both days the training unit was extensively used for the hands-on troubleshooting scenarios.

Before the single tasks were assigned the system was explained by the wiring schematics and the basic functionalities were shown. For the troubleshooting exercises one trainee left the room and the fault was implemented and explained in front of the other trainees. The trainee who has left the room was given a brief explanation of the error (cf. Table 7) afterwards. At the troubleshooting the trainee should look for the source of error by following the wiring and functional schematics (Appendix E) and test each device in the relevant signal chain. The proper way to approach fault finding was taught at the lecture before. If the troubleshooting took too much time the other trainees were allowed to help or little hints were given by the trainer. At the end of the training the most complicated fault was implemented in the training unit and all of the trainees should find the solution for the error.

After the two days of training the trainees were asked for feedback. Thereby the troubleshooting part was commended by all participants. After finishing the training the trainees received a certificate which is accredited by the Professional Yachting Association (PYA) as well as a handout of the training content.

5. Summary and outlook

The aim of this bachelor thesis was the development of a training unit which demonstrates the complex AV systems on private superyachts through a mobile hardware-based training unit.

In coordination with experts from the AV yachting industry an integrated system based on hard- and software modules was specified for the usage in a basic AV training course for yacht crew members.

The development of the training unit started with a schematic of the first proposed devices for the rack at the end of November 2014. During the six month until the first training course the system was tested and optimized in different phases of the build. Because of the ongoing improvements a fully functional and effective training tool could be used at the first AV training course held by Bond. The feedback from the trainees acknowledged the application of the rack as a central part of the training course.

Although the first usage of the training unit were successful some aspects of the rack can be optimized. At first the cabling can be executed even better by reducing the length of the CAT cables as for now prefabricated cables are used which are not in the right length. Furthermore the single devices in the training rack shall be discussed more in detail. By now just a few functionalities of the hardware are exhausted. The differentiated usage of each device could also be extended at the troubleshooting scenarios.

Because of the positive feedback regarding the training rack it also should be considered to integrate the unit during the first parts of the training as currently the theoretical input prevails the first half of the course.

Regarding the further development of the training unit it should be noted that Bond is planning to realize a second AV training for advanced yacht crew members who are specialized in AV systems. According to the level 2 IT training profound AV knowledge for superyachts shall be mediated at this course. Whereas the target group of the level 1 AV training are yacht crew members who are taking care of the AV system besides other tasks the level 2 training shall be educational for full-time ETOs. On this course the training unit shall be used still more frequent and might be equipped with further devices.

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Appendix A – Training syllabus

Audio Visual Systems Training

CONTACT:

+377 979 858 93

training@bondtm.com

COURSE LOCATION:

Bond Office

Orlyplein 10,

Crystal Tower

1043 DP

Amsterdam, NL

INFORMATION:

Duration: 2 Days

Maximum student: 8

Price: 990€

Flight and hotels are not included.

REQUIREMENT:

A suitable technical background

The following topics will be covered during the 2 day training course. The theory will be emphasized through practical hands-on parts on corresponding AV and IT hardware.

DAY 1: AV SYSTEMS

1. Video
   a. Displays and projectors
   b. Video sources
   c. Cables and connectors
   d. Signals and formats
   e. Processing
   f. Integration

2. Audio
   a. Speaker types
   b. Amplifier and processors
   c. Audio sources
   d. Cables and connectors
   e. Signals and formats
   f. Surround sound
   g. Integration

3. System Design
   a. Distribution
   b. AV tools

4. Hands-on and basic troubleshooting

DAY 2: CONTROL

1. Control systems
    a. (Crestron) Basics
    b. Controlling other Crestron products (Switchers, Cresnet, ...)
    c. 3rd party control (RS-232, IP, CEC, ...)
    d. Software basics
        i. Programming
        ii. Layout
        iii. Configuration & maintenance
2. Interfaces
    a. Keypads
    b. Touchpanels
    c. iPad
    d. xPanel

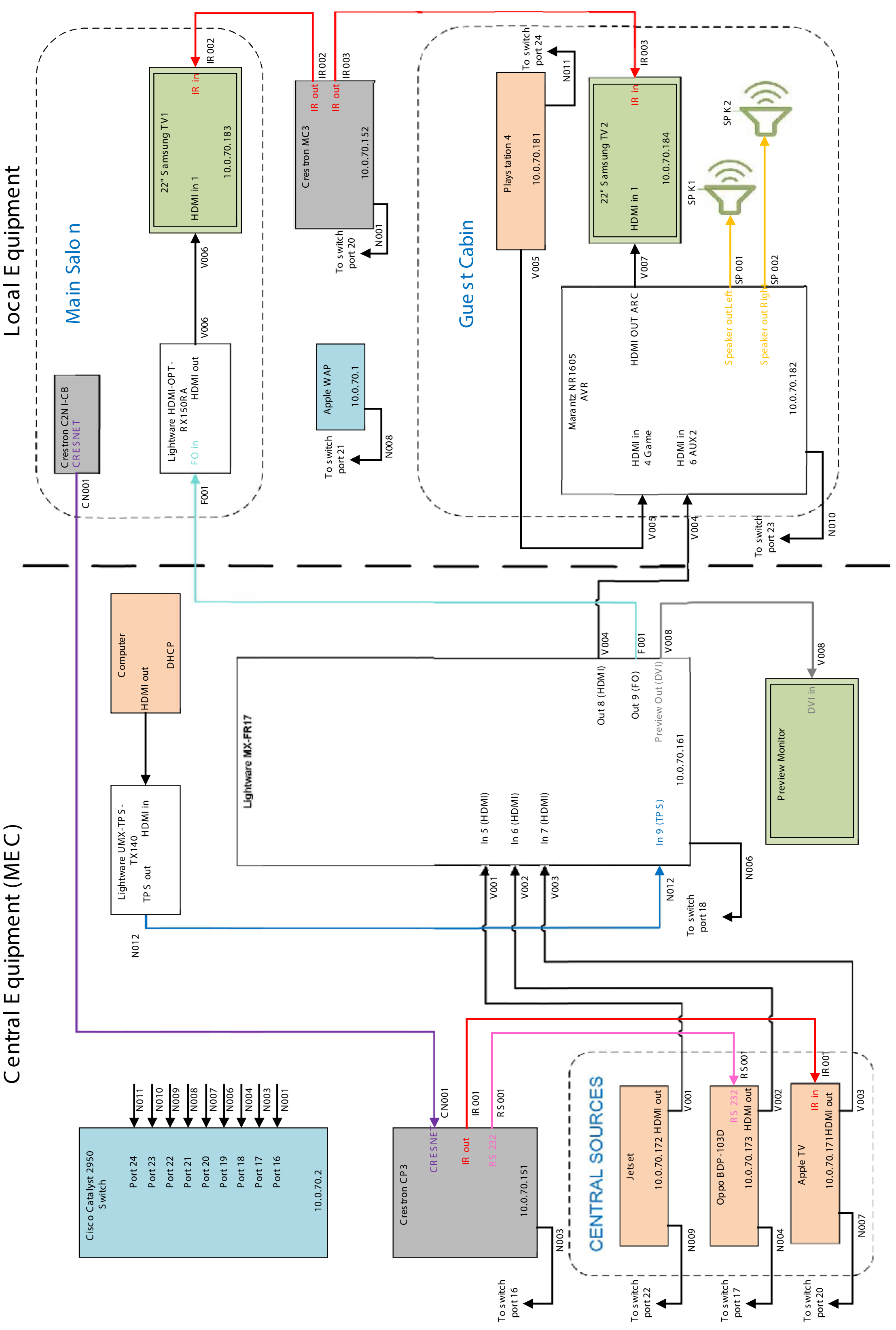
3. Networking for AV (DHCP, VLANS, Wireless & Roaming, ...)

4. Hands-on and basic troubleshooting

PYA Accredited

Telephone: +377 9798 5893
Email: info@bondtm.com
Website: www.bondtm.com

Appendix B – Wiring schematic



Appendix C – Cable plan

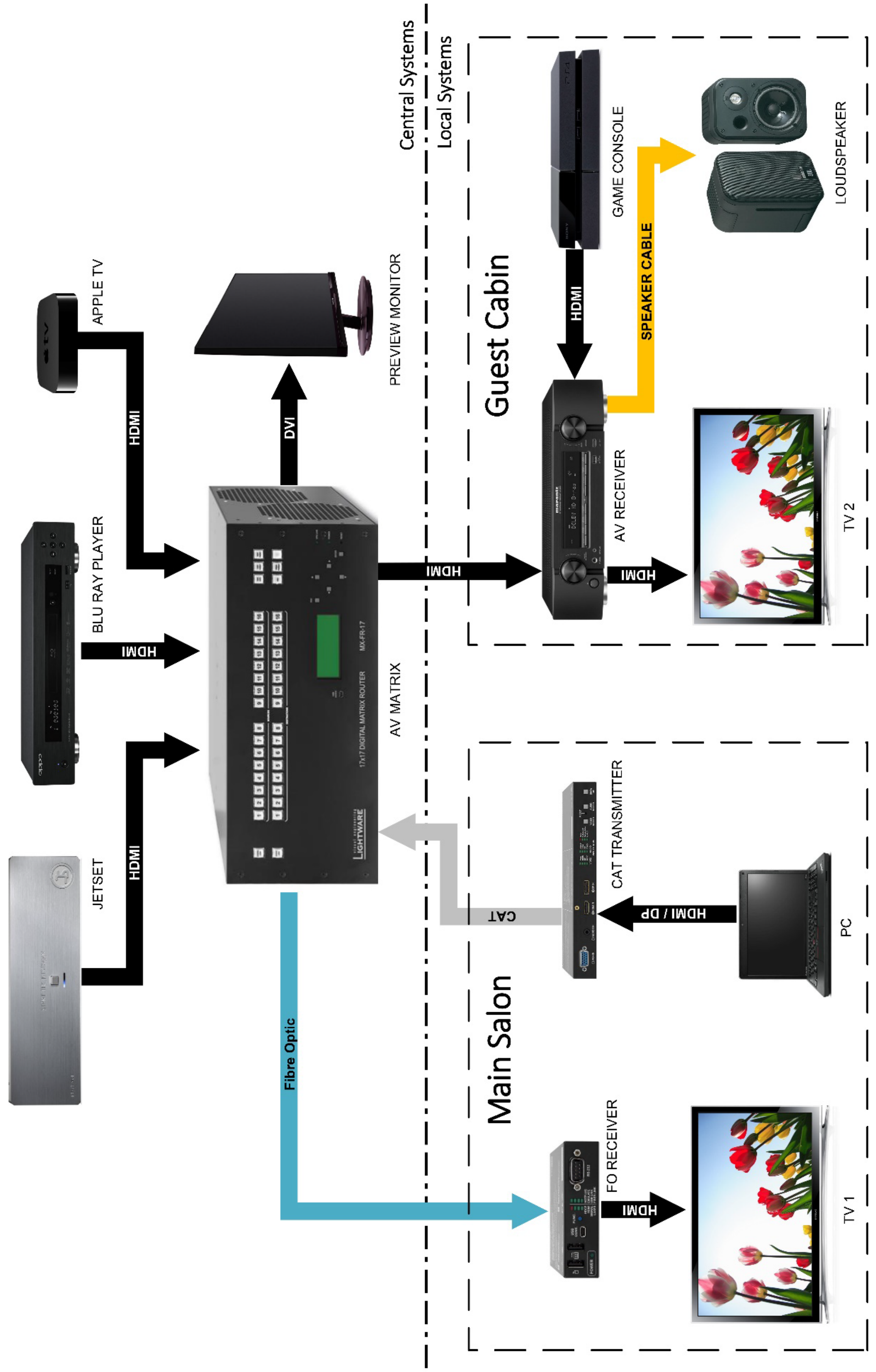
Number	Cable Name	Cable Description	Start Room	Start Device	Output	End Room	End Device	Input
01	V001	HDMI-1m	MEC	Jetset	HDMI	MEC	MX-FR17	IN 5
02	V002	HDMI-1.5m	MEC	BDP	HDMI Out 1	MEC	MX-FR17	IN 6
03	V003	HDMI-1m	MEC	Apple TV	HDMI	MEC	MX-FR17	IN 7
04	V004	HDMI-1.5m	MEC	MX-FR17	Out 8	Guest Cabin	AVR	HDMI IN 6 AUX2
05	V005	HDMI-1m	Guest Cabin	PS4	HDMI	Guest Cabin	AVR	HDMI IN 4 GAME
06	V006	HDMI-0.5m	Main Salon	OPT-RX150	HDMI	Main Salon	TV1	HDMI IN 1
07	V007	HDMI-5m	Guest Cabin	AVR	HDMI OUT ARC	Guest Cabin	TV2	HDMI IN 1
08	V008	DVI-1.5m	MEC	MX-FR17	Preview Output	MEC	Preview Monitor	DVI IN
09	N001	CAT6 UTP 28 AWG	Guest Cabin	MC3	LAN	MEC	Switch	Port 14
10	N003	CAT6 UTP 28 AWG	MEC	CP3	LAN	MEC	Switch	Port 16
11	N004	CAT6 UTP 28 AWG	MEC	BDP	LAN	MEC	Switch	Port 17
12	N006	CAT6 UTP 28 AWG	MEC	MX-FR17	LAN	MEC	Switch	Port 19
13	N007	CAT6 UTP 28 AWG	MEC	Apple TV	LAN	MEC	Switch	Port 20
14	N008	CAT6 UTP 28 AWG	MEC	WAP	LAN 1	MEC	Switch	Port 21
15	N009	CAT6 UTP 28 AWG	MEC	Jetset	LAN	MEC	Switch	Port 22
16	N010	CAT6 UTP 28 AWG	Guest Cabin	AVR	Network	MEC	Switch	Port 23
17	N011	CAT6 UTP 28 AWG	Guest Cabin	PS4	LAN	MEC	Switch	Port 24
18	N012	CAT6 UTP 28 AWG	Main Salon	TPS-TX140	TPS OUT	MEC	MX-FR17	TPS IN
19	IR001	IR extender cable	MEC	CP3	IR 1	MEC	Apple TV	LAN
20	IR002	IR extender cable	Guest Cabin	MC3	IR 1	Main Salon	TV1	-
21	IR003	IR extender cable	Guest Cabin	MC3	IR 2	Guest Cabin	TV2	-
22	RS001	RS232 / D-Sub9/M-F	MEC	CP3	COM 1	MEC	BDP	RS-232C
23	SP001	2x 2.5 sqmm OFC	Guest Cabin	AVR	FRONT L	Guest Cabin	SPK1	INPUT
24	SP002	2x 2.5 sqmm OFC	Guest Cabin	AVR	FRONT R	Guest Cabin	SPK2	INPUT
25	CN001	CAT6 UTP 28 AWG	Main Salon	C2NI-CB	NET	MEC	CP3	NET
26	F001	SC/SC simplex 50/125 10m	MEC	MX-FR17	OUT 1	Main Salon	OPT-RX150	FIBER INPUT

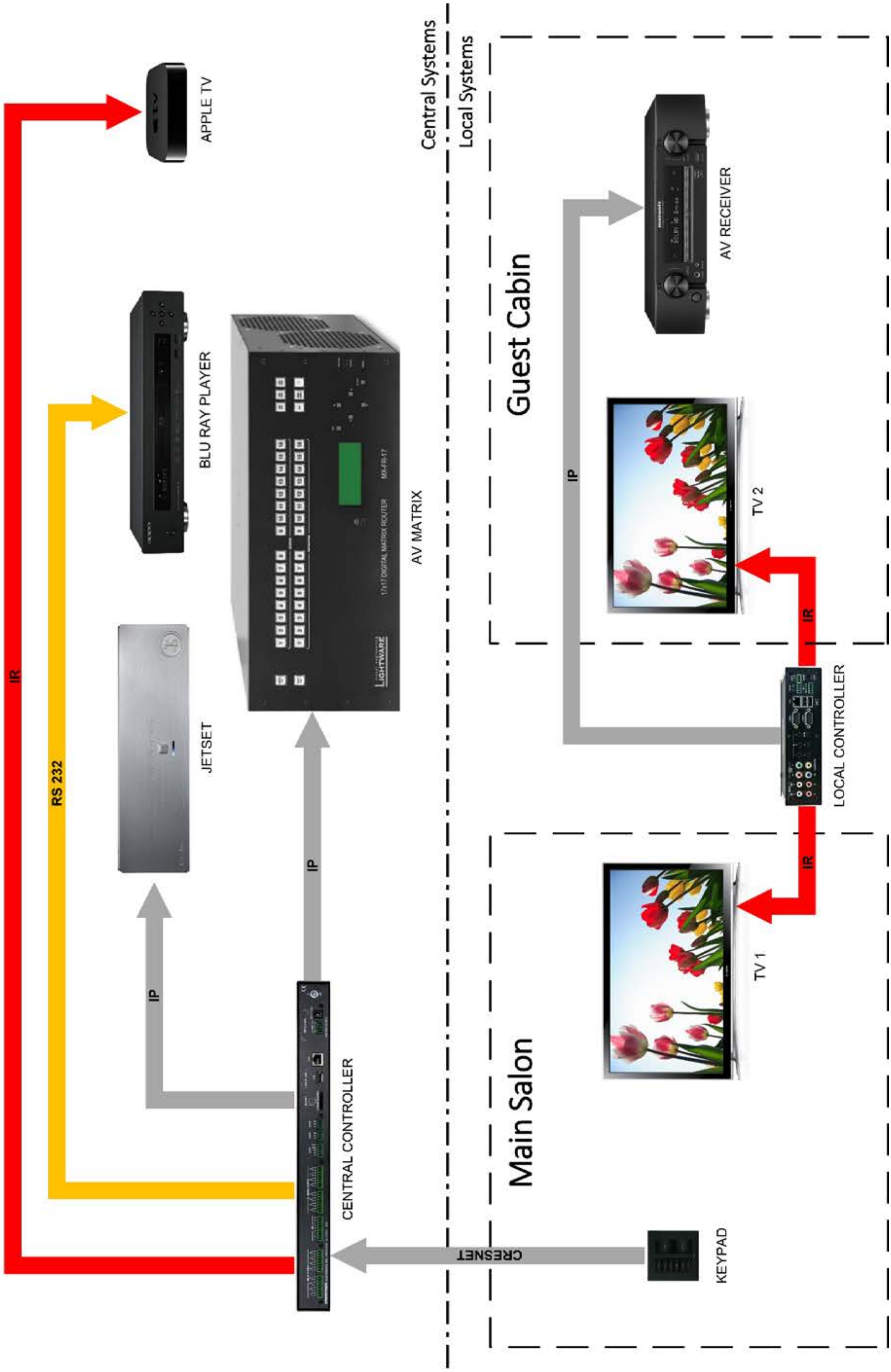
Appendix D – IP table

IP Table

Device	Model	Group	IP	Connection
WAP	Airport Extreme	Network	10.0.70.001	LAN
Switch	Cisco Catalyst 2950	Network	10.0.70.002	
Central Controller	Crestron CP3	Control	10.0.70.151	LAN
Local Controller	Crestron MC3	Control	10.0.70.152	LAN
Touchpad	Apple iPad Air 2	Control	10.0.70.153	WLAN
Matrix	Lightware MX-FR17	Distribution	10.0.70.161	LAN
Roombox	Lightware UMX-TPS-TX140	Distribution	10.0.70.162	LAN
Set-Top-Box	Apple TV	Central Source	10.0.70.171	LAN
Set-Top-Box	Jetset	Central Source	10.0.70.172	LAN
BluRay Player	Oppo BDP-103D	Central Source	10.0.70.173	LAN
Game Console	Playstation 4	Local Source	10.0.70.181	LAN
AV Receiver	Marantz Nr1605	Distribution	10.0.70.182	LAN
TV1	Samsung UE22H5670	Sink	10.0.70.183	WLAN
TV2	Samsung UE22H5670	Sink	10.0.70.184	WLAN
PC		Local Source	DHCP	WLAN

Appendix E – Functional schematics





APPLE TV
BLU RAY PLAYER
JETSET
AV MATRIX
IR
RS 232
IP
IP
CENTRAL CONTROLLER
CRESNET
KEYPAD
Central Systems
Local Systems
Guest Cabin
Main Salon
AV RECEIVER
TV 2
TV 1
IP
IR
IR
LOCAL CONTROLLER

Statutory declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources/ resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Hamburg, 21.09.2015

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(Hannes Winkel)