

Chapter 2

Literature Study

Chapter 2 presents a comprehensive literature study concerning communication systems. This particular chapter will also study all the relative aspects concerning digital communication systems. Finally the chapter will conclude with a critical literature review.

2.1 Introduction

One of the first applications of electrical technology was electronic communication systems. In an era where high speed fibre optic communication, ISDN and WAP enabled cell phones are considered cutting edge technology, electronic communication can still be considered at the leading edge of electronics [14].

In this particular chapter the different components of an electronic communication system will be documented. The aspects that will be focussed on are:

- Electronic communication systems.
- Progression from analogue communication towards digital communication.
- Analysis and design of communication systems.
- The OSI reference model and the relevance of this model.
- A selection of busses will be investigated.
- The limitations of busses, keeping in mind that it is of fundamental importance that the system does not fail due to the limitations of the bus selected for the specified interface.
- Transmission line modelling.
- Methods used to measure the technical performance of communication systems.
- Methods used to measure the efficiency of a communication system.

2.2 Electronic communication systems

Information is shifted from a source to a destination through a specified channel by means of a communication system [15]. The basic elements of an electronic communication system is; a transmitter, receiver and a channel. A simplified electronic communication system is illustrated in Figure 2-1 [16].

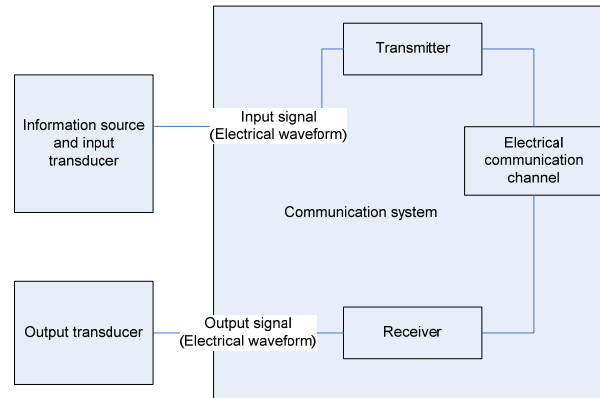


Figure 2-1: Model of an electronic communication system [16].

The basic operating principle of an electronic communication system is as follows: The source generates data in a form that cannot be transmitted over a channel, and a transmitter is used to convert the data into an information signal that can be moved over a specified channel. At the end of the channel the information signal is converted by a receiver situated at the destination. Now the information can be utilized by the end unit. It must be noted that the information signal can either be an analogue or a digital signal.

The channel that is used to move the information signal from the source to the destination can be fibre optics, unshielded twisted pair, coaxial, a pair of conductors or free space in the case of radio communication.

Electronic communication systems can be divided into three classes [16] ;

- *“Analogue communication systems, designed to transmit analogue information.”*
- *“Digital communication systems, designed to transmit digital information.”*
- *“Hybrid systems that use digital modulation for transmitting sampled and quantized values of analogue information signal.”*

To develop an optimal electronic communication system for the ADES, it will be necessary to look at these different communication techniques. In the following section the focus will be on analogue and digital communication.

2.3 Analogue transmission

Several types of signal transmission exist. This section will focus on analogue transmission. Analogue transmission can be obtained by directly transmitting the analogue information from the analogue source to the analogue destination via a baseband channel as shown in Figure 2-2. Another method that can be used to obtain analogue transmission is by modulating the analogue signal onto a carrier waveform and then moving the signal across the specified channel. When the information signal reaches the destination the signal is demodulated. This method of analogue communication is illustrated in Figure 2-3 [15].

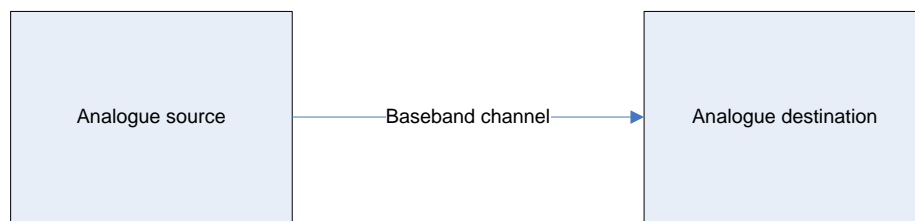


Figure 2-2: Analogue signal and baseband transmission [15]

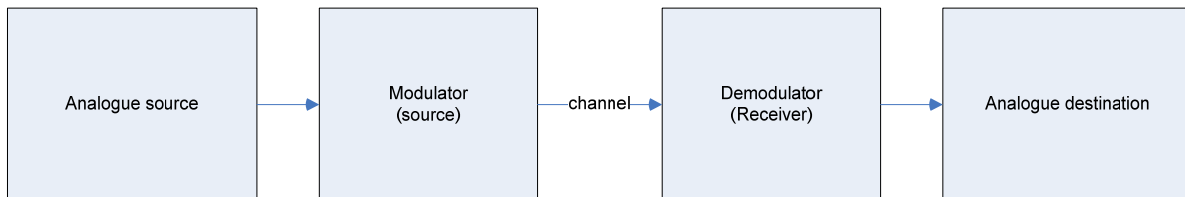


Figure 2-3: Analogue transmission using modulation and demodulation [15]

Although it seems sensible to implement analogue transmission when the source and destination is of type analogue, this is certainly not the case. A crucial disadvantage of implementing analogue transmission is, when noise is injected into the channel these effects cannot be removed and will only accumulate [15].

The conclusion can be made that if the specified system is to be implemented in a noisy environment it will certainly not be feasible to make use of analogue transmission. From here on forth the literature study will focus mainly on digital communication systems bearing in mind that the ADES will be situated in a very noisy environment.

2.4 Digital communication

Digital communication can be obtained by directly transmitting a digital signal over a digital channel as shown in Figure 2-4. *“In essence digital communication implies taking discrete, quantized samples of an original signal, transmitting the digital values and reconstructing the signal at the destination end”* [15] [17].

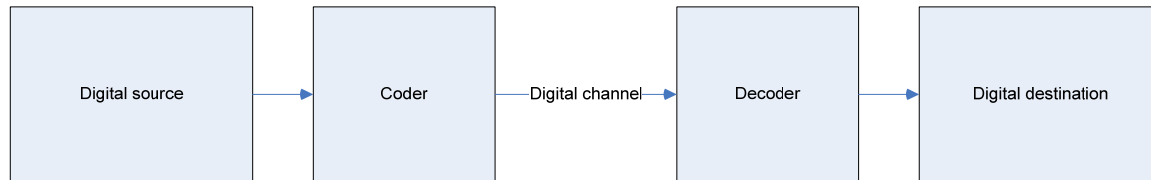


Figure 2-4: Digital signal transmitted over a digital channel [15]

Although it seems ineffective to convert data into a digital format before transmission occurs a crucial advantage does exist. The main advantage is that noise and distortion will not necessarily cause the system to receive the wrong information. Furthermore noise issues can be addressed and reduced by implementing repeaters and digital filters [15].

2.5 Analogue versus digital communication

Although digital communication uses more bandwidth than analogue communication, the benefits of implementing digital communication outweighs this disadvantage. Some of the key advantages are; simplicity, low power consumption, lower cost components and a lower signal to noise ratios [17].

2.6 Analysing and designing a communication system

Working with communication systems implies, analyzing and designing communication systems. Communication systems analysis focuses on evaluating the current performance of a communication system. Furthermore it focuses on designing a communication system according to given specifications [16].

When designing a new communication system the engineer faces various constraints, these constraints are, time-bandwidth constraints, noise limitations and equipment constraints [16]. Time-bandwidth constraints entail that as much data as possible must be sent in a very short time, else the communication system is considered to be inefficient. This however is not always possible.

Noise refers to unwanted electrical interference that corrupts the message signal. Noise can be divided into two sections, internal noise and external noise. Internal noise is generated by the components in the communication system itself and external noise is generated by external systems. Noise limitations, limits the information that can be correctly identified at the destination [16].

Time- bandwidth- and noise limitations do dictate the performance of communication systems. However one aspect that also effect communication performance is, equipment limitations. Which hinders communication system from reaching specified theoretical limits. For example the theoretical estimation of the data signalling rate of RS 485 is 20 Mbps, however to obtain this high data signalling rate is almost impossible due to equipment limitations and cost limitations [16].

“To conclude, bandwidth and signal-to-noise ratio constraints limit the maximum rate at which information transfer can take place in communication systems. Thus the designer has to come up with a signaling scheme that offers the best compromise between transmission time, transmitted power, transmission bandwidth, and equipment complexity while maintaining an acceptable level of performance.” [16]

2.7 Digital communication system

After studying analogue and digital transmission and concluding that implementing digital communication in the ADES will increase system efficiency, reliability and robustness the focus shifts towards understanding digital communication and learning more about the terminology used in the field. In this section common digital communication terms will be studied and thoroughly documented.

2.7.1 Digital transmission

“A digital transmission format has to specify four parameters” [17]:

1. Voltage range, voltage level to be associated with binary 1, and voltage level to be associated with binary 0.
2. Standard clock speed, to ensure that the transmitter and receiver check the digital line at the correct intervals for incoming data.
3. Timing methods.
4. Framing methods.

The following paragraphs will focus on the various timing methods that exist.

2.7.1.1 Asynchronous transmission

Asynchronous transmission is achieved by setting the receiver and transmitter clock to the same value. These two clocks are considered to be free running. The framing is set by a start bit where

after data follows, the frame is ended by a parity bit and a stop bit. After the stop bit is received the receiver and transmitter clocks are reset. Asynchronous transmission is usually implemented where data transfer is not tied to a specific transfer time. Asynchronous communication is illustrated in Figure 2-5.

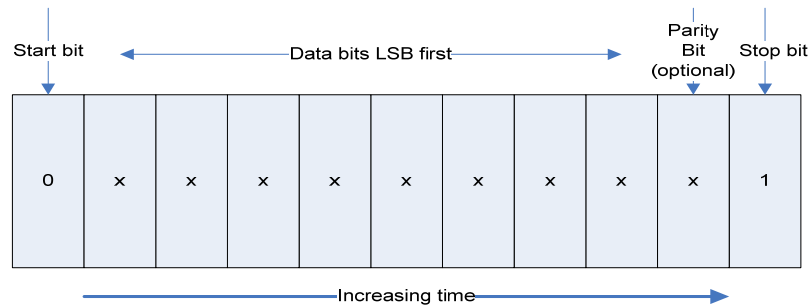


Figure 2-5: Asynchronous communication

Not all the received bits can be utilized by the receiver; it is because of this that the start bit, parity bit and stop bit are referred to as overhead. These bits reduce the efficiency of the communication system. Communication system efficiency can be calculated by using (2.1)

$$\eta = N_D / N_T \quad (2.1)$$

where η is efficiency, N_D is the number of data bits and N_T is the total number of bits.

2.7.1.2 Synchronous transmission

Synchronous transmission is achieved by synchronizing the receiver and transmitter clock frequency to be exactly the same. This is achieved by transmitting the clock and the data. This is a more complex method but requires no overhead in return, increasing the efficiency of the communication system. One of the greatest advantages of this method is that much higher data transfer speeds can be attained. Synchronous transmission is illustrated in Figure 2-6.

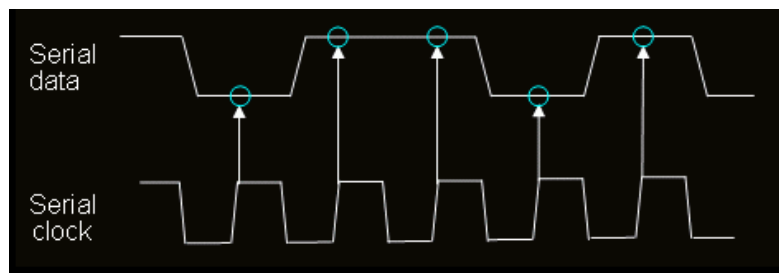


Figure 2-6: Synchronous transmission

2.7.1.3 Isochronous transmission

Isochronous transmission, transmits data that must be delivered uninterrupted and at the rate expected. Isochronous transmitters request an amount of bandwidth and a channel number. Once the bandwidth and channel have been allocated, the information is sent to the specific receiver. It is important to know that isochronous transmission takes priority over asynchronous traffic.

2.7.1.4 UART – Universal asynchronous receive and transmit

A UART is an integrated circuit used to convert parallel data from a computer or device into a serial form by adding start and stop bits and clocking the data out at the correct clock rate [15].

2.7.2 Data transmission

Data transmission can be defined as moving data from one location to another. When selecting the correct data transmission standard to use for a certain interface, two parameters need to be defined, speed and distance. The term distance can be defined as the distance between the source and the destination. The term speed can be defined as the rate at which data shifts from the source to the destination. Different systems have different specifications. Therefore it will be crucial to compare a diversity of data transmission standards [14].

Data transmission can take place by means of serial or parallel transmission. In order to select which data transmission standard will be suitable for the ADES, it is necessary to compare serial and parallel transmission. Furthermore it is necessary to study the advantages and disadvantages in order to select the best data transmission standard for the specified interfaces. Table 2-1 compares the two data transmission methods.

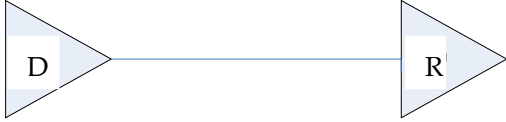
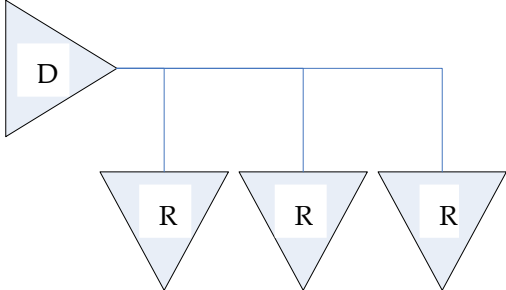
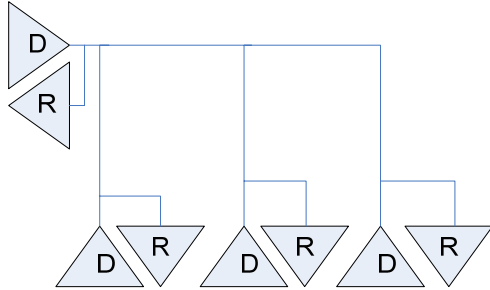
Table 2-1: Serial and Parallel data transmission comparison [14]

Data transmission type	Definition	Advantages	Disadvantages
Serial transmission	Serial data transmission can be defined as the data transmission method that transmits one bit at a time. Serial data transmission requires only a single channel.	<ol style="list-style-type: none"> 1. Requires only one channel for communication, making it more cost effective. 2. Line-to-line timing skew does not exist. (Line-to-line timing skew can be defined as the time difference between different signal paths for example if one bit reaches the destination before the other bits reach the destination.) 3. Saving on-board space, because fewer components are required. 	<ol style="list-style-type: none"> 1. Requires higher data signalling rate due to overhead. 2. As the serial link distance increases the data signalling rate will decrease.
Parallel transmission	Parallel data transmission can be defined as the data transmission method that transmits multiple bits simultaneously and requires multiple channels	<ol style="list-style-type: none"> 1. This method can obtain higher throughput, because multiple bits can be transmitted simultaneously. 2. Parallel transmission is widely used in industrial applications, due to the speed. 	<ol style="list-style-type: none"> 1. Link distance is limited. 2. If line-to-line timing skew does exist parallel transmission can be slower than serial transmission. 3. Increase in cost, because more conductors are required for parallel transmission

2.7.3 Data transmission topologies

Not only must the data transmission method be investigated thoroughly, but also the data transmission topologies. The specific data transmission topology that will be implemented will rely on two factors, the direction of transmission and the number of units present in the communication system. The various data transmission topologies are summarized in Table 2-2.

Table 2-2: Data transmission topology comparison

Data transmission topology	Definition	Figure
Point-to-Point (Simplex)	One transmitter is connected to one receiver per line. Only unidirectional data transfer is possible (simplex) [14].	 <p><i>D represents the driver</i> <i>R represents the receiver</i></p>
Multidrop (distributed simplex)	A point to point connection with one transmitter and many receivers per line. Only unidirectional data transfer is possible (simplex) [14].	
Multipoint (Duplex)	A connection where many transmitters are connected to many receivers. Bi-directional data transfer is also possible (duplex) [14].	

2.7.4 Electrical interface circuitry

Determining which electrical interface must be used is of utmost importance. Factors that will influence this choice are, the necessity of noise immunity, data transfer rate, communication link distance, simplicity of implementation and cost [14].

Currently there exist two types of electrical interface circuitry:

- Single-Ended transmission
- Differential transmission

2.7.4.1 Single-Ended transmission

Single-ended data transmission, also known as unbalanced transmission, requires one signal line. The logic state is interpreted with respect to ground [14]. Figure 2-7 shows the electrical interface circuitry of single-ended transmission.

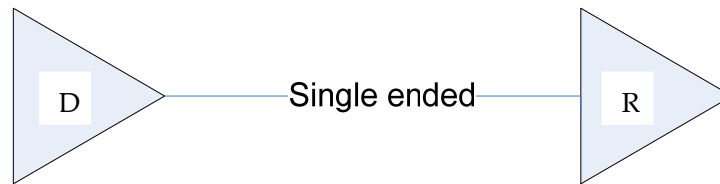


Figure 2-7: Single-ended transmission

2.7.4.2 Differential transmission

In order to understand more about differential data transmission it will be necessary to understand differential mode signalling first. Differential mode signals can be explained by the following equations as well as Figure 2-8 [18].

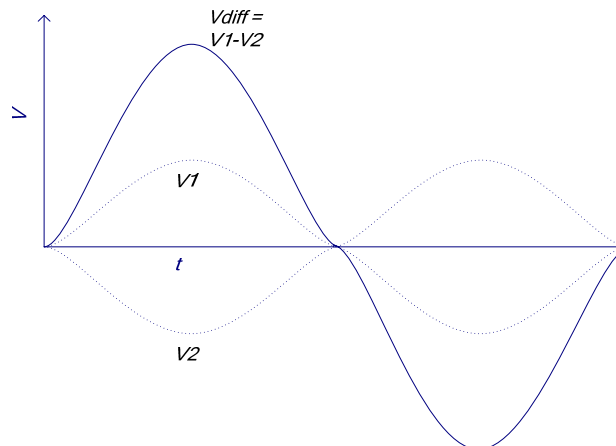


Figure 2-8: Differential mode signalling

Consider a two-wire cable terminated at the end by a load impedance of R_L

$$V_1 = -V_2 \quad (2.2)$$

$$0 = V_1 + V_2 \quad (2.3)$$

$$V_{DIFF} = V_1 - V_2 \quad (2.4)$$

Current does not flow to the ground, due to the symmetry of V_1 and V_2 about ground as illustrated in Figure 2-8. The instantaneous sum of V_1 and V_2 is always zero. It is important to note that in cable based transmission systems the differential mode signal is the “wanted” signal that carries the relevant information [18].

The conclusion can be made that, differential data transmission requires a pair of signalling lines for each channel as well as a signal return path as can be seen from Figure 2-9. One line is used to transmit the true signal, V_1 and another line to transmit the inverted signal, $-V_2$. At the destination the receiver detects the voltage difference and the output is switched according to the most positive input line. Differential data transmission can also be referred to as balanced transmission. Due to the balanced interface circuitry noise immunity can be achieved. This is possible, because the same noise is induced into both the signal lines (V_1, V_2), thus yielding rejection of the noise. This phenomenon is referred to as the common mode rejection capabilities of differential transmission [14].

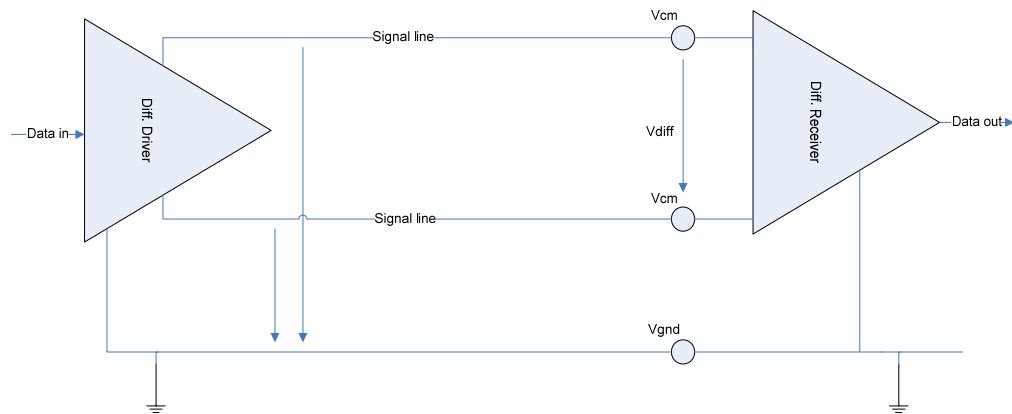


Figure 2-9: Differential transmission

2.7.4.3 Differential transmission versus single ended transmission

In order to decide which electrical interface circuitry will best suit the ADES it is important to compare the different advantages and disadvantages of single-ended transmission and differential transmission.

Table 2-3: Differential transmission versus single ended transmission

Transmission method	Advantages [14]	Disadvantages [14]
Single ended	<ol style="list-style-type: none"> 1. Simplicity 2. Low cost, because it requires only one transmission channel. 	<ol style="list-style-type: none"> 1. Reduced noise immunity, due to the fact that the ground wire forms part of the system which can induce shifts in voltage potential. 2. Increased susceptibility to electromagnetic fields. 3. Increased susceptibility to crosstalk, becoming more severe at high frequencies. 4. Increased susceptibility to external noise. 5. "Radiation of electro-magnetic interference is increased compared to differential systems". [14]
Differential	<ol style="list-style-type: none"> 1. Decreased susceptibility to common-mode noise due to common mode noise rejection capabilities. 2. Rejection of external noise. 3. Decreased radiation of electro-magnetic interferences. 4. In combination with correct line termination it can obtain very high data signalling rates. 	<ol style="list-style-type: none"> 1. Increased cost 2. Due to high data signalling rate, it is vital to define the line impedances correct to avoid line reflections.

2.7.5 Data signalling rate, data signalling frequency and data transfer rate

Apart from determining the optimum data transmission method, data transmission topology and electrical interface circuitry, it is also important to determine these parameters; *data signalling frequency, data signalling rate and data transfer rate*. Considering that timing is one of the most important specifications in communication systems it is imperative to determine these parameters to ensure that the selected data transmission standard can realize the timing requirements. These three parameters are shortly explained here after.

2.7.5.1 Data signalling frequency

“The data signalling frequency can be defined as $\frac{1}{2T}$, where T is the minimum interval and is expressed in Hertz (Hz).” [19]

2.7.5.2 Data signalling rate

“The data signalling rate can be defined as $\frac{1}{T}$; where T is the minimum unit interval and is expressed in bits per second (bit/s).” [19]

2.7.5.3 Data transfer rate

“The data transfer rate can be defined as the number of desired bits of data received per unit time. It may be different from the data signalling rate, which uses the same units.” [19]

2.7.6 Data transmission standard

In Section 2.7.2 the term data transmission has already been defined. It is imperative to recognize that countless data transmission *standards* exist. These data transmission standards define important information of exactly how the information is transferred between the source and the destination. The basic specifications of busses include [13];

- Electrical specifications - the voltages ranges.
- The maximum communication distance between the source and the destination.
- The maximum data transfer rates that can be achieved.
- Physical layer specifications (cabling solutions).
- Transmission type.
- Protocol specifications.
- Transmission topologies.

Well known data transmission standards that exist are, RS 232, RS 422 and LVDS. These data transmission standards can also be referred to as busses. The term busses can be defined as the part of a computer that allows devices to easily be plugged into computers, and allow orderly flow between one device and another. Each bus in a system performs a certain function and is more suitable for certain applications. The following parameters specify different busses [13];

- Data rate – defines the maximum amount of data that can be transferred at a time.
- Maximum number of devices which connect to the bus – for example how many slaves and masters can be linked to the bus.
- Bus reliability - the ability of the bus to detect errors.

- Data robustness- the ability of a bus to isolate faulty devices.
- Electrical robustness – the ability of the bus to cope with electrical faults, for example surges.
- Electrical characteristics – the voltages ranges.

2.7.6.1 *Types of busses*

There exists a vast amount of busses; busses can be divided into four types [13];

- PC busses/ internal busses – Internal busses connects the processor to its memory.
- Local busses / External busses – External busses allow systems or devices to connect to computers or embedded systems.
- Instrumentation busses.
- Network busses.

From here on each of the busses that will be investigated and documented will be classified into these four types.

2.8 Open Systems Interconnection (OSI) reference model

Communication systems can be divided into a layered structure. Each of these vertical layers perform a certain task and functionality to enable one system to communicate with another system. The functions in each layer are collected into groups referred to as entities. These entities in the same layers enable communication between systems using protocols. The term protocol can be defined as the rules that enable transferring of information [20].

This layered communication architecture was developed by the International Organization for Standardization (ISO) and is called the OSI (open systems interconnect) model. The objective of developing this model was to attempt to define and standardize data communication. Although almost all real-world implementations deviate from this reference model in order to accommodate specific application requirements, it is still considered crucial for any communication engineer to study and understand this model. The reason being to ensure that the standardized data communication methods are understood and implemented correctly, as well as **getting** a new developed standard as near as possible to this model to encourage standardization of data communication. The seven layers the OSI model consist of are;

1. **Application layer, presentation layer and session layer**

The session, presentation and application layers are closest to the user and can be addressed simultaneously. The session layer includes establishment, management and termination of

application connections. Functionalities incorporated in the presentation layer are data encryption, data decryption and data compression. Lastly the application layer provides end-user services such as mail and file transfer [21].

2. Transport layer

The transport layer provides network independent, end-to-end integrity between two modules communicating through networks. This is done by providing effective error detection and correction with reliable delivery of packets. These functions are implemented by using software [22].

3. Network layer

The network layer is responsible for delivering the data packets between the source and the destination. Considering that this layer is network independent, it is able to effectively communicate between different communications networks for example an Ethernet network can communicate with an ISDN network. This specific layer can use either software or hardware to determine the correct or optimal route between the source and the destination [22].

4. Data link layer

It is a well known fact that the physical layer is inherently unreliable and vulnerable to electrical noise. The data link layer therefore helps to provide reliable transmission of frames between peer nodes by incorporating error detection by using cyclic redundancy checks (CRC). These framing and error detection methods are mainly implemented by hardware controllers. However some of these methods used must be implemented by using software coding [22].

5. Physical layer

The physical layer defines the hardware used to transmit data between various modules. Parameters that are defined include; defining the transmission lines, electrical specifications, voltage levels, mechanical components and signalling pins [22].

2.9 Data transmission standards

Although numerous data transmission standards exist, only a selected few will be documented in this section to avoid a lengthy dissertation. The documented standards are relevant to this specific project.

2.9.1 RS 232

The RS 232 standard is considered to be one of the most popular and straightforward standard [14]. All the important information about the RS 232 standard is discussed in

Table 2-4

Table 2-4: RS 232 standard specifications

Characteristic	Specification
Data transmission method	Serial
Transmission topology	Point to point connection (Simplex)
Data signalling rate	512 kbps
Distance	20 m
Bus type	Local bus
Electrical	The RS 232 standard has high signal amplitudes (± 5 V to 15 V) and triggering commences only after the receiver receives an input of greater than 3 V or less than -3 V.
Protocol	The RS 232 data transmission standard not just specified the electrical-layer, but also the pin connector and the protocol. RS 232 incorporates asynchronous communications in conjunction with a start/stop data format [13].

2.9.2 RS 422

The RS 422 data transmission standard can be considered an upgrade of the RS 232 data transmission standard. This standard allows a distributed simplex transmission topology which can establish communication to ten receiving devices, unidirectional. In Table 2-5 the basic standard specifications are listed. The RS 422 is once again only an electrical standard, thus it cannot be categorized as a complete interface standard.

Table 2-5: RS 422 standard specifications

Characteristic	Specification
Data transmission method	Serial
Transmission topology	Multidrop (distributed simplex)

Data signalling rate	10 Mbps
Distance	10 m (up to 1200 m with lower data signalling rate capabilities)
Bust type	Local bus
Electrical	<p>When implementing the RS 422 data transmission standard, signalling rates of 10 Mbps can be obtained over short connection distances. However if a certain application requires long connection distances the data signalling rate will decrease drastically. RS 422 is a differential transmission method.</p> <p>The electrical specifications entail that the output must supply at least 2 V then the receiver will detect the bus state with as little as 200 mV differential and up to 7 V common-mode signal [14]. The interface connection medium that is commonly used in conjunction with the RS 422 standard is twisted-pair. Figure 2-10 illustrates the balanced interface circuitry of the RS 422 data transmission standard.</p>
Protocol	RS 422 is only an electrical specification, thus no protocol is specified. It is advised that the RS 422 standard is used in conjunction with other higher level standards.

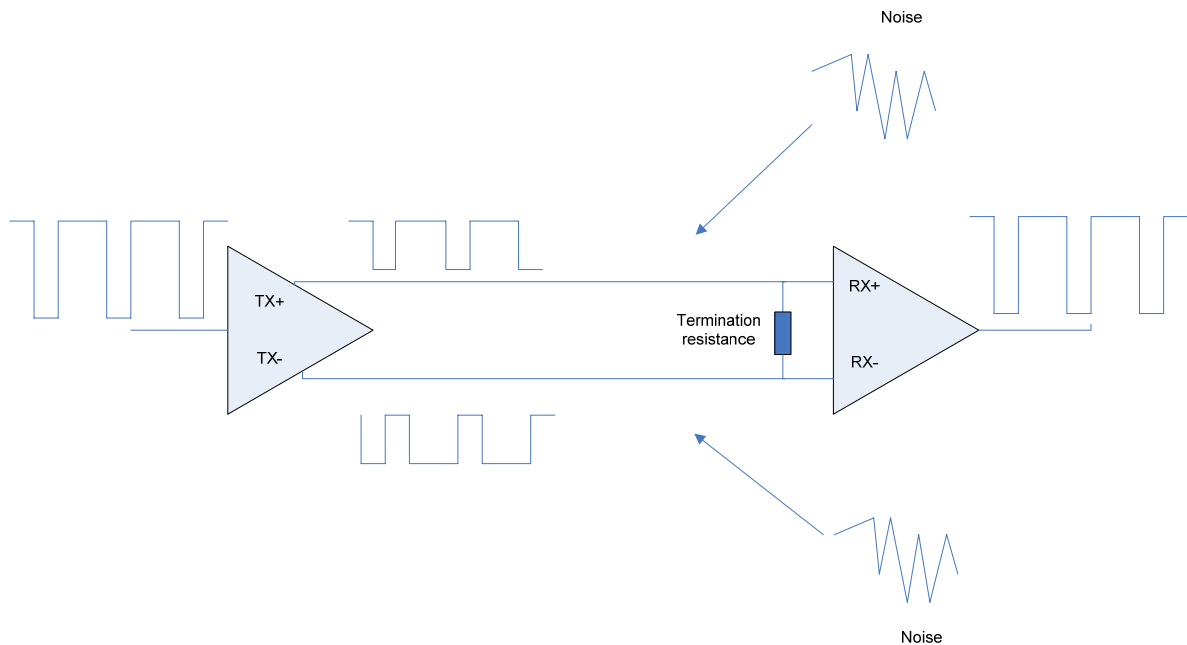
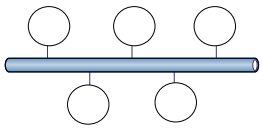


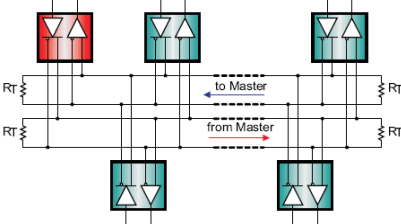
Figure 2-10: Balanced interface circuitry

2.9.3 RS 485

The RS 485 data transmission standard was developed after the RS 422 standard. Although the RS 422 was an improvement on RS 232 it still lacked the capability to transfer data bi-directionally. This resulted in the development of the RS 485 data transmission standard that enabled bi-directional communication. This was not the only improvement to the RS 422 standard; the RS 485 also supports higher data transfer rates up to 35 Mbps as well as a communication link distance of over 1 km. It must however be noted that both these limits cannot be achieved simultaneously. Why this limitation exists will be discussed in Section 2.10. In Table 2-6 the basic standard specifications are listed.

Table 2-6: RS 485 standard specifications

Characteristic	Specification
Data transmission method	Serial – Asynchronous
Transmission topology	Multipoint
Data signalling rate	35 Mbps
Distance	10 m (up to 1200 m with lower data signalling rate capabilities)
Bust type	Local bus
Electrical	<p>The RS 485 standard defines the electrical characteristics of the interconnections, the driver, line and the receiver. The standard requires that the drivers must deliver a minimum differential output voltage of 1.5 V across a 54 Ω load [23]. The common-mode voltage level of the bus can vary between -7 V and 12 V and the receiver must be sensitive enough to determine an input down to 200 mV allowing correct data transmission even if the signal degrades tremendously across the cables and the connectors.</p> <p>The standards suggest that the nodes should be connected in a daisy chain (direct run from chassis to chassis) or as a bus topology structure [23]. This bus network connection can be seen in Figure 2-11 where the receivers, transmitters and drivers connect to a main cable.</p> 

	<p style="text-align: center;">Figure 2-11: Bus topology</p> <p>Although RS 485 is considered to be a half-duplex interface, it can also be designed to function as a full-duplex interface. The full-duplex interface as shown in Figure 2-12 will require four wires in order to establish two signal paths [23].</p> <div style="text-align: center;">  </div> <p style="text-align: center;">Figure 2-12: Full-duplex bus structure for RS 485 [23]</p> <p>The interconnection media is the part of the system that connects the interface points. Interconnection media include cables, connectors and terminations. Any interconnection media can be used however it must be noted that it will have an effect on the performance of the data transmission method. The RS 485 design guide recommends the use of sheathed, unshielded twisted-pair cables, since this particular cable avoids two very common problems, radiated EMI and received EMI.</p>
Protocol	<p>It is important to note that the RS 485 is only an electrical standard excluding the protocol, thus it cannot be categorized as a full interface standard. It is however advised to use the RS 485 with higher level standards for example the DL/T645 which defines the protocol for electronic energy-meters in China [23].</p>

2.9.4 Serial peripheral interface (SPI)

The SPI bus is a data transmission standard used to communicate between devices such as Field programmable gate arrays (FPGAs), ADCs and DACs over relatively short distances at high data transmission rate. Figure 2-13 shows how a typical SPI functions by using four lines. The four lines are SPICLK (clock), SIMO (slave in master out), SOMI (slave out master in line) and SS (slave select). The master provides the clock (SPICLK), the slave provides the data via the SOMI and the master controls the data flow by actively switching the SS to low. Data flow can be duplex as shown in Figure 2-13 when four lines are used, however it can also be simplex when three lines are used [24].

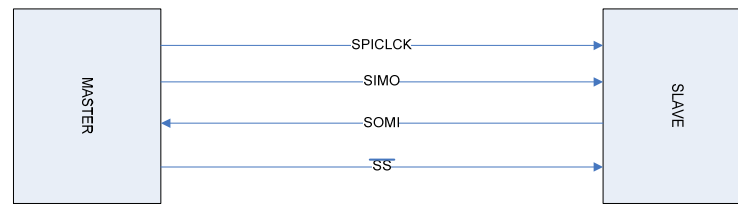


Figure 2-13: SPI configuration

Table 2-7: SPI standard specifications

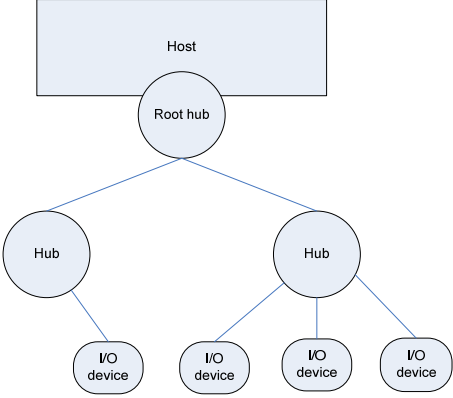
Characteristic	Specification
Data transmission method	Serial - Synchronous
Transmission topology	Point to point connection
Data signalling rate	Up to 50 MHz (depending on the hardware)
Distance	Very short distances (preferably onboard)
Bust type	Local bus
Protocol	SPI is a synchronous protocol which allows a master to commence communication with a slave device where after data is exchanged [25].

2.9.5 Universal serial bus (USB)

USB is a complex data transmission standard that enables bi-directional, serial data transmission against very high data transfer rates [26]. Two different USB standards exist, USB1 which supports full speed mode and USB2 which supports high speed mode. USB2 is fully backwards compatible with USB1 devices.

Table 2-8: USB standard specifications

Characteristic	Specification
Data transmission method	Serial
Transmission topology	The USB architecture layout is relatively simple and requires a root hub to which devices can connect. From here on point-to-point connections are used to connect the different devices. Figure 2-14 illustrates the tree structure topology. Each of the connected devices communicates with the host as if it has its own connection.

	 <p style="text-align: center;">Figure 2-14: USB system architecture</p>
Data signalling rate	12 Mbps (full speed mode) 480 Mbps (high speed mode)
Distance	5 m
Bust type	Local bus
Protocol	<p>This particular data transmission standard implements an advanced protocol that implements a polled bus which implies that the host controller starts all data transfers. Each data transfer transaction involves three packets. The first packet (token packet) describes the type, direction, address and the endpoint. Only one of the devices then replies by sending the data. The destination replies with a handshaking packet indicating successful data transfer. The one essential assertion that must be made is that this data transmission standard is in a totally different league than the previously mentioned data transmission standards, considering that it includes a detailed protocol that incorporates error detection methods, error correction methods and so much more specifications that provide efficient communication [14].</p>

2.9.6 Low voltage differential signalling (LVDS), LVDS – multi point (LVDM) and

Multi-point LVDS (M-LVDS)

In this section three data transmission standards will be discussed. Each of these three data transmission standards implements low voltage differential signalling. LVDS is a differential data transmission method that uses lower voltage swings. RS 422 is also a differential data transmission method with one crucial difference; it is not able to reach the same data transfer rate. By lowering the voltage swing the LVDS data transfer rate is increased drastically [27].

LVDM stands for LVDS – multipoint, implicating that the data transmission standard has the same properties as LVDS with just one added feature; it enables half-duplex operations at the same speed and voltage levels. LVDM is a standard available for Texas Instruments exclusively.

M-LVDS is an enhanced version of LVDS which led to the development of a new TIA standard (TIA/EIA 899) which can support multipoint bus configurations. This was done by modifying the electrical specifications of the LVDS standard [14]. The various specifications of each of the data transmission methods are listed in Table 2-9.

Table 2-9: Basic low voltage standard specifications

Specifications	LVDS	LVDM	M-LVDS
Data transmission method	Serial	Serial	Serial
Transmission topology	Point to point	Multipoint	Multipoint
Data signalling rate	400 Mbps	400 Mbps	500 Mbps
Distance	0.5 m (~30 m)	0.5 m (~30 m)	0.5 m (~30 m)
Bus type	Local bus	Local bus	Local bus
Electrical	As previously mentioned LVDS utilizes low voltage differential transmission with low signal amplitudes. The voltage swing is in the range of 350 mV, generated on a 100 Ω termination resistor. A driver can also be selected that delivers a current mode value between 2.47 mA and 4.54 mA. The specified common mode range is between 0 V and 2.4 V [14].	LVDM is LVDS with doubled driver output currents. Bi-directional communication is enabled so line terminations must be present on both ends of the line. Doubling the line terminations entail that the output currents must be doubled in order to obtain the required amplitude on the loads [14].	The differential output voltages of the drivers are between 480 mV and 650 mV across a load of 50 Ω . For more information about the electrical specifications refer to the TIA/EIA 899 standard document.
Protocol	No protocol specified, electrical standard only [14].		

2.9.7 PCI and CompactPCI (Peripheral Component Interconnection)

The main goal was to develop a local bus that had the following requirements; low cost, flexibility, high performance and low power dissipation. These requirements led to the development of the PCI bus. The Personal Computer (PC) industry was the first area that used this as a local bus to connect the internal devices in PCs. After PCs standardized to PCI as their local bus, the PCI bus became a major player in the industrial area, prompting the development of a new local bus standard – CompactPCI. CompactPCI is also a high performance industry local bus that originates from the PCI bus which implements the Eurocard form factor as well as hot swappable capabilities [28].

Table 2-10: PCI specifications [28]

Characteristic	Specification
Bus type	Local bus
Data signalling rate	The PCI bus uses 32 bit address space and a 32 or 64 bit data path. The bus clock speed can be either 33MHz or 66MHz. A maximum data rate of 1 Gbps can be achieved for a 32 bit data path and a 33MHz bus clock speed. A maximum data rate of 4 Gbps can be achieved for a 66MHz bus clock speed and a 64 bit data path.
Data transmission method	Parallel
Electrical	The bus can function at 5V or at 3.3V. It is important to note that the electrical specifications of CompactPCI are exactly the same as the PCI bus [14].
Protocol	It is imperative to know that before a PCI bus can become operational each of the devices needs to be configured. After configuration any device can become the master and can transfer data between the different configured devices. This bus requires burst transfer to be efficient. It must be noted that the specifications of CompactPCI are exactly the same as the PCI bus [14].
Distance	0.2 m

2.9.8 Comparing local bus solutions

In Table 2-11 the different local busses are compared.

Table 2-11: Tabulated local bus comparisons [14]

Standard	Advantages	Disadvantage	Applications
RS 232	<ol style="list-style-type: none"> 1. Simplicity of the protocol. 2. Low cost. 	<ol style="list-style-type: none"> 1. Very low data signalling rates. 2. Short connection distance. 3. Extensively susceptible to noise. 4. Not viewed as a technologically advanced bus. 	RS 232 was mainly used to interface slow peripheral devices with computers. Today it is widely used to program certain devices as well as construct basic tests.
RS 422	<ol style="list-style-type: none"> 1. Lower susceptibility to noise due to balanced interface circuitry. 2. Can reach higher data signalling rate. 3. Can communicate over longer distances. 	<ol style="list-style-type: none"> 1. Requires additional hardware when implementing two-way communication. 2. Only ten receivers can connect to one transmitter. 	This specific standard can be used to create computer networks or where a direct connection is desired in the presence of ground noise [14].
RS 485	<ol style="list-style-type: none"> 1. Robust against electrical noise [14]. 2. High level of data integrity. 3. Low radiated emissions. 4. Up to 256 nodes can connect on the bus. 5. Communication link can be up to 1 km. 6. Wide common mode voltage range. 	<ol style="list-style-type: none"> 1. Signalling rate is not as fast as other standards i.e. M-LVDS. 	The RS 485 standard can be implemented in industrial environments where an economical rugged interconnection between two or more modules is required. It can also be implemented to share data between single board computers, communication processors, sensors and actuators [29].

SPI	<ol style="list-style-type: none"> 1. Synchronous data transmission, allowing faster data transfer rates. 2. Relatively simple transmission protocol. 	<ol style="list-style-type: none"> 1. Bi-directional communication requires four lines per device. 2. Can only communicate over short distances. 	It is an ideal solution when implementing digital communication between FPGAs, ADCs and DACs.
LVDS	<ol style="list-style-type: none"> 1. Lower susceptibility to common-mode noise due to implementation of differential data transmission method. 2. Tends to radiate less noise due to implementation of differential data transmission methods. 3. Higher data transfer rates can be achieved due to lower voltage swing. 4. Lower power consumption. 5. FPGAs consist of built in LVDS drivers. 6. Reduced EMI susceptibility [30]. 	<ol style="list-style-type: none"> 1. LVDS is restricted for use over long distances due to the common-mode input voltages limitations. [14] 2. It is not advised to implement LVDS in electrically noisy environments [14]. 	LVDS is suitable for applications that require low power or low EMI.
LVDM	<ol style="list-style-type: none"> 1. Similar advantages as LVDS 2. Enables bi-directional communication 	Similar disadvantages of LVDS	It is advised to implement LVDM when the specified application requires bi-directional communication, over a connection distance of 30 m as well as obtain high data transfer rates [14].
M-LVDS	Lower power consumption	<ol style="list-style-type: none"> 1. M-LVDS is restricted to shorter distances due to the lower operating voltages and it is still advised to use RS 485 for longer distance applications [24]. 2. Cannot provide the noise immunity which RS 485 can provide [24]. 	Implement this data transmission standard under the following circumstances: <ol style="list-style-type: none"> 1. A multipoint bus configuration is necessary. 2. High data transfer rate is required. 3. Low power consumption is of the essence. 4. If it is necessary to minimize EMI
USB	<ol style="list-style-type: none"> 1. Ideal for portable systems. 	<ol style="list-style-type: none"> 1. Cable distances are limited to 5 m. If 	USB is an ideal data transmission standard that can

	<ol style="list-style-type: none"> 2. Hot swapping is possible. 3. Up to 127 devices can connect to one port. 4. High data transfer rates can be achieved making it compatible with high-speed peripherals. 5. Standard incorporates a detailed protocol. 	<p>longer distances are required repeaters is necessary - increasing system cost.</p> <ol style="list-style-type: none"> 2. Not compatible with older peripherals. 3. Slower than PCI. 4. Very complex protocol which requires a great deal of overhead. 	<p>be used to interface peripherals with PCs [14].</p>
PCI	<ol style="list-style-type: none"> 1. Can reach bandwidths up to 264 Mbps. 2. Low power consumption between 5 V and 3.3 V. 3. Low cost due to the multiplexed architecture which reduces pins and package size. 4. Is relatively easy to use, because of the broad operating system and application software support. 	<p>Connection distances are short because of reflected wave switching. If a longer distance is required PCI-to-PCI bridges are required.</p>	<p>Due to the tremendous amount of success this bus received in the PC industry it is suggested to be used as a computer bus system [14].</p>
Compact PCI	<ol style="list-style-type: none"> 1. Hot swappable. 2. Supports twice as many PCI slots. 3. Uses the Eurocard form factor which is durable and rugged[28]. 4. Is ideal to implement in industrial environments. 	<ol style="list-style-type: none"> 1. Cannot obtain the same bandwidths as PCI. 2. Requires a special adapter to connect to PCs [31]. 5. Incompatible with older system. 	<p>It is recommended to implement the CompactPCI form factor in industrial computer applications as well as in the telecommunication industry [28].</p>

2.9.9 Profibus

Profibus is an international fieldbus dedicated to acquire data as well as control sensors and actuators. Although numerous fieldbus solutions exist, the focus will be on Profibus, bearing in mind that it is one of the world's most popular fieldbus solutions in discrete manufacturing and process control with as much as 20 million devices installed worldwide [32]. There exist three Profibus variants; Profibus-FMS (Fieldbus message specification), Profibus-DP (Decentralized periphery) and Profibus-PA (Process automation) [33]. Table 2-12 will discuss the various standard specifications and Table 2-13 will list the advantages, disadvantages and application fields.

Table 2-12: Profibus specifications

Characteristic	Specification
Data transmission method	Serial
Transmission topology	Bus topology (most common topology implemented)
Data signalling rate	9.6 kbps – 12 Mbps (maximum data transfer speed of Profibus –DP)
Distance	Depends on the transmission medium implemented ¹
Bust type	Instrumentational bus
Protocol	Profibus also implements a very complex protocol including error detection and correction methods. However the protocol will not be discussed in detail.
Electrical	The three Profibus variants use the same transmission technique - RS 485. The electrical characteristics were already discussed in Section 2.9.3. The transmission media that are commonly used in Profibus systems are; shielded twisted pairs or fibre optics [33].

Table 2-13: Profibus variants comparison

Variant	Advantages	Disadvantages	Applications
Profibus-FMS	<ol style="list-style-type: none"> 1. Provides a wide variety of functions. 2. Is the ideal variant to implement when the 	<ol style="list-style-type: none"> 1. Complex to implement against the other Profibus variants. 2. Does not include 	It is advised to use for complex communication tasks between automation systems

¹ Twisted pair cabling can reach 1200 m without repeaters.

	communication task is complex.	transmission techniques that include safe installation methods. 3. The field devices cannot be powered over the bus cables.	operating at average transmission speeds.
Profibus-PA	<ol style="list-style-type: none"> 1. The field devices are powered by the bus cable. 2. Very reliable data transmission method 3. Interoperability 4. Intrinsically a safe transmission technique. 	Data transfer rates are extremely slow.	Profibus-PA is the Profibus variant used to meet special requirements of process automation [33]. Usually this variant is embedded in a Profibus-DP system.
Profibus-DP	<ol style="list-style-type: none"> 1. Profibus-DP is the high speed Profibus solution. 2. Is the ideal variant to implement when the communication task is complex. 	<ol style="list-style-type: none"> 1. Does not include transmission techniques that include safe installation methods. 2. The field devices cannot be powered over the bus cables. 	This is the Profibus variant to select when the network consists of automation systems and decentralized field devices which require time critical communication.

2.10 Limitations of busses

It is important to thoroughly investigate the different limitations of various bus solutions, in order to select the correct busses for the ADES. Important bus limitations that exist are data transfer rate and bus length. Maximum bus length and data signalling rate are limited by transmission line losses. Transmission line losses include losses due to attenuation, jitter and drift. Jitter and drift are classified as timing errors that exist on digital waveforms. In order to ensure reliable and accurate digital communication it is necessary to understand these concepts thoroughly.

2.10.1 Attenuation

The maximum transmission line length is limited by various factors. The most important factors are transmission line losses, data signalling rate and attenuation. Transmission line losses include the voltage drop due to the resistance in the conductors. If the resistance causes the receivers differential voltage input to drop below the threshold, the signal will not be recovered. As the distance increases the resistance will increase until the minimum voltage level necessary for the driver to detect data transmission will not be obtained. There exists no simple electrical model for attenuation with data signalling frequency and the designer should determine these effects empirically. Figure 2-15 shows how the cable length decreases as the data signalling rate increases for various data transmission standards.

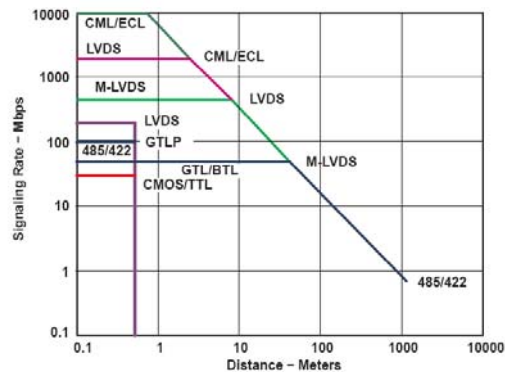


Figure 2-15: Signalling rate vs. cable length [14]

2.10.2 Jitter

The term jitter can be defined as the deviation from ideal timing of an event and can be measured from the zero-crossing of a reference signal or clock signal. Crosstalk, simultaneous switching of outputs and other interfering signals cause jitter. Jitter varies over time and can be measured or quantified by using different methods [34]. Methods that can be used to quantify jitter are:

- Visual estimation of jitter on an oscilloscope in jitter per second.
- A statistical-based measurement based on the standard deviation over time.
- Visual inspection of eye diagrams.

Figure 2-16 illustrates the effect of jitter. Bearing in mind the ADES consists of various sub-systems there will certainly be interfering signals that cause jitter, thus it will be of crucial importance to monitor this effect.

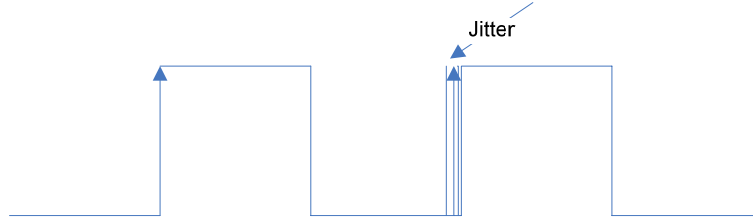


Figure 2-16: Jitter

2.10.3 Drift

Drift occurs when there is a difference between the transmitter's and receiver's clock. This effect only becomes noticeable after numerous clock periods or at the end of a lengthy transmission line. Clock accuracy is measured in parts per million or parts per billion. Assuming that the clock generated in the FPGA is 100 MHz with 25 ppm accuracy, the generated clock frequency will be 100 MHz \pm 2.5 kHz. If data is acquired for 5 s then the units will be out of synchronization with up to 500 μ s. Once again it will be necessary to monitor this effect closely in the ADES.

2.11 Transmission lines

A communication system consists of three basic elements, a transmitter, receiver and a channel. This channel can be referred to as a transmission line. The term transmission line can be defined as any configuration of wires and conductors that carry opposing currents. Transmission lines are commonly found in electrical systems and commonly take the form of cables, such as twisted pair, coaxial, microstrip and two-wire. The ADES consists of various functional units that need to be connected by means of transmission lines. For example a specified transmission line will be used to connect the ten power amplifiers with the main controller.

In the next section different types of transmission lines will be discussed. Ultimately assisting in the selection of the optimal transmission line for this specific application.

2.11.1 Types of transmission lines

Various cables can be used to connect the different devices situated in the ADES. In this section the most common cables that are used in data transmission systems will be discussed. These types include; coaxial cables, two-wire cables, twisted-pair cables, optical fibre and planar transmission lines.

2.11.1.1 Coaxial cables

Coaxial transmission lines are commonly used transmission lines. A coaxial cable consists of a solid centre conductor which transports the data surrounded by a dielectric (insulator) core and an outer conductor. The outer conductor can be either solid or braided and is usually grounded at one or both ends [35]. Figure 24 is an illustration of a coaxial cable.

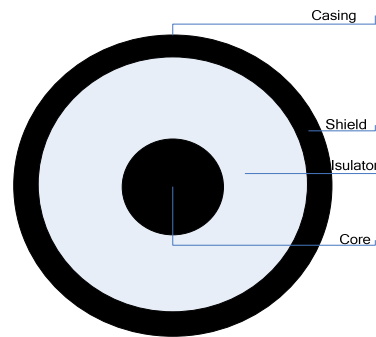


Figure 2-17: A coaxial cable.

Coaxial cables are able to transmit data over long distances and against high data transmission rates, because of the advanced shielding. The casing protects the cable from external environmental noise; the shield surrounds the cable and protects the data transmitted on the medium from interference that can degrade the data integrity. The insulator surrounds the core and is made of dielectric materials that prevent contact with the shield in order to prevent electrical interaction. Finally the core transports the data [36].

2.11.1.2 Two wire (Parallel conductors)

Two wire transmission lines imply that both of the conductors are similar and have the same relationship to ground, therefore they can be referred to as balanced transmission lines. This type of transmission lines are not shielded and are highly susceptible to noise. However the inductive coupling to outside sources can be limited by twisting the wires.

A twisted pair transmission line consists of two insulated wires twisted together to form a flexible line without the use of spacers. Two types of twisted pair cables are recognized; Shielded twisted pair (STP) and Unshielded twisted pair (UTP).

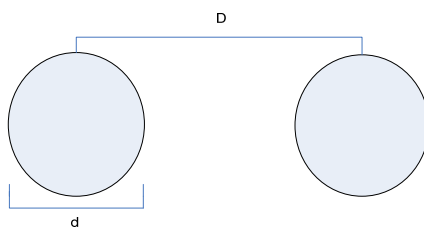


Figure 2-18: A two-wire transmission line

Twisted pair cables as shown in Figure 2-19 are often made of several twisted pairs grouped together inside a protective jacket. The twisting eliminates noise. It is recommended to use twisted pair cables in local networks with few nodes. Implementing unshielded twisted pair (UTP) cables are simple and low cost; however it is strongly advised not to implement this cabling solution when transmitting at high frequencies over long distances, because data integrity is not guaranteed [36].

Shielded twisted pair cables as illustrated in Figure 2-20 implements a better quality copper jacket providing more protection. STP cables also contain protective envelopes between each pair and around each pair. Each STP pair is twisted providing excellent shielding and more protection against interference. It is advised to use STP cables when faster data transmission is necessary over longer distances.

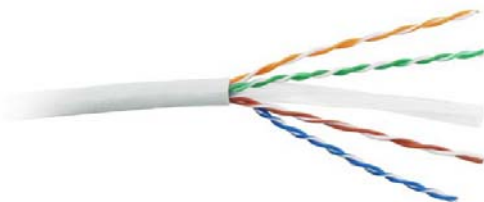


Figure 2-19: Unshielded twisted pair

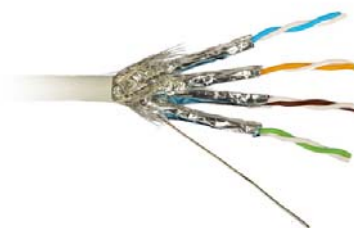


Figure 2-20: Shielded twisted pair

2.11.1.3 Fibre optic

Fibre optics has various advantages including; noise immunity, low attenuation and high data transfer rates over long distances. Fibre optics is one of the most cutting edge data transmissions cabling solutions in the new communication however it is very expensive, difficult to install and requires special training and tools [37].

2.11.1.4 Planar transmission lines

Transmission lines found on circuit boards are mostly planar transmission lines where the conductors lie on a flat dielectric sheet. An example of a planar type transmission line is microstrip lines. Microstrip transmission lines are the most popular transmission lines used on printed circuit boards due to their attractive electrical properties and simple fabrication methods. Figure 2-21 shows a microstrip transmission line [35].

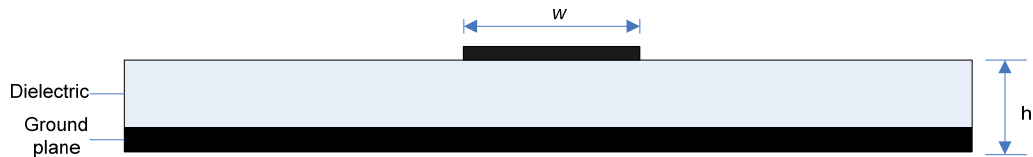


Figure 2-21: A microstrip transmission line

2.11.2 Transmission line modelling

If a transmission line is connected to a source electrical and magnetic fields are induced. These fields are functions of the cross sectional dimensions of the specified line, the materials used in the line, the operating frequency on the line and the nature of the source. [35]. An infinite number of field patterns can be generated; each of these patterns is referred to as modes. These modes can be classified under three classes; TEM modes, Quasi TEM modes and waveguides

First the concept TEM transmission lines needs to be defined. The term TEM stands for transverse electromagnetic also well-known as transverse electric and magnetic [38]. This refers to a phenomenon where the electric and magnetic fields are parallel to a boundary plane, excluding any longitudinal components of either field [39]. Transverse electromagnetic lines are lines with homogenous dielectrics and no losses. A dielectric can be defined as a material that can sustain an electric field and act as an insulator [40].

Transmission lines can also be classified into Quasi-TEM lines if the dielectrics are considered non-uniform. Even though these transmission lines are dominantly TEM they still consist of a longitudinal component when operating above dc. In this case the transmission lines cannot only be controlled by the dielectric constant of the particular material used, but also how the materials are configured. Examples of Quasi-TEM lines are; micro strip transmission lines and slot transmission lines [35].

For the remainder of the section all the transmission lines will be considered for TEM modes considering it is the most desirable mode for most practical applications and simpler to model [35].

The first two essential equations that describe the voltages and currents related to TEM models are;

$$\frac{\partial V}{\partial z} = -L \frac{\partial I}{\partial t} \quad (2.5)$$

$$\frac{\partial I}{\partial z} = -C \frac{\partial V}{\partial t} \quad (2.6)$$

where C is the capacitance per unit length and L is inductance per unit length.

These equations were derived for a special case where it was assumed that the conductor conducts flawlessly and the dielectric is homogeneous and lossless ($R=G=0$). Considering that this will not be the case in real world applications, these equations will not be sufficient for modelling transmission lines. These equations are slightly modified when taken losses into account;

$$\frac{\partial I}{\partial z} = -GV - C \frac{\partial V}{\partial t} \quad (2.7)$$

$$\frac{\partial V}{\partial z} = -RI - L \frac{\partial I}{\partial t} \quad (2.8)$$

where R is resistance per unit length and G is conductivity per unit length.

The parameters L , C , R , G depend on the cross sectional dimensions as well as the materials used in the transmission line. In order to correctly model a transmission line it will be necessary to determine these parameters. Various techniques can be used to determine L , C and G ; however it is more difficult to determine R , because R is dependent on the penetration of the fields into the conductors. The previous equations shows that a transmission line can be expressed in terms of voltages and currents, thus an equivalent circuit does exist. The equivalent circuit of a transmission line is called a unit cell and is illustrated in Figure 2-22. By placing these unit cells in cascading form a transmission line of finite length can be modelled

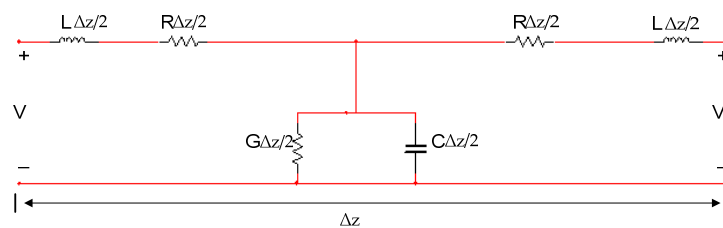


Figure 2-22: Unit cell representation of a transmission line

A transmission line can be modelled by means of time-domain analysis and frequency domain analysis. Time-domain analysis is used to describe and predict the voltage and current waves initiated onto the specified transmission lines. The frequency domain method is better suited to model sinusoidal varying waveforms. The time domain model for lossy transmission lines will be discussed.

As can be seen from (2.7) and (2.8), both V and I satisfy the equations. Equations that involve just V or I will be needed. By differentiating (2.7) and (2.8) with respect to z and t , correspondingly, and substituting these equations into each other, the following equation is obtained in terms of V .

$$\frac{\partial^2 V}{\partial z^2} = LC \frac{\partial^2 V}{\partial t^2} + (RC + LG) \frac{\partial V}{\partial t} + RGV \quad (2.9)$$

By differentiating (2.7) and (2.8) with respect to t and z , correspondingly, and by substituting these new equations into each other the following equation is obtained in terms of I .

$$\frac{\partial^2 I}{\partial z^2} = LC \frac{\partial^2 I}{\partial t^2} + (RC + LG) \frac{\partial I}{\partial t} + RGI \quad (2.10)$$

By using (2.9) and (2.10) transmission lines can be modelled using the time-domain analysis method for lossy lines.

The last very important affect that must be discussed concerning lossy transmission lines is the characteristic impedance which becomes complex and is given by (2.11).

$$Z_0 = \sqrt{\frac{\bar{Z}}{Y}} \quad (2.11)$$

where Z and Y are given respectively by (2.12) and (2.13).

$$\bar{Z} = R + j\omega L \quad (2.12)$$

$$Y = G + j\omega C \quad (2.13)$$

Transmission line modelling was studied to obtain an in-depth insight concerning transmission lines. Although this subject will not be discussed later on in this dissertation it is still very useful to be aware of concepts involving transmission lines when developing a communication system.

2.12 Communication systems evaluation

The last part of the literature survey will focus on evaluating a communication system. This section will be divided into; the physical layer evaluation and data link layer evaluation.

2.12.1 Physical layer

The physical layer of a digital communication system can be analyzed by using various methods, in this section two highly effective methods will be discussed; eye diagrams and jitter analysis.

2.12.1.1 Eye diagrams

In order to assess the quality of a digital signal it is of immense importance to understand eye diagrams. An eye diagram is constructed by overlaying different bit sequences. These different bit sequences then show weaknesses in the present system design. A simple eye diagram is shown in Figure 2-23. It is important to know that an eye diagram only shows the effects derived from the physics of the system, for example bandwidth health, it is not able to show protocol or logical problems [41]. However what can be characterized from analysing eye diagrams are; rise times, fall times, jitter (at the middle of the crossing point of the eye) and overshoot present in the system. An eye diagram can be analysed by using visual inspection and the statistical method.

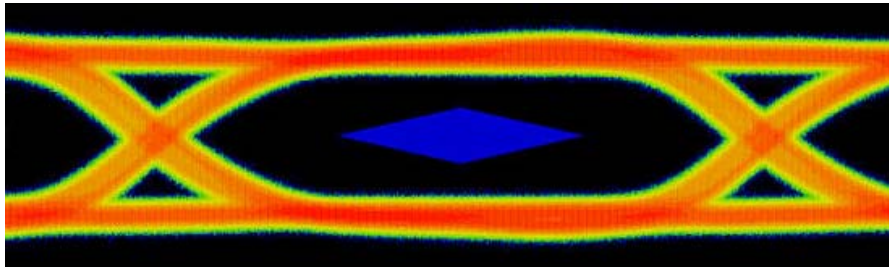


Figure 2-23: Eye diagram

- *Visual inspection:*

Visual inspection is frequently used in the R&D environment to quickly study the quality of a signal. In the most basic sense, visual inspection involves studying the openness of the eye, for example, an open eye indicates a good quality signal, where a closed eye indicates a poor quality signal [42].

- *Statistical method*

A more advanced method used to determine the quality of a signal is by using the statistical properties obtained from an eye diagram. This method involves acquiring data in an infinite persistence mode. This involves recording data points in a three dimensional database by using a

digital oscilloscope. What this three dimensional database does in principle is it constructs various histograms at different cross sections. By using these histograms, maximum and minimum signal values can be obtained as well as the standard deviation, σ , from the maximum and the minimum values. These measurements are suitable for validation [42].

2.12.1.2 Jitter analysis explained

Jitter can be referred to as a variation in delay, which causes the performance of a communication system to decrease immensely [43]. When excessive jitter occurs as the frequency increases it results in bit errors, causing the bit error ratio to increase (bit error ratio is defined as the ration of bad bits incurred to the number of valid bits in a data pattern)[44]. Thus it is of utmost importance to conduct a jitter analysis to determine how much jitter is present in a communication system. These results will then be analysed to evaluate a developed communication system as well as adjust the system to minimize the effect of jitter [44]. Eye diagrams are also used to study jitter analysis.

2.12.1.3 Jitter analysis with a BERT (Bit error ratio tester)

The basic rule of jitter analysis is – it concerns the bit error ratio. Thus a method must be found to define total jitter in terms of the bit error ratio. Figure 2-24 depicts a data stream with jitter, and the dashed line is the signal clock. In an ideal system with no jitter present, the data stream would be exactly on the dashed line which is in this case the reference clock [45].

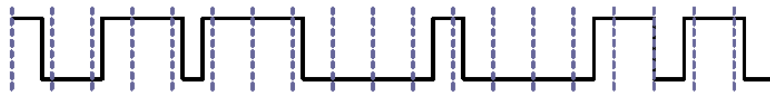


Figure 2-24: Data stream with jitter [45]

The total jitter of this particular data stream can be defined in terms of the bit error ratio. Proposed standards suggest that a system should perform with a BER that is less than 10^{-12} (only one bit error for every one trillion bits transmitted) thus the following equation can be obtained (2.14) [45] :

$$\text{Total Jitter (defined in terms of the bit error ratio = } 10^{-12}) < \text{bit period} \quad (2.14)$$

Measuring total jitter in terms of the bit error ratio can be done by using a BERT (bit error rate tester) which is a very expensive instrument. The question now is, how does a BERT define jitter in terms of the bit error ratio? A BERT machine has various functionalities; the first important functionality of this instrument is to transmit known patterns and monitoring the output, while keeping track of the bits transmitted as well as the bit errors. With this information it is possible to obtain the BER. Whilst studying Figure 2-25 a red dot is noted which indicates the ideal sampling point in an eye diagram. If the logic level of the bit transmitted is above the red dot it is registered

as a “1” and if the logic level of the bit transmitted is below the red dot it is registered as a “0”. The next functionality of the BERT machine is to move the sampling point horizontally (the blue dot) by changing the time delay of the sampling point, which sets a delay with respect to the reference clock. By doing this the curve shown in Figure 2-26 is obtained, which is a plot of the BER as a function of time, which as discussed is the time-delay [45].

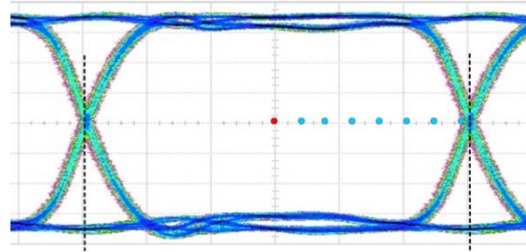


Figure 2-25: Sampling point variation [45]

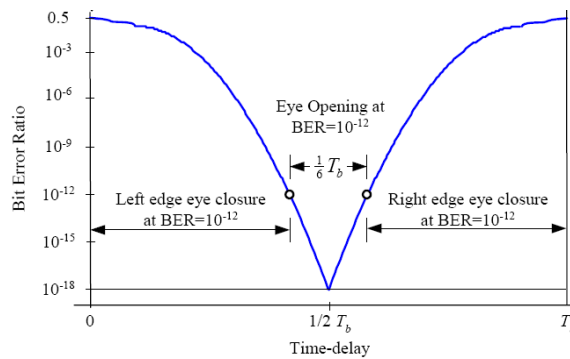


Figure 2-26: BER graph (bathtub plot) [45]

Now with this BER graph it is possible to obtain total jitter in terms of the bit error ratio by studying the graph. The distance between the left BER and the right BER curve is referred to as the eye opening. As can be seen from the figure the eye closes where the two curves meet, at 10^{-18} . Total jitter in terms of the bit error ratio can now be given by the following equation (2.15) [45]:

$$\text{Total Jitter(BER)} = \text{Difference between the bit period and the eye opening} \quad (2.15)$$

As noted previously the standard suggests that no more than one error may occur for every trillion transmitted bits. The eye opening at 10^{-12} BER is $1/6$ of the bit period, thus the total jitter is given in (2.16);

$$\begin{aligned} \text{Total jitter}(10^{-12}) &= \text{Bit period}(Tb) - \frac{1}{6}Tb \\ &= \frac{5}{6}Tb \end{aligned} \quad (2.16)$$

Jitter analysis can be summarized by the following three rules [45];

- In order to obtain the total jitter in a system it is necessary to obtain the bit error ratio.
- Jitter is analysed best by using a BERT data analysis measurement machine.
- In order to determine jitter it needs to be compared with a reference clock. This it is of vital importance to reconstruct the embedded clock.

This is the advanced method of determining jitter. In the case when a BERT can not be used percentage jitter can be obtained by examining an eye diagrams statistical properties.

2.12.2 Protocol analysis (data link layer)

Until now the focus was mainly on evaluating the physical layer. A data transmission standard includes not only the electrical specifications but also the protocol. Thus it is of importance to, not only evaluate the physical layer, but also the protocol. Modelsim® will be used to analyse the protocol.

2.12.2.1 Modelsim®

Modelsim® is verification and a simulation tool used to verify hardware description languages (HDLs). Using Modelsim® enables verification of digital designs by simulating HDL code and constructing the digital waveforms the code produces. Thus it will be possible to visually inspect and examine digital waveforms to determine whether the protocol executes correctly.

In order to simulate digital designs it is necessary to design a test bench. A test bench will supply test data to the digital design under test and monitor the output of the digital design by plotting the results and flagging errors shown in Figure 2-27.

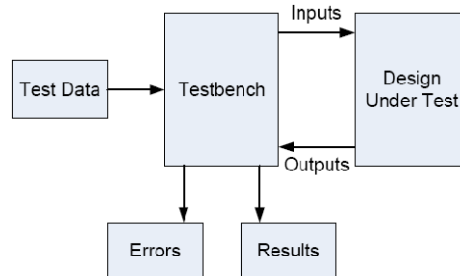


Figure 2-27: Modelsim® simulation design

The simulated waveform that Modelsim® produces is shown in Figure 2-28

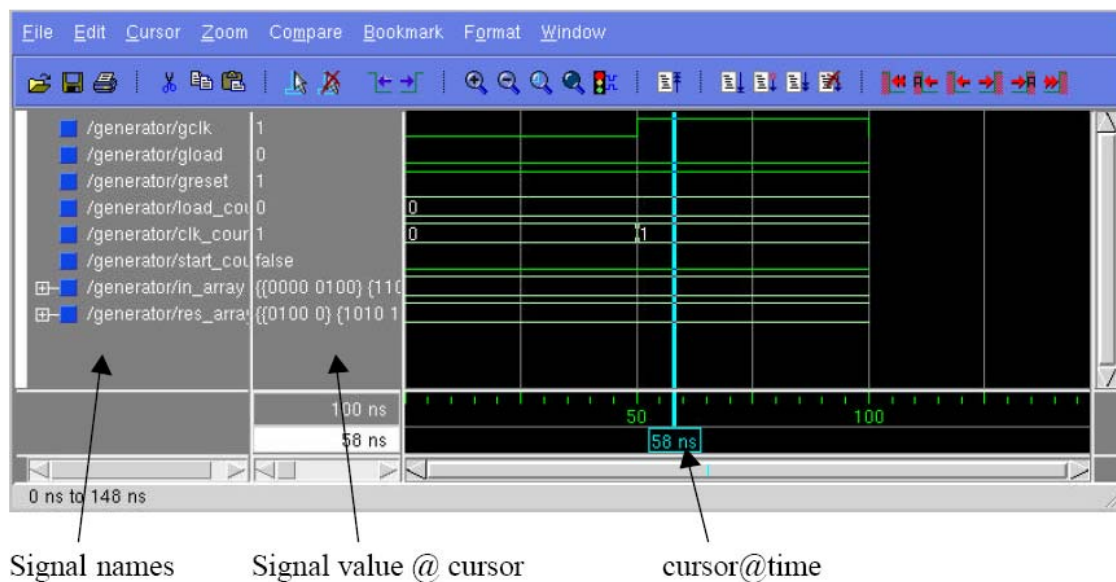


Figure 2-28: Digital waveform simulation

2.12.3 Transmission line analysis

It is of crucial importance that the optimum transmission lines are selected for each interface to ensure a watertight communication system. Thus it is necessary to determine how efficient the selected mediums are. This will be done empirically, by developing the appropriate experiments. The aim of these experiments will be to investigate the behaviour and efficiency of the selected transmission lines by analysing the digital waveforms.

2.13 Critical literature review

This section will focus on establishing a relationship and connection between the research documented in the literature study and the main goal of developing a communication sub-system for the ADES.

The literature chapter commences by discussing the basic operating principles of electronic communication systems. The necessity for studying electronic communication systems are unambiguous, keeping in mind that an electronic communication system will be designed for the ADES.

For this particular project it was considered crucial to study how to develop and analyse communication systems. The main reason being to understand which constraints are crucial when working with communication systems as well as what dictates the performance of communication systems.

The next section of the literature study focussed on comparing analogue communication against digital communication. Until now all the AMB systems developed by the McTronX research group implemented analogue communication between the various functional units. However it came under the groups' attention that companies developing AMB systems recently started to divert and make use of digital communication. Keeping in mind that AMB systems operate in very noisy environment it can certainly be considered feasible to implement digital communication. After comparing analogue and digital transmission it was concluded that digital communication will increase efficiency, reliability and robustness of the ADES. Therefore the remainder of the literature study focussed on digital communication.

The digital communication section discussed relevant terminology which included; digital- and data transmission methods, data transmission topologies, electrical interface circuitry. It was of the essence to understand these terms in order to know which solutions would suite the ADES best. Important communication parameters were also studied. These parameters included data signalling frequency, data signalling rate and data transfer rate. This was done to determine the most important specification of any communication systems, which is timing.

A data transmission standard comprises out of a set of specifications. In the next section of the literature study these specifications were listed and explained. The OSI layered structure was also discussed, because it is considered crucial for any communication engineer to study and understand this model. The reason being to ensure that the standardized data communication standards are understood and implemented correctly. Furthermore this will also assist in **creating** a new developed standard as near as possible to this model to encourage standardization of data communication.

The ADES communication system has a set of specifications. Some of these specifications includes connection distances, data transfer rates and the number of nodes present in the system. Therefore it was considered necessary to study various data transmission standards to know which standards will be able to realize the ADES specifications. Countless data transmission standards exist; however only a few relevant data transmission standards were documented to avoid the dissertation from becoming to lengthy.

After the data transmission standards were explained and compared, the limitations of these standards were addressed, once again to ensure that the correct standards were selected for the ADES.

A communication system consists out of receiver a transmitter and a channel. The next item that needed to be addressed was the “channel” better known as a transmission line. In the literature study a section was set aside to document various transmission lines, aiding in the selection of the most effective medium for the ADES system.

After the development of the communication system for the ADES it is crucial to measure the technical performance of the communication system as well as the efficiency of the communication system. Thus a section was set aside to determine what must be measured and how it must be measured, in the end aiding in the verification and validations of the communication system.

2.14 Conclusion

During the literature study the different aspect of this dissertation were studied comprehensively. After considering all the information the project can commence to the next level, which entails the conceptual design of the total communication system.