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Line Encoding for 25 Gbps over one Pair Balanced Cabling

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***Abstract*—In this paper, research projects with 30 meter balanced cabling and data rates up to 25 Gbps over one single pair are described. The project aim is to achieve 100 Gbps via a four pair balanced cabling channel. In the following, spectral characteristics of the used prototype twisted pair are presented. Therefore, the insertion loss of the single cable in comparison to the insertion loss of the cable in combination with an equalizing amplifier, as well as the group delay of the cable and the cable connected to the equalizing amplifier is shown. Furthermore, a carrierless Pulse Amplitude Modulation with 32 different levels (PAM-32) as an approach for a possible line encoding is presented. Finally, research measurements of the data transmission with a data rate up to 25 Gbps via shielded twisted pair is shown.**

Keywords—Balanced cabling; twisted pair, 100 Gbps data rate; prototype cables; line encoding.

I. INTRODUCTION

The consumer’s request is to get more data within a shorter period of time. Therefore the data rates are crucial for the consumers and it is important to get the optimum information out of the existing network as well as knowing the requirements for the future. The request of higher data rates advances innovations and new technologies.

Although it is possible to realize higher data rates with fiber optic cables, there are some applications where copper cables are necessary or easier to realize. Therefore, maximum data rates of copper cables are examined here.

Currently, it is possible to transmit 10 Gbps over 100 m balanced cabling [1]. The corresponding cable category is the cable category 6_A. Under development at IEEE 802.3bq, there is a new technology that transmits 40 Gbps (40 GBASE-T) over four pair balanced cabling with a length of 30 meter, requiring at least category 8.1 [2][3].

The aim of this research project is to achieve the data transmission of 100 Gbps over a four pair balanced cabling system. In ITG-Fachbericht 232 channel capacity of different balanced cabling channels are provided [4]. This analysis shows a sufficient channel capacity for the system of this investigation.

The paper is divided into three parts. The first part covers the characteristic behavior of the prototype cable concerning the insertion loss and the group delay. It describes the behavior of the single cable and thereafter the insertion loss and the group delay of the cable connected with the equalizing amplifier.

The second part covers an approach for line encoding to realize a data transmission of 25 Gbps over a one pair balanced cable. The presented line encoding is called carrierless Pulse Amplitude Modulation.

The third and last part deals with the first measurement results of a data transmission of 25 Gbps per pair. The transmission over a four pair balanced cable results in the desired data rate of 100 Gbps. To obtain these measurements, a twisted pair with individually shielded pairs with a length of 30 meter was used. This reflects a typical application in data centers.

II. INSERTION LOSS AND GROUP DELAY

This chapter characterizes the experimental copper cable concerning the insertion loss and the group delay. For the following measurements, the same prototype twisted pair was utilized. It has a length of 30 m and each pair of the four pair cable is single shielded. The used cable fulfils the cable category 7_A requirements of EN 50288-9-1, which are specified up to 1 GHz [5].

Each transmission is primarily influenced by attenuation. Due to the skin-effect the cable has a low-pass characteristic. Figure 1 shows the insertion loss of the prototype cable used for the measurements in the last part of this paper.

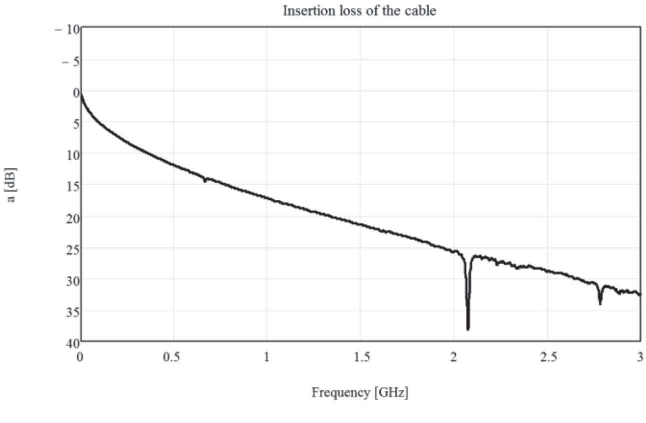

Fig. 1. Insertion loss of the cable

The measurement concerning the insertion loss of the cable shows this low-pass behavior of the cable. The attenuation is increasing smoothly as expected until about 2 GHz. At 2 GHz the attenuation is about 25 dB. Compared to other copper cables in the category of 7_A it has a higher usable bandwidth.

To counteract the insertion loss of the cable, a special equalizing amplifier was developed. The aim was to minimize the insertion loss by flattening the transmission characteristics of the used copper cable.

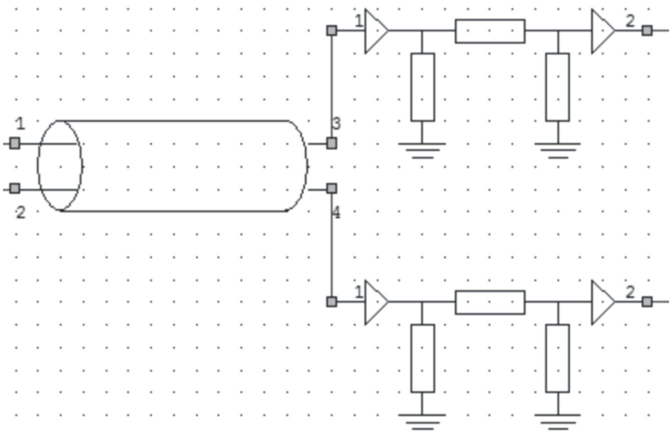

Fig. 2. A wires pair and it’s compensator

Figure 2 shows the construction of the equalizing amplifier. It is divided into two identical compensation branches, one for each conductor. It consists of a preamplifier, a flattening attenuator and a post amplifier.

The result of the insertion loss measurement of the cable connected to the prototype equalizing amplifier is shown in Figure 3.

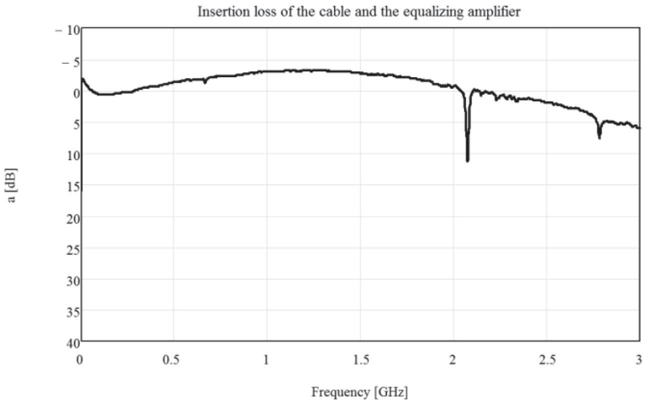

Fig. 3. Insertion loss of the cable and the equalizing amplifier

Figure 3 illustrates the positive effect of the connected equalizing amplifier. Now the deviation up to a frequency of 2 GHz is about 4 dB dynamic instead of 25 dB dynamic without the equalizing amplifier. Therefore it results in a flatten transmission over a 2 GHz frequency range.

Figure 4 shows the group delay of the prototype cable and the cable connected to the equalizing amplifier.

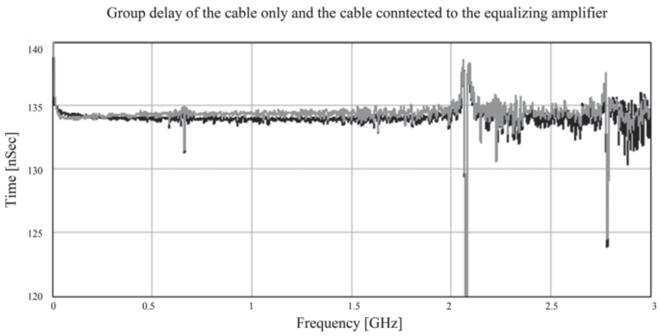

Fig. 4. Group Delay: black line: 30 m cable only, gray line: cable and equalizing amplifier

The Group Delay is steady up to a frequency of more than 2 GHz. This is similar to the already presented insertion loss measurements. The maximum deviation, up to a frequency of 2 GHz, is 4 nanoseconds.

III. LINE ENCODING

Line encoding is used to transfer information. Therefore a digital logic has to be transferred so that it is possible to use the physical attributes of the channel.

For the line encoding, a carrierless Pulse Amplitude Modulation (PAM) with 32 different relative levels of amplitude to transfer the information was selected. The PAM with 32 levels is a multilevel line encoding [1]. One symbol, represented by one of the 32 relative levels is equal to 5 bits. Therefore, the symbol period is five bits. The resulting symbol rate for a data rate of 25 Gbps is about 5 GBd.

The selected line encoding is based on a minimum symbol rate to achieve a minimum transmission bandwidth. For the transmission the PAM was used with a specially formed Raised-Cosine impulse. This impulse is defined as:

$$g_i(t) = \frac{\sin\left[\frac{\pi t}{T_S}(1-\alpha)\right] + \frac{4\alpha t}{T_S}\cos[\frac{\pi t}{T_S}(1-\alpha)]}{\frac{\pi t}{T_S}[1-\left(\frac{4\alpha t}{T_S}\right)^2]} \tag{1}$$

with $\alpha = 0.15$.

T_S defines the symbol period [6].

To realize a transmission of 25 Gbps over one twisted pair of a four pair channel, the Raised-Cosine impulse ($g_i(t)$) was factored with the 32 different levels of amplitude.

IV. DATA TRANSMISSION

A. General

In this last part, the first results of the transmission with the data rate of 25 Gbps is presented using two different measurement setups. Both setups will be explained in detail in the following.

Both measurement setups consist of the Tektronix Arbitrary Waveform Generator AWG 70001A and the Tektronix Sampling Oscilloscope CSA 8000 or the Teledyne LeCroy Real-Time Oscilloscope SDA 820Zi-A.

The Waveform Generator generates the desired waveform to transmit the data. For the first measurement setup it is connected directly to the oscilloscope. This setup is used to receive the generated signal at the output of the arbitrary waveform generator. In the following the measurement of this setup is called transmitted signal.

The second measurement setup includes the copper cable and the equalizing amplifier, which is connected at the end of the cable. The measurement of the second setup is called received signal.

B. Measurement results

For the first measurements the PAM was used as a line encoding as previously described. The selected test sequence of signals included all 32 possible levels in decrementing order. That means the first symbol is the symbol with the largest positive amplitude, followed by the symbol with the largest negative amplitude. This process is repeated in decreasing order until the symbol with the smallest positive and negative amplitudes have been sent.

Figure 5 shows the result of the first measurement setup. This represents the transmitted signal at the output of the arbitrary waveform generator.

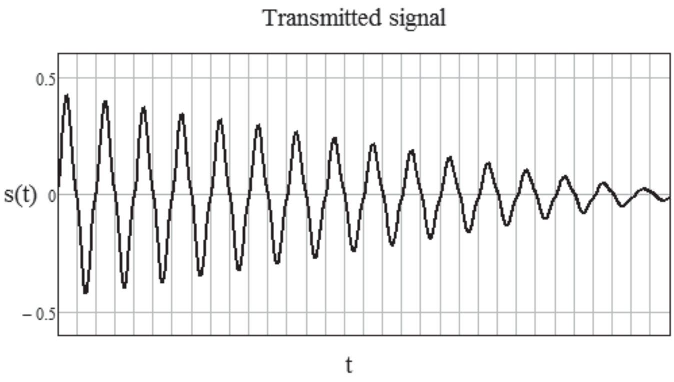

Fig. 5. Transmitted PAM 32 signal (200 ps per division and 500mV per division)

It illustrates that all 32 different levels of amplitude can be easily distinguished. The selected test sequences could be completely decoded.

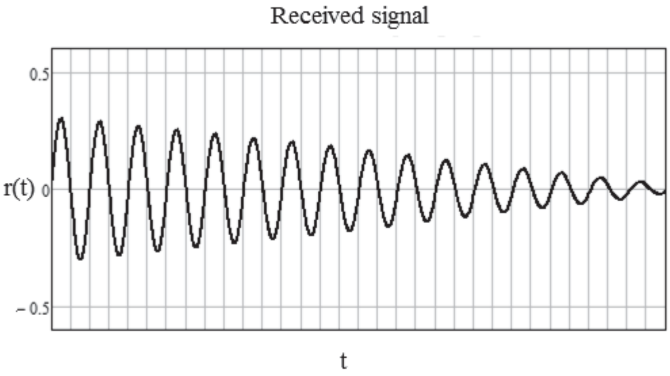

Fig. 6. Received PAM 32 signal (200 ps per division and 500mV per division)

Figure 6 shows the received signal. Similar to the transmitted signal, the received signal could be decoded with all 32 different amplitude levels [7].

The comparison of the different symbols of the transmitted and the received signals are shown in Figure 7.

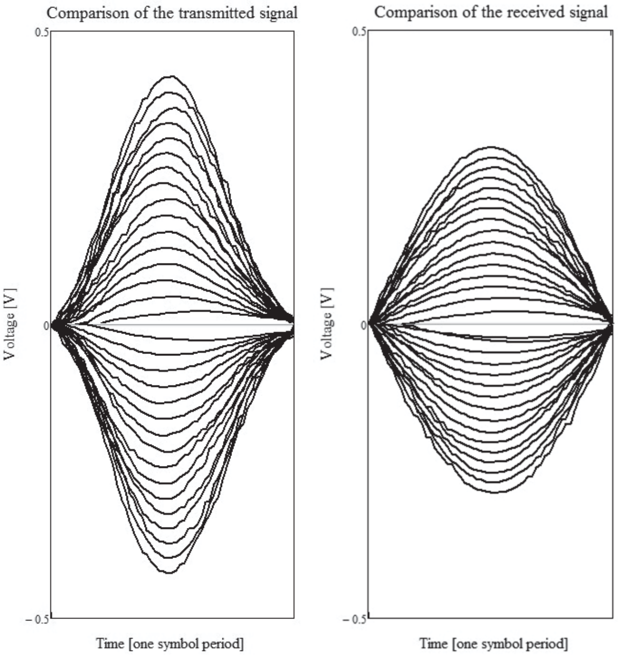

Fig. 7. Comparison of the transmitted and the received signal

Figure 7 illustrates the distinguished levels of amplitude of both the transmitted signal and the received signal. Thus a digital transmission with 31 decision levels is possible.

The voltage loss between the transmitted signal and the received signal is induced by the attenuation of the cable at a frequency of 2.5 GHz. This attenuation is about 3 dB.

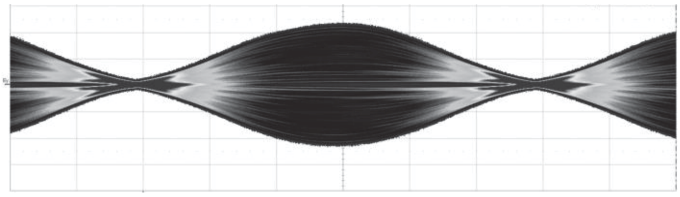

Fig. 8. Eye diagram of the transmitted signal (33.4 ps per division and 100 mV per division)

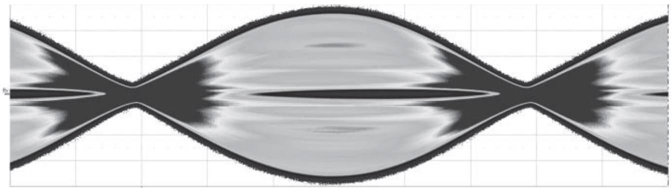

Fig. 9. Eye diagram of the received signal (33.4 ps per division and 50 mV per division)

Figure 8 shows the eye diagram of the transmitted signal, Figure 9 shows the eye diagram of the received signal. Both diagrams are not optimal because the number of effective bits used from the real time oscilloscope is limited.

V. OUTLOOK

For the future, further measurements with other line encodings are in process. In addition, we would like to optimize the equalization of the signal, as well as the signal generation of the arbitrary waveform generator.

Furthermore, we will measure statistical sequences instead of the presented selected sequence to identify the bit error rate of the data transmission.

Additionally, we are working on eye diagrams with higher resolution.

VI. CONCLUSION

In this paper we first described the results of a transmission with a data rate of 25 Gpbs over one twisted pair of a four pair cable. Therefore, there was a total data rate of 100 Gbps over all four twisted pairs can be achieved.

Furthermore we characterized the spectral behavior of the experimental copper cable. We presented the insertion loss and the group delay of the single cable and compared it to the cable and the special produced equalizing amplifier.

A line encoding is introduced allowing a transmission rate of 25 Gbps over one twisted pair. The presented line encoding, the PAM, is capable of transmitting high data rates by minimizing the symbol rate and the transmission bandwidth as well as taking the noise floor into account.

Finally initial test sequences of the PAM with all different amplitude levels are presented. Conclusively, the transmission and the subsequent demodulation of transmitted signal sequence with a data rate of 25 Gbps are possible.

VII. ACKNOWLEDGMENTS

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