Data Links Modelling under Radiated EMI and its Impact on Sampling Errors in the Physical Layer

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Abstract—This paper deals with the effects of radiated EMI on serial communication links using software modelling with particular emphasis on the physical layer. The effect of EMI in data links is an important problem to solve in many harsh environments such as the automotive and the transport sector as well as communications, in fact the EMI effect is able to produce sampling errors in digital/binary operations. Currently binding standards prefer the analysis in frequency domain to account for EMI impact, however when dealing with data links, time domain analysis might report useful information, therefore a link between those two is needed. The cable models are developed using SACAMOS modelling software, taking into consideration the frequency parameters. The model can be used on almost any SPICE simulator to analyse the effect of EMI. The simulations performed in this research are verified on a real laboratory experiment in order to demonstrate the capabilities of SACAMOS.

Index Terms—EMC, EMI, electromagnetic emissions, Fourier square wave, serial communication, Spice modelling, SACAMOS.

I. INTRODUCTION

The current effort for understating radiated emissions in the field of Electromagnetic Compatibility (EMC) is working towards the frequency domain. This is due to the fact that radiated emissions can be found in higher frequencies (from 150 KHz to 1 MHz or even more). However, in many DC systems the time domain is needed to achieve an accurate measurement of information. When a digital system is measuring data the most important task is to classify when the data represents a high level or a low level. The shape, the timing and the amplitude of a signal are key parameters in a robust digital communication system. A digital signal degrades over the cable length, at the same time is affected by other problems such as parasitic capacitance and inductance, noise, crosstalk, skew of signals and delays. It is therefore necessary to simulate the cable bundles to have a deeper understanding in the real applications.

The research presented in this paper follows a research in [6], where different emission sources are used to interfere with the data signal in which a Bit Error Rate (BER) tester is employed to obtain the relationship between the noise emission and data errors. As seen there, the more "square" the injected signal is, the more BERs are seen in the data signal. The previous analysis of how the bits can be affected by an EMI signal will give a better idea of how this effect is directly linked with the BER of a given communication protocol for further experiments. In our research, the focus is on physical foundations of this phenomenon and understanding how an analogue signal is translated into digital domain. For this purpose the paper research is divided into 3 main features.

- Use of ideal signals for the EMI and the data, the frequencies are kept the same.
- How a crosstalk bit sampling error can affect the BER in digital systems, even though no simulations of BER are performed.
- Digital systems define a certain voltage threshold to define whether a logic zero or logic one is measured.

To this end, the simulation techniques are used. However, to ensure reliability of results obtained via simulation, laboratory measurements were carried out on and the results were compared with the simulation outcomes.

The software used to create the Spice models is SACAMOS [1], an Open Source platform for EMC studies in cable modelling. The models created in SACAMOS can be used straightaway on Spice software. Simulation tests are developed using LTspice as the software to simulate the cable bundles. The models created are suitable for both frequency domain and transient simulation providing the capability to incorporate realistic transmission line effects into circuit level simulation, including interactions with non-linear terminations [2].

II. CABLE DATA TRANSFERRING AND EXPERIMENTAL SETUP

Generally, in many industrial and laboratory environments the data is transmitted over a long distance using a cable of a suitable diameter. In this research the focus to study is the physical layer of the OSI model of serial communication data links. This model is an standard that deals with the Physical and Data Link layers as defined by the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) [3]. The physical layer takes into consideration properties of the communication such as electrical parameters for a given data link, this can include the voltages, the length of the cables and data rate. Physical layer protocol is the use of typical problems concern what kind of physical signals for data 0 and 1 [4].

Serial communication is widely used as a previous stage interface to communicate with the environment, in fact many

protocols such as CAN bus and RS485 use TTL Uart as the previous interface. This protocol uses signals of 5 Volts amplitude and 8 bits of data, while at the same time a Start bit and Stop bit can be included. In the serial communication, both sender and receiver maintain the same data frame format and baud rate. That means each side sent and received the same data frame: header, data bits and frame tail. Also the data transfer speed is consistent to ensure the success of data transmission [5].

The EMC analysis of this interface is mandatory to avoid subsequent issues and ensure the signal integrity which is highly important in digital systems. The research presented in this paper accounts for a communication cable used for transferring data using a TTL Uart communication affected by a periodic interfering signal. In order to keep the simulation and the experimental setups as simple as possible the signals have the same frequency and amplitude.

The proposed setup for serial communication link consists of 3 cables, the first wire (victim) transmits the data over certain length, the second wire is the ground of the data and finally the third cable is the EMI signal (source). The length for the 3 cables is 1.5 m however some tests were done with shorter cables.

III. NOISE INJECTION PROCEDURE

In [6], the authors showed that when a serial signal is exposed to a non-sinusoidal pulsed waveform the data of the signal can be extremely affected. Following the research presented therein, in our experiment an emission source was created using a square wave Fourier series based formula. Let $x(t)$ be the emission waveform of frequency f as a function of time t, approximating an ideal square wave. Then, the equation representing the source emission is

$$x(t) = A \frac{4}{\pi} \sum_{k=0}^{m-1} \frac{\sin(2\pi f(2k+1)t)}{2k+1}, \qquad (1)$$

where m is the desired number of Fourier terms and A is the emission amplitude. In the same paper [6] it was presented that an increasing number of Fourier terms in the emission waveform caused higher Bit Error Rate (BER). One of the aims of the research presented hereafter is to find the cause of this behaviour and the relationship between interfering source and bit sampling error. Let us notice that a waveform created with the above equation exhibits a peculiar behaviour known as *Gibbs phenomenon*, which means that when a square wave changes its state, ringing oscillations are observed near the jump. Mathematically speaking, it can be related to the fact that a discontinuous function is approximated by a finite series of continuous sin functions and higher approximations fail to remove the overshoot [7]. Example of Gibbs phenomenon can be seen on Fig. 1, where two squares waves with $m = 5$ and $m = 50$ Fourier terms are shown both in time and frequency domain. As it is seen and what can be deemed to be rather obvious is that in the latter case, where $m = 50$, more spectral content is present in the signal, therefore one

of the explanations of the physicality behind the result of [6] is that as the consequence of Maxwell's equations the higher the current oscillation, the greater the magnetic field around the emission source cable. Current in the data cable tries to oppose the change, which results in the interference on the victim side. Supposedly, with higher m not only the amplitude of the interference is greater, but also the duration for which the interference occurs.
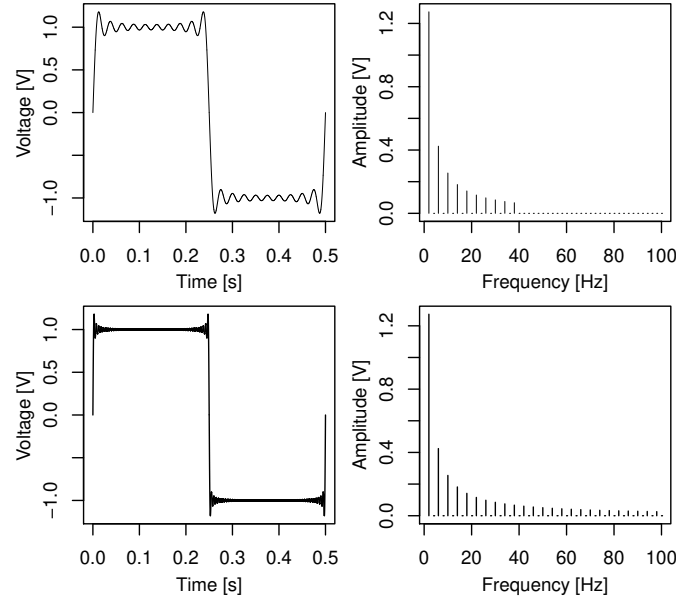

Fig. 1. Example of square wave showing Gibbs phenomena in time and frequency domain with $m = 5$ (top panel) and $m = 50$ (bottom panel) Fourier terms.

IV. SAMPLING THEORY BACKGROUND

One of the aims of this work is to understand the cause of bit sampling errors by analysing the shape of the data signal under a given EMI signal. Digital systems calculate the BER by classifying the bits sent and comparing them with the received bits according to certain predefined voltage threshold. For a logic low the TTL voltage level should be between 0.0 V to 0.4 V, while for a logic high the voltage level should be between 2.7 V to 5.0 V. For this aim a Square Wave Fourier Series is taken as the interfering signal. The formula for achieving the change in the number of Fourier terms is represented by Equation (1) are present in the source emission waveform.

As can be inferred, a relationship between the analogue signals and digital domain is needed to measure how a EMI signal affects a communication link. In the field of signal processing one of the rules that governs the main theory is the Shannon-Nyquist sampling theorem [8]. However, when applying this result in the real world scenarios, at least two issues arise, i.e.:

1) Real world signals do not have an entirely limited bandwidth,
2) Devices for measuring and filtering are not ideal [9].

Although this research is not completely focused on measuring BER, a knowledge of how Bit Error Rate testers work should be taken into consideration because digital hardware functioning has to be chosen correctly for future simulations and experimental tests. Current digital signal processors use an internal clock signal of N times the frequency to define the time at which one measurement has to be taken or a process has to start. This is one of the most common strategies that digital systems such as BER testers use to decide if there is an error in the data frame, this method is often called an oversampling and it is useful when a big frame of data is measured.

V. SIMULATION TEST

Considering the time-domain impact that an analogue signal has on the digital signal, it is clear that there exists a relationship between the frequencies and phases of the two. Such a relationship has been shown in [10], where a deterministic model for errors induced on a system by operation of a DC/DC converter has been presented. From a purely mathematical point of view, such simplified model can be applied to any deterministic setting without considering the mechanism behind noise injection. However, in digital domain the most important factor which gives rise to erroneous readings is the amplitude of the data signal, which is again affected by the source emission signal properties. Table I shows the basic signal parameters for the experiments in this research.

TABLE I
SIGNALS MAIN PARAMETERS

Parameter	Value
Frequency of interference	1 MHz
Number of terms	4-64
Frequency of data	1 MHz
Simulated data signal	Pulse train of 50% DC

In the experiments carried out in this research the source emission is modified according to the rules listed below:
1) Modify the number and amplitude of Fourier terms in the Equation (1) generated by the Arbitrary Function Generator,
2) Change the phase of the emission source signal.

To see how the cable bundle is affected by the radiated EMI source the output signal is compared with the input signal and the differences between those two are obtained. Fig. 2 shows the basic cable model with the measurement points.
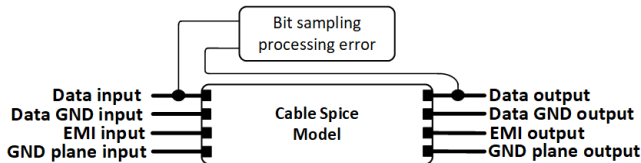

Fig. 2. Basic cable setup measurement of bit error sampling

The basic parameters for the cylindrical cables can be seen in the Table II .

TABLE II
SIGNAL MAIN PARAMETERS

Parameter	Dimension
Conductor radius	9.65e-5 m
Dielectric radius	9.65e-5 m
Conductivity	59.6e6 S/m

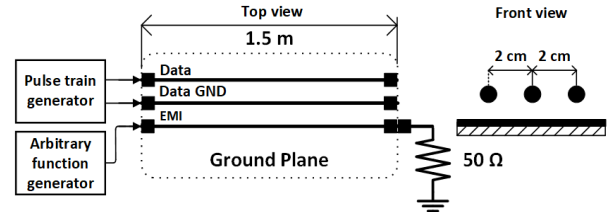The basic setup for the TTL Uart is shown in Fig. 3.

Fig. 3. Serial setup for radiated emissions experiment

VI. SIMULATION RESULTS

Fig. 4 shows the sample time-domain simulation results with $m = 8$ Fourier terms present in the noise signal. Top panel presents a situation, where both the data signal and the emission source signal are aligned with each other, i.e. the phase between those signals is equal to 0. As it is seen, the emission signal interferes with the data signal, resulting in a short transient, visible just before the data carrier changes its state from low to high, or from high to low. However, in such case, no errors are detected - both low and high states are recognized correctly. Fig. 4 b) presents a result, where the phase between emission and data signal is approximately 90 degrees. As seen on the picture, the short transient caused by the emission is again present in the data signal. In this case, however, an error can be detected because a certain predefined threshold is exceeded.

VII. EXPERIMENTAL TEST

The experimental results were done with slightly minor changes. In order to ensure the properties for the emission source in the best quality possible, a power amplifier has been used to amplify the noise signal to 4 Vpp. The equipment used for this is purpose is given by two function generators and one power amplifier. The first function generator, used to create the emission source, is the Agilent 81150A. The second function generator, responsible for generating the data signal, is the Agilent 33120A. The latter, apart from creating the data signal, is used for synchronization of the two generators. Finally, the power amplifier is the Prana DT70. The experimental equipment block diagram can be seen in Fig. 5

Fig. 6 shows the experimental cable setup inside the anechoic chamber.

VIII. EXPERIMENTAL RESULTS

Fig. 7 presents results of the time-domain measurements, where the noise source, modeled by the Equation (1) uses
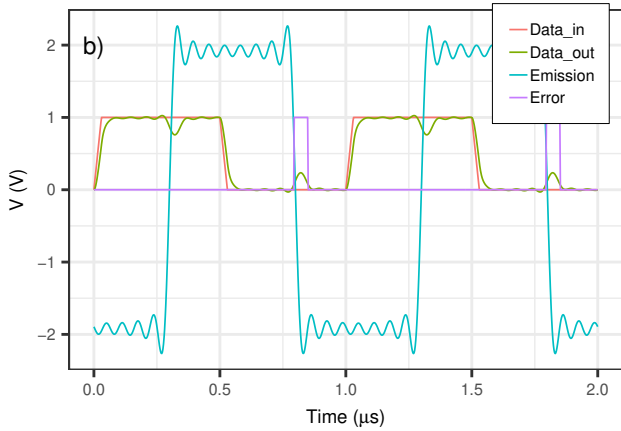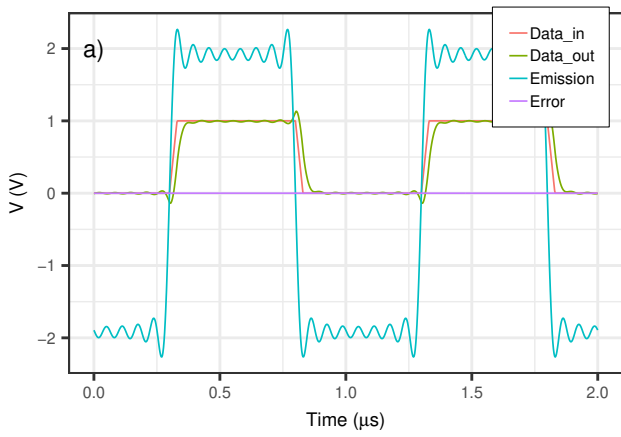
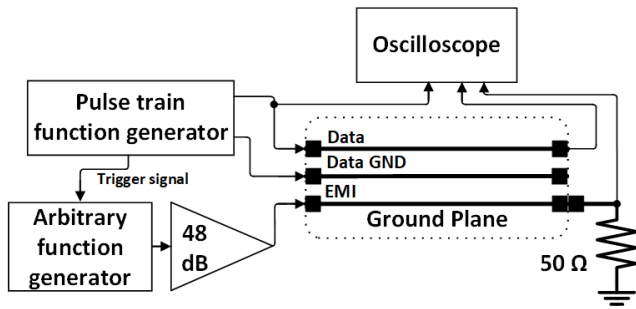Fig. 4. The input/output data and source emission simulated measurements.

Fig. 5. Experimental setup for radiated emissions experiment

Fig. 6. Experimental cable setup inside the anechoic chamber

Fig. 7. The input/output data and source emission experimental measurements.

8 Fourier terms. Top panel shows the result, where phase between source emission and data signals is 0 degrees, while bottom panel shows the result of approximately 90 degrees offset between the two. Similarly to the simulation results, an error can be detected in the latter case, due to the short transient induced by the emission source signal. It can be noticed that the simulated data signal has some ringing due to the long cable used for this test.

IX. CONCLUSION AND FUTURE WORK

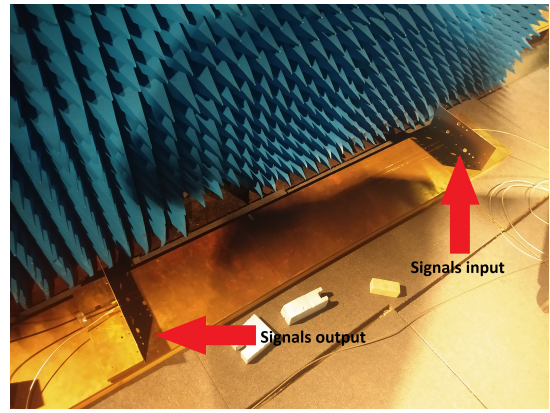This paper has demonstrated how radiated emissions can affect a given cable setup for serial communication protocols.

It has been shown that this impact can be simulated using an open source software SACAMOS. It is important to know how sampling errors are generated under radiated EMI in order to clearly understand the operations of digital signal processors and strategies to measure errors correctly. The use of a predefined radiated source of emission such as the square wave Fourier term formula was helpful to relate the amplitude in a digital signal bit sampling. Although the simulations were

performed with ideal cases they show that having both signals (interfering and data) similar frequency with a phase of 90 degrees the effect of the interference might affect the data link with possible bits wrong. One of the future aims for the research will focus on BER tests for analysing the impact of different types of noise.

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