The Effect of Coupling Circuits on Impulsive Noise in Power Line Communication

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***Abstract*—Most researchers in the Power Line Communications (PLC) field have adopted the practice of using idealized impulse noise models directly at the input of the demodulator, as is widely done in simulations. The effect of the coupling circuit on the impulse noise tend to be ignored. However, coupling circuits produce transients. This paper focuses on investigating the effect of the coupling circuit on the impulse noise. Experimental measurements are used to determine the effect of the coupling circuit. An equivalent circuit of the coupling circuit is developed and further simulations are conducted to gain in-depth knowledge on how the impulse noise is affected by the coupling circuit. A literature survey suggests that this topic has not been studied yet.**

***Keywords*—PLC, Power Line Communication, Impulse noise, Coupling circuit, Band-pass filter.**

I. INTRODUCTION

Noise is one crucial factor that affects any communication system. Different classes of noise are experienced in PLC systems which disturb transmitted signals. The various sources of noise are classified as narrow band noise, background noise and impulsive noise [1]. Unlike many other communication systems, the noise in a Power Line Communication environment cannot be described only by an additive white Gaussian noise (AWGN) model [2]. This leads to a greater need to thoroughly investigate and analyze these different classes of noise in order to come up with a reliable model.

Most PLC research over the years has confirmed through practical measurements that impulsive noise has the most degrading/distorting effects to communication signals compared to other types of noise [3], [4], [5]. It is therefore imperative to acquire more knowledge and understanding of impulsive noise and its effect on communication over power line channel, in particular when coupling circuits are used. In order to transmit or receive any signal from power lines a coupling circuit is utilized. The purpose of the coupling circuit is to block the low frequency, high voltage/current signal from the power line side and allow the high frequency and low voltage/current communication signal to pass through [6]. Understanding how the coupling circuit affects or changes the impulsive noise passing through it from the power line is of crucial importance. Practically measuring the different characteristics of impulse noise and its impacts as it passes through a coupling circuit will provide results to help gain in-depth knowledge on how impulse noise affect PLC performance and in designing better PLC systems. Investigating the effect of coupling circuits on impulsive noise will also help to understand and possibly modify or validate/invalidate the practice of using idealized impulse noise models (usually Middleton Class A) directly at the input of the demodulator, as is widely done in simulations. A search of the published literature suggests that the effect of coupling circuits on impulse noise has not been studied yet. This investigation focuses on determining the effect of coupling circuits on impulsive noise. In this paper, the terms impulse noise and impulsive noise will be used interchangeably.

This paper is organized as follows. Section II describes the experimental set-up and environment that was used for measurements. Also, the coupling circuit used in all the measurements is described. In section III, the measurement results and analysis are presented. An approximate equivalent circuit of the coupling circuit is discussed in section IV. Section V deals with the simulations conducted on the equivalent circuit of the coupling circuit.

II. MEASUREMENT SET UP AND HARDWARE

A. Measurement set-up

Careful considerations were made to come up with the best configuration to conduct the impulse noise measurements. Fig. 1 illustrates the experimental set-up. It shows the connections of the power cables from the Low Voltage (LV) transformer to the measuring equipment. This set-up was crucial to minimize ground loops as this is one of the major challenges that is faced when conducting noise measurements. To determine the effect of the coupling circuit on the impulse signal a clean 50Hz mains signal is required. To achieve this, a Line Impedance Stabilization Network (LISN) was used to filter out all external RF noise that may affect our measurements. The isolation transformer with ratio 1:1 was utilized to provide galvanic isolation to humans and electrical equipment for improved safety. A digital storage oscilloscope was used to capture the time domain data from our measurements.

B. Coupling circuit

All measurements were conducted using an off-the-shelf coupling circuit for the Narrow Band Power Line Communication Shield called the Mamba board [7]. See Fig. 2 for the schematic diagram. In order to perform measurements the

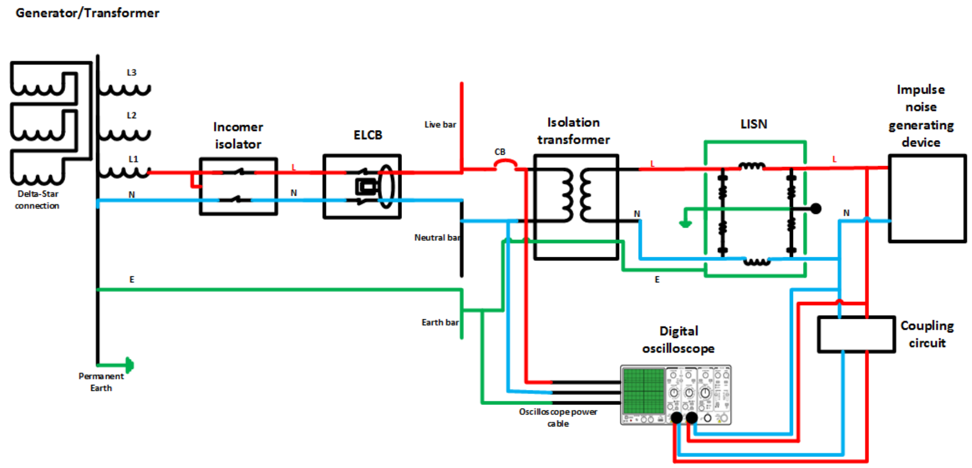

Fig. 1. Measurement set-up.

coupling circuit was isolated by cutting off the PCB tracks that joined the coupling circuit to the rest of the Mamba Board.

C. Measurement approach

Having some control on the impulsive noise generated in our measurements was crucial. The LISN was utilized to isolate the individual electronic devices that generated the noise allowing noise measurements of the particular device in its different states of operation. This allows test repeatability and easier interpretation of results. The ON-OFF and OFF-ON status was used to generate impulsive noise on all the devices for our measurements. The following devices were used to generate the impulsive noise for the measurements:

- 100Ω load with on/off switch
- Fan / heater
- Hair dryer

Impulsive noise measurements were taken before and after the coupling circuit to determine its effect on the noise. A X100 probe was used to measure the impulse noise before the coupling circuit. It is crucial to note that even though the LISN was used, the 50Hz mains signal was not a perfect sinusoide.

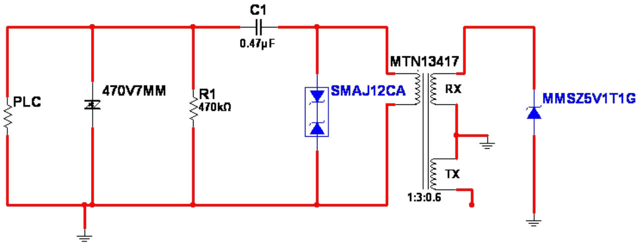

Fig. 2. Coupling circuit schematic.

III. MEASUREMENT RESULTS AND ANALYSIS

Fig. 3 shows the transfer function of the coupling circuit. According to the results, the transfer function shows the occurrence of two resonant points which are around 5kHz and 200kHz. The input impedance graph in Fig. 4 further confirms the existence of resonant points that are occurring in the coupling circuit. This phenomena plays a very important role in affecting high frequency signals that pass through the coupling circuit as shall be revealed with more results in this section. Resonance has adverse effects in PLC coupling circuitry and in most electronic technologies [8]. In the circuit in Fig. 2, the capacitor C1, inter-winding capacitance and winding inductance of the transformer cause resonance in the coupling circuit. It occurs when the magnetic energy stored in the inductance and the electric energy stored in the capacitors are transferred to and from, between these components [9].

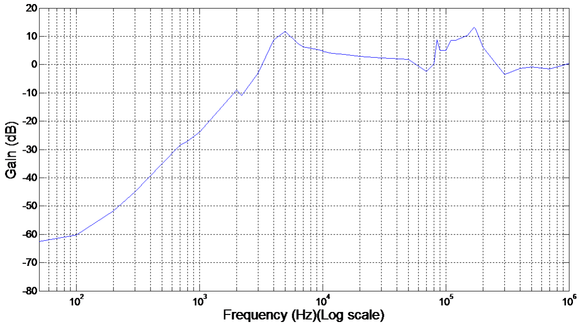

Fig. 3. Coupling circuit transfer function.

The impulse noise generated by the 100Ω load with on/off switch, fan/heater and Hair dryer were also captured in time domain. It was observed that the 100Ω load and fan/heater did not produce impulse noise during normal operation. The impulsive noise was detected using the trigger level method. The measured results show that the coupling circuit has an effect on the generated impulsive noise signal when it passes through it (See Fig. 5- Fig. 8). Before the coupling circuit the impulse noise is superimposed on the 50Hz mains signal and after the coupling circuit the 50Hz signal is blocked. The results show that the coupling circuit introduces ringing

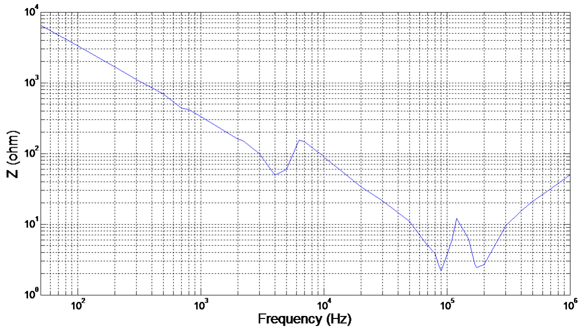

Fig. 4. Coupling circuit input impedance graph.

resulting from the impulsive noise signal. The ringing slowly dampens out.

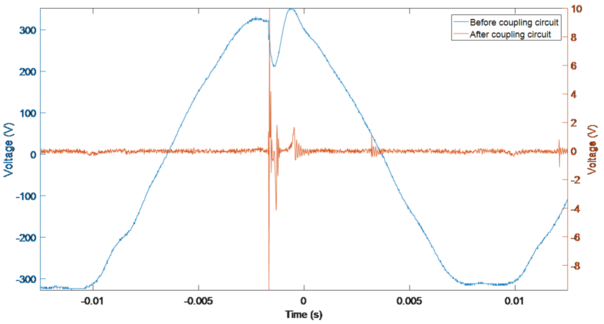

Fig. 5. Measured results from the 100 Ω resistor with on/off switch.

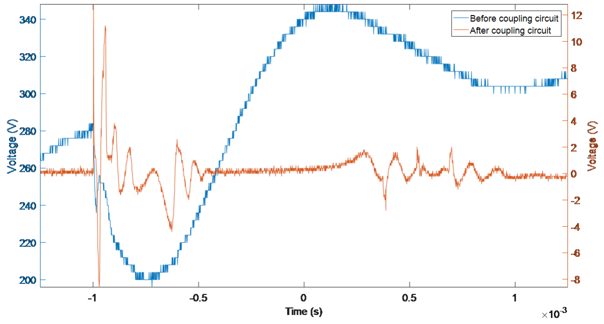

Fig. 6. Enlarged measured results from the 100 Ω resistor with on/off switch.

As the impulse signal passes through the coupling circuit, it excites the resonant points of the coupler resulting in resonance which introduces ringing. This changes the time domain parameters of the impulsive signal namely the impulse amplitude, duration and inter-arrival time [10], [11], as is evident from the results obtained. Time domain parameters have the most adverse effects on data transmission on power lines. Most of the impulsive noise models in literature were developed based on long time experimental measurements in specific power line networks in which electrical devices were connected randomly [1], [10], [12]. Recently in [13], the statistical information of the impulsive noise time domain parameters were used to characterize and model it. It is crucial to factor in the effects of the coupling circuit on the impulsive noise when characterizing and developing models.

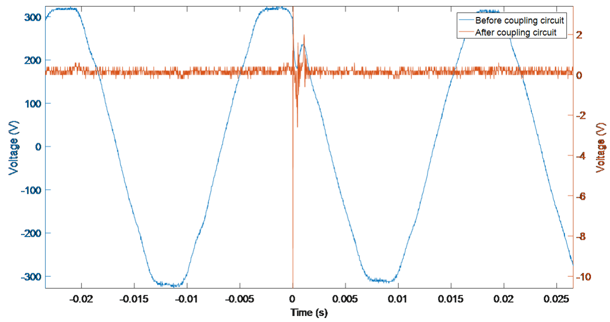

Fig. 7. Measured results from the fan/heater.

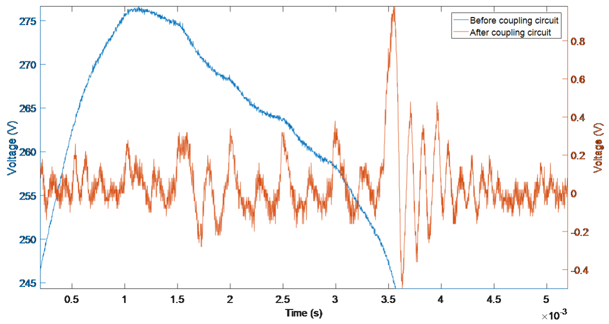

Fig. 8. Measured results from the the hair dryer.

A. Coupler equivalent circuit

The coupling circuit is fundamentally a band-pass filter. It allows a specific band of frequencies to pass through while blocking the rest. The one used in this research was a narrowband coupling circuit. In order to further understand the effects of the coupling circuit to impulsive noise an equivalent circuit was designed in the form of a band-pass filter which allowed a frequency band of 3kHz-150kHz. Using Spice simulation software (Multisim) a guided Trial and error method was used to come up with a filter that has a transfer function approximately similar to that of the coupling circuit in question. Fig. 9 shows the obtained equivalent circuit of the coupling unit as a whole. The obtained circuit was a high impedance circuit which is one of the many outcomes that could have been obtained through the trial and error method.

IV. SIMULATION

A. Bode plots

In this research, the coupling circuit in Fig. 2 was simulated with Spice simulation software (Multisim). Fig. 10 and Fig. 11 show the transfer function and phase plot obtained from the simulations. PCB track effects were assumed to be negligible since we were mainly focusing at frequencies below 1MHz.

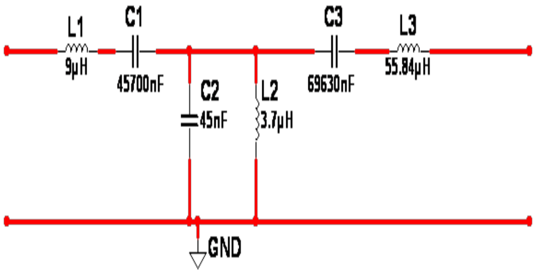

Fig. 9. Coupler equivalent circuit.

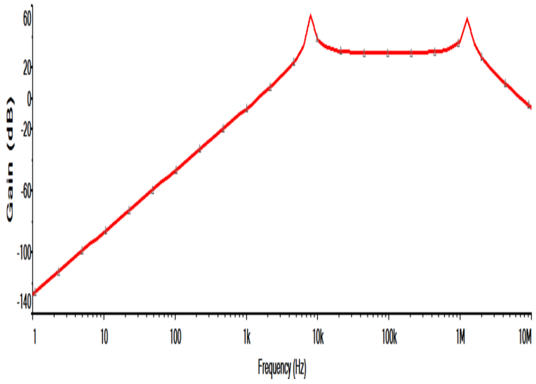

Fig. 10. Simulated transfer function of coupling circuit.

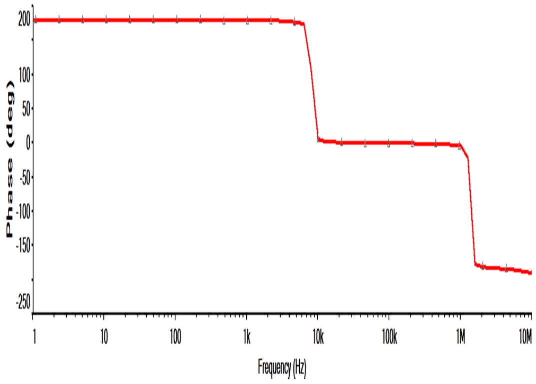

Fig. 11. Simulated phase plot of coupling circuit.

It is evident that resonance occurred in the simulated coupling circuit at a frequency of approximately 6kHz and 350kHz. Similarly the coupler equivalent circuit in Fig. 9 was simulated and the transfer function and phase plot were obtained as shown in Fig. 12 and Fig. 13. The bode plots for the coupling circuit and its equivalent circuit are approximately the same. Since the equivalent circuit closely approximate the experimental coupling circuit, further simulations were conducted on the equivalent circuit.

B. Simulink

In this section random impulsive noise was generated in Matlab. The generated noise on the 220V mains represents the widely used Middleton Class A noise because it has random

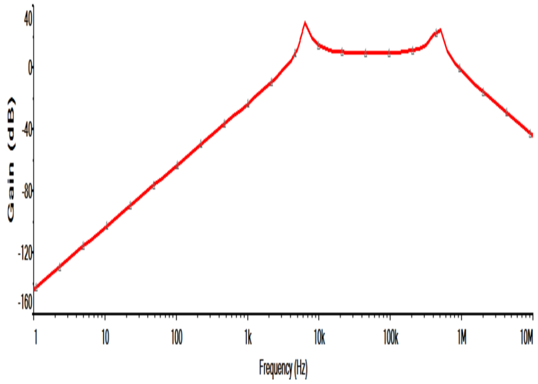

Fig. 12. Simulated transfer function of coupler equivalent circuit.

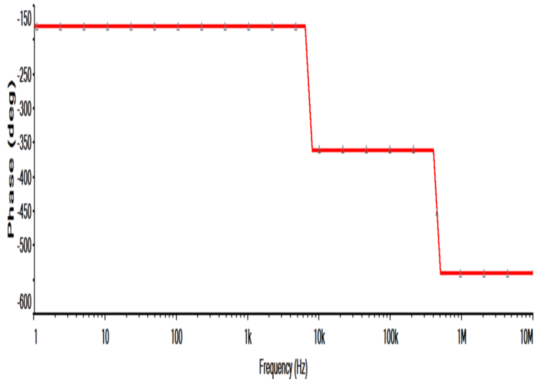

Fig. 13. Simulated phase plot of coupler equivalent circuit.

occurrence and amplitude [14]. The produced random impulse noise was used as the input to the coupler equivalent circuit and the output was measured. Fig. 14 represents the generated impulse noise. The coupler equivalent circuit introduces ringing to the impulse noise. Fig. 15 shows the output of the coupler equivalent circuit. The output shows that when an impulse occurs the equivalent circuit introduces ringing or a burst of impulses. The resulting output noise is in the shape of damped sinusoids. See Fig. 16 for the enlarged part enclosed by the rectangle in Fig. 15. These results correspond to the experimental results as they both show how the coupling circuit introduces ringing to the impulsive noise thus distorting its time domain parameters.

V. CONCLUSION

In this contribution, the effect of coupling circuits on the impulse noise was investigated. Experimental measurements and simulations have shown that the coupling circuit introduces ringing to impulse noise. This affects the time domain parameters of the impulse noise which have the most adverse effects to data transmission on power lines. In addition, this investigation also revealed the occurrence of resonance in the coupling circuit which causes ringing on the impulse noise. Through this research it has been demonstrated that coupling circuits have an effect on impulse noise and these effects must be taken into consideration. For generality of the obtained

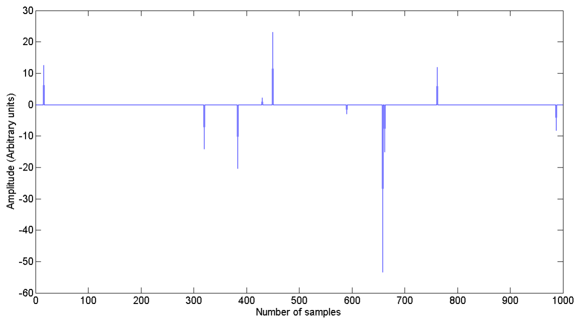

Fig. 14. Generated random impulse noise (Middleton Class A).

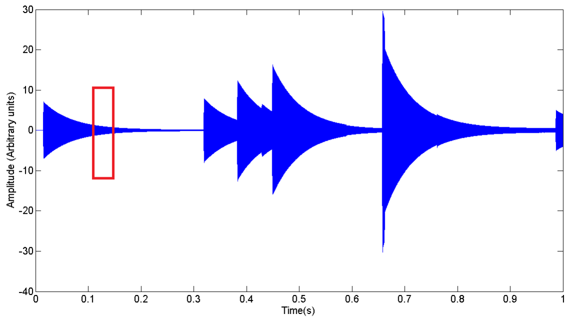

Fig. 15. Equivalent circuit output impulse noise.

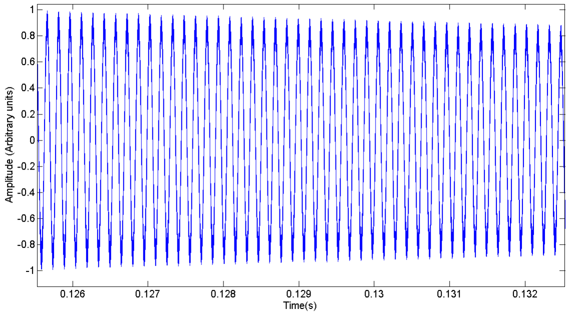

Fig. 16. Enlarged output impulse noise.

results, more measurements will be conducted on different sets of coupling circuits in future work.

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