STUDY OF IMPULSE NOISE IN WIRELINE COMMUNICATION

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Abstract

We designed and constructed a suitable circuit for detecting and measuring the powerline impulse noise which appears between live and neutral lines as well as between neutral and earth lines. Our study also involved in measuring the characteristic impedance over two different types of powerline cables differ in cable diameters using the network analyzer, over the range of frequencies starting from 9kHz to 30MHz. The constructed PCB has the ability to observe the impulse noise over the two considered channels of powerline within a wide frequency spectrum of around 50kHz - 15MHz through an oscilloscope. Using the circuit we studied the impulse noise segments from different sources mainly of household appliances, and have plotted them using matlab for future analysis. Apart from that, we also modified an existing circuit for measuring impulse noise in twisted pair communication systems in a wide frequency spectrum. The Eagle software was used to design the schematic diagram and PCB layout of the measurement circuit.
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Chapter 1

Introduction

Impulse noise consists of a set of random pulses with a short duration, but relatively large amplitudes which is one of the primary causes of errors in data communication. It can be occurred due to several sources like external electromagnetic disturbances such as lightning, vehicle ignition systems, heavy-duty electrical equipment, and dropouts or surface degradation of audio recordings, etc. [1]

High impulsive noise can degrade the performance and reliability of the system despite of a high signal-to-noise ratio. Therefore the characteristics of the noise must be taken into account to effectively filter out the impulsive interference. As the first step, one should be able to observe the impulsive noise over the target medium accurately. And this study has focused on design and construction of coupling circuits to study the impulse noise in twisted pair communication and powerline communication.

In twisted pair there are two types of impulse noise involved namely, Common-mode noise and Differential-mode noise. As the first part of this project, we modified an existing circuit which was first developed in a previous research project, to enhance the capability of successful measurement of the effect of both types of impulse noise over twisted pair communication.

The Power-Line-Communication (PLC), a technology which is capable of transferring data over power lines, is becoming popular as a reliable, cost effective and a simplistic communication technology in the modern world. With a very short history began in end of 1990s, PLC have achieved a rapid growth in several applications in day to day life including the smart grid, lighting control, solar-panel monitoring, energy metering, in-home video distribution, and electric cars.

While the ubiquity, low installation and maintenance cost, as well as no - new - infrastructure approach lead towards the advantages of PLC, it has become a hostile and a harsh medium for data transmission besides the signal attenuation and several types of noises severely impulse noise. In the power line, impulse noise can come from many sources connected to the grid, simply for instance, from a switched-on blender in the kitchen. Therefore, in order to increase the performance of powerline communication, it is essential to have a system which suppresses the unpredictable impulse noise without affecting to the data transmission rate [3].

As the second part of the research, a circuit was constructed to observe the impulse noise over the power line cables. Starting from measuring the characteristic impedance of the powerline cables, a circuit was designed, implemented and tested for observing the impulse noise between the two pairs, the live line and neutral lines, as well as the neutral and the earth lines.
Chapter 2

Background

2.1 Impulse noise in twisted pair communication

In twisted pair there are two types of impulse noise involved:
1) Common-mode noise
2) Differential-mode noise

2.1.1 Common-mode noise

"The twisted pair cabling is a type of wiring in which two conductors (the forward and return conductors of a single circuit) are twisted together for the purposes of canceling out electromagnetic interference (EMI) from external sources. The two wires carry equal and opposite signals, and receiver detects the signal as a difference between the two, when the pair operates as a balanced signal pair. This type of transmission is known as differential mode transmission. Noise sources introduce signals into the twisted pair by coupling of electric or magnetic field. The noise signals tend to couple to the wires equally. Thus common-mode signals are produced.

Let's assume two induced signals on the twisted pair are $V_A$ and $V_B$, respectively. Mathematically, the common-mode signal can be defined as

$$V_{CM} = \frac{V_A + V_B}{2}$$

2.1.2 Differential-mode noise

Differential mode involves a pair of traces (wires) between the driver and receiver. We typically say that one trace carries the positive signal and the other carries a negative signal that is equal and with opposite polarity to the first. Since the signals are equal and opposite, there is no return signal through ground. Let’s assume two induced signals on the twisted pair are $V_A$ and $V_B$, respectively [2]. Mathematically, the differential-mode signal can be defined as

$$V_{DM} = V_A - V_B$$
2.2 Impulse noise in Powerline communication (PLC)

2.2.1 Impulse noise sources of PLC

The major reason of errors occurred in data transmission over powerline is the impulse noise. Unlike in any other transmission medium, the powerline shares many different kinds of electrical sources, which cause to produce impulse noise every time when the source is connected to the powerline as same as when it is removed from the powerline. Not only with the switching functions, but also when the source acquire power from the mains to operate an AC motor inside the appliance, an impulse noise is generated whenever the speed of the motor changes. The situation is same in most of the time when the source has any kind of ability which results in sudden change of acquired amount of power taken from the mains grid.

“One common example of impulse noise sources is triac-controlled light dimmers. These devices introduce noise as they connect the lamp to the AC line part way through each half AC cycle. When the lamp is set to medium brightness the inrush current is at a maximum and impulses of several tens of volts are imposed on the power network. These impulses occur at twice the AC line frequency as this process is repeated in every 1/2 AC cycle” [4]. Figure 2.1 shows an example of similar kind of noise after a high pass filter has removed the AC power distribution frequency.

Figure 2.1: Low frequency Impulse noise occurred on powerline from a house hold

There are sources which result in high frequency impulse noise as well. One such type of high frequency impulse noise generator is the drilling machine. The series-wound AC motors inside such kind of sources can produce impulse noises in several kHz range repetitively. Vacuum cleaners, electric shavers and many kitchen appliances are some other common examples which generate high frequency impulse noise [4]. Figure 2.2 is an oscilloscope plot of noise from a high frequency household appliance.
2.2.2 Influence of Impulse noise in PLC Technologies

The impulse noise limits the data rate in powerline communication. Since the low frequency impulse noise can spread over several bits, the resulting bit pattern can get distorted and hence appeared with wrong information at the receiving end. As a result, in a very noisy environment, the high data rates cannot be achieved. The appearance of impulse noise is very unpredictable and unavoidable in any communication system, but introducing a process to suppress the impulse noise while in data transmission can lead to solve the problem. Figure 2.3 is an illustration of the output from the receiver with an attenuated input signal - disturbed by an impulse from a light dimmer located next to the receiver. As the graph shows, two of the received bits are in error.\cite{4, 8}

Figure 2.3: Errors in received bit pattern due to Impulse noise
2.2.3 Impedance Matching

When designing a coupling circuit for any wireline communication system, the value of the characteristic impedance over the transmission medium is very important. The impedance that a signal sees on a power line affects the signal power that the transmitter can transfer into the power line. Power-line impedance changes whenever you plug an appliance or a node into a power socket. Maximum signal power transfers when the impedance that the signal sees in the power line matches that of the transmitter circuit. The greater the difference between these two impedances, the less the transferred signal power; as a result, PLC performance degrades. “PLC transmitters and receivers must anticipate these impedance changes in the power line and thereby continually matching the impedance of the transmitter to that of the power line allows maximum signal transfer, and high receiver impedance ensures minimal signal loss on the receiver side.”[5]

The transmission line is characterized by its characteristic impedance \( Z_0 \) and its propagation constant, also known as secondary line parameters, \( y = \alpha + j\beta \), where \( \alpha \) is the attenuation in Neper per length unit and \( \beta = \frac{2\pi}{\lambda} \) is the phase constant per length unit.

In measuring the secondary line parameters, one would typically consult open and short-cut measurements with a network analyzer that offers impedance or S-parameter measurements in a frequency range of around DC up to, e.g., 40 MHz. From the impedance transformation we obtain,

\[
\gamma l = \text{atanh}(\sqrt{\frac{Z_s}{Z_0} e^{j\pi n}}) + j\pi
\]

\[
Z_0 = \sqrt{Z_s Z_0} e^{j\pi n}
\]

where Zo and Zs are open and shortcut impedances. The terms with multiples of \( \pi \) represent the periodicities of the square root and the atanh.

It is convenient to measure the corresponding s-parameters of the cable using the network analyzer, instead of the impedances. As an example, the reflection factor, \( S_{11} \) of a given cable is measurable with a network analyzer and thus the corresponding impedance can be determined as,

\[
Z_1 = Z_0 \frac{1 - r_{11}}{1 + r_{11}} = Z_0 \frac{1 - S_{11}}{1 + S_{11}}
\]

Figure 2.4 shows the corresponding measurement setup with a balun for determining the characteristic impedance of the cable.

Figure 2.4: measurement set-up with 3-point (open, short and termination with 100 \( \Omega \)) measurement together with a balun
Chapter 3

Implementation

3.1 twisted pair noise measurement circuit

3.1.1 Earlier circuit approach

The circuit contained so-called balun to obtain the common-mode noise signal from the primary side center-tap point, and the differential mode signal had measured from the secondary side of the transformer. An amplifier and a bipolar junction transistor had used to make the common-mode signal measurable to the oscilloscope. The amplifier had used as a source-follower for the common-mode signal, and the transistor had used to feed the signal into the coaxial cable. More specifically the unity gain amplifier had used to transfer a signal from a first circuit, having a high output impedance level, to a second circuit with a low input impedance level. The overall measurement set-up is represented graphically in the Figure 3.1. From the center-tap point of the transformer, common-mode noise is taken. The differential-mode noise is taken from the secondary side of the balun.[2]

![Graphical representation of the earlier measurement set-up](image)

Figure 3.1: Graphical representation of the earlier measurement set-up

3.1.2 The new circuit approach

The earlier design had a bandwidth limitation with its selection and arrangement of the op-amp and the transistor. With the new design, those components has been replaced by
a high bandwidth op-amp, LT1227. The dimensions of the previous design could reduced with the new replacement, as the new op-amp has the feature to drive the output signal directly into a coaxial cable without a transistor. Circuit was further reduced as the regulators for $\pm 5V$ supplies are no more needed. The new circuit works well with 0V as the reference voltage which makes the analysis simple rather than the earlier circuit which had to use -5V reference voltage with the coaxial connector. Further, the new design is confined into a single sided PCB, and with spatial reduction than the earlier circuit. The Figure 3.2 and Figure 3.3 represents the schematic diagram and the PCB layout corresponding to the new design.

Figure 3.2: The schematic design of the new approach for twisted pair impulse noise measurement
Figure 3.3: The PCB layout of the new approach for twisted pair impulse noise measurement.
3.2 Construction of the coupling circuit for Powerline noise measurement

3.2.1 Measurement of characteristic impedance of powerline cables

Finding out the characteristic impedance of the powerline cable was the first major task of designing the coupling circuit. Due to the variety of cable standards from one country to another as well as very few studies have been taken in the corresponding field so far, less information was found regarding the values of characteristic impedances of powerline cables. Thereby the setup was built up according to the figure 2.4 in order to measure the characteristic impedance of two different kinds of powerline cables which were differ in cable diameter. A cross section of one type of the cables is shown in figure 3.4. The thicker wire had the length of 64.5m while the thin cable was 67m long. Measurements were carried out with unrolling the cable on a flat flow for minimizing the bending effect of the cable. The characteristic impedances together with the transmission line characteristics of two types of cables were plotted against the frequency spectrum, using a matlab routine.

![Cross section of powerline cable](image)

Figure 3.4: The cross section of the small powerline cable [6]

3.2.2 Design and construction of the coupling circuit

The design of the circuit can be divided into two sections naming the high voltage circuit and the low voltage circuit.

The high voltage part is composed of two 1:1 transformers with 40 turns in each, combination of capacitors and resistors, two fuses and two LEDs together with two resistors. The transformer isolates the high voltage circuit from the low voltage circuit while providing the induced current to the low voltage circuit, thereby allows the low voltage section to behaves corresponding to the mains supply. The resistors which are equivalent to the characteristic impedance of the powerline cable combined with selected values of capacitors suppress the low frequency(50Hz) components of the mains power supply and allows high frequency components to pass through the circuit. In our design we chose the capacitor values in one channel to allow frequency components from 33.5kHz onwards, while the other channel to allow from 67kHz theoretically. A red LED in the circuit indicates a wrong turn plug in to the power socket, and the green LED indicates the correct direction of plug in. The fuses have included in the circuit to protect the rest of the circuit from flowing of large currents.

The low voltage circuit has the purpose of coupling the signal into the oscilloscope. The induced voltage from the high voltage part is used to bias a transistor and the transistor
output is fed into two co-axial connectors which are corresponding to each of the two powerline channels. ±5V is supplied using an external power supply, in order to provide the DC power for transistor and to produce a reference voltage for the co-axial connector. External high frequency noise components have been blocked by the capacitors embedded near by the external power supply connector. The co-axial connectors are terminated with 50 Ω resistor in order to drive the signal through coaxial cables.

From the coaxial connectors, the signal is fed into the oscilloscope via coaxial cables. In order to couple with the 1 MΩ internal resistance together with a 16pF parallel capacitor of the oscilloscope, the end of the coaxial cable which is going to the channel of the oscilloscope, has to be joined with 4.7pF series capacitor together with a 50 Ω parallel resistor.

Finally, the circuit was designed using the Eagle schematic editor as shown in figure 3.5 and a very compacted PCB layout followed by the figure 3.6 was created according to the dimensions of an enclosure available in the market. The physical representation of the final prototype and the measurement setup is shown in the figure 3.7.

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Figure 3.5: The schematic design of the powerline impulse noise measurement circuit
Figure 3.6: The PCB layout of the powerline impulse noise measurement circuit

Figure 3.7: Final prototype and the set up for the powerline noise measurements
Chapter 4

Results and Analysis

4.1 The analysis of the results of characteristic impedance in powerline cables

The figure 4.1 to figure 4.4 represents the graphs obtained for the second line parameters 2.2.3 of each power cable. The smaller cable had 3 equivalent wires and the measurement results were same for all three wires taken separately. The result of the corresponding cable is shown in figure 4.1.

The large cable contained 5 wires which had 2 more live wires in addition to the small cable. The measurements were carried out for all wires and the results were obtained with a difference from each other for the 3 live wires and the results are shown in figures 4.2 to 4.4.

Unlike in lossless cable, a complex characteristic impedance was observed for the powerline cables, according to the graphs. Since we were interested of measuring the noise over a wide range of frequency, it was important to figure out the characteristic impedance of the powerline cables for higher frequencies. It should be clear in lossy cables the characteristic impedance is varying with the frequency. It is clearly observed on the graphs which has obtained in our measurements. The oscillating behavior at the high frequencies was further reduced as much as the bends in the cables was straightened.

Finally, the characteristic impedance of the powerline cable was determined as 75Ω for the circuit designing purpose, considering the range of interest of the frequencies.
Figure 4.1: The second line parameters corresponding to the small cable of powerline
Figure 4.2: The second line parameters corresponding to the wire1 in big cable
(a) Characteristic impedance vs. frequency

(b) The phase vs. frequency

(c) The attenuation constant vs. frequency

(d) The phase constant vs. frequency

Figure 4.3: The second line parameters corresponding to the wire2 in big cable
Figure 4.4: The second line parameters corresponding to the wire3 in big cable
4.2 Transfer function of the constructed circuit

The transfer function of the circuit was measured for the both channels separately, using the oscilloscope. Due to the difficulty in matching of the impedances, the network analyzer could not use for this purpose. The AC sweep function of the function generator was used to feed a spectrum of frequencies to the channels of the circuit and the output of the circuit was obtained from the oscilloscope. The oscilloscope for the sweep was triggered by the function generator using its internal triggering function.

Since the spectrum of the frequencies had a wide range starting from $1\mu Hz$ to 20MHz, the default sampling rate of 1000kS/s of the oscilloscope had to increase upto 50MS/s with 20ms time/division, in order to obtain the complete output over the full range of frequencies.

The figures 4.5 and 4.6 shows the oscilloscope result obtained for the both channels, LN and NE and the figures 4.7 and 4.8 gives the graphical representation of the frequency response of the circuit for both channels, LN and NE. In each figure, the green line represents the trigger pulse of 200ms wide, and pink/yellow represents the LN/NE channel output response. According to the oscilloscope results, the following filter characteristics were computed for both channels separately.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Lower cut off frequency</th>
<th>Upper cut off frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>LN</td>
<td>51.75kHz</td>
<td>15.36 MHz</td>
</tr>
<tr>
<td>NE</td>
<td>101.14kHz</td>
<td>13.81 MHz</td>
</tr>
</tbody>
</table>

Table 4.1: The channel transfer function characteristics
Figure 4.5: The frequency response for the LN channel

Figure 4.6: The frequency response for the NE channel
Figure 4.7: Graphical representation of the frequency response for the LN channel

Figure 4.8: Graphical representation of the frequency response for the NE channel
4.3 Results of the impulse noise measurements in powerline using the constructed circuit

We could successfully use our circuit to observe the impulse noise generated on powerlines due to the switching on/off of different appliances, through the oscilloscope. The drilling machine produced very spiky high-voltage impulses with a broad spectral effect compared to the other sources. The noise generated by drilling machine were more directive and less dispersive. We measured the impulse noise segments acquired due to switching on/off different household appliances at different times. It was clear that the different appliances have different patterns of impulse noise generated on powerline but, the pattern was same in all the time for the same appliance.

The figures 4.9 to 4.13 illustrates how the powerline impulse noise was appeared on oscilloscope with the switching of different appliances. It is very clear that the impulse noise occurred in both channels at the same time has a strong relationship to each other in all the time.

Figure 4.9: The impulse noise generated over powerline due to the switching on the drill

Figure 4.10: The impulse noise generated over powerline due to the switching on the drill, with a periodic signal in the background
Figure 4.11: A zoomed version of an impulse segment from the drilling machine
Figure 4.12: Impulse segment from different sources switched on/off at home environment

Figure 4.13: A single impulse segment and a repetitive impulse segment from a source operated at home environment
Chapter 5

Conclusion

Our study was carried out for designing and construction of a coupling circuit to observe the powerline impulse noise through the oscilloscope. Apart from that our study was dealt with modifying an existing circuit for measuring the impulse noise over twisted pair communication.

The earlier design for twisted pair noise measurements had a bandwidth limitation with its selection and arrangement of the op-amp and the transistor. With the new design, the op-amp and the transistor has been replaced by a high bandwidth op-amp and the whole circuit size is reduced and was able to integrate in a single layer board. The new circuit is more reliable than the earlier circuit, apart from the wide bandwidth ability, as it uses 0V as the reference voltage rather than the earlier circuit had used -5V as the reference.

The second approach of designing a coupling circuit to observe the impulse noise over powerline was successful and we have created a coupling circuit with a transfer function over a wide range of frequencies. Our circuit is able to observe any impulse noise generated on the powerline through an oscilloscope. The circuit is able to measure the impulse noise generated over the Live and Neutral (LN) channel as well as the Neutral and Earth (NE) channel. It was identified that there is a close relationship of impulse noise generated between LN and NE. Further, it can be concluded that the different sources generate different patterns of impulse noise which is occurred during switch them on/off.
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