Study of Impulse Noise in Wireline and MIMO Wireless Communication

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Abstract

In communication systems, we experience impulse noise from different sources in the indoor and outdoor environments. In order to address the detection and mitigation problems that arise in wireless and wireline communications when the noise is impulsive, we need to analyze the effect of impulse noise separately.

We constructed a multi-antenna system to detect impulse noise from several sources. We measured impulse segments from different noise sources, and visualized those in time domain using Matlab.

We designed a suitable circuit for measuring impulse noise in twisted pair communication systems. The Eagle software was used to design schematic diagram and PCB layout of the measurement circuit.

Finally, we built the PCB board, and constructed the circuit on it. We analyzed the impulse segments measured by multi-antenna system, and saved the data for further analysis.
1 Introduction

In wireless communication, we can experience several kinds of noise. Most common noise is the thermal noise which can be represented by a Gaussian model. We refer to this thermal noise as Additive White Gaussian Noise (AWGN). We can experience several different types of human-made and natural noise which can not be modelled by Gaussian density and are mostly impulsive. Impulsive noise is characterized by larger values, which occur too frequently for the Gaussian model to be an accurate description of the process, which generally leads to a non-Gaussian noise model. There is several sources of electromagnetic interference that occurs in the indoor and outdoor environment. In the indoor environment like home and office, we can experience interference from microwave oven, drilling machine, LCD displays, washing machine, photocopier, etc.. There are several types of outdoor impulsive noise sources such as car ignition, overhead power grid-line with ionization and corona effect, electric train and trams, welding, etc.. In industrial environments, such as power generation and distribution stations, we often use wireless communication to monitor and control different processes where we experience high impulsive noise that can degrade the performance and reliability of the system despite of a high signal-to-noise ratio. The true characteristics of the noise must be taken into account to effectively filter out the impulsive interference. To do so, one needs to accurately model the impulsive noise.

One statistical and physical model for characterizing impulsive noise was given by Middleton with three models (i.e., A,B and C) which includes non-Gaussian components of natural and man-made noise sources. The models are parameter based with parameters determined by the underlying physical mechanisms, and are canonical, i.e., their mathematical form is independent of the physical environment. The distinction between the three models is based on the relative bandwidth of noise and receiver. Middleton’s models have been shown to accurately model the non-Gaussian phenomenon governing electromagnetic interference. These models have been widely used in electromagnetic applications and communication problems [1].

In our study of the effect of impulse noise in MIMO wireless system, we constructed a multi-antenna wireless receiving environment with monopole-antennas which are designed to receive the bandwidth of WLAN systems, and analyze the effect of impulses on each channel with different antenna-spacings and receiving distances.

In wireline communication, two types of impulse noise, such as common-mode and differential-mode impulse noise, are experienced. We constructed a circuit to successfully measure the effect of both types of impulse noise.


2 Motivation

In communication systems, noise-effects have always been a matter of great concern. For the reliability of a certain communication channels, we need to have almost error-free communication. In the light of flaw-less communication, we need to efficiently estimate the probability of error and construct a set-up both physically and statistically to analyze and synthesize the problems of a communication link. Therefore, we need sufficient knowledge of the source that might be responsible for causing a certain level of disturbance that causes a probable error in the link. It is required to have the knowledge of different distribution models which may fit to our purpose of mathematical modelling of such type of interference. Different sources might have different statistics as well as require different characterization, and in the end, a certain combination of the models is necessary to have an overall view of impulsive interference that might pop-up in different environments, i.e., indoor and outdoor.

The effect of each interfering source needs to be measured and analyzed separately and independently by taking each source into account. Each interfering source needs to be modeled according to different distribution functions. The impulses experienced by each receiver of a multi-antenna system should be analyzed with respect to the correlations in space as well as in time between different receivers at different spacings and distances to the source of interference. Based on sufficient statistics of different noise sources we need to construct methods to reduce resulting bit-error-rate (BER) probabilities.

In this particular project, we constructed a suitable set-up for measuring impulse noise in twisted pair communication, and in wireless communication using a multi-antenna receiver and different impulsive electromagnetic interference sources. We used Eagle software package to design both the schematic diagram and PCB layout of the wireline impulse noise measurement circuit. We practically generated impulses from one of the sources of interest at a time, measured, and saved the received impulses using a digital oscilloscope to further analyze the signal.

In short, our study was focused on generating, receiving and analyzing impulse noise. These would help us making the wireless and wireline communication much user-friendly and less subject to impulse noise affect, and as a result, would cause wireless communication leaps to a level where reliability and security would be of utmost interest.
3 Theoretical Background

3.1 Classification of electromagnetic noise

There are different theoretical models to classify man-made and natural radio noise. This is done to provide realistic and quantitative descriptions of man-made and natural electromagnetic (EM) interference environments.

The classification of a noise model aims at providing analytical models which:

- combine statistical and physical models of EM noise environments,
- can be managed analytically,
- possess general canonical properties, i.e., are not specialized to individual noise mechanisms, source distributions, and emission waveforms,
- can be verified by experiment and are predictable for that particular environment [2].

According to David Middleton, general EM noise or interference has been classified by three broad categories, which are:

CLASS A interference: This particular noise is spectrally narrower than the receiver bandwidth. Therefore, it generates ignorable transients in the receiver’s front-end (i.e., initial linear stages) when the noise emission terminates.

CLASS B interference: In this category the incoming noise bandwidth is wider than the receiver’s front-end stages, therefore, there is sufficient intensity of transient at both build-up and decaying phase.

CLASS C interference: This is the combination of both Class A and Class B interference [2].

The above three categories describe the complete effect of EM noise. This categorization is useful because the receiver response is statistically different for each case. In order to distinguish between man-made and natural noise, we further classify the noise as “intelligent” and “non-intelligent” emission. Accordingly, the following are defined further:

1) “intelligent” noise or interference is man-made and intended to convey a message or information;
2) “non-intelligent” noise or interference may be attributable to natural phenomena, e.g., atmospheric noise or receiver noise, for example, or may be man-made, but conveys no intended communication, such as auto-mobile ignition, or radiation from power lines, etc. [2].

The importance of distinguishing between intelligent and non-intelligent noise lies in the fact that the “intelligent noise” is controllable, i.e., subject to elimination, but the latter one is natural and very much impulsive and uncontrollable. Therefore, we can only study the effect of the “unintelligent noise” and have the knowledge to see the effect on the information transfer.

3.1.1 Middleton’s Class-A Model

Middleton’s Class-A model refers to narrow-band noise where interference spectrum is narrower than the receiver bandwidth. In this model, the received interference is assumed to be a process having two components [1, 3, 4]:

\[ X(t) = X_P(t) + X_G(t), \]  

where \( X_P(t) \) and \( X_G(t) \) are independent processes. They represent the non-Gaussian (impulsive) and Gaussian components, respectively. The probability density function (PDF) of \( X(t) \) is given in [3]:

\[ f_{P+G}(x) = e^{-A} \sum_{m=0}^{\infty} \frac{A^m}{m! \sqrt{2\pi} \sigma_m^2} e^{-x^2/2 \sigma_m^2}; \text{ where } \sigma_m^2 = \frac{m^2}{A^2} + \Gamma. \]  

\( f \) is a weighted sum of zero-mean Gaussians with increasing variance. \( A \) and \( \Gamma \) are the basic parameters of the model. Let us consider their definitions and physical significance:

1) \( A \) is the overlap index or non-structure index [1].

\[ A = v T_s, \]  

where average number of emission events impinging on the receiver per second is denoted by \( v \). \( T_s \) denotes the mean duration of a typical interfering source emission. The lesser \( A \) is, the fewer the number of emission (events) and/or their durations. Therefore, the waveform characteristics of individual events dominate the (instantaneous) noise properties. As \( A \) is made larger, the noise becomes less structured, i.e., the statistics of the instantaneous amplitude approach the Gaussian distribution (according to central limit theorem [4]). Hence, the non-Gaussian nature of the noise input to the receiver is measured by \( A \) [1].
2) Γ is called the Gaussian factor. It is the ratio of powers between the Gaussian and non-Gaussian components [1],

\[ \Gamma = \frac{X_G}{X_P}, \]

where \( X_P(t) \) and \( X_G(t) \) are independent processes. They represent the non-Gaussian (impulsive) and Gaussian components, respectively. In general, \( A \in [10^{-4}, 1] \) and \( \Gamma \in [10^{-6}, 1] \) [5]. By adjusting the parameters A and G, the density in (2) can be made to fit a great variety of non-Gaussian noise densities.

### 3.2 Modified Middleton’s Class-A model for a multi-antenna system

Middleton’s Class-A model is addressing a single antenna system. For multi-antenna systems we need to extend the Middleton’s Class-A model to the multivariate case. A bivariate Middleton’s Class-A model for 2 antenna system has been considered in [7]. An extension for \( n_r \geq 2 \) has been derived in [1]. The Equation (2) has been derived as,

\[ f(x) = \sum_{m=0}^{\infty} a_m g(x, \sigma_m^2), \]

where \( a_m = \frac{e^{-A} A^m}{m!} \), \( \mu = 0 \) and \( g(x, \sigma^2_m) = \frac{1}{\sqrt{2\pi\sigma^2_m}} e^{-\frac{x^2}{2\sigma^2_m}} \). The density of Middleton’s Class-A model has been approximated by a two-term model \((m=0,1)\) [5],

\[ f(x) = e^{-A} g(x, \sigma_0^2) + (1 - e^{-A}) g(x, \sigma_1^2). \]

Let assume \( x = [x_1, x_2, \ldots, x_k] \) to be a vector of \( k = n_r \) random variables, each variable follows a Middleton’s Class-A density function, and \( x_k \) is the noise observation at the \( k^{th} \) antenna. Then, the multivariate density of \( x \) has been derived as [5],

\[ f_x(x) = \sum_{m=0}^{\infty} a_m g(x, K_m), \]

where \( a_m \) is as in (5), \( K \) is the covariance matrix which represents the spatial correlation in the noise and \( g \) is a multivariate Gaussian function

\[ g_x(x) = \frac{1}{(2\pi)^{\frac{n_r}{2}} |K|^{\frac{1}{2}}} e^{-\frac{x^T K^{-1} x}{2}}, \]
where $| \cdot |$ denotes the determinant. From (7) and (8), we obtain

$$f_x(x) = \sum_{m=0}^{\infty} \frac{a_m}{(2\pi)^{\frac{n_r^2}{2}}} e^{-\frac{\pi K_m}{2}} e^{-\frac{x^T K_m^{-1} x}{2}}. \tag{9}$$

Equation (9) represents a general extension of Middleton’s Class-A model for multi-antenna systems. The approximation has been used as in (6) for $(m = 0,1)$. Then, an approximate version has been obtained for the extension,

$$f_x(x) = \frac{e^{-A}}{(2\pi)^{\frac{n_r^2}{2}}} e^{-\frac{\pi K_0}{2}} e^{-\frac{x^T K_0^{-1} x}{2}} + \frac{1 - e^{-A}}{(2\pi)^{\frac{n_r^2}{2}}} e^{-\frac{\pi K_1}{2}} e^{-\frac{x^T K_1^{-1} x}{2}}, \tag{10}$$

where $K_m$ is an $n_r \times n_r$ covariance matrix and is defined as

$$K_m = \begin{pmatrix} \text{Var}(x_1)_m & \cdots & \text{Cov}(x_1, x_k)_m \\ \vdots & \ddots & \vdots \\ \text{Cov}(x_k, x_1)_m & \cdots & \text{Var}(x_k)_m \end{pmatrix}, \tag{11}$$

where

$$\begin{align*}
\text{Var}(x_k)_m &= \frac{m + \Gamma_k}{1 + \Gamma_k} \sigma_{km}^2 \\
\text{Cov}(x_k, x_i)_m &= \rho_{ij} \sigma_{im} \sigma_{jm}
\end{align*}$$

$\Gamma_k$ is the Gaussian factor at the $k^{th}$ antenna and $\rho_{ij}$ is the correlation coefficient between the noise observations at $i$ and $j$ antennas, $-1 \leq \rho \leq 1$.

Finally, we can write $K_m$ as

$$K_m^{-1} = \begin{pmatrix} \sigma_{1m}^2 & \cdots & \rho_{1k} \sigma_{1m} \sigma_{km} \\ \vdots & \ddots & \vdots \\ \rho_{kl} \sigma_{km} \sigma_{1m} & \cdots & \sigma_{km}^2 \end{pmatrix}. \tag{12}$$

### 3.3 Impulse noise sources

As described earlier, thermal noise at the receiver is modeled using AWGN model. Other sources have more impulsive nature like atmospheric interference, radio frequency interference, and man-made noise. In this section we will describe the different noisy sources.

#### 3.3.1 Radio Frequency Interference from house-hold appliances

There are several interfering sources that are available in indoor environments such as

\footnote{[1] was used for whole derivation process of $K_m$}
1) Microwave oven: It is a very strong interference source. It generates continuously “non-intelligent” RFI for any wireless receiver. It has been observed that it produces periodic impulses, i.e., impulsive sinusoids.

2) Drilling machine: It is also an interfering source used frequently. It is due to the varying contact quality of the rotor connections.

3) Others: There are several different kinds of interfering sources available in the indoor environment such as LCD monitor, PCI express bus, washing machine, etc..

3.3.2 RFI generated in out-door environments

There are unintentional emitters that generate impulse noise such as

i) Electrical power-lines generate impulse noise by generating high-frequency harmonics.

ii) Electric transformers generate impulse noise due to sudden upsurge of power and a sudden occurrence of fault-current.

iii) Corona-effect of over-head power-lines is also a source of interference.

iv) Power generators produce high-frequency noise signal on the area of the power-station which is an impediment for wireless control of different systems.

v) Medical equipment (e.g., MRI scan) in the hospital and clinics produces noise that may hamper communication reliability.

vi) Electro-mechanical switches such as electrical relay and protective systems also generate impulse noise.

vii) Natural sources like thunder-storm, solar radiation are potential sources of interference. Distance Measuring Equipment (DME) in L-band is also a source of interference.

viii) Welding machines are also a strong source of impulsive interference.

ix) While starting and driving our car, we generate powerful impulses.
4 Experimental setup and measurement

For MIMO communication we need multiple antenna systems. We chose to design four antennas resonating at 2.45 GHz center-frequency for measurement. We needed filters for filtering a bandwidth of 190 MHz. The overall set-up consists of antennas, bandpass filter, down-converting mixer, oscillator, and a digital oscilloscope for acquiring the sampled and down-sampled data at an intermediate frequency.

![Block diagram of multi-antenna receiver](image)

**Figure 1:** Block diagram of multi-antenna receiver

4.1 Description of instrument set-up

The following are the design steps of the overall set-up, and impulse noise measurement:

1) Designing monopole-$\lambda/4$ antennas where $\lambda$ is the wavelength of center RF-frequency 2.45 GHz. They were checked for the resonating frequency using the scattering-parameter, i.e., $S$-parameters-$S_{11}$. They had omni-directional receiving pattern of EM fields and were used only for receiving purpose. The antennas were positioned vertically to the base (ground-level) and spaced with equidistance forming a *Uniform Linear Array* (ULA).

2) The antennas were wired to the bandpass filter which filtered the RF signal with a bandwidth ranges from 2530 MHz to 2340 MHz. The outputs of the bandpass filter were fed to the RF input of the down-converting
mixer which were down-converting according to the frequency of local-oscillator signal that was applied to the local-oscillator (LO) input port of the mixer. Signals from both port are mixed to yield the Intermediate Frequency (IF) of interest. The IF was inherently filtered by the scope.

3) There needed a signal-generator for the input of the LO port of the mixer. The generator mixing-frequency was set to 2.1 GHz.

4) Digital oscilloscope was used for filtering, sampling and down-sampling the IF signal for further use of the data.

The whole set-up was housed in measurement-frame so that the measurement orientation, structure, environment and surroundings remain the same for all types of measurement.

4.2 Procedure of measurement

We investigated different impulse-noise sources- drilling machine, microwave-oven, and car ignition with sources positioned symmetrically to all four-antennas. Different steps of the measurement are as following:

First, the measurement-frame was placed at a suitable place to achieve a Line of Sight (LOS) path from the noise-source.

The antennas were placed uniformly in an antenna-base to create a ULA from the noise source, and the inter-antenna distance have been documented for each measurement. The ULA were positioned perpendicular to the LOS path.

All the coaxial cable connections were made accordingly as designed. The transfer functions of the filter-mixer pair were measured using network-analyzer, and were saved for later normalization of the measurement-data.

Using Matlab data-acquiring routine for acquiring signals, the oscilloscope was set for acquiring impulse segments with a triggering threshold of 10 mV. When the noise source was turned-on, impulses were generated, and the oscilloscope was triggered. The signal was sampled at 5 GHz and saved after down-sampling with 2.5 GHz. The segment size of impulse was 0.2 µs.
The measurement have been taken for different distances from the noise-source. For car ignition, the measurement have been taken for the distances of 50 cm, 100 cm, 150 cm and 200 cm, for drilling machine the measurement distances were 25 cm, 50 cm and 75 cm, and for the microwave oven measurement distances were 100 cm, 200 cm, and 300 cm.

The inter-antenna distance were taken at distances of \( \lambda/4 \), \( \lambda/2 \), and \( 3\lambda/4 \) to compare the correlation of the noise.

Orientation of the noise sources were kept the same for all distances and antenna-orientations.

The data were read using a Matlab reading routine in time-domain, and later the data were filtered and demodulated digitally for further analysis.

### 4.3 Measurement results

The measurement data is visualized in time-domain. The data can be used to make statistical distributions after normalization of data in frequency domain.

![Figure 2: Impulse segment from car ignition at 100 cm distance for \( \lambda/4 \) inter-antenna spacing](image)

For \( \lambda/2 \) and \( 3\lambda/4 \) distances, we obtained signal patterns that are almost similar to the signal patterns of \( \lambda/4 \)-spaced antennas. Theoretically however, we expect some differences in the correlations between adjacent antennas.
Figure 3: Impulse segment from car ignition at 100 cm distance for $\lambda/2$ antenna spacing

Figure 4: Impulse segment from car ignition at 100 cm distance for $3\lambda/4$ antenna spacing
We can see from the figures that sufficient change is visible at different inter-antenna distances. To see the subtle differences among different configurations, we need to analyze the data statistically.

Our measurement using the drilling machine was also successful in terms of noise-disturbance generated by it. The impulse segments from the drilling machine visually almost looks the same as those from the car ignition.

Figure 5: Impulse segment from the drilling machine at 50 cm distance for $\lambda/4$ antenna spacing

The impulse segments acquired from the drilling machine were more frequent than that caused by car ignition. The noise generated by drilling machine were more directive and less dispersive unlike the car ignition. The drilling machine produced very spiky high-voltage impulses with a broad spectral effect compared to the other sources.

A microwave oven is like an “unintelligent” radio station at home. The shape of the noise is seen to be mostly long-lasting periodic sinusoids (see figure 8 and 9).

For microwave oven, visually it is intuitive that the impulse is long-lasting in time period, and would cause burst-error on the communication system if the noise is not cancelled effectively.
Figure 6: Impulse segment from the drilling machine at 50 cm for $\lambda/2$ antenna spacing

Figure 7: Impulse segment from the drilling machine at 50 cm for $3\lambda/4$ antenna spacing
Figure 8: Impulse segment from the microwave oven at 300 cm for $\lambda/4$

Figure 9: Impulse segment from microwave oven at 300 cm for $\lambda/2$ antenna spacing
5 Impulse noise in wireline communication

Our study was also focused on 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

5.1 Common-mode noise

We know that 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.

![Diagram of common-mode noise](image)

Figure 10: Common-mode noise level at twisted pair cables

Common mode signals are typically more difficult to understand. They may involve either single-ended traces or two (or perhaps even more) differential traces. The same signal travels along both the trace and its return
path (ground) or along both traces in a differential pair. Most of us tend to be unfamiliar with common mode signals because we tend never to intentionally generate them ourselves. They are usually the result of noise being coupled into the circuit from some other (nearby or external) source.

Finally, when the difference signal is taken at the receiver, the common-mode noise signal is cancelled. The twisted pair cables are needed to be balanced to successfully cancel the induced impulse noise, otherwise noise would appear at the receiver from common-mode noise coupling. Therefore, we always need to use balanced twisted pair on transmission line. To couple the balanced line to an unbalanced transmission line, we use balun. A balun is a typical transformer that can convert balanced electrical signals (differential) to unbalanced signals (single ended), and vice versa.

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

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

5.2 Differential-mode noise

We generally think of signals propagating through our circuits in one of the three modes, single-ended, differential mode, or common mode. Single ended mode is the mode we are most familiar with. It involves a single wire or trace between a driver and a receiver. The signal propagates down the trace and returns through the ground system.

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. Mathematically, the differential-mode signal can be defined as

$$V_{DM} = V_A - V_B.$$
The study was involved design and test of a suitable measurement circuit. In the circuit we have so-called balun to obtain the common-mode noise signal from the primary side center-tap point, and the differential mode signal is measured from the secondary side of the transformer. A high bandwidth amplifier and a bipolar junction transistor were used to make the common-mode signal measurable to the oscilloscope. The amplifier was used as a source-follower for the common-mode signal, and the transistor was used to feed the signal into the coaxial cable. The following are the components of the measurement circuit:

i) Rectifier,

ii) Voltage regulator,

iii) Coupling capacitor,

iv) Decoupling capacitor,

v) Unity gain amplifier circuit,

vi) Voltage divider,

vii) Bipolar transistor,

viii) Balun.

**Component description**

i) Rectifier: It was used to convert input alternating current (AC) to direct current (DC).

ii) Voltage regulator: Regulators were used to provide steady, 5 V and 10 V, voltage levels.
iii) Coupling capacitor: It is normally used to connect two circuits such that only the AC signal from the first circuit can pass through to the next while DC is blocked. In our case, we used it to couple the common-mode signal to the input of op-amp.

iv) Decoupling capacitor: Decoupling capacitors were used to shunt the disturbances caused by other circuit components on the regulator output, reducing the effect they have on the rest of the circuit.

v) Amplifier: Unity gain amplifier was 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.

vi) Voltage divider: Switch-able voltage divider was used at the input of the amplifier.

vii) Bipolar transistor: Bipolar transistor was used to feed the signal into the coaxial cable.

viii) Balun: It was used to convert the signal from balanced twisted pair to feed into unbalanced coaxial cable.

In figure 13, the overall measurement set-up is shown. From the center-tap point of the transformer, we take the common-mode noise. The differential-mode noise is taken from the secondary side of the balun.

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

**Figure 13:** Graphical representation of the measurement set-up
5.4 Schematic and layout design using *Eagle* editor

The following are the design steps for making the layout using *Eagle*:

i) First, we need to list all the circuit components that are required to construct the circuit. Then, we have to find out the appropriate component packages from the library of the *Eagle* schematic editor.

ii) We have to place all the components at suitable places of the schematic editor. Then, we need to connect all the components according to the circuit requirement.

iii) We need to generate layout editor from the schematic layout window. A new window will be opened with the layout view of all the circuit components.

iv) In the layout editor, there is a default area specified within which we need to fit all the components at suitable places.

v) The circuit components should be connected either manually or using automatic routing of circuit connections.

vi) Now, we need to simulate ground plane in which we have to define the isolation, line-width, and spacing of the circuit components. According to the specification, the ground plane is generated.

vii) When we finish the layout editing, we should save the file as a board file which would be further used for manufacturing the PCB board.

We designed the circuit to make it available for further noise measurement. The schematic and lay-out were simulated for manufacturing. The schematic design and layout of *Eagle* is shown in figure 14 and 15, respectively.
Figure 14: Schematic diagram of the measurement circuit
6 Conclusion

Our study dealt with design of appropriate system to measure impulse noise in wireless and wireline communication. So far, we have discussed different impulse noise sources, and their effect on multi-antenna wireless channels. The impulse noise sources were chosen from both the indoor and outdoor environment. In the indoor environments, we chose microwave oven and drilling machine as a source of impulse noise. In the outdoor environment, we chose car ignition as a source of impulse noise. The impulse segments from car ignition system and drilling machine were non-periodic, and quite similar to each other; on the other hand, impulse segments from the microwave oven were long-lasting periodic signal segments.

We constructed a circuit for the measurement of impulse noise in twisted pair communication. In twisted pair communication, we experience two different types of impulse noise- common-mode noise and differential-mode noise. For measurement of the common-mode noise, we take the signal from the center-tap of the balun. We measure differential signal from the secondary side of the balun. Separately, we observe the effect of common-mode and differential-mode impulse noise in the scope. The circuit was designed using Eagle schematic and layout editor.
References


