Investigation of the Effect of Crosstalk on a Shielded Wire Conductor using a Three Line Transmission Model

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***Abstract*—Electromagnetic compatibility have been a major source of concern for Electronics Engineers in product design due to electromagnetic field effect on the electrical and electronics circuits during the system design. While in operation, it is expected that all electronic systems to coexist in harmony in the same electromagnetic environment without interference, but this is seldom achievable due to the high density and increasing speed of small low power semi-conductor devices which posed a serious challenge to the engineers in finding solutions of electromagnetic emission. For this reasons many simplified system models were developed which are used by system design engineers to simplify the complexity of electromagnetic interference problems. This work focuses on the use of a shield wire conductor techniques using a three wire transmission line model. This was investigated through an experiment to validate its accuracy, and the results obtained shows that inductive-capacitive crosstalk in an intra system circuit is reduced significantly by shielding the victim conductor and grounding it at both ends.**

Keywords- Compatibility, coupling path, Crosstalk, Emission, Interference

INTRODUCTION

Electromagnetic wave radiation and emission in communication systems gives rise to an important interest in the study of electromagnetic interference in electrical and electronics circuits, equipment's or systems. In every EMC problem there is a source of electromagnetic interference. Electromagnetic interference is said to exist when an undesirable voltages and currents are present to affect adversely the performance of a device [1].This interference is classified by its mode of transmission either conductive or radiative.

The cause of electromagnetic interference problem can be within the system which is termed an intra-system. When the interference problem comes from the outside of the system the case is labeled as an inter-system problem. The most common cause of both intra-system and inter system problems is an electrical signal which intended for one circuit reaches a circuit for which it was not intended. For the above problem to be solved, Electrical systems have to operate in the same environment without interfering with the operation [2].

Electromagnetic compatibility is then defined as the ability of an electrical system to function satisfactorily in its intended electromagnetic environment without introducing intolerable electromagnetic disturbance to any other device in that environment [3]

According to Gloedbloed '[2]', international Electro technical commission (IEC), described emission as an occurrence when electromagnetic energy originates from a particular source. This emission can be due to flow of electrical current in a particular circuit which set up an electromagnetic field. Also Gloedbloed '[2]' described susceptibility as the inability of a device or equipment to function properly without being affected in its operation by any electromagnetic disturbance environment.

Crosstalk prediction in electromagnetic compatibility studies formed as integral part of electromagnetic interference. Crosstalk can be defined as the disturbance to signal path generated from another signal path particularly between wires and cables or tracks in printed circuit boards which the field separation is close to another, it can be caused by electric field coupling through the mutual capacitances and magnetic field coupling through the mutual inductance or by the radiated coupling in the far end [4].In intra-system interference where the noise source or the EM emission and the receptor are within the same system, crosstalk results when the voltages or currents in one circuit are *unintentionally* coupled to another circuit. If the coupling is large enough, then the coupled signal can affects the amplitude of the signal received by the receptor circuit which causes the malfunctioning of the system. In practical designed the crosstalk is determined as the ratio of the noise voltage appearing across the load receptor circuit to the input signal voltage at the source circuit "[5]".

Crosstalk can also be measured in both ends of the conductor or wire either near end of the field or far end of the field.

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Crosstalk occurs in a multi-conductor transmission line where more than two conductors are considered. Since Maxwell's theory deal with the wave theory, depth understanding of the Maxwell equation will be needed which is extremely difficult, therefore the application of circuit theory to model the system into electrical circuit to investigate the electromagnetic interference either through the mutual capacitances or inductances that causes the crosstalk [6].

In investigating the crosstalk reduction techniques the model of multi-conductor transmission line was used with two conducting wires with same radius ***r*** separated by a distance ***D*** over a ground plane of height ***h*** as a reference conductor.

Base on the foregoing the research study will focus on the investigation of the phenomenon of crosstalk reduction in intra-system Electronics devices through an experimental method using a shield coaxial cable conductor, given an excitation at the near end field.

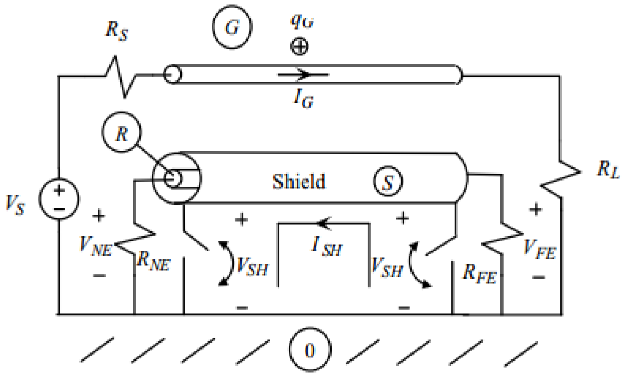

Figure1; Configuration showing a shied receptor wire conductor

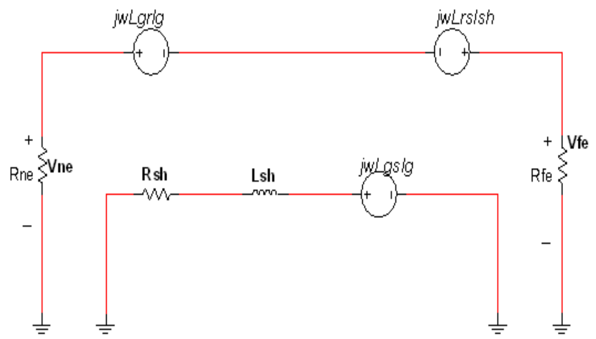

Figure 2; Shield receptor conductor equivalent circuit

From figure 1, the receptor conductor was shied at the center with the ends of the inner conductor terminated at each end in order to determine the crosstalk in the receptor conductor. In order to determine the near end inductive-capacitive crosstalk, we have to calculate all the circuit parameters that resulted to the crosstalk in the receptor circuit.

Considering figure 1 and 2, the generator current I_G induced a current to a receptor conductor I_R through the mutual inductance L_{GR} in the first loop and also, I_G induced another current I_{SH} to the shield portion of the receptor conductor reference to the ground plane through the mutual inductance L_{GS} in the second loop. This is a case where the shield is not grounded at both ends and thus the current I_{SH}= 0.

Now consider a case of both ends of the shield grounded, the current will flow through the shield and can only be limited by the shield resistance R_{SH} and its inductance L_{SH} as shown in figure 2.[7]

$$I_{SH} = \frac{j\omega L_{GS}}{R_{SH}+j\omega L_{SH}} \quad (1)$$

The mutual inductances L_{GR} between the generator and the receptor as well as between the generator and the shield can be determined from the physical geometry of the inductive-capacitive circuit. If h_G and h_R is the height of the generator conductor and the shield respectively above the ground plane separated by a distance D then,

$$L_{GR} = L_{GS} = \frac{\mu_0 l}{4\pi} In\left(1 + 4\frac{h_G h_R}{D^2}\right) \quad (2)$$

For the self inductances of the generator and the receptor conductor l_G and l_R respectively is determined by;

$$l_G = \frac{\mu_0}{2\pi} l\, In\left(\frac{2h_G}{r_{WG}}\right) \quad (3)$$

$$l_R = \frac{\mu_0 l}{2\pi} In\left(\frac{2h_R}{r_{WR}}\right) \quad (4)$$

$$L_{SH} = L_{RS} = \frac{\mu_0 l}{2\pi} In\left(\frac{2h_R}{r_{sh}+t_{SH}}\right) \quad (5)$$

Where r_{sh} and t_{SH} are the interior shield radius and the shield thickness.

Placing the shield on the receptor conductor and grounding it at both ends results in removing the mutual capacitances between the generator and receptor conductor C_{GR}. This result in reducing the total crosstalk by eliminating the capacitive coupling and leaving the inductive coupling to the minimum [7].For homogeneous medium with permittivity and permeability of free space parameters, ε_0 *and* μ_0 the per unit length parameter matrices "[8]", are;

$$L = \begin{bmatrix} l_G & l_{GS} \\ l_{GS} & l_S \end{bmatrix} \text{ and } C = \begin{bmatrix} C_G + C_{GS} & -C_{GS} \\ -C_{GS} & C_S + C_{GS} \end{bmatrix} \quad (6)$$

With L and C as per unit inductances and capacitances respectively

If $LC = CL = \varepsilon_0\mu_0$ and L is known from (5), then C can be computed from $C = \varepsilon_0\mu_0 L^{-1} = {}^{1}/_{v^2}\, L^{-1}$

Therefore for three conductor line in homogeneous medium the per unit length parameters is;

$$\begin{bmatrix} C_G + C_{GS} & -C_{GS} \\ -C_{GS} & C_S + C_{GS} \end{bmatrix} = \frac{l_{GS}}{v^2(l_G l_S - l_{GS}^2)} \begin{bmatrix} l_G & l_{GS} \\ l_{GS} & l_S \end{bmatrix} \quad (7)$$

Hence the mutual capacitance between the generator conductor and the shield is;

$$C_{GS} = \frac{l_{GS}}{v^2(l_G l_S - l_{GS}^2)} \quad (8)$$

Also, mutual capacitance between the receptor conductor and the shield is;

$$C_{RS} = {}^{2\pi\varepsilon_0\varepsilon_r}\Big/_{In\left({}^{r_{SH}}/_{r_{WR}}\right)} \quad (9)$$

ϑ is the velocity of the wave propagation of the transmission line.

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With C_{GR} eliminated due to grounding of both ends of the receptor conductor, therefore the near end inductive crosstalk is calculated from

$$\frac{V_{NE}}{V_S} = j\omega\left[\left(\frac{R_{NE}}{(R_{NE}+R_{FE})(R_S+R_L)}L_{GR}\right)\left(\frac{R_{SH}}{R_{SH}+j\omega L_{SH}}\right)\right] \quad (10)$$

$$R_{SH} = {}^{1}/_{\sigma 2\pi r_{SH} t_{SH}} \quad (11)$$

Where R_{SH}, is the shield resistance per unit length

Consider the case of both ends of the shield is not grounded. The shield receptor conductor will acts like the shield is removed and the current will not flow along the shield conductor surface and L_{GR} remains unchanged with C_{GR} been active (Paul, 2006).

$$C_{GR} = \frac{l_{GR}}{v^2(l_G l_{R13} - l_{GR}^2)} \quad (12)$$

Therefore the near end inductive – capacitive crosstalk is calculated from;

$$\frac{V_{NE}}{V_S} = j\omega\left[\left(\frac{R_{NE}R_{FE}}{R_{NE}+R_{FE}}C_{GR}\frac{R_L}{R_S+R_L}\right)+\left(\frac{R_{NE}}{R_{NE}+R_{FE}}l_{GR}\frac{1}{R_S+R_L}\right)\right] \quad (13)$$

MATERIALS AND METHOD

The objective of the experiment is to show a shield when placed on a wire conductor has an effect in reducing crosstalk in intra-system circuit and also investigate the improve performance over the capacitive and inductive coupling models. The emphasis is on the grounding the shield on both ends of the receptor wire to form a closed loop with the reference ground plane for the current path return in order to determine the near end crosstalk of an electrically short length of less than wavelength. In both cases measurements will be carried out and compared with the model derived equations from the theory.

A. Methodology

A physical hardware build structure consisting of a generator conductor and a shield coaxial cable PF 100 above a conductive ground plane is used as the experimental set up for a three conductor transmission line model to measure the near end crosstalk as shown in figure 3.The generator and a shield conductor are both terminated by a 50ohm impedance at far end side. The experimental model was given an excitation by a function generator to the input of the generator conductor and the near end output voltage over a frequency range of 150-KHz to 20-MHz and measured by the dual trace oscilloscope.

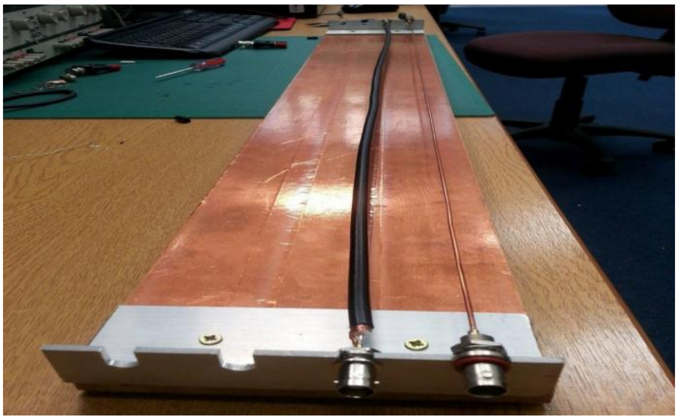

Figure 3; Physical build structure for the Experiment

B. Experimental Procedure

The experiment was performed in two stages for measurement of near end crosstalk.

(i) Both end of the shield is grounded

(ii) Both ends of the shield not grounded

Physical configuration of the build structure which determines the circuit parameters is; $l = 0.99m$, $D = 0.03m$, $r_{WG} = 0.0009m$, $r_{WR} = 0.0005m$, $r_{SH} = 0.0026$, $t_{SH} = 0.0005m$, and cable dielectric constant = 3.2.In the first stage the shield on the receptor conductor is grounded at both ends.

The model was excited with an input voltage $\boldsymbol{V_S}$ **,**by a function generator and both ends of the generator conductor were terminated by 50ohm impedance. The near end voltage was then measured at the near end output voltage $\boldsymbol{V_{NE}}$, of the shield conductor by an oscilloscope. The result was obtained, recorded and plotted against frequency

The circuit inductance parameters obtained from the physical build model configuration for both ends of the shield grounded are calculated from the equations: - (2), (3), (4) and (5), as; $\boldsymbol{L_{GR}}$= $\boldsymbol{L_{GS}}$ = 0.069µH; $\boldsymbol{L_G}$= 0.694µH; $\boldsymbol{L_R}$= 0.810µH; and $\boldsymbol{L_{SH}}$ = $\boldsymbol{L_{RS}}$ = 0.45µH respectively. And the capacitance parameters are also calculated from the equations: - (8), (9) and (11) as; $\boldsymbol{C_{GS}}$ = 2.49pF, $\boldsymbol{C_{RS}}$ = 106pF respectively. Shield resistance, $\boldsymbol{R_{SH}}$ = 2.1Ωm.Near end crosstalk was computed from equation (10).At both ends of the shield not grounded the procedure remain same with $\boldsymbol{L_{GR}}$ = 0.069µH unchanged. But $\boldsymbol{C_{GR}}$ is computed from (12) as; $\boldsymbol{C_{GR}}$ = 1.38pF.

RESULTS AND DISCUSSION

Aim of this experimental research is the comparison between the calculated values obtained from the derived theoretical model equations with the measured values obtained from the experiment conducted as well as reduction of crosstalk between the shield circuit and the disturbance circuit which is the generator conductor operating in the same electromagnetic field at the near end field. Therefore, the figures below shows relationship of different results obtained.

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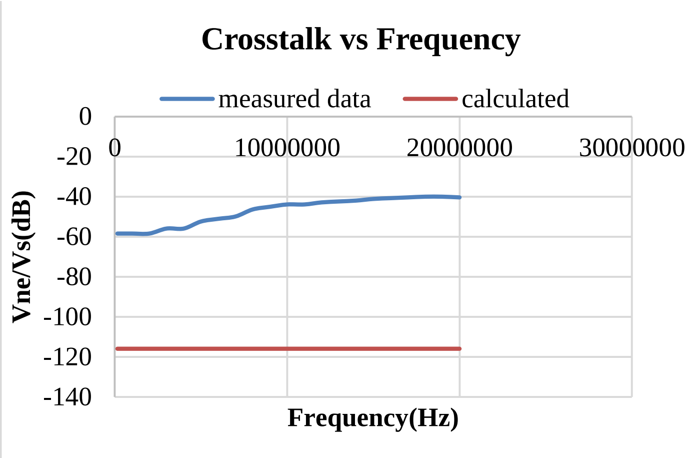

Figure 4; Comparison between measured and calculated crosstalk when both ends of shield is grounded

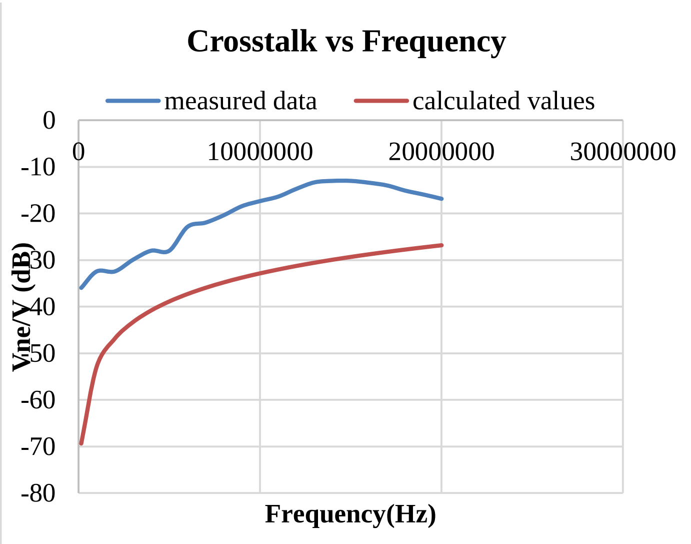

Figure 5; Comparison between measured and calculated crosstalk when both ends of the shield is not grounded

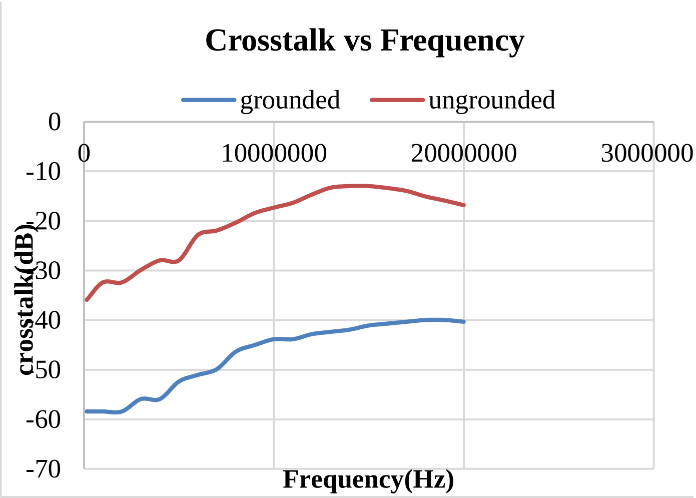

Figure 6; Comparison between the measured shield grounded at both ends and ungrounded at both ends

Figure 4, shows a comparison between the measured and calculated data near end crosstalk when both ends of the shield are grounded. From the graph it was deduce that shielding the receptor conductor and grounding it at both ends reference to the conductive plane, the shield voltage reduce to zero. This shows that effect of shielding on the receptor conductor eliminates capacitive coupling. The electric field line which originates from the generator conductor is block by the shield therefore not interfering with the receptor conductor. Thus the capacitive coupling between the generator and the receptor conductor is removed and the inductive coupling becomes dominant because the termination is low impedance. It can also be seen that effect of grounding both shield end the coupling is inductive and becomes constant above frequency of 15MHz as seen from the measured data.

when both end of the shield not grounded, the measured and calculated values shows same pattern with the calculated values slightly below the measured value as shown in figure 5. This shows that not grounding the shield ends, the electric field lines from the generator conductor will induced an amount of charges into the shield and then to the receptor conductor through the mutual capacitances between generator and the shield C_{GS} and also shield to receptor C_{RS} this will allow the current to return through the reference conductive plane and causing both the capacitive and inductive coupling between the loop wire conductors.

Comparing the two cases of the experiment, shows that the crosstalk significantly reduced with the grounding of both ends of the shield as shown in figure 6.When compared there is a crosstalk drop level of about 22.5dB which shows an improvement when both ends of the shield conductor is grounded.

CONCLUSION

A crosstalk reduction technique was investigated in an experiment using a shield conductor in a three wire conductor transmission line model to validate the existing theorems on the developed models of electromagnetic compatibility. Most of the results obtained shows that crosstalk in an intra system circuit will be reduced significantly by shielding the victim circuit and grounding it at both ends. The method also shows an improvement in the performance of that circuit operating in the near end field of electromagnetic environment.

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