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Reduction of Analog Noise in PCB for Photodetection System

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***Abstract*—Most of photodetection systems need to be satisfied high rate of data processing and high frequency. In response to the demands, EMI (Electro-Magnetic Interference) has emerged as an important factor to be considered for the photodetection system stability. In this study, experiments were carried out on methods of controlling impedance in the stage of design and improving signal integrity of PCB trace for consideration of the EMI problem. Programmed time varying electric field (vectorial signal) was composed for minimized loop in the layout with 8 types of traces as same schematic and examined their structural effects on the trace. In conclusion, the stacked structure was found to be more effective to control impedance. This study is a preliminary work for more complicated cases, providing the basic theory to reduce noises effectively with the shape of return path and more various vectorial signals.**

***Index Terms*—Analog noise, EMC, EMI**

I. Introduction

Recently, fast data processing speed and high frequency are required for electric circuit systems. To satisfy this is needed, EMI (Electro-Magnetic Interference) problem which is a key point that considering stability of the system. If data is processed fast in the circuit board, digital signal have some characteristics of analog signal. There are many solution to resolve the EMI and sensitivity problems, however, the best one is design of considering EMC (Electro-Magnetic Compatibility) which is hard technical work and is providing low cost.

Normally, simple design used by CAD tool in the case of circuit board operating in low frequency is beside the problems, but it is necessary to analysis some analog characteristics to deal with large amount of data and high speed processing. More approximate analyses are meaningless and necessary electromagnetic theories. Moreover recent PCB design is composed with multi layer which is necessary for LSI (Large Scale Integration) electronic systems. For this reason, EMC factors were considered during the first step of the PCB layout designing.

Actually, there are too many points have to be considered in the circuit board design with EMC factors and PCB layouts have an effect on system operation extremely. Researche has been made on in the EMI problems with controlling impedance of PCB layout works.

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II. Materials and Methods

A. Fundamental EMI Theory

Most useful method to analysis the electric and electronic engineering system is the circuit theory. Because the circuit has electric charges and which make electromagnetic fields. This circuit system has to be analyzed by general electromagnetic equation which is composed of the Maxwell's equation. The circuit theory, however, is just approximation in the actual circuit. It cannot be applied in some circuits which have size over 10cm with high frequency. Hence, it is necessary to do some spatial analysis by electromagnetic theory.

Maxwell equations are below:

$\nabla \times \vec{E} = -j\omega\vec{B} - \vec{M}$ Faraday's Law (1)

$\nabla \times \vec{H} = -j\omega\vec{D} + \vec{J}$ Generalized Ampere's Law (2)

$\nabla \bullet \vec{D} = \rho$ Gauss's Law (3)

$\nabla \bullet \vec{B} = 0$ Continuity of Magnetic Flux (4)

Three important informations can be considered from these four equations. First, changing electric and magnetic force are in existence a pair and construct vertical electromagnetic force. Second, if electric charges exist, there is electric flux in proportion to the amount of the charges. Third, the magnetic force make closed loop all the time. This means the magnetic field has no source of its existence. Time varying electric field is a source of electric and magnetic field. Hence, the spatial action of trace affects to other boards or be affected by them in the actual circuit board. This spatial action means the formation of electric current loop. If the electric current making loop flows on top side of PCB, it radiates RF energy as a good antenna. Hence, it affects another trace in the circuit or IC operation which has been more affective in the high frequency system.

In this study, the time-varying programmed electric field was made for minimizing the current loop, and the experiments were carried out to realize the spatial effect of trace.

B. Return Path

In general, EMI is generated by unexpected radiant magnetic field, or leak current. The return path is the most important fundamental notion to minimize the EMI in almost part of the electronic circuits. There are currents to be return toward the ground when we make a trace has single-ended route structure, which might be radiated to another type of energy if it has no path. The reference plane is used to make return path, which leads flux cancellation. In the layout stage of trace, moreover, it has to be considered that return path has been formed the current loop.

There are two types of current. They are common (even) mode and differential (odd) mode, to transfer RF energy. Currents from the source and to the source in the odd mode have same amplitude, reversed direction and phase. So, if return path is located near trace from the source, there are correlated coupling effects and it affect positive effect not noise. This belongs to the case of realizing signal or information from the source. The even mode current, however, is in existence when it contains defective odd mode cancellation, ground bounce, power fluctuation, or sharing of return path. This is the point we have to control and the even mode currents generate EMI (Electro-Magnetic Interference) because of the same direction and phase. The source is electrical noise in this experiment. Information cannot be predicted and recognized. Hence, the attention has been given to the changing noise level controlling the even mode currents.

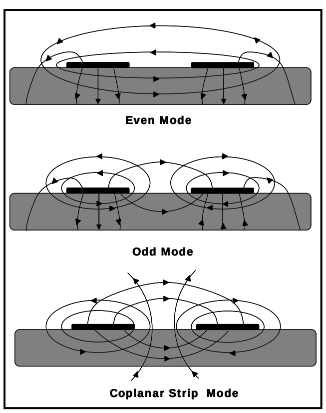

Fig. 1 Current modes transferring RF energy

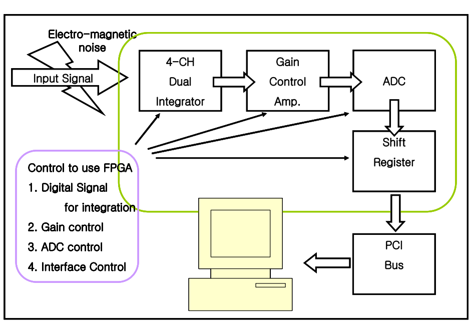

Fig. 2 Block Diagram of the DAQ System

III. System Description

A. DAQ Board Summary for Experiments

The DAQ (Data Acquisition) system for carried out the experiments consists of IC unit with amplifier and ADC, and simple FPGA unit. The DDC114, integrator with ADC, works for current-to-voltage integration of current from the input terminal. This current data is digitalized by the Delta-Sigma ADC, passed filter, and release with serial formation. Moreover, a special method was used, a daisy-chain offered by DDC114 for large number of channel numbers. This produces a combination of data sets for several chips; the data is moved serially by this system. This method is remarkably useful in systems which have many sensors that required pre-amplification. FPGA controls CONV, DVALID, CLK, DCLK signals of DDC to operate the integrator. Clock in all the systems are synchronized to 4 MHz. All of the terminals are plated with gold for sensitive response and the option for digital resolution of DDC114 is 20 bits. Fig. 2 shows the block diagram of the system for experiments.

B. Layout

All of DDC114s' input terminal have same dimension and signal level. The most important point of this experiment is variation of noise with the different layout types. For these eight layouts with different types of path was constructed. With characteristics of PCB structure, the stacked structure offers more easier examination than the sided structure. To compare with these structures, the stacked layouts and the sided layouts were constructed separately. Moreover, the vectorial signal which can be predictable is offered to parts around some traces, and the experiments are based on this layout. The four directional fine noise currents which are 5 nA and 10 nA with 16 MHz and 24 MHz are generated from 5V clock in 16 MHz, 24 MHz oscillator with 1 GΩ and 500 MΩ .

C. Data Processing

Data processing is a step for simple comparison of noise, but it is an important portion of final imaging and data collecting. One channel makes 20 bits output and totally 80 bits are shifted and collected for four channels in one DDC114, as shown in Fig. 3.

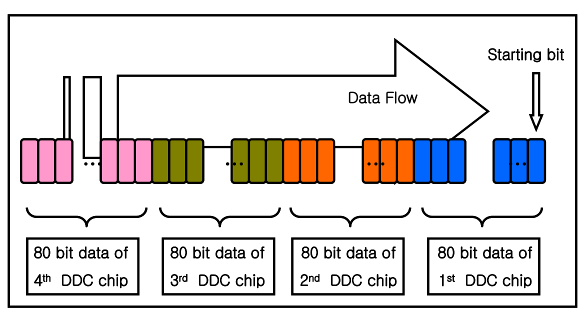

Fig. 3 Data Processing Flow

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Because of the daisy-chain technique which makes serial data output between DDC114s, 640 bits data sets are produced orderly. Numerical results have been obtained which are binded with 20 bits and can make an expression of 1,048,575 in decimals. The results are saved in the text file, and it acquires data in process time.

IV. Experimental Conditions

Eight types of layouts were considered, designed, and constructed in one PCB as shown in Fig. 4.

A. 1st Case: Simple Trace without Shielding

First path is simple trace without shielding. There is just routing trace on top side on PCB, and there are no planes or another path. Generally, this routing trace in top or bottom on PCB is called 'Microstrip'.

B. 2nd Case: Simple Trace with Shielding

The second path is simple trace with shielding. This trace is routed on third plane of PCB which has six layers totally. There are no planes or path like the first case. The routing trace in the inner layer of PCB is called 'Stripline'. These cases are for comparison with the first case, and both of them have no reference plane and return path.

C. 3rd Case: Complicated Trace with Stacked Return Path

The third path is complicated trace with return path. The second and fourth plane is grounded, the stripline is constructed in the third plane between the two.

D. 4th Case: Complicated Trace with Sided Return Path

The fourth path is complicated trace with sided return path. It is routed in the third plane, and the small grounding planes are located in the same plane. There are no elements in the other planes to examine the electro-magnetic effect with the reference plane around the trace. The results from this case were compared with the results of the third case. The good results can be obtained if distance of path and reference plane are as narrow as possible. However, the 5 mil, as same value of 0.127 mm is chosen for limitations of manufacturing process.

E. 5th Case: Sided Vectorial Signal with Forward Direction

The fifth path is the trace with stacked return path and directional noise currents which can be adjustable, called 'vectorial signal'. The direction of the vectorial signal has the same direction of input signals. We carried out the experiments that used four types of vectorial signal with 16 MHz, 24 MHz and 5 nA, 10 nA.

F. 6th Case: Stacked Vectorial Signal with Forward Direction

In the sixth path, there is a trace which is sided with return path and the vectorial signal. This vectorial signal can be adjustable direction noise currents and flows in the upper and under plane widely. The direction, is as same as the fifth case, has the same direction of input signals. The experiments were carried out in the same condition of the fifth case.

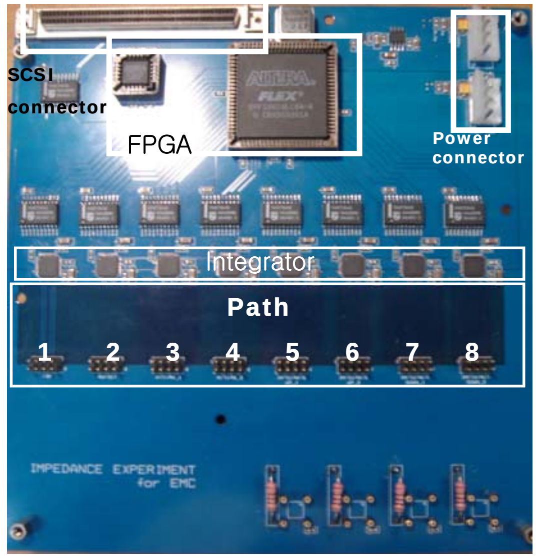

Fig. 4 PCB for Experiments consisting of eight paths

G. 7th Case: Sided Vectorial Signal with Reverse Direction

The seventh path has the trace which has stacked return path with the vectorial signal, directional noise current around the trace which can be adjustable direction. The different condition with the fifth case is in the opposite direction. This case has same condition of vectorial signals as mentioned above.

H. 8th Case: Stacked Vectorial Signal with Reverse Direction

The eighth path has the trace with sided return path and vectorial signal in the other plane as like the sixth case. The direction, moreover, has the opposite direction as like the 7th case, and the condition of the vectorial signals is same as the 7th case.

V. Results and Discussion

A. Existence of Shielding

Table 1 shows the mean values in decibel (dB) scale. Comparing the data from the experiments, the trace without shielding has the SNR of 56.17 dB as electrical noise and the trace with shielding has the SNR of 63.04 dB. The SNR level of the shielded trace has not much higher value than the SNR value of not shielded trace. However, Absence of any elements for stable power supply has to be focused

The SNRs of the shielded trace and the not shielded trace has the gap of 6.87 dB. This result shows the necessity of the careful consideration to construct the layout by signal characteristics or structure of the ICs.

Table 1. Experimental Results for Existence of Shielding

	Input of Trace w/o Shielding				Input of Trace w/ Shielding			
	1	2	3	4	1	2	3	4
Trial 1	96.019	96.202	96.018	96.019	93.034	93.033	93.034	93.033
Trial 2	96.018	96.017	96.017	96.018	93.034	93.036	93.035	93.034
Trial 3	96.017	96.019	96.018	96.018	93.034	93.033	93.033	93.034

Table 2. Experimental Results for the types of Return Paths

	Input with Stacked Return Path				Input with Sided Return Path			
	1	2	3	4	1	2	3	4
Trial 1	85.533	85.457	85.496	85.408	92.353	92.308	92.252	92.330
Trial 2	85.461	85.475	85.488	85.561	92.255	92.315	92.345	92.405
Trial 3	85.340	85.397	85.319	85.359	92.337	92.350	92.254	92.296

Table 3. Experimental Results for Vectorial Signal with Forward Direction

		Forward Sided Vectorial Signal				Forward Stacked Vectorial Signal			
		1	2	3	4	1	2	3	4
500MΩ	**16MHz**	94.176	94.274	94.261	94.286	93.552	93.625	93.623	93.573
	24MHz	93.983	94.112	94.156	94.103	93.062	93.427	93.326	93.069
1GΩ	**16MHz**	94.455	94.577	94.566	94.521	94.290	94.013	94.375	94.308
	24MHz	94.346	94.466	94.309	94.394	93.994	94.165	94.215	94.046

Table 4. Experimental Results for Vectorial Signal with Reverse Direction

		Reverse Sided Vectorial Signal				Reverse Stacked Vectorial Signal			
		1	2	3	4	1	2	3	4
500MΩ	**16MHz**	95.909	96.438	96.185	96.233	97.286	97.189	97.167	97.166
	24MHz	96.670	96.542	96.779	96.670	97.569	97.407	97.519	97.631
1GΩ	**16MHz**	94.618	94.673	94.755	94.818	95.018	94.961	94.986	95.074
	24MHz	95.103	95.187	95.170	95.216	95.552	95.578	95.585	95.440

B. Types of Return Paths

Table 2 shows the mean SNR values of the third path and the fourth path. The trace with stacked return path has SNR value of 80.53 dB and the trace with sided return path has SNR value of 64.69 dB. This second experiment shows similar result that the gap value of 15.83 dB and it shows that the return path has to be considered more than trace shielding. Actually, many technical papers deal with the return path and this is regarded as most effective method to minimize the effect from RF energy in high frequency systems.

We can recognize that the experiment of return path has more wide error range which increases the sensitivity with low noise level. The current entered at input has to come back to ground of the source, however, if there are no ground lines or planes, the energy is radiated as other form and it is changed to noise. Hence, it is recommended that making the flow of unartificial current with RF return path and making the maximum effect of cancellation locating return path near the trace.

The second path and the fourth path have almost no difference, as shown in the table 4.2. The fourth path is the case of added return path around the trace in the second path, and return path in the side of the trace cannot be performed well. The stacked return path, however, can perform well.

C. Types and Direction of Vectorial Signals

The big noise level was measured from the experiments for cases 5, 6, 7, and 8. It was due to the miss design of the final part of input and routing. Hence, each cases were handled with relative values.

Some types of the vectorial signal to examine the variance of impedance in input terminal were offered. The signal with the resistance of 500 MΩ is affected to change of noise and make more current flow than the signal with the resistor of 1 GΩ. The vectorial signal with 24 MHz, however, affects the more big EMI effect than 16 MHz as high frequency.

More important point is that the effects of stacked, sided structure with forward, and reverse direction. As shown in the experiments for the return path, signal with stacked structure affects more than sided structure in the trace. In cases 6 and 8, the vectorial signal was stacked structure, but it was composed by plane. Hence, wide area has an effect on the trace consisting one magnetic field in forward direction and decreasing impedance as like differential pair. It is undeniable fact that the stacked structure is more effective method to control impedance. The noise is increased with reverse direction, and the stacked reverse signal is the most interruption structure in current flow.

VI. CONCLUSIONS

There is some trend that engineers make a focus to just each part separately in the design of system. The system, however, assembled with those each parts, have some problems sometimes. Most representative origin is EMI problems which offer to us that the analog approach is necessary for signal processing with high speed digital system. This approach has to be considered in concept, design, and layout steps.

We compared structural return path in this study. This return path is the most important point for EMI problem, and it has to be around the trace with a stacked plane structure. The vectorial signal, moreover, can reduce the impedance with forward direction like as differential pair which has important factor, current level of the signal.

The careful layout for ideal connecting of current in PCB may guarantee the stable circuit performance in photodetection for the next design and manufacture.

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