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Using Parametric Design to Reduce the EMI of Electronics Products — Example of Medical-Grade Touch Panel Computer

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Abstract—With technical advancement and development, the amount of electronic equipment is increasing, while the functions of products are enhanced, and the routing density of Printed Circuit Boards (PCBs) becomes larger. In the electronic industry, medical instruments are used to diagnose, treat, mitigate or prevent human diseases, and maintain and promote health. Industrial PCs for medical use and their accessories should be immune to interference from external electromagnetic noise, and should not become interference sources of electromagnetic noise radiation, so they have become issues of interest with respect to ensuring safety of medical equipments in medical operation environments in recent years.

This research relates to parametric design using the Taguchi Method in the early stage of product development for medical-grade touch panel computers. In considering the use of Radiated Emission (RE) in Electromagnetic Compatibility (EMC) as a response value, the experiment covers control factors such as PCB and mechanism design related parameters. In addition, peripheral devices used in conjunction with a product are considered as noise factors when the product is in use, while interaction between the control factors is studied. The Taguchi Method is used to select an appropriate inner/outer orthogonal array, and a response diagram and a variance method are used for analysis to provide an optimal set of design parameters, in which the number of routing layers of a riser card is 6; the EMI filter on the isolated card is $600\,\Omega$; the shunt capacity for the clock on main board is 33p; and the isolated card is grounded. Moreover, it is found that an interaction exists between the number of routing layers of the riser card and the EMI filter of the isolated card. From the result of the experiment, with such a set of parameters, the SN (Signal to Noise Ratio) lies in the confidence interval, indicating good reproducibility of the experiment. Such a parametric design effectively improves the electromagnetic interference (EMI) characteristics of a product to meet design specifications required by customers, accelerate the R&D process of electronic products, and pass EMI test regulations required by various countries in order to improve industrial competitiveness.

1. BACKGROUND AND MOTIVATION OF THE RESEARCH

The Industrial PC (IPC) was first used in factory automation to act as a CNC (Computer Numerical Control) and as the control core of machines, such as a CNC lathe, capable of monitoring, controlling or testing machines or instruments in manufacturing process. With advanced techniques and more convenience required by human beings in life, its new application has gradually been oriented to industrial automation and life automation. In additional to the manufacturing industry, computer automation control is currently used in the financial sector, telecommunication network industry, and even medical care and monitoring.

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From the medical industry's position in people's welfare, the scope of the medical service market is extending, including various medical care related industries, such as the traditional hospital industry, pharmaceutical industry, and emerging biotech industry. Generally, the medical industry refers to industries/institutions regarding prevention, examination, treatment, rehabilitation, nursing and care for physical and mental health and disease, including manufacturers and suppliers of medical devices, manufacturers and dealers of various medicines, as well as various people working in various medical institutions, such as hospitals/clinics, inspection stations, and nursing homes.

In the electronic industry, medical instruments are used to diagnose, treat, mitigate or prevent human diseases, and maintain and promote health. Medical devices feature a diverse set of products, high technical complexity and integration, high margins, high uncertainty of R&D and profit, as well as a high closure of market, etc. However, Small Medium Enterprises (SMEs) play a main role in the medical device industry in Taiwan, and traders are mainly import oriented. Production, manufacturing and channels have been increased in recent years. Since the domestic market is small, and finished products are mainly export oriented, raw materials are mainly sourced overseas. Most manufacturers are assembly Original Equipment Manufacturers (OEMs) based on production technology, and most products are social welfare devices.

The amount of electronic equipment is increasing, while the functions of products are enhanced, and the routing density of Printed Circuit Boards (PCBs) becomes larger [1, 12, 18]. Further, the clock rate of the Central Process Unit (CPU) is becoming faster, so that the operating frequency tends to high frequency. Crosstalk issues will appear accordingly to cause Electromagnetic Interference (EMI), coupling signals and time delays, such that normal functions of the product are influenced in operation. Medical equipment with reversible interference issues can result in faulty diagnosis or treatment.

The accuracy of EMI/EMC measurement depends on many factors, including whether the measurement environment is qualified, whether the measurement instrument is standard, whether the electromagnetic coupling between the measurement instrument and the Equipment Under Test (EUT) is eliminated, whether artificial operation procedure is correct, etc. There are standard regulations or international certifications for many existing EMI/EMC measurement procedures, environments, instruments, etc. In recent years, advanced countries, such as USA, Japan and the European Union (EU), have proposed regulations for EMI levels generated by electronic products, together with control, successively in order to protect radio communication and computer information control. For example, regulations such as the Federal Communications Commission (FCC) of USA, Voluntary Control Council for Interference (VCCI) of Japan, Communate Europpene (CE) mark of European Union (EU) and C-tick of Australia require that electronic information products which are to be imported shall apply and be tested to be qualified prior to legal transportation and sale. The Bureau of Standards, Metrology and Inspection (BSMI) has also implemented control measures since 1996 in our country.

As for hand phone, notebook, as well as medical devices emit electromagnetic fields (EMF), these emissions are a risk exposure for the human beings in the proximities due to the energy that is absorbed by tissues. In these conditions, the specific absorption rate (SAR) is defined as the amount of energy absorbed by tissues. Factors affecting the amount of absorbed energy are features of the wave, features of the body, and also environmental features. About the features of the wave, the SAR depends on the features of the signal emitted by the radiation source, such as frequency [14] and polarization [11]. About the dependence with the body, the SAR depends on the type of tissue, the posture of the body [22], frontal or back incidence [10], etc. Accordingly, before selling products to domestic or overseas markets, in most cases domestic electronic companies cannot pass the EMI test standards required by the regulations of client countries, so that the time to market is delayed, and business opportunities are lost significantly.

With respect to the causes and improvement measures of EMI, scholars have already had discussions, in which Kchikach et al. [15] indicated that EMI comes mainly from the high switching frequency of DC voltages of power converters. That research is limited to influence Common Mode (CM) current noise on switching power supply without mentioning how to improve the EMI of PCB [16]. Adams [2] indicated that the direction of cm current causes cables or wires on products to generate electromagnetic radiation, radiation immunity and conduction radiation. Also, a low cost EMI troubleshooting technique is designed for engineers to evaluate products quickly at an early stage in order to comply with EMC standard. Bait-Suwailam et al. [4] studied EMI generation mechanisms and improvement approaches in the aspects of theory research and design in order to improve EMI by blocking the interference path to suppress interference, and by using grounding, shielding, filtering and PCB layout. Colotti [8] indicated that EMI is formed due to three keys, including an interference source, coupling path and interfered susceptor, and EMI issues are mitigated by reducing the noise of the interference source, or developing and maintaining relevant control plans. However, the research above is only limited to explanation of theory without describing countermeasures and introductory methods which improve EMC effectively in detail for specific products or regulations.

In references, scholars also used masking approaches to reduce EMI noise. Lin et al. [19] set forth the EMI masking characteristic of methyl vinyl silicone composite materials with bamboo-like carbon nanotubes of different concentrations. However, the concentration of liquid cannot be controlled easily, so the conductivity is influenced, thereby reducing the effectiveness of masking. Zhao et al. [26] proposed independent cables and motors for evaluating the EMC design of one converter and simplified different model constructions/configurations to execute this verified hypothesis. Moreover, some scholars studied grounding. Researchers used grounding approaches to reduce EMI noise [6]. Liu [20] studied and controlled EMI due to a grounding loop, which is increased with the complexity of system. In this research, EMI is reduced by eliminating the grounding loop and limiting its area. However, harmonic waves due to the oscillator (crystal) cannot be eliminated by this approach.

The scholar below reduces EMI noise by using a filtering approach [21]. Aksoy [3] proposed design of an EMI power line filter, which filters out transient signals coupled to military system power lines, and conducted and radiated noise generated by the switched mode power supply. However, a common mode choke with a large volume and occupied space was used as the inductive component to suppress low frequency noise in this research, so it is not applicable to products with limited space.

In references, the number of routing layers of PCB was proposed to suppress EMI noise [9, 17]. In this research, multilayer is mainly studied, in order to increase the area for routing, increase functional density and reduce EMI. In a multilayer PCB, the entire layer is connected to the ground line and power directly. Layers are classified into signal layer (Signal), power layer (Power) and ground line layer (Ground). In the case that different power supplies are required for parts on a PCB, such a PCB usually has two or more power and wire layers. Huang & Chen [13] studied an industrial panel display, and electromagnetic fields and electromagnetic waves may result in an adverse influence for peripheral equipment in use to malfunction, resulting in system failure or unintentional accidents and inducing worry of severe public safety incidents. The three EMC characteristics, including RE, conduction interference and fast transient impulse immunity of power, are considered response values; control factors are determined with respect to relevant parameters for PCB and mechanism design of the product; and peripheral devices used in conjunction with the product are considered as noise factors. Grounding in PCB routing design with EMI is studied to reduce design cost and reduce the influence of EMI and ESD.

In order to meet the requirements of medical-grade computers, riser cards are mounted on the main boards additionally for transmitting signals to isolated cards through riser cards. The purpose is to meet the requirements that medical products have to be connected with various peripheral devices. Thus, connection ports are additionally arranged on the isolated card [7]. Since electrostatic discharge or surges may occur for external devices, grounded regions of the main board and isolated card are isolated to prevent the main board from being impacted [5, 23]. However, EMI issues for the noise of the isolated cad cannot be reduced through grounding, so it is more difficult to pass the regulation test.

1.1. Purpose of the Research

This research is intended to propose countermeasures which reduce EMI for medical-grade touch panel computers in order that such electronic products can meet relevant standards and regulations.

(1) For EMI test standards required by regulations, influences of parameters (i.e., control factors) with respect to circuit board and mechanism are considered systematically. Even though the products can fit external factors, such as end customers in different service environments and different countries, the influence of noise variation may result.

(2) Interaction which may exist between control factors, such as PCB designs and electronic component characteristics, is considered. Orthogonal Array (OA) is planned by using the Taguchi Method to

conduct the experiment. Data analysis is used in conjunction to determine the optimal set of parametric designs, in order to suppress EMI effectively and to meet design specifications required by customers, such that EMI test regulations stipulated by various countries for products can be passed quickly.

(3) They are provided to operation/management decision makers as reference for the direction of product design. EMI issues can be considered in the early stage of product design to reduce countermeasure components, product cost and labor consumption due to a number of design changes in the R&D cycle, and to accelerate the R&D process.

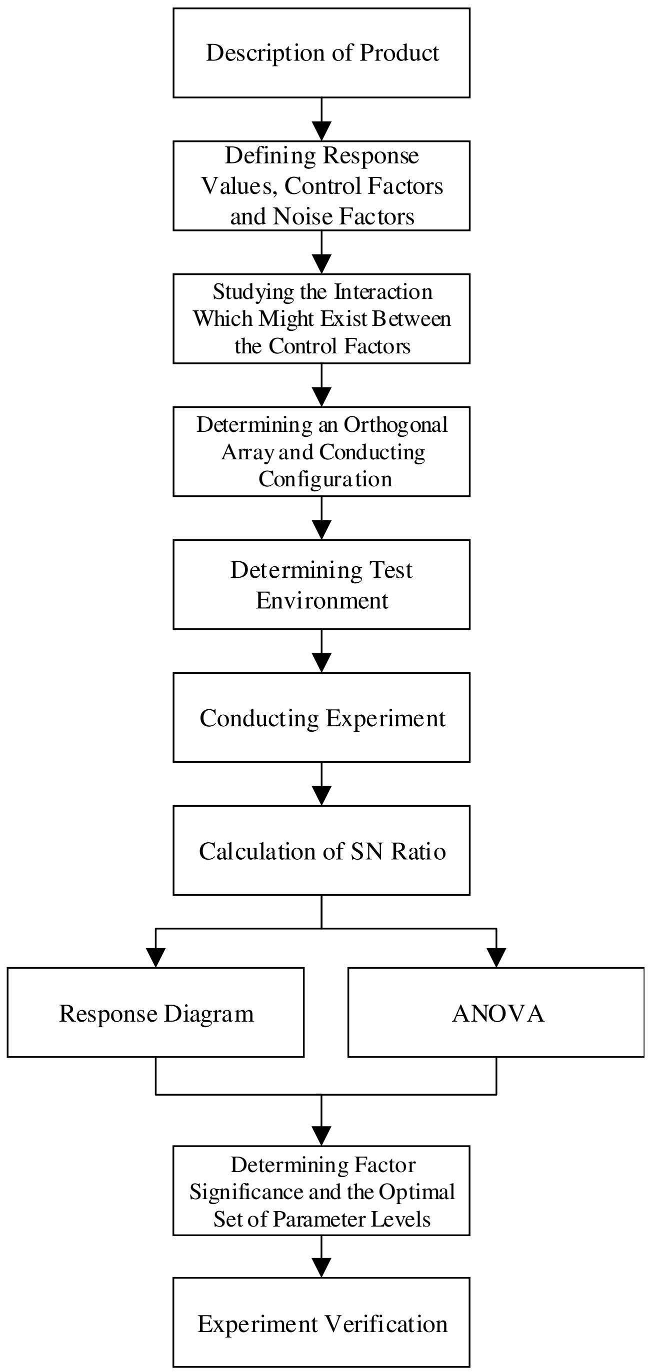

Figure 1. Research process.

1.2. Research Process

In this research, the EMI of electronic products is studied for medical-grade touch panel computers. First, important parameters are filtered through engineering knowledge, such as electronics, electrical machinery, mechanisms, and PCB routing design. The quality characteristics (response values) for measuring EMI and the control factors and noise factors which influence EMI are determined, and the interaction which might exist between the control factors is studied. The Taguchi Method is used to select the appropriate orthogonal array, linear graph and configuration of the experiment. Next, the test environment is identified, and the experiment is conducted to obtain data, which is converted into the signal to noise ratio (SN ratio). A response table and a response diagram are used to determine the influence of various factors in different levels, followed by conducting Analysis of Variance (ANOVA) to determine factor significance, and the optimal set of parameters is provided. Lastly, a verification experiment is executed to ensure the effectiveness of the result. The research process is as shown in Figure 1.

2. DESCRIPTION OF PRODUCT

In this research, a medical-grade touch panel computer is studied, in which a main board and a circuit board of the product are as shown in Figure 2. Such a product is widely used for medical and commercial

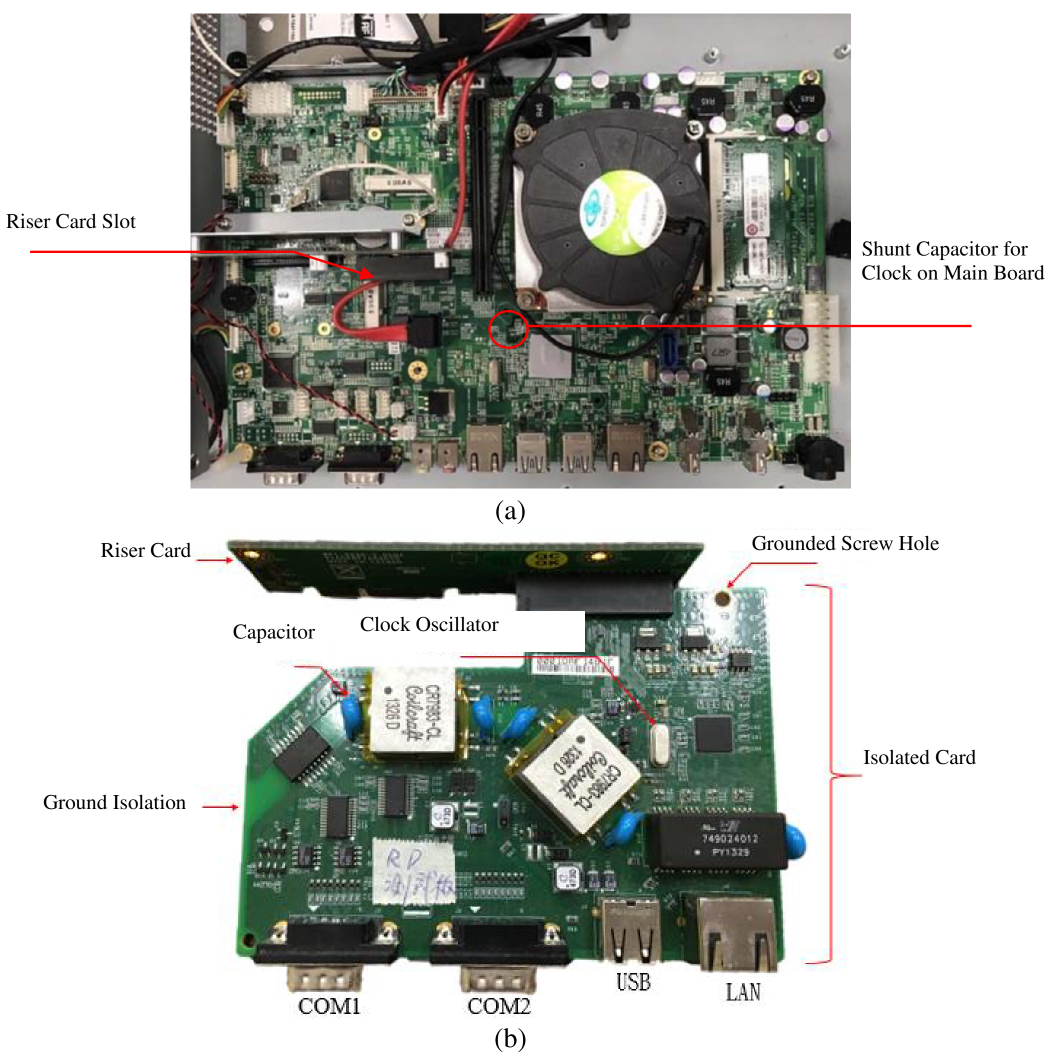

Figure 2. Medical-grade touch panel computer. (a) Main board. (b) Circuit board.

purposes, mainly to monitor information, such as conditions of patients, external connection to other medical equipment, patient records and physical conditions. It seems to have become the main stream in the market due to its high return and high gross margin. Such a product has to accommodate specially designed models of circuit boards and components to achieve high performance operation and may be used in an environment regarding artificial life safety, etc.

3. EXPERIMENT PLANNING

This research relates to parametric design using the Taguchi Method in the early stage of product development for medical-grade touch panel computers. In consideration of the use of radiated emission in electromagnetic compatibility as response values, the experiment covers control factors such as PCB and mechanism design related parameters. In addition, peripheral devices used in conjunction with a product are considered as noise factors when the product is in use, while interaction between the control factors is studied.

3.1. Response Values

EMC means that one device can have its emitted EMI limited without influencing the normal operation of peripheral systems, while resisting external noise and operating normally in an electromagnetic environment. Thus, it includes two characteristics, including EMI and EMS. In this research, the radiated emission which may influence normal operation of a product by a medical-grade liquid crystal computer during use is considered as a response value, test environment and data collection for the experiment as described below:

Radiated Emission (RE) (dB): It means that the electromagnetic noise is radiated and propagated through a space in the form of electromagnetic field energy, and coupled to interfered devices (or their circuits) [24, 25]. Noise of various frequencies may be generated in the EMI measurement of a product. In this research, the noise with the highest frequency is selected, and the noise measurement value acts as a response value. The smaller the value is, the lower the RE level is, so it belongs to the Smaller The Better (STB) characteristic of Taguchi quality.

3.2. Control Factors

In this research, the important parameters related to PCB and mechanism designs of a medical-grade touch panel computer are considered as the control factors of the experiment, and the selection reasons and their levels are described as following:

A. "Number of Routing Layers on Riser Card": The number of layers can influence product characteristics, including functional density, EMI, product size and cost. The larger the number of layers is, the more helpful it is for isolating noise, that is, for reducing EMI. In this research, two levels of layer numbers are considered for riser cards, including a 4-layer board and a 6-layer board.

B. "EMI Filter on Isolated Card": The filter technique allows signal frequencies required in design to pass, while unnecessary noise frequencies are degraded to suppress noise interference. In order to avoid common mode impedance coupling due to the pickup of noise when being provided for various IC powers, ferrite bead suppression components are added at the entrance where the power enters the IC on PCB, thereby filtering out high frequency interference of the local circuit. In this research, a ferrite bead inductor is provided at the entrance mentioned above where power enters IC. Two resistance levels of inductor are considered, including $0\,\Omega$ and $600\,\Omega$.

C. "Clock Shunt Capacitor Component": The clock component and capacitor component are designed in parallel connection on the main board to increase the capacity and storage charges. Moreover, adding a capacitor may reduce the radiation of the current loop to suppress noise. In this research, two levels are considered for the capacitor, including 0p and 33p.

D. "Grounding of Isolated Card": Grounding is an electrical conduction path created between electrical and electronic components to an earth reference in a system for the purpose of conducting electromagnetic noise to the ground surface through grounding, while releasing a large number of charges to the ground surface, in order to avoid high voltage formed due to charge accumulation, such that the influence of static electricity will not occur easily when being contacted by the human body, and sparks will not be caused inside the equipment. In this research, two levels are considered, including that without grounding and that with grounding.

3.3. Second Order Interaction

PCB design and electronic component characteristics are considered. In the research, the second order interactions between the following three sets of control factors will be studied:

(1) "Number of Routing Layers on Riser Card" and "EMI Filter on Isolated Card": The influence of resistance of the EMI filter on the isolated card on the magnitude of electromagnetic noise may vary with the number of routing layers on the riser card.

(2) "Number of Routing Layers on Riser Card" and "Shunt Capacitor for Clock on Main Board": The influence of resistance of the shunt capacitor for the clock on the main board on the magnitude of electromagnetic noise may vary with the routing layers on the riser card.

(3) "Number of Routing Layers on Riser Card" and "Grounding of Isolated Card": The influence of grounding of the isolated card on the magnitude of electromagnetic noise may vary with the number of routing layers on the riser card.

3.4. Noise Factors

The level of noise which may be influenced by peripheral devices in conjunction with the product during use is considered. For example, connection wires and their placement may all generate different levels of EMI. Thus, the following noise factors are considered in this research:

E. "Switching Power Supply": Switching power supply uses high frequency switching technology of semiconductor switches, for which common mode noise is the main noise source. Most such products are provided by suppliers, and their EMI levels may differ. In this research, 5-stage and 4-stage power suppliers are considered, with power efficiencies of 92% and 95%, respectively. Less stages indicate more saved power and higher energy efficiency.

F. "Signal Cable Filter": As an electronic product is connected with a peripheral device, a signal line may bring out and emit noise to air, forming an interference noise source. Most manufacturers add a ferrite core filter when a signal line is close to the EMI originator. As the signal line passes through the ferrite core (Figure 3), a signal may pass through effectively with almost no degradation, while interference noise is blocked and converted into heat, which is dissipated, such that noise is filtered and transmission quality of the signal improved. In this research, two numbers of signal line filters are considered, including 1 core and 2 cores.

(a) (b)

Figure 3. Signal line with added immunity magnetic ring. (a) 1 core. (b) 2 cores.

G. "Use of Voltage": Electronic products may be sold all over the world, while the voltages/frequencies and certifications used in various countries are different. For example, 110 V/60 Hz (BSMI) is used in Taiwan; 100 V/50 Hz (VCCI) is the voltage used in Japan; 120 V/60 Hz (FCC) is used in the

USA/Canada; 240 V/50 Hz (C-TICK) is used in Australia; and 230 V/50 Hz (CE) is used in Europe, while the used voltage may influence EMI level. Since Europe and the USA are the key sales markets, two test voltage/frequency levels are considered, including 120 V/60 Hz and 230 V/50 Hz.

3.5. Configuration of Orthogonal Array

In this research, an $L_8(2^7)$ inner orthogonal array is built, and the second-order interaction which may exist between the control factors mentioned above is considered. In this experiment, four 2-level factors (A, B, C, D) are considered, and the second-order interactions, $A \times B$, $A \times C$ and $A \times D$, are evaluated. The L_8 orthogonal array and standard point plot are as shown in Table 1 and Figure 4. In turn, noise factors (Table 2) are considered in conjunction with an $L_4(2^3)$ outer orthogonal array to ensure that the optimal set of control factor parameters is applicable to various noise factor sets.

Table 1. Experimental configuration of the L_8 control factors.

Control Factors	A. Number of Routing Layers on Riser Card	B. Design of EMI Filter	$A \times B$	C. Shunt Capacitor for Clock Signal on Isolated Card	$A \times C$	$A \times D$	D. Grounding of Isolated Card
1	4 Layers	$0\,\Omega$		0p			With Grounding
2	4 Layers	$0\,\Omega$		33p			Without Grounding
3	4 Layers	$600\,\Omega$		0p			Without Grounding
4	4 Layers	$600\,\Omega$		33p			With Grounding
5	6 Layers	$0\,\Omega$		0p			Without Grounding
6	6 Layers	$0\,\Omega$		33p			With Grounding
7	6 Layers	$600\,\Omega$		0p			With Grounding
8	6 Layers	$600\,\Omega$		33p			Without Grounding

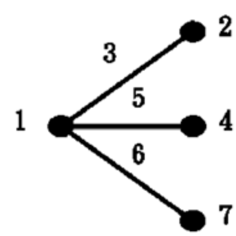

Figure 4. Linear graph of L_8 interaction.

Table 2. Experimental configuration of the L_4 noise factors.

Noise Factors	E. Switching Power Supply	F. Signal Line	G. Used Voltage
1	4 Stages	1 core	120 V/60 Hz
2	4 Stages	2 core	230 V/50 Hz
3	5 Stages	1 core	230 V/50 Hz
4	5 Stages	2 core	120 V/60 Hz

4. TEST ENVIRONMENT AND DATA COLLECTION

In the research, Radiated Emission (RE) generated by a medical-grade touch panel computer during use is considered and described as follows:

RE: The instrument/equipment includes a test receiver (EMI test receiver), a wireless (radio frequency; RF) cable, a monopole biconical antenna (Figure 5), an antenna elevation unit, and an Equipment Under Test (EUT) rotation disk with a frequency ranging from 30 to 1000 MHz. The test site is a semi-anechoic chamber with a dimension of 7 m (length) × 4 m (width) × 3 m (height). In measurement, the distance between the EUT and the antenna is 3 m. The EUT is placed on a non-conductive table with a height of 80 cm and is located on a 360-degree rotational disk, while the antenna is elevated at a height of 1–3 m. An electromagnetic wave signal is transmitted outside the laboratory through the coaxial cable. The signal is amplified by a low noise preamplifier, followed by being transmitted to a spectrum analyzer for observation in order to discover the maximum radiation measurement value (Figure 6).

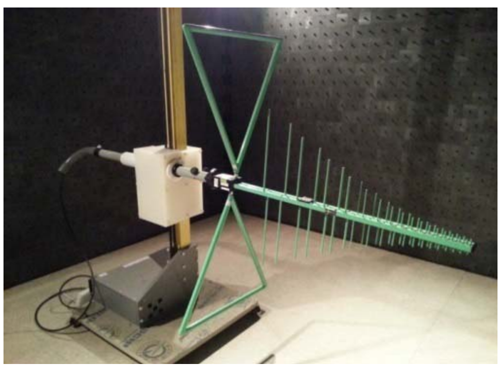

Figure 5. Monopole biconical antenna.

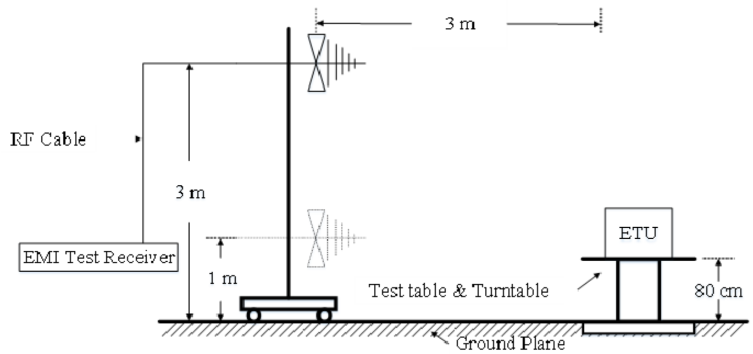

Figure 6. Architecture diagram of RE test.

In the research, the test condition of EN60601 radiation class B, an international EMI test regulation, is referenced. For a test environment with an enclosed space, upper bounds of 40 dB and 47 dB are allowed for frequency bands between 30 MHz and 230 MHz, as well as between 230 MHz and 1000 MHz. In an upfront experiment, two antenna erections are considered, including the erection in which an antenna is horizontal to ground surface and the erection in which an antenna is vertical to ground surface. The antenna is tuned to heights of 1 m, 1.4 m and 1.8 m, respectively, together with a 360-degree rotation of the rotation disk to collect the maximum noise radiation value. From the result, in the horizontal test, the maximum measurement value is over a limit of 7.585 dB at a frequency of 99.84 MHz, while in the vertical test, the maximum measurement value is below a limit of 5.073 dB at a frequency of 165.8 MHz. Further, the noise measurement values under the antenna height conditions mentioned above are compared. From the result, the highest radiation level occurs at 1.8 m. Thus, the worst case scenario with the highest noise interference level is selected in this research, i.e., the vertical test and the antenna height of 1.8 m with a frequency of 165.8 MHz are adopted as the measurement conditions for subsequent experiments, in order to ensure that the data are obtained in the worst case scenario.

5. DATA ANALYSIS

In this research, the Taguchi Method is used to select an appropriate inner/outer orthogonal array, and factorial effect and ANOVA are used for analysis to provide the optimal set of design parameters and conduct experiment verification. Such a parametric design allows the EMI characteristics of a product to improve effectively to meet design specifications required by customers, accelerate the R&D of products, and pass EMI test regulations required by various countries in order to improve competitiveness in the electronic industry.

5.1. Factorial Effect Analysis

The experimental data are as shown in Table 3. Since RE level belongs to the Smaller The Better (STB) characteristic of Taguchi quality, Formula (1) is used to calculate SN ratios under various parameter sets. Averages of SN ratios for various control factors at various levels are calculated, and a response table and a response diagram as shown in Table 4 and Figure 7, respectively, to show levels of influence of various factors on the quality characteristic (SN). From the results, the optimal set of parameter levels for EMI reduction is: the number of routing layers on riser card is 6; the EMI filter on the isolated card is 600 Ω; the shunt capacity for the clock on the main board is 33p; and the isolated card is grounded, in order to obtain a smaller RE.

$$SN_{STB} = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right) \tag{1}$$

where y_i is the ith measurement value, and n is the number of samples ($n = 4$).

Table 3. Configuration of inner/outer orthogonal array and experimental result for EMC parametric design.

Control Factors				Noise Factors			G		120V/60 Hz	230V/50 Hz	230V/50 Hz	120V/60 Hz		
							F		1 core	2 core	1 core	2 core		
							E		4 Stages	4 Stages	5 Stages	5 Stages		
No.	A	B	A*B	C	A*C	A*D	D	Response Value (dB)	1	2	3	4	$\bar{y}$	SN
1	4 Layers	0Ω		0p			With Grounding	RE	44.6	45.9	45.3	49.4	46.3	-33.32
2	4 Layers	0Ω		33p			Without Grounding	RE	43.1	43.1	44.6	45.2	44	-32.87
3	4 Layers	600Ω		0p			Without Grounding	RE	42.6	42.7	40.5	43.6	42.35	-32.54
4	4 Layers	600Ω		33p			With Grounding	RE	38.9	37.1	38.8	38.7	38.375	-31.68
5	6 Layers	0Ω		0p			Without Grounding	RE	44.6	45.7	46.6	46.3	45.8	-33.22
6	6 Layers	0Ω		33p			With Grounding	RE	42.5	42.1	39.9	41.7	41.55	-32.37
7	6 Layers			0p			With Grounding	RE	41.2	40.7	41.5	43.7	41.775	-32.42
8	6 Layers	600Ω		33p			Without Grounding	RE	40.1	37.7	36.8	40.5	38.775	-31.78

5.2. ANOVA of Taguchi Quality

Table 5 is a response table for various control factors and their interactions. Further, ANOVA is conducted for SN ratios. Contributions are used for aiding F values to show the significance of influence of factor levels on error variations (Table 6). From the results, the contributions of factors B and C are 55.72% and 38.53%, respectively, and P values are 0.003 and 0.005 (< 0.05), respectively, showing that there are significant influences for "EMI Filter on Isolated Card" and "Shunt Capacitor for Clock on

Table 4. Response table for SN ratio of RE parameter set.

Control Factors		A. Number of Routing Layers on Riser Card	B. EMI Filter on Isolated Card	C. Shunt Capacitor For Clock on Main Board	D. Grounding of Isolated Card
RE	Level 1	−32.60	−32.95	−32.87	−32.45
	Level 2	−32.45	−32.11	−32.18	−32.60
Full Range		0.155	0.8399	0.6983	0.1528
Rank		3	1	2	4

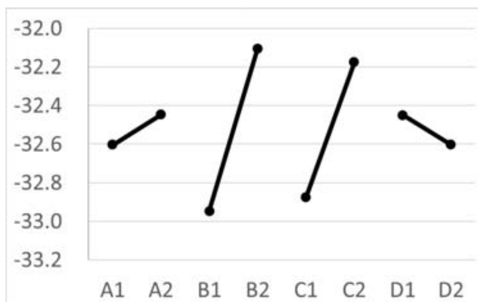

Figure 7. Response diagram for SN ratio of RE parameter set.

Main Board". The result is consistent with the analysis result of factorial effect. Accordingly, electronic circuit design engineers of products are recommended to reserve an Inductance-capacity circuit (LC circuit) for the purpose of suppressing EMI.

Moreover, $A \times B$ (i.e., "Number of Routing Layers on Riser Card" and "EMI Filter on Isolated Card") is more significant than other interactions. Its interactions are as shown in Figure 8. It is known that the improvement for magnitude of electromagnetic noise is more significant by adding "EMI Filter on Isolated Card" as the "Number of Routing Layers on Riser Card" is 4 because the suppression effect for electromagnetic noise has been achieved as the number of routing layers is 6, and thus the effect of further improvement is limited to the installation of a filter.

Table 5. Response table for various control factors and their interactions.

Control Factors		*A* Number of Routing Layers on Riser Card	*B* EMI Filter on Isolated Card	$A \times B$	*C* Shunt Capacitor For Clock on Main Board	$A \times C$	$A \times D$	*D* Grounding of Isolated Card
RE	Level 1	−32.60	−32.95	−32.60	−32.87	−32.50	−32.50	−32.45
	Level 2	−32.45	−32.11	−32.45	−32.18	−32.55	−32.55	−32.60
	Ideal Parameters	2	2	2	2	1	1	1

Table 6. ANOVA for SN ratio of RE.

	Freedom	Sum of Squares	Mean Square	F Value	Net Sum of Squares	Contribution Rate (%)	P-Value
A	1	0.0481	0.0481	9.9728	0.0433	1.90%	0.087
B	1	1.4107	1.4107	292.6535	1.4107	55.72%	0.003
C	1	0.9753	0.9753	202.3269	0.9753	38.53%	0.005
D	1	0.0467	0.0467	9.6857	0.0467	1.84%	0.090
$A*B$	1	0.0412	0.0412	8.5437	0.0412	1.63%	0.100
Error	2	0.0096	0.0048			0.38%	
Total	7	2.5316					

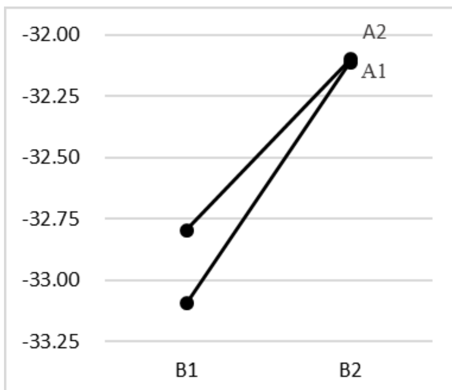

Figure 8. Diagram showing interaction of SN ratios for "number of routing layers on riser card" × "EMI filter on isolated card".

5.3. Experiment Verification

Experiment verification is executed for A2B2C2D1, the optimal parameter set, to ensure reproducibility of RE levels under such conditions. Formula (2) is used to predict that the SN ratio () obtained with the optimal parameter set is −31.60 dB, and Formulas (3) and (4) are used for calculation to identify that the 95% confidence interval ± of the experiment is (−31.9013 dB, −31.3038 dB). From identification, the experimental result is as shown in Table 7, in which the SN ratio (−31.77 dB) lies in the confidence interval mentioned above, showing better reproducibility of the experiment, wherein,

$$\eta = \overline{S/N} + \left(\overline{S/N_{A_2}} - \overline{S/N}\right) + \left(\overline{S/N_{B_2}} - \overline{S/N}\right) + \left(\overline{S/N_{C_2}} - \overline{S/N}\right) + \left(\overline{S/N_{D_1}} - \overline{S/N}\right) \quad (2)$$

$$\mathrm{CI} = \sqrt{F_{\alpha;1;V_2} \times V_e \times \left[\frac{1}{n_{eff}} + \frac{1}{r}\right]} \quad (3)$$

$$n_{eff} = \frac{L}{1 + Df^*} \quad (4)$$

α is the significance level ($\alpha = 0.05$);
v_2 is the freedom of pooled error variance ($v_2 = 2$);
V_e is the pooled error variance ($V_e = 0.0048$);
n_{eff} is the effective observation number;
L is the total process number ($L = 8$);
Df^* is the sum of freedoms of the factors for estimating averages ($Df^* = 5$);
r is the number of samples for identifying the experiment ($r = 4$).

Table 7. Identifying experimental data.

					Experiment Set			1	2	3	4			
					Noise Factors		G	1	2	2	1			
							F	1	2	1	2			
							E	1	1	2	2			
Experiment Set	Control Factors							Observation Value (dB)						
	A	B	A*B	C	A*C	A*D	D	y_1	y_2	y_3	y_4	$\bar{y}$	s	SN
1	2	2		2			1	38.2	37.9	40	38.9	38.75	0.932	-31.77

6. CONCLUSION

This research relates to parametric design using the Taguchi Method in the early stage of product development for EMC issues of medical-grade touch panel computers. In this research, radiated emission is used as a response value. The experiment covers control factors such as PCB and mechanism design related parameters. Also, peripheral devices used in conjunction with a product are considered as noise factors when the product is in use, while interaction between the control factors is studied. This experiment was planned and executed by using an L8 orthogonal array, and the response diagram and table are used together with ANOVA for analysis of the experimental data to provide the optimal set of design parameters, in which the "Number of Routing Layers on Riser Card" is 6; the "EMI Filter on Isolated Card" is 600 Ω; the "Shunt Capacity for Clock on Main Board" is 33p; and the "Isolated Card is Grounded". The "EMI Filter on Isolated Card" and the "Shunt Capacity for Clock on Main Board" influence EMI more significantly, so electronic circuit design engineers of products are recommended to reserve an LC circuit. Moreover, interaction exists between the "Number of Routing Layers on Riser Card" and the "EMI Filter on Isolated Card". The parametric design proposed in this research improves the EMI characteristic of a product effectively to meet design specifications required by customers, accelerate the R&D process of electronic products, and pass the EMI test regulations required by various countries in order to improve industrial competitiveness.

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