EMC design of AI products

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Abstract. This paper investigates electromagnetic compatibility (EMC) problems in artificial intelligence (AI) products and summarize corresponding solutions. Concept and theories of EMC are introduced in Section II, analysis of EMC problems in AI products basing on three elements of EMC is given in Section III, solutions are presented in Section IV, and conclusions are given in the final Section.

1. Introduction
As AI techniques are increasingly widely used in manufacturing, finance, retail, home, transportation, security, medicine, education, logistics and other fields, a large amount of AI products is designed, manufactured and sold on the market. A high-level EMC design will improve the performance and reliability of the products, reduce their maintenance costs, and hence raise the design and production efficiency of AI products.

EMC is significant in electronic products[1]. The importance of EMC in AI products is firstly owing to the complex electromagnetic (EM) environment in modern life. Mobile phones, computers, fridges and other electronic appliances generate EM waves under working condition. The popularization of AI products and the development of 5G network further promote the complicacy of the EM environment. Therefore, the requirement of AI product immune ability to EM interference is getting higher. On the other hand, to achieve better functions, the working frequency of the electronic products is increased, leading to more noises[2]. The EM interference caused by the AI products should be reduced to maintain the EM environment acceptable for other products. Strong EM interference will not only influence other electronic products but also threaten the health of product users.

Thus, EMC design of an AI product should reduce or eliminate the EM interference generated by the product and enhance their immune ability to EM interference from the environment. Additionally, EMC design should prevent the subsystems of the product to interfere with each other under working conditions. Because AI products always have many integrated functions with multiple subsystems working at the same time, their EM interference problems are diverse and complex.

2. Concept and theories of EMC
2.1. Concept of EMC
Electromagnetic compatibility (EMC) refers to the ability of multiple products or systems to neither interfere with nor be interfered with by each other in the same electromagnetic environment[3]. In other words, EMC means the ability to not cause or be influenced by EM interference. EM
interference is the phenomenon of product performance degradation caused by EM disturbance[3]. Therefore, analyzing EM disturbance is an efficient method to find EM interference problems.

2.2. Three elements of EMC
As shown in figure 1, the three elements of EMC are noise source, coupling path and receiver.

Noise source refers to any elements, circuits, systems or natural phenomena like lightning that generate EM disturbance. EM disturbance can therefore be divided into artificial disturbance and natural disturbance. This paper will only discuss artificial disturbance.

Coupling path refers to the transmission path or medium of EM disturbance. According to the coupling path of EM disturbance, it can be divided into conduction coupling and radiation coupling disturbance. Conduction coupling requires complete circuit conduction between noise source and sensitive equipment, through which the EM disturbance is transmitted.

Sensitive equipment refers to the equipment, circuit or system that is interfered with.

2.3. EMC design strategy
To solve EMC problems efficiently, a correct EMC design strategy is necessary. Because of the significant impact of EM interference, EMC design continues during the design, trial-production and production phases of an electronic product. Figure 2 indicates that the earlier an EMC problem is solved, the lower the cost and the higher the returns. Contrarily, the cost rises, the returns are lowered, and the problem might not be fundamentally solved. Therefore, for any electronic product design, EMC design should be taken into account from the beginning of the whole process[4]. Only this strategy can make it possible that the product passes EMC test the first time. Even if it does not, the EM interference will not be serious and will be easily reduced or eliminated. Reserving some space in the design phase will make improvement more convenient.

3. Analysis of EMC problems in AI products
Figure 3 is a block diagram of a simple AI product. Each block can be considered as a subsystem. An actual AI product can have a more complex structure. There can be more electrical appliances, the sensors can be installed everywhere in the product, and there can be other functional modules. But this block diagram is enough for finding EMC problems in an AI product.

The main noise sources inside the product are the electrical appliance and the signal transmitter. The power lines can also cause noises though they are not shown in the diagram.

The EM waves of some particular ranges of frequencies from the environment can also be noises. The EM waves can be absorbed by the wires in the product if the wire lengths are 1/4, 1/2, 3/4 or ... of the wavelengths. The EM waves of the signal frequencies can be absorbed by signal inputs and outputs in the product as noises.
The sensitive equipment in the AI product is sensors and signal receiver. Electrostatic discharge (ESD) is also considered as EM interference impacting or damaging the product.

![Figure 3. Block diagram of an AI product.](image)

4. EMC design in AI products

4.1. Circuit design

In circuit design, EMC design is for EM interference of different coupling paths. There are conduction coupling and radiation coupling. Conduction coupling is divided into resistive coupling, capacitive coupling and inductive coupling.

Resistive coupling noises are usually removed by circuit decoupling and potential isolation. Bypass capacitors are used for decoupling between circuits using a same power bus, and sometimes between possible noise source and sensitive elements. Potential isolation is usually required between systems using potentials with a large difference. For digital signal circuits, relays, transformers and optoelectronic coupling elements are used for potential isolation.

Capacitive coupling noises usually appear between wires. To reduce or remove the noises, the wires should be designed short, far from each other, and not parallel with each other. “0” line can be added between the noise source wire and sensitive wire to isolate them.

Inductive coupling noises mainly exists between wires and cables. To lower the noise, the wires and cables should be short, far from each other, and not parallel with each other. The inductive elements should be properly located and shielded.

The noise source of radiation coupling noises in AI products is the electrical appliance and signal transmitter. For the electrical appliance, shielding and electrical grounding can be used to reduce or eliminate EM interference. If shielding method cannot be used due to limitations, or the EM interference is still strong, the sensitive equipment like sensors and signal receiver should be set far from the noise sources. If the product performance reaches requirements, lowering the sensitivity of the sensitive elements is also a practical method to reduce EM interference. For signal transmitter, the EM interference can be reduced by utilizing directivity and polarization characteristics of the antenna. Adjusting the spectra and bandwidths of signal transmitter and receiver is also effective for improving EMC.

4.2. Cable design

Cables are used to transmit signals and power between systems. As mentioned, to avoid EM interference, cables should be short, far from each other, and not parallel with each other. However, designing an AI product, a designer should consider the volume, cost and other factors, which means sometimes the cables have to be bound into bundles. In these situations, the following EMC design for cables is very useful.

Firstly, dividing the cables into digital signal lines, analogue signal lines and power lines. Digital signals are not sensitive to EM interference, but it generates noises. Analogue signal is very sensitive to noises. The power lines can cause strong noises. The solution is bound the same kind lines together.
For digital signal lines, because the noise they generate is not strong, the impact can be reduced by set spacing. The digital signal lines are mainly interfered with by the noise from the electrical appliance, therefore using twisted-pair cables to transmit digital signals will minimize EM interference. The analogue signal is most easily to be interfered with. The best solution is to convert it into digital signal before transmission. In situations where ADC cannot be set because of space or other limitations, using twisted-pair cables to transmit analogue signals can reduce the impact of EM interference.

4.3. Filtering design
Filtering is commonly used in EMC design at sensitive equipment. Because filters are not ideal, the noises with frequencies near the passband will not be totally removed. Therefore, to maximize the effect of the filters, the noise frequency should be far from the signal frequency. As mentioned in Section III, a transmission line absorbs noises of particular wavelengths as a resonator. The absorbed noise frequency is determined by the length of the line. Adjusting the transmission line length and signal frequency can make the noise frequencies far from the signal frequencies. For the noises very close to the signal frequency, a good circuit layout will reduce their impact, and shielding should be used.

4.4. Grounding design
Safely grounding is connecting the frame or shell of the product to the ground, which has a protective function. For products that cannot be connected to the ground, the negative pole of the source can be used as the ground, which is called floating grounding. If the structure of the product is an equipotential body, using its structure as the ground will shield the product from external EM interference.

4.5. Shielding design
Shielding cuts off EM interference coupling path, therefore shielding at sensitive equipment is effective in EMC design. However, it requires space and thus is limited by product appearance design, which is the reason why it is usually not used throughout the product. Shielding must unite grounding to function. A structure of shielding cuts off the transmission of EM waves, which should improve the EMC of the product. But if the structure is not well grounded, it will become an antenna, which reduces the EMC of the product.

4.6. Anti-ESD design
On one hand, anti-ESD design is preventing ESD to enter the internal circuit of the product. The best method is to make the whole product an equipotential body, which cannot always be achieved. Another way is using a shell to isolate the internal circuit and the environment.

On the other hand, anti-ESD design is protecting the circuit from ESD. A shunt-wound transient voltage suppressor diode can absorb a large transient current. A tandem low-pass filter will remove the ESD of high frequencies. Using a Multilayer Printed Circuit Board (PCB) is also an effective anti-ESD design, which can reach a better PCB EMC.

4.7. Algorithm design
In an AI product, it is practical to use algorithms to improve its EMC, because of its powerful processing module. Using algorithms can optimize the performance of the filters. With different algorithms, the performances of the filters are different[5]. Adjusting algorithms is much more convenient than changing filters in the product when it has been produced. Combining several algorithms will reach even better results in solving EMC problems[6]. If algorithm design is included in EMC design of an AI product, the producer will be able to keep improving the product performance just by updating algorithms.
5. Conclusion
Using AI products is going to be a lifestyle of modern life. A large amount of AI products appears on the market, which enriches our choices. At the same time, the product qualities are uneven. AI products with low EMC not only have poor functionality and reliability but also interfere with other products. Even the producers improve the EMC of these products after production, a lot of resources will be wasted with limited returns. This paper emphasizes EMC design beginning from the start of an AI product design and summarizes several practical EMC designs in AI products. Hopefully, this paper can guide readers to improve the EMC of an AI product.

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