EMC hardware design of intelligent watt-hour meter

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Abstract. Electromagnetic compatibility (EMC) is very important for intelligent instruments, and it is an important guarantee for its reliable operation. The complexity of EMC is mainly reflected in how to quickly and accurately locate the disturbance source, effectively suppress the disturbance source, and correctly judge the disturbance coupling path. Intelligent instruments have similar hardware characteristics. In this paper, the characteristics of common hardware characteristics of disturbance source and coupling path are analyzed, the equivalent antenna model of disturbance is analyzed, and the disturbance suppression method is given. Finally, the correctness of the method is verified by experiments.

1. Introduction
With the application of new technologies such as wireless meter reading and remote upgrading control, the electric energy meter has gradually changed from a single electric energy measuring device to an intelligent device integrating measurement, intelligent control, data processing, communication and other functions. The intelligent watt-hour meter is designed with micro control units, modern electronic and communication technology. Electromagnetic interference is an important reason for its failure or performance degradation. Centralized installation layout, high voltage and current, complex electromagnetic environment, and high-precision measurement requirements all put forward higher requirements for electromagnetic compatibility of smart meters[1].

2. Hardware design

2.1. Essence of EMC test
The three elements of electromagnetic compatibility include interference sources, coupling paths and sensitive units. Electromagnetic interference generated by disturbance source is coupled to sensitive unit through coupling paths, thus resulting in electromagnetic compatibility problem. Solving one of them can avoid electromagnetic compatibility problems[2]. EMC test is divided into EMI (electromagnetic interference) and EMS (electromagnetic interference immunity). In EMI test, the source of disturbance is usually high dV/dt and dI/dt circuits such as clock crystal, high-speed bus and DC/DC power module of the product under test; the coupling path includes inductive coupling (between inductors), capacitive coupling (between wires), conductive coupling (common power
supply, ground impedance), radiation coupling of the equivalent antenna and multiple coupling formed by free combination; conduction test The sensitive unit in the test is the equivalent impedance after the 1KΩ impedance in LISN is paralleled with the 50 Ω impedance of the receiver, and the sensitive unit in the radiation test is the test receiving antenna. In the EMS test, the disturbance source is the transmitting antenna, injection clamp and other test equipment, which acts on the sensitive circuit or equivalent antenna of the equipment under test through line conduction and space radiation, resulting in electromagnetic interference.

2.2. Hardware Design of General Intelligent Instrument
Intelligent equipment is a kind of instrument that combines computer technology, sensor technology, network communication and intelligent control with traditional equipment, and has high independent control ability according to preset program or remote control. In addition to the actuator to meet the requirements, its hardware circuit has certain similarity, including switching power supply module, intelligent control module, data storage module, sensor interface module, digital to analog conversion module, display and communication module, etc. similar hardware circuits have similar EMC characteristics, and similar circuit modules have similar electromagnetic compatibility. The research and analysis is of great significance to the design and production of intelligent instruments and equipment.

![Hardware design of intelligent instruments](image)

2.3. Analysis of disturbance source and equivalent antenna in intelligent instrument
The antenna has two kinds of conversion functions, which convert voltage and current into an electromagnetic wave and transmit it into space; or convert electromagnetic waves in space into voltage and current signals. In the process of intelligent instrument design and production, there are inevitably many equivalent antennas in its circuit board and cable harness. The equivalent antennas not only have emission characteristics but also accept characteristics. Acting as a transmitting antenna in an EMI test leads to excessive emission. Acting as a receiving antenna in the EMS test, resulting in product functional performance problems.
2.3.1. Analysis of disturbance source and equivalent antenna in switching power supply

The core devices of switching power supply are power control chip, transformer and output rectifier diode. At the same time, these three devices are also the source of EMI disturbance. The fundamental cause of electromagnetic interference is the drastic change of current and voltage in the circuit, that is, dI/dt or dV/dt contains more high-frequency components to produce electromagnetic radiation and coupling, forming electromagnetic interference[2].

When the power control chip is turned off, the transformer primary current charges the parasitic capacitance Coss of the switch control chip in a short time. When the voltage across Coss is the sum of the input voltage and the reflected voltage of the transformer, the total leakage inductance of the transformer primary Lk and Coss Resonance occurs between them, producing high-frequency and high-voltage oscillations. At this time, the output diode D is forward-biased and the voltage of the secondary coil is clamped to be equal to the output voltage Vo. It is coupled back to the primary side via a transformer with a turns ratio of n so that the parasitic capacitance Cp voltage of the primary side of the transformer is charged to nVo. After the freewheeling discharge of the side inductor Lp ends, the output diode D is reversely biased and cut off, and Lp, Coss, and Cp resonate. Due to the reverse turn-off time, when the diode is turned off, the reverse recovery current resonates with the diode junction capacitance, transformer leakage inductance, and wire parasitic capacitance, which causes great electromagnetic interference[3]. The time domain waveform of the disturbance source is shown in Figure 3 and Figure 4.
There are parasitic capacitances between the heat sink of the power control chip and the metal shell (earth), between the input, and output cables and the metal shell (earth), on the primary and secondary sides of the transformer. Multiple sets of equivalent antennas will appear at the switching power supply. The schematic diagram of the equivalent antenna is shown in Fig. 5, and each parasitic antenna is described in Table 1.
Table 1. Electromagnetic disturbance source and equivalent antenna model of switching power supply.

| Source of harassment | Antenna path                              | Antenna type       |
|----------------------|-------------------------------------------|--------------------|
| 1                    | Q1、C1、T、Q                               | Loop antenna       |
| 2                    | DP5、T、DP5、C2                            | Loop antenna       |
| 3                    | Q1、LISN、Diode bridge、T、Q                | Loop antenna       |
| 4                    | Q1、LISN、Diode bridge、CJ3、PE             | Loop antenna       |
| 5                    | DP5、C1、CJ1、DP5、CJ2、RE                  | Loop antenna       |
| 6                    | Q1、Switching power supply chip VDS drives | Dipole antenna     |

2.3.2. Disturbance source and equivalent antenna in PCB layout

With the increasing integration and speed of the circuit board, higher requirements are put forward for PCB layout and routing. The common EMC problems are often caused by the unreasonable layout of components, ground plane design, and high-speed limited wiring.

The PCB layout that is not divided according to function and signal characteristics will cause the wires to be too long. Due to the capacitive coupling of the wires, the noise signals of different circuit modules are coupled to other cable lines and emit noise.

The unreasonable design of the power/ground plane causes the parasitic inductance of the power/ground plane to increase, and excessive parasitic inductance brings greater noise voltage. The noise voltage drives the PCB traces and cable harnesses. The equivalent dipole antenna leads to excessive conduction and radiation.

High-speed signal traces without impedance matching and across different ground planes will bring greater reflected noise and excessive signal loop area, resulting in excessive radiation emission. PCB layout of hidden parasitic antennas are shown in Fig. 6 and Table 2 describes these types of hidden antennas.
1. PCB layout

2. Splits in the power plane

3. Slotted ground plane

4. Ribbon cable configurations

Figure 6. PCB layout of hidden parasitic antennas.

Table 2. Hide the description of the antenna.

| analysis |
| --- |
| 1 | The high-frequency noise of the high-speed circuit is coupled to the IO interface, and then the noise electromagnetic wave is emitted through the interface cable. |
| 2 | The equivalent loop antenna area increases. The noise signal drives the ground planes on both sides through the connecting line to form a dipole antenna. |
| 3 | The return current path of the high-frequency signal is forced to increase. |
| 4 | Common ground impedance coupling. |

2.4. Processing method of disturbance source and equivalent antenna

2.4.1. EMC design of switching power supply

Four methods are used to deal with the electromagnetic compatibility problem of intelligent instruments. Use RCD absorption circuit to absorb the noise source for the primary side disturbance source of the transformer; use high-frequency capacitors for the circuit board equivalent loop antenna to reduce the antenna area; use ferrite beads to increase the impedance of the dipole antenna; aiming at the loop antenna caused by the parasitic capacitance of the primary and secondary sides of the transformer and the parasitic capacitance of the switch chip to the ground, the Y capacitor is used to change the common-mode current loop to reduce the equivalent antenna area and prevent noise from flowing through the LISN. The schematic diagram of the power supply is shown in Figure 7.
2.4.2. EMC design of PCB layout

The circuit board is divided by function and frequency. The top is the control and displays circuit module, which communicates with the left half of the metering module and the right half of the switching power supply circuit module through the optocoupler; Keep the spacing between modules to avoid coupling of high-frequency signals.

The layout principle of switching power supply is to reduce the equivalent ring antenna area and the length of the dipole equivalent antenna arm. The absorption circuit is arranged close to the disturbance source. The equivalent large ring antenna area is controlled by the Y-capacitor, and the power input terminal uses the filter circuit.

In the high-frequency circuit, the chip clock chip is used and placed close to the IC pin, and there is a complete ground plane under the clock chip, and there is no long-distance wiring nearby; the long-distance wiring is accompanied by the ground, and a large number of via holes are used to connect the ground plane with low impedance; the decoupling capacitance and bypass capacitance are connected to the IC pin in a short distance; the IC reset pin avoids long-distance wiring[4], and the PCB is shown in Figure 8.
3. Laboratory testing

Through the analysis and targeted design of potential disturbance sources and equivalent antennas of smart meters, smart meters have successfully passed the GB/T 17215.211-2006 Electricity metering equipment(a.c.)—General requirements, tests and test conditions—Part 11: Metering equipment. Radiation disturbance field intensity curve is shown in Figure 9, and Power terminal disturbance voltage curve is shown in Figure 10.
4. Conclusions
Following the forward design thinking of electromagnetic compatibility, EMC design is integrated into the research and development process. Taking the standard test item assessment requirements as a guide, the interface filter circuit, AC/DC power conversion, circuit board layout, etc. were designed as key objects. The smart meter finally passed the laboratory EMC test. The electromagnetic compatibility design of the smart meter has a certain versatility and can be applied to the design of other smart devices.

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