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Analysis of Conducted Immunity Test for a Signal Processing Circuit

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Abstract:

The signal processing circuit is a traditional digital circuit, and its immunity to interference is a weak point. Through typical cases, this article starts with the conducted immunity test of the signal processing circuit. Using simulation software, electromagnetic compatibility analysis and circuit design improvements are carried out for the signal processing circuit, achieving good results. This article provides a reference for circuit designers and reliability simulation personnel.

Keywords:

Signal processing circuit
Circuit immunity
Electromagnetic compatibility simulation

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1. Introduction

Signal processing is a collective term for the extraction, transformation, analysis, synthesis, and other processing procedures of signals. In this context, the term “signal” refers to electrical signals, and the processed signals originate from “analog signals.” Signal processing involves three steps: (1) analog-to-digital conversion (A/D conversion); (2) digital signal processing; and (3) digital-to-analog conversion (D/A conversion). A signal processing circuit refers to a circuit that processes electrical signals. Besides the circuits involved in the three steps mentioned above, it also includes input interface circuits, filtering circuits to remove noise or interference, and output interface circuits, among others [1].

This article focuses on a specific and typical signal processing circuit, conducting a baseline test for its conducted interference immunity induced by radio frequency fields. Simultaneously, the study employs mature commercial software from ANSYS to perform simulation analysis on the typical circuit. The circuit is redesigned based on the test and simulation results, achieving favorable outcomes.

2. Signal processing circuit

The composition of a conventional signal processing circuit and the general signal transmission path are illustrated in **Figure 1**.

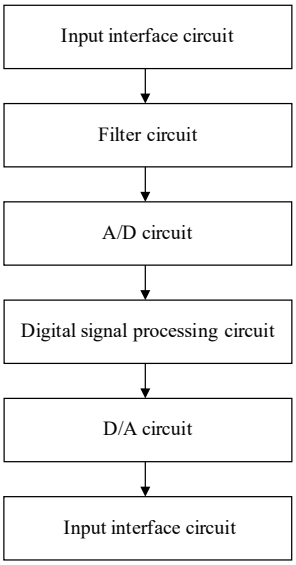


Figure 1. Signal transmission path diagram.

Electrical signals enter the "input interface circuit," where they undergo attenuation or amplification to be converted into the "analog signals" required by the "A/D (analog-to-digital) circuit." These "analog signals" pass through a "filtering circuit" to eliminate noise or interference before being input into the "A/D circuit" centered around an A/D signal processing chip. The "A/D circuit" is responsible for converting the "analog signals" into "digital signals" acceptable to the DSP (digital signal processing) chip. After being processed by the "digital signal processing circuit" with a DSP chip as its core, the signals are outputted to the "D/A (digital-to-analog) circuit" centered around a D/A chip. The "D/A circuit" outputs "analog signals," which are then converted by the "output interface circuit" into a signal mode that can be received externally, completing the entire process of signal processing.

The signal processing circuit mainly consists of chips such as operational amplifiers, A/D converters, D/A converters, DSPs, and their external resistors and capacitors. The signal flow includes two conversions (input and output), two transformations (A/D and D/A), one filtering process, and one processing step. From the composition of the signal processing circuit and the signal flow process described above, it can be seen that the signals to be processed go through multiple stages. Coupled with the increasing demands for real-time and precise signal processing, the requirement for its immunity performance becomes particularly prominent. From the perspective of electromagnetic compatibility, the electromagnetic immunity (sensitivity) of this type of circuit is a key focus. This article illustrates the entire process of testing, simulation analysis, and confirmation to improve the power conduction immunity of a signal processing circuit through a typical case study.

3. Analysis of the immunity of a gyroscope digital circuit

The gyroscope digital circuit modulates gyroscope position signals, performs logical processing, and handles data communication in aircraft. The operating frequency for signal processing is in the MHz range. This circuit, powered by +5VDC, processes the gyroscope angular rate signals received via optical fiber input and then outputs them through two output ports in serial format to subsequent circuits.

Its specific functions include analog gating and filtering of instantaneous digital quantities, amplification of detector signals, A/D conversion of amplified signals, signal logic processing, D/A conversion of feedback signals, and processing of output signals. It is a typical signal processing circuit. In addition, this circuit is required to provide accurate and real-time feedback on gyroscope-related information, making its electromagnetic compatibility (EMC) immunity a critical aspect due to the high demand for signal timeliness.

Given that this circuit is used in aircraft and employs components with iron shell packaging, which exhibit strong radiation resistance, radiation immunity issues have not been observed based on previous application experience. Therefore, the focus is on the circuit's ability to resist conducted interference. Since the circuit's input signal lines are optical fibers and the serial output signal lines are shielded cables, the EMC test for conducted immunity primarily considers whether the circuit output remains normal under the induced coupling of the input power supply's radio frequency (RF) field.

In the following sections, targeted design suggestions are proposed based on EMC testing and simulation analysis of the gyroscope digital circuit, providing insights into addressing EMC issues, especially those related to conducted immunity, in signal processing

circuits.

3.1. Conducted disturbance immunity test of the gyroscope digital circuit

According to the national standard for immunity to conducted disturbances induced by RF fields, the frequency range of electromagnetic disturbances is 150 kHz to 80 MHz, meeting the requirements for the frequency and interference injection location of the gyroscope digital circuit's conducted immunity test. This test involves coupling the gyroscope digital circuit's input power and ground lines with an RF field while monitoring the status of the chip's power port, output port 1, and output port 2.

During the test, the signal level set according to the standard test procedure, is swept within the frequency range. The disturbance signal is a 1 kHz sinusoidal wave with amplitude modulation (80% modulation depth). The frequency step during the sweep does not exceed 1% [2]. When the test field strength is 3V, the test waveform appears normal. When increased to 5V, significant disturbances in the test waveform appeared at the frequencies of 30 MHz and 70 MHz. The abnormal test waveform diagrams are shown in **Figure 2** and **Figure 3**.

Observing the above abnormal waveforms, when a 5V disturbance is applied to the +5V power input terminal, the power supply at the chip's power test terminal becomes abnormal at a disturbance frequency of 30 MHz, leading to abnormalities in the entire circuit's output signal. At a disturbance frequency of 70 MHz, the power supply at the chip's power test terminal remains normal, but the output signal is abnormal. In other words, the power filter circuit does not function effectively around 30 MHz and disturbances around 70 MHz couple

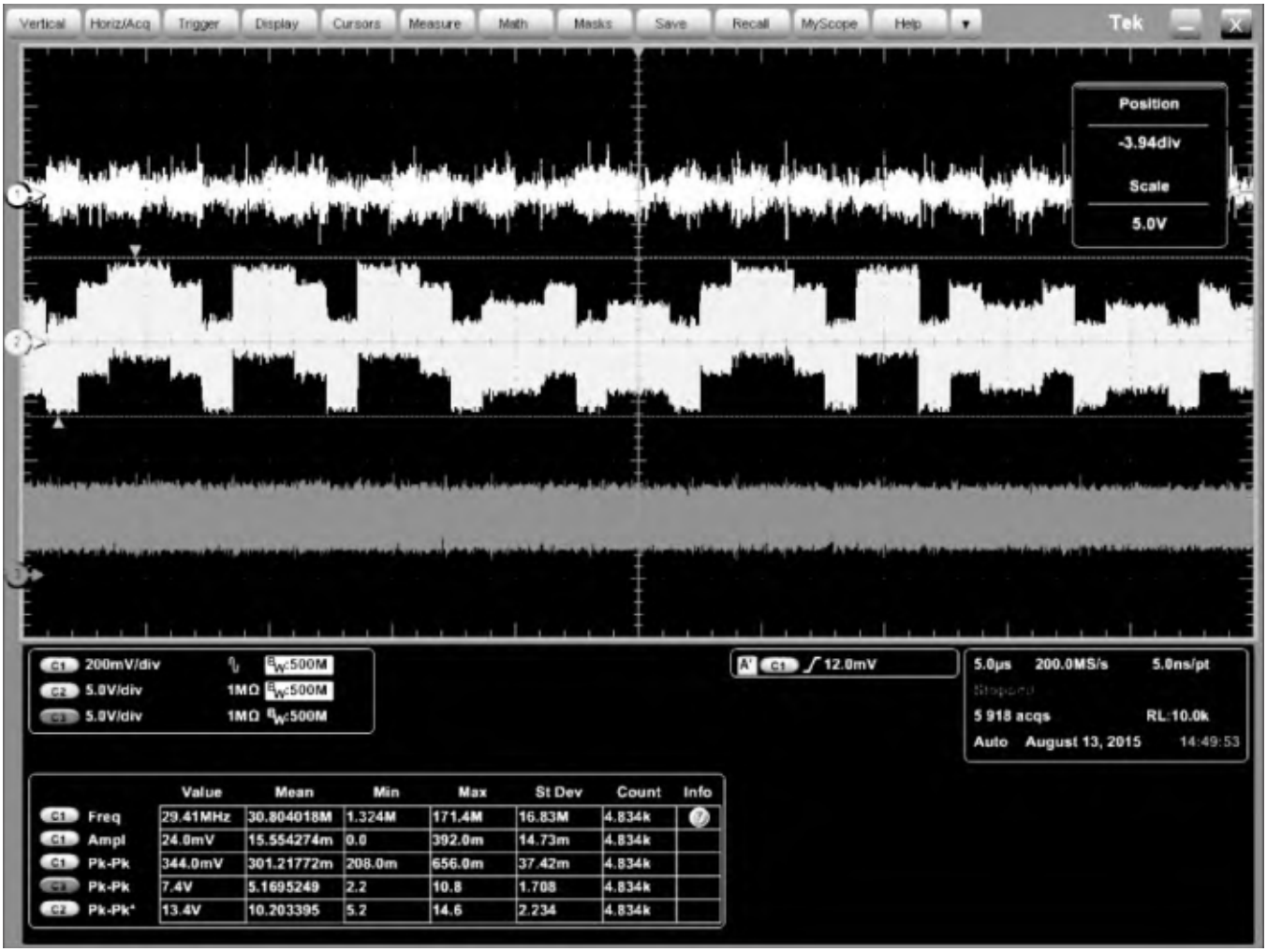


Figure 2. Abnormal test waveform at 30 MHz (CH1 output port 1, CH2 output port 2, CH3+5V test port).

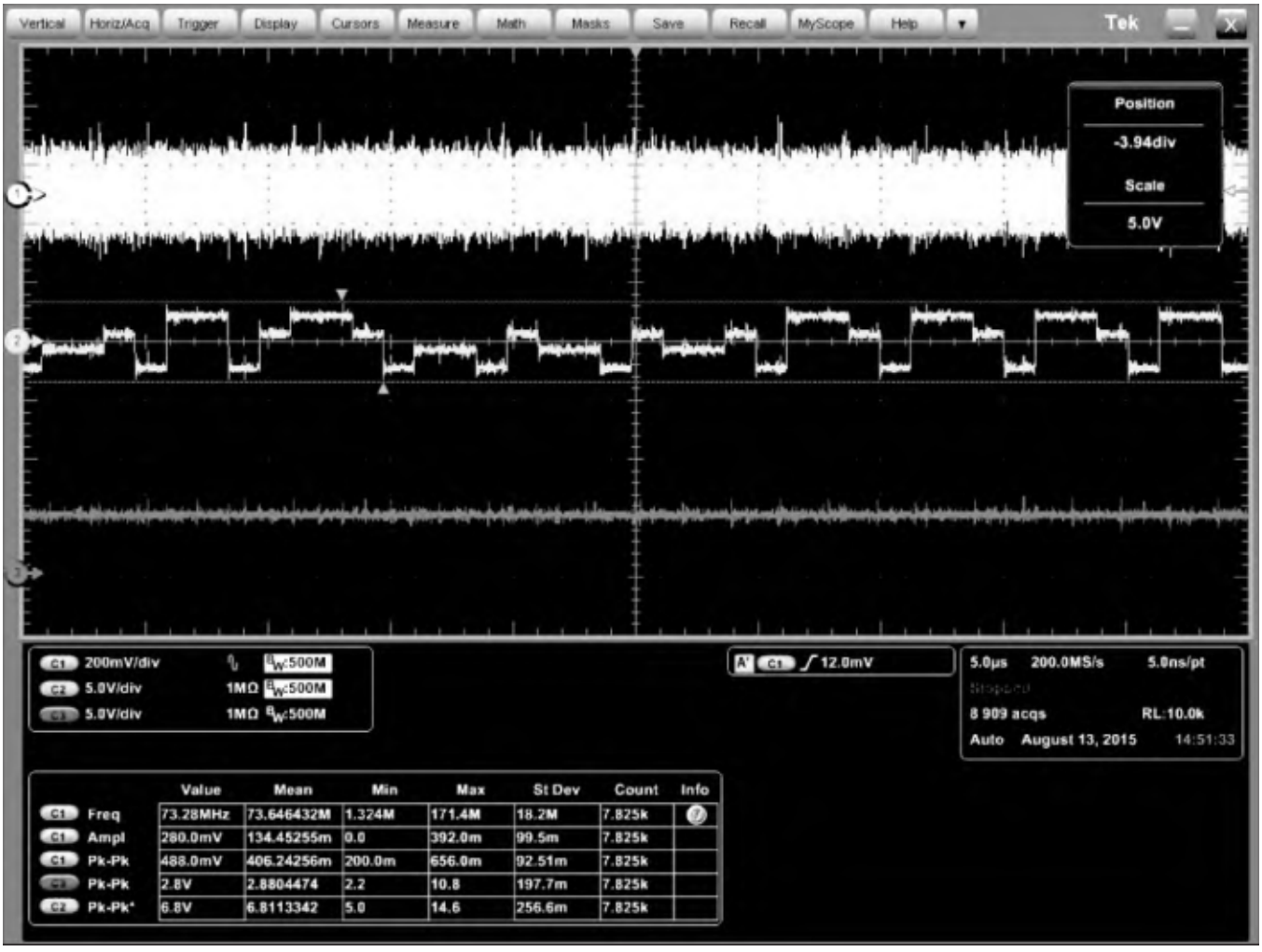


Figure 3. Abnormal test waveform at 70 MHz (CH1 output port 1, CH2 output port 2, CH3+5V test port).

onto the signal through the ground plane or other means. Based on this initial analysis, simulation analysis will be conducted for the power supply, signal port coupling, and planes, and suggestions will be provided accordingly.

3.2. Simulation of gyroscope digital circuit

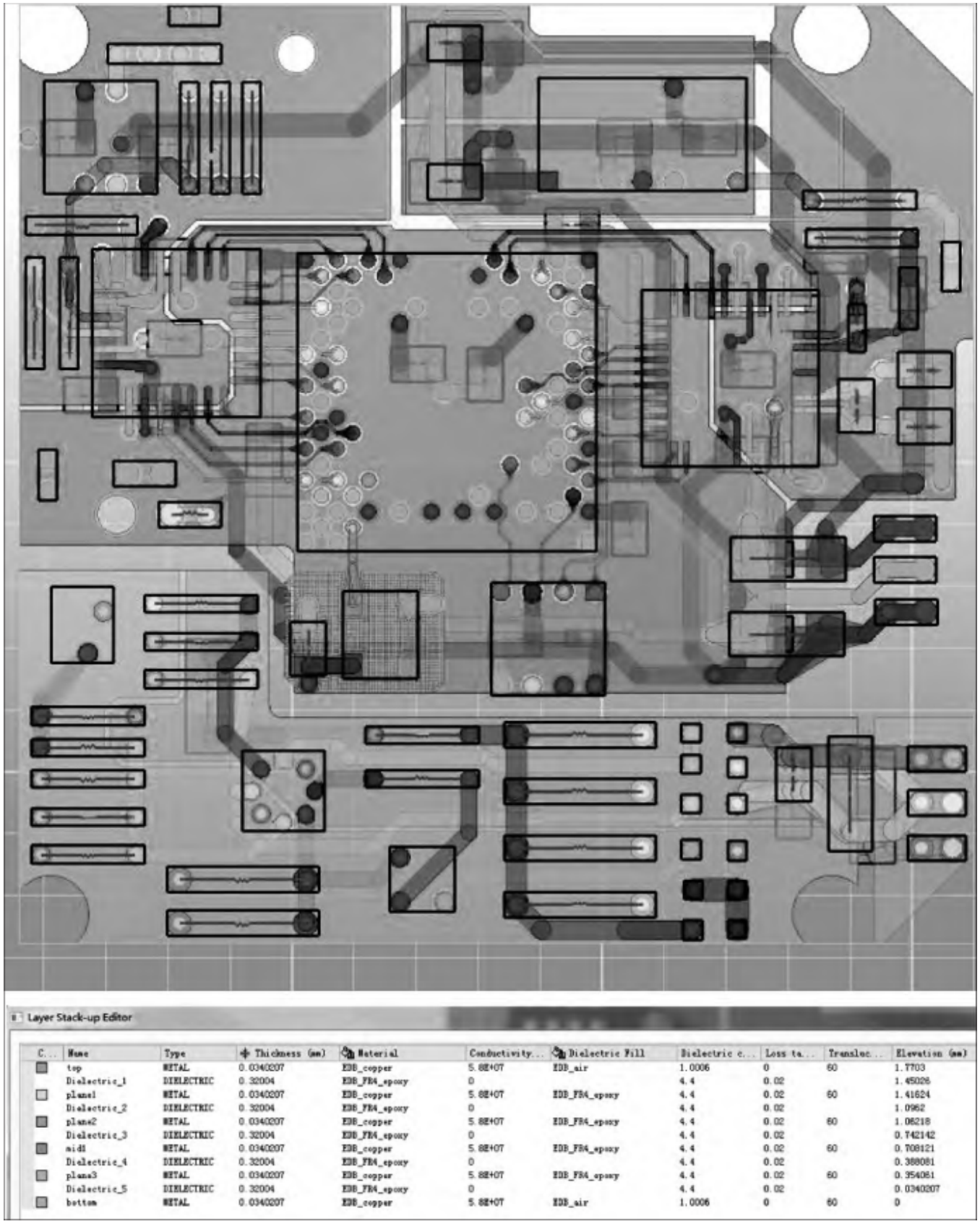
Electromagnetic compatibility (EMC) simulation involves the modeling and analysis of electronic components, cables, electronic equipment, and even entire systems using electromagnetic simulation software [3].

The simulation product used in this study is from ANSYS. Based on the actual conditions of this project, SIwave and DesignerSI are used primarily for field-circuit co-simulation analysis [4]. SIwave is a precise full-wave electromagnetic field analysis tool for the entire board level. It can simulate the resonant frequency of the entire power and ground structures, the effects of decoupling capacitors placed on the board, and time-domain effects such as noise coupling between signal lines and power boards [5]. Combined with DesignerSI for field-circuit co-simulation, the ultimate goal of simulation analysis is achieved.

3.2.1. Modeling and port coupling simulation

Based on the analysis of test issues, it is necessary to conduct coupling simulation and plane simulation for power and signals. The actual PCB is used for modeling with a total thickness of 1.77 mm and typical FR4 as the dielectric material. The modeled PCB is shown in **Figure 4**.

To address electromagnetic compatibility (EMC) issues, the primary focus is on identifying the locations and frequency bands where coupling problems occur. Hence, simulation tools are used to extract



Layer Stack-up Editor

C...	Name	Type	Thickness (mm)	Material	Conductivity...	Dielectric Fill	Dielectric c...	Loss ta...	Transluc...	Elevation (mm)
	top	METAL	0.0340207	EDB_copper	5.8E+07	EDB_air	1.0006	0	60	1.7703
	Dielectric_1	DIELECTRIC	0.32004	EDB_FR4_epoxy	0		4.4	0.02		1.45026
	plane1	METAL	0.0340207	EDB_copper	5.8E+07	EDB_FR4_epoxy	4.4	0.02	60	1.41624
	Dielectric_2	DIELECTRIC	0.32004	EDB_FR4_epoxy	0		4.4	0.02		1.0962
	plane2	METAL	0.0340207	EDB_copper	5.8E+07	EDB_FR4_epoxy	4.4	0.02	60	1.06218
	Dielectric_3	DIELECTRIC	0.32004	EDB_FR4_epoxy	0		4.4	0.02		0.742142
	mid1	METAL	0.0340207	EDB_copper	5.8E+07	EDB_FR4_epoxy	4.4	0.02	60	0.708121
	Dielectric_4	DIELECTRIC	0.32004	EDB_FR4_epoxy	0		4.4	0.02		0.388081
	plane3	METAL	0.0340207	EDB_copper	5.8E+07	EDB_FR4_epoxy	4.4	0.02	60	0.354061
	Dielectric_5	DIELECTRIC	0.32004	EDB_FR4_epoxy	0		4.4	0.02		0.0340207
	bottom	METAL	0.0340207	EDB_copper	5.8E+07	EDB_air	1.0006	0	60	0

Figure 4. Top view and stackup of the PCB.

the S-parameter model. S-parameters, also known as scattering parameters, are crucial in microwave transmission. They describe the characteristics of a high-frequency network, similar to Z-parameters and Y-parameters in circuit theory. However, due to the presence of open and short circuits during the measurement of Z and Y parameters, they are not suitable for high-frequency applications, making S-parameters the preferred choice. For a common two-port interconnection structure, four S-parameters can be defined (as shown in **Figure 5**). Among them, S11 and S22 represent insertion loss, reflecting the signal's ability to pass through the transmission line network; S21 and S12 are known as return loss, indicating the signal's reflection status on the transmission line network. As the number of ports increases, a multi-port S-parameter model can be obtained, revealing the coupling characteristics between any two ports.

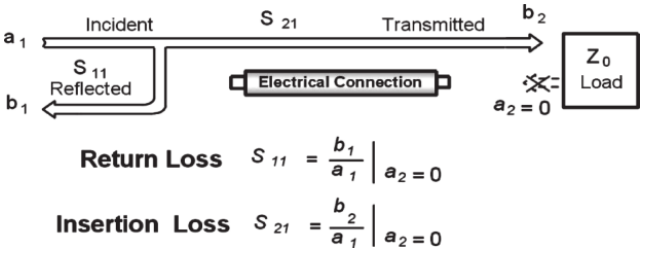


Figure 5. Schematic diagram of S-parameter model.

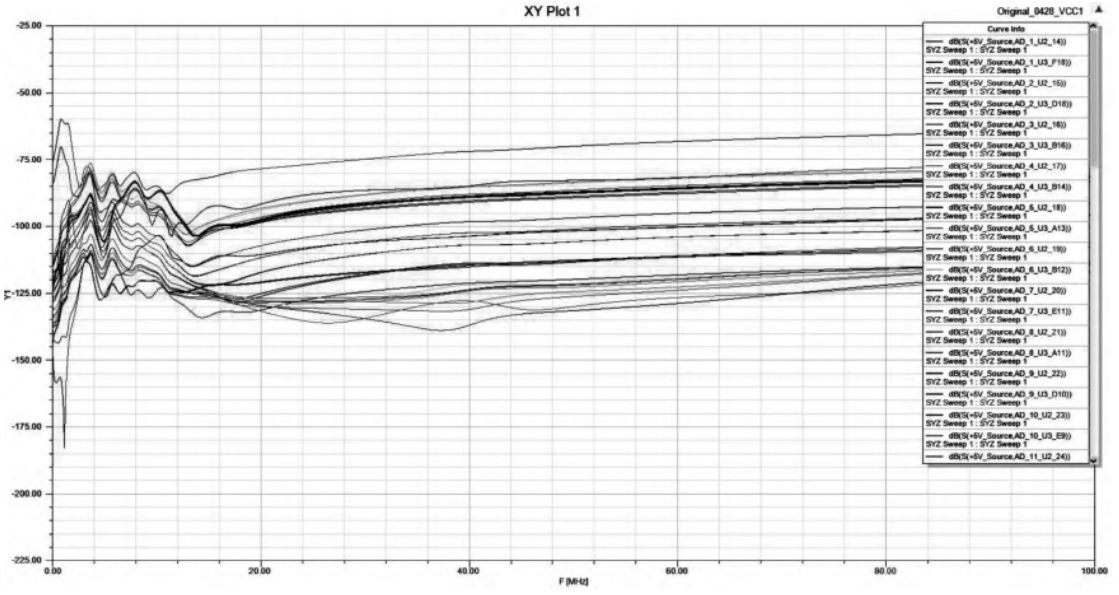


Figure 6. Coupling between the +5V input port and other signals.

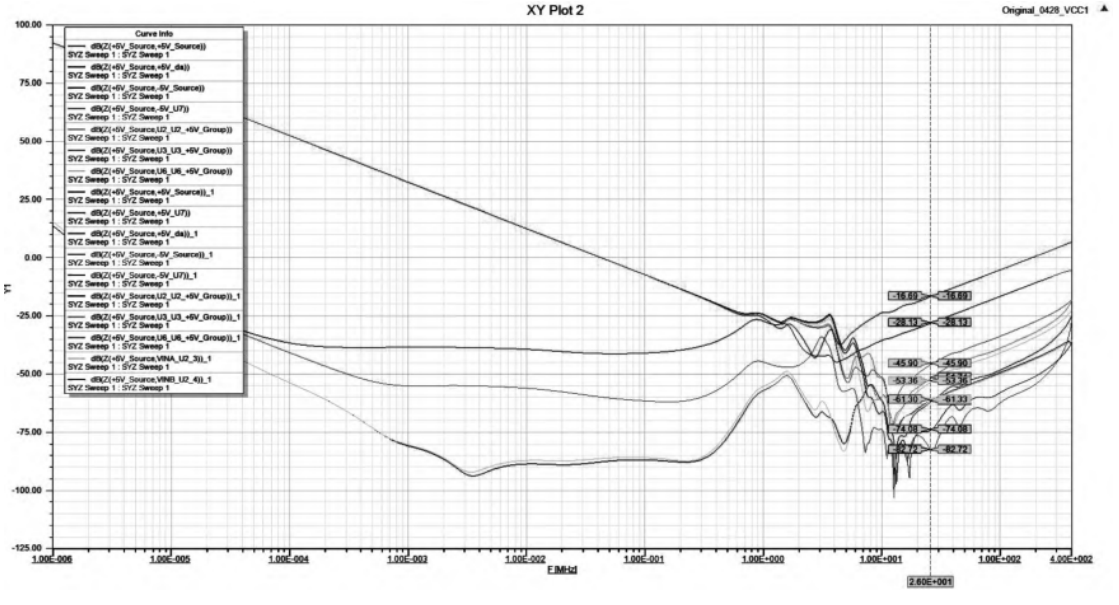


Figure 7. Coupling between the ports of the +5V power supply.

Based on the EMC failure phenomena, ports were added between the +5V input power pins and signal pins of key chips on the PCB. The resulting S-parameter coupling curves between the +5V input port and signals are shown in **Figure 6**. It can be observed that the curves are generally smooth with a relatively small absolute amplitude of about -100 dB.

Further examination of the transfer impedance between various +5V power ports (as depicted in **Figure 7**) reveals the first resonance point in the coupling of PCB power ports, occurring at approximately 26 MHz. Before this frequency point, the impedance shows a decreasing trend, indicating that the PCB is predominantly capacitive with some filtering effect. However, beyond this point, the impedance of the PCB rises, suggesting a transition from capacitive to inductive impedance. The risk of EMC issues increases significantly due to the inductive component's hindrance to alternating current energy.

From the above S-parameter port coupling simulation analysis, it is evident that signal problems are likely to occur at frequencies above 0.4G, which are outside the scope of this rectification. The power supply is prone to issues around 26 MHz, necessitating targeted EMC protective measures.

3.2.2. Simulation of gyroscope digital circuit

Based on the above circuit model, abnormal test +5V waveform data is injected to simulate the electromagnetic field and planes. The simulation software's PWL source is used to introduce excitation into the circuit simulator, and the Push Extraction function is employed to import the introduced test waveform as an excitation source into the PCB for simulation. The main focus is to observe the energy distribution during abnormal waveforms and conduct field map analysis, as illustrated in **Figure 8** and **Figure 9**, showing the areas with the highest radiation at 30 MHz.

The electric and magnetic field maps reveal that the +5V input and the signal output area in the lower right corner are the two points with the highest electromagnetic radiation, requiring relevant EMC protective measures.

Further examination of the voltage distribution on the AGND layer and the +5V layer is presented in **Figure 10**. This planar distribution diagram clearly shows the energy distribution areas and paths. The strongest energy is concentrated in the central to lower right region, flowing from the 5V power entry point from the bottom right to the top left. The power plane below the DSP chip is the primary path for concentrated energy transmission.

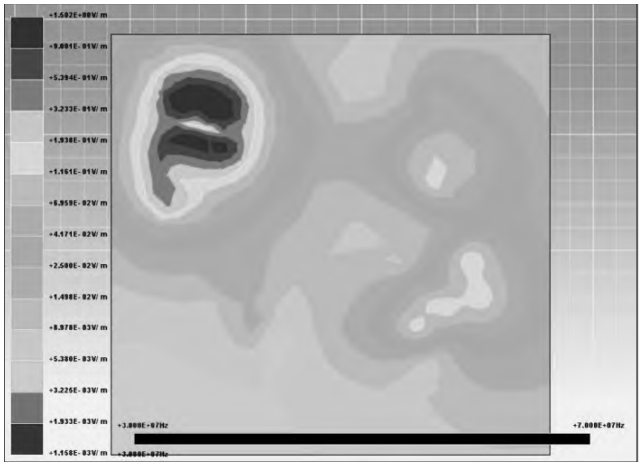


Figure 8. Electric field diagram @30M.

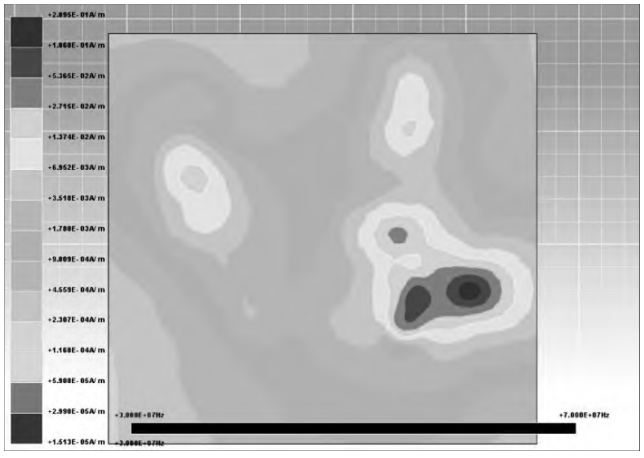


Figure 9. Magnetic Field Diagram @30M.

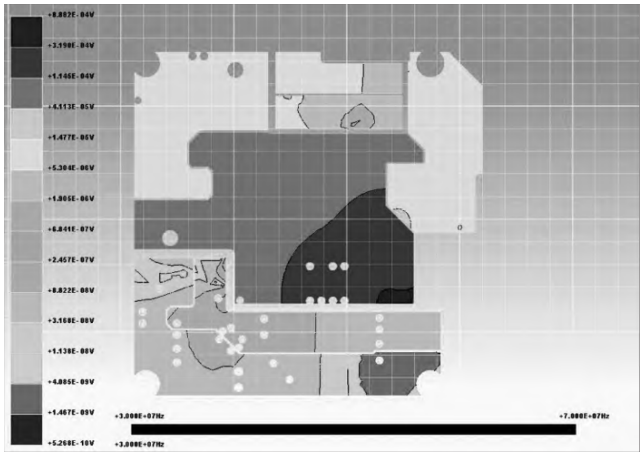
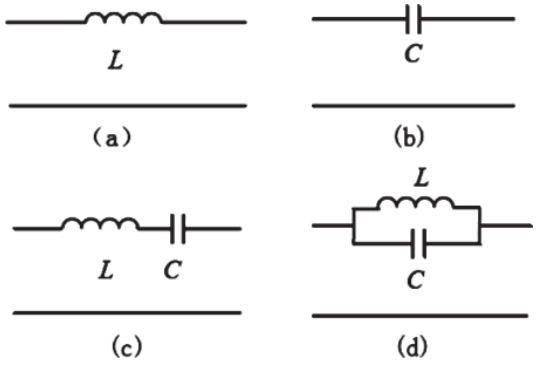


Figure 10. Plane distribution @30M.

3.3. Design rectification of gyroscope digital circuit

The simulation process reveals that energy enters through the +5V power entry point and the DSP ground plane, transmitting to the output. The existing EMC suppression measures at the +5V power input have been ineffective, and corresponding treatments are needed for the DSP plane and signal pins. Considering EMC rectification methods comprehensively, the decision is made to adopt filtering and modify the ground plane layout for circuit rectification.

Filtering involves the use of capacitors, inductors, or combinations of them to form filter circuits that disrupt the propagation of electromagnetic interference (EMI) along conductors. The primary functions of a filter circuit typically include two aspects. One is to eliminate EMI signals that have coupled into devices, preventing these signals from affecting the normal operation of the devices. The other is to prevent the circuit itself from emitting EMI signals externally through wires. **Figure 11** illustrates some simple filter circuit models, which are classified as low-pass, high-pass, band-pass, and band-stop filter circuits based on their frequency characteristics. Depending on the analysis of actual electromagnetic compatibility issues, appropriate filter circuits with suitable frequencies are selected and connected to strategic locations, such as the cable ends of single boards or standalone devices, between wires, between a wire and ground, between a pin and ground, or between two pins. Since the primary sources of interference originate from the +5V power supply and ground, and the existing EMI filters have proven ineffective, a π-type filter circuit is added at the input of the 5V power supply circuit. This filtering approach combines low-pass and high-pass filtering, positioned near the input, between wires, and between the wire and ground, effectively performing mixed common-mode and differential-mode filtering. The schematic diagram is shown in **Figure 12**. Simultaneously, high-pass filtering is added to some critical signal pins in the digital circuit (such as the crystal oscillator output, DA analog output, and modulation signal output), positioned between the pin and ground.



(a) Low-pass filtering; (b) High-pass filtering; (c) Band-pass filtering; (d) Band-stop filtering

Figure 11. Schematic diagram of filter circuits.

Grounding refers to the establishment of a conductive path between two points, connecting electrical or electronic components to a reference point or plane called “ground.” Grounding is not only a necessary means to protect human safety but also a primary method to suppress electromagnetic noise and prevent electromagnetic interference. The purpose of grounding is to find an equipotential surface with zero impedance. However, in practical engineering, a conductor with zero impedance does not exist. Any conductor has a certain impedance, causing different potential points when any current passes through it. Therefore, a suitable grounding method can provide a low-impedance path for interference signals. Commonly used grounding methods include single-point grounding, multi-point grounding, and mixed grounding.

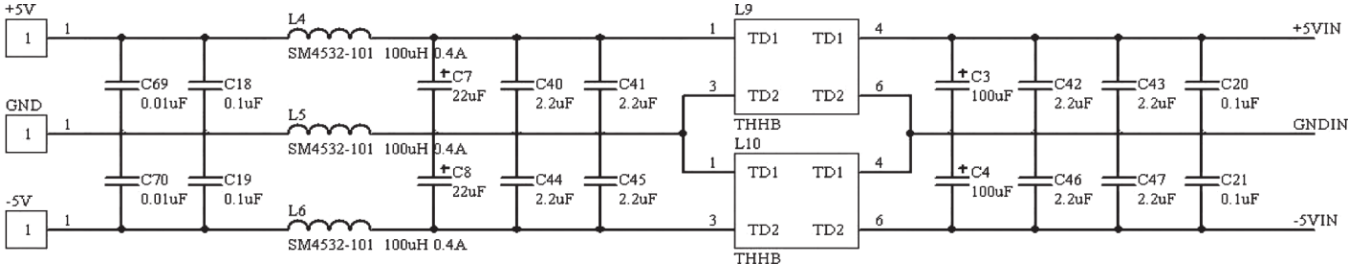


Figure 12. Power supply filter circuit.

Single-point grounding means that the ground loop of a subsystem (circuit, equipment, etc.) is only connected to a single point within that subsystem. Using single-point grounding can effectively prevent two different subsystems from producing common impedance coupling. Single-point grounding is typically applied at lower frequencies, generally in the kHz range and analog subsystems.

Multi-point grounding refers to directly connecting each circuit that requires grounding in the system to the nearest grounding plane to minimize the length of the grounding wire. In multi-point grounding, subsystems are connected to the grounding conductor at different points. Multi-point grounding is often used in systems with higher operating frequencies, such as systems above 10MHz, due to its shorter ground wires and lower impedance.

Mixed grounding involves using different grounding methods for systems with signals of different frequencies. Mixed grounding not only incorporates the characteristics of single-point grounding but also possesses the advantages of multi-point grounding, making it suitable for circuits with a wide frequency band.

The circuit in this case also employs mixed grounding. However, the original mixed grounding was directly connected through a copper foil. As seen from the previous simulation, the DSP ground plane is a significant path for interference, which directly affects other ground planes through the copper foil. Therefore, an "RC" circuit is adopted for the signal common ground plane between various power sources. The schematic diagram is shown in **Figure 13**.

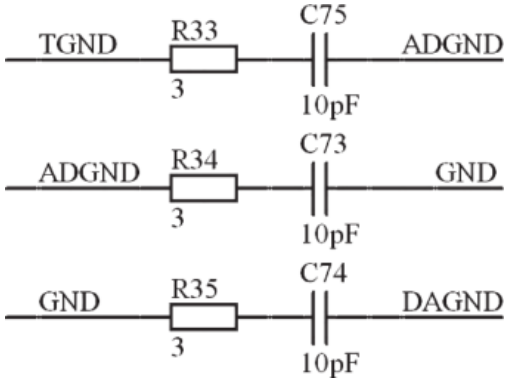


Figure 13. Ground plane RC circuit.

After complementing and rectifying the circuit through the above three measures, it was re-verified according to the previously conducted immunity test of the signal processing circuit. As shown in **Figure 14**, the test results are normal. This analysis and circuit modification has achieved the goal of improving the immunity performance of the signal processing circuit.

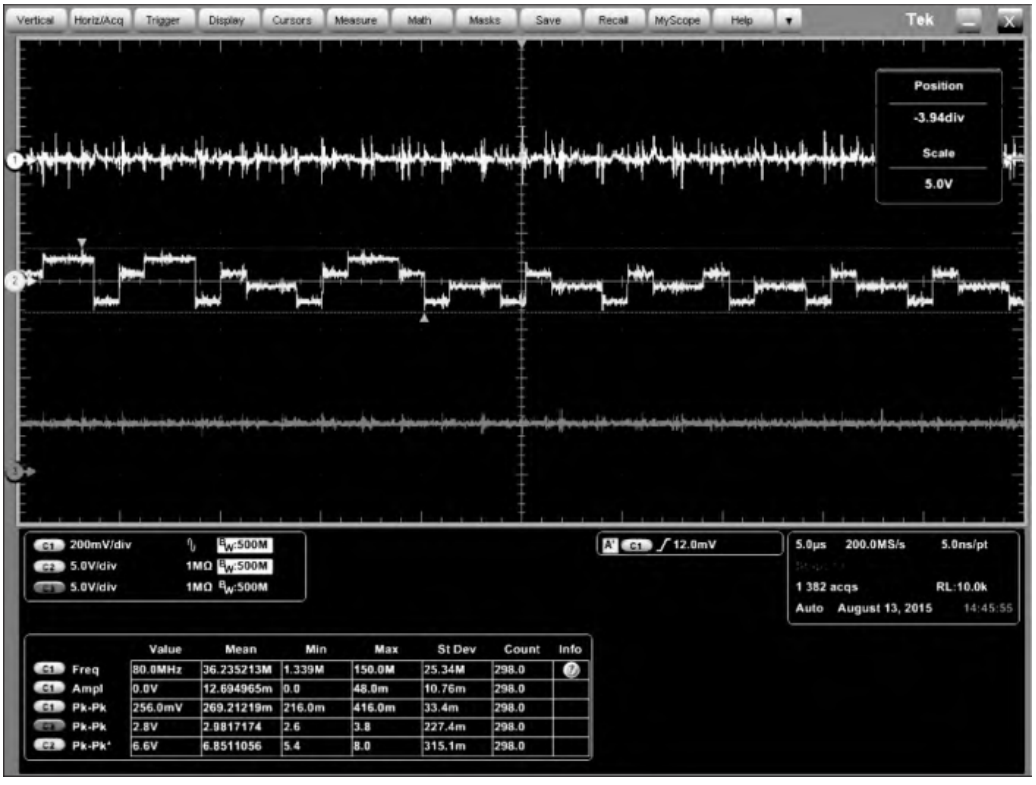


Figure 14. Normal test waveform during perturbation (CH1 output port 1, CH2 output port 2, CH3+5V test terminal).

4. Conclusion

The immunity of signal processing circuits is a key design focus and a weak point. Through this simulation analysis and circuit modification, it can be seen that power supply filtering and the processing of related power planes and ground planes are decisive factors that affect signal immunity. At the same time, the processing of key signals is also crucial. Simulation methods can be used to analyze and evaluate the electromagnetic compatibility characteristics of the circuit, especially its immunity characteristics, to improve the electromagnetic compatibility of the signal processing circuit and effectively support product quality and reliability efforts.

Disclosure statement

The authors declare no conflict of interest.

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