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Conducted Electromagnetic Susceptibility Analysis of Chips Based on BCI Method

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Abstract

The bulk current injection (BCI) technique can simulate electromagnetic interference in the environment coupled with the power or signal cables of electronic devices. It is an important method for studying the conducted electromagnetic susceptibility in electromagnetic compatibility. This paper focuses on the conducted electromagnetic susceptibility of chips using the bulk current injection technique. The bulk current injection probe is integrated with various types of interference signals to design a conducted electromagnetic susceptibility test for chips based on multi-waveform interference. According to the results of the conducted electromagnetic susceptibility test, the susceptibility of integrated circuits to different types of interference signals is analyzed. The effectiveness of the test system is verified through experimental testing and data analysis. The research results show that the bulk current injection test method can accurately assess the conducted electromagnetic susceptibility of chips. It provides valuable references for the design optimization of electronic systems and the improvement of electromagnetic compatibility. This study contributes to improving the reliability of chips in complex electromagnetic environments.

Keywords

Bulk Current Injection, Interference Signal, Conducted Electromagnetic Susceptibility, Chip, Electromagnetic Environment.

Introduction

With the continuous improvement of the integration level of integrated circuits and electronic devices, their working environment and operating modes are undergoing significant changes. At the same time, the electromagnetic environment these devices face during actual operation is becoming increasingly complex, which has led to a series of electromagnetic interference and conducted electromagnetic susceptibility issues that occur during the working phase (Leong, 2024a; 2024b). Modern electronic systems generally adopt a multi-cable interconnection

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architecture, which inevitably couples electromagnetic energy from the working environment （International Organization for Standardization [ISO], 2011）. Electromagnetic interference conducted through cables can transfer energy into the interior of the devices, causing varying degrees of performance interference to key electronic components such as integrated circuits. Research has shown that cable-coupled spatial electromagnetic interference can lead to the conduction of a bulk amount of interference power, thereby inducing transient currents and voltages in terminal devices （Fu et al., 2021）. This phenomenon ultimately manifests as conducted electromagnetic susceptibility issues in the circuits connected to the terminal electronic devices or within the system.

Against the backdrop of the increasingly complex electromagnetic environment, it is of great value to conduct and analyze the bulk current injection conducted electromagnetic susceptibility tests for electrical equipment, electronic components, and integrated circuits (IEC 61000-4-6 2013). Conducted electromagnetic susceptibility tests and analyses can provide a scientific basis for the evaluation of system interference resistance performance. As an important testing method in the field of electromagnetic compatibility, the bulk current injection technique has been widely recognized as an effective alternative to standard radiated susceptibility testing and has long played a key role in interference resistance testing and susceptibility assessment. However, there is a lack of comparative research on the impact of waveform-specific on the electromagnetic susceptibility of chips. Testing the impact of various waveforms on chip susceptibility can help analyze the anti-interference performance of chips under different electromagnetic environments and types of electromagnetic interference.

It should be particularly pointed out that there is a wide variety of electromagnetic interference signals in space environments. By accurately simulating and analyzing the impact patterns of various electromagnetic interference sources on the conducted electromagnetic susceptibility of integrated circuits, more reliable theoretical support and engineering guidance can be provided for electromagnetic interference protection design. This kind of research is of great significance for improving the reliability of electronic systems in complex electromagnetic environments.

Methodology

Design of a Chip Bulk Current Injection Conducted Electromagnetic Susceptibility Testing System

A primary advantage of the Bulk Current Injection testing system is that it is non-invasive. The probe can be simply clamped onto any cable with a diameter not exceeding its maximum acceptable diameter without any direct connection to the cable conductor, and it does not affect the operating circuit connected to the cable.

Based on IEC standards and actual testing requirements, a chip BCI conducted electromagnetic susceptibility testing system has been set up, as shown in Figure 1 (IEC 62132-3 (2004)). The system mainly consists of the equipment under test, signal generator, BCI injection probe, power amplifier, directional coupler, power meter, DC power supply, and oscilloscope. The signal generator provides the working signal for the chip and generates interference signals for the injection probe. The power amplifier amplifies the power of the noise signal. The directional coupler has a frequency range of 4 kHz to 1 GHz with a coupling coefficient of 40 ± 1.5 dB and measures the actual injected and reflected power. The bulk current injection probe injects interference signals into power lines or signal lines. The oscilloscope monitors changes in the chip's output waveform. The power meter measures the actual injected power of the interference signal. The DC power supply provides DC power for the normal operation of the chip.

The bulk current injection probe is typically connected to a signal generator capable of providing bulk currents of specific frequencies and amplitudes. This current is injected into the cable or wiring harness of the equipment under test through the probe, simulating real-world electromagnetic interference. The injected interference signal enters the chip pins through the board's ports and transmission lines, causing conducted electromagnetic susceptibility phenomena. During injection, the performance of the equipment under test is monitored to assess whether it can operate normally; this involves detecting changes in output, data error rates, and functional failures.

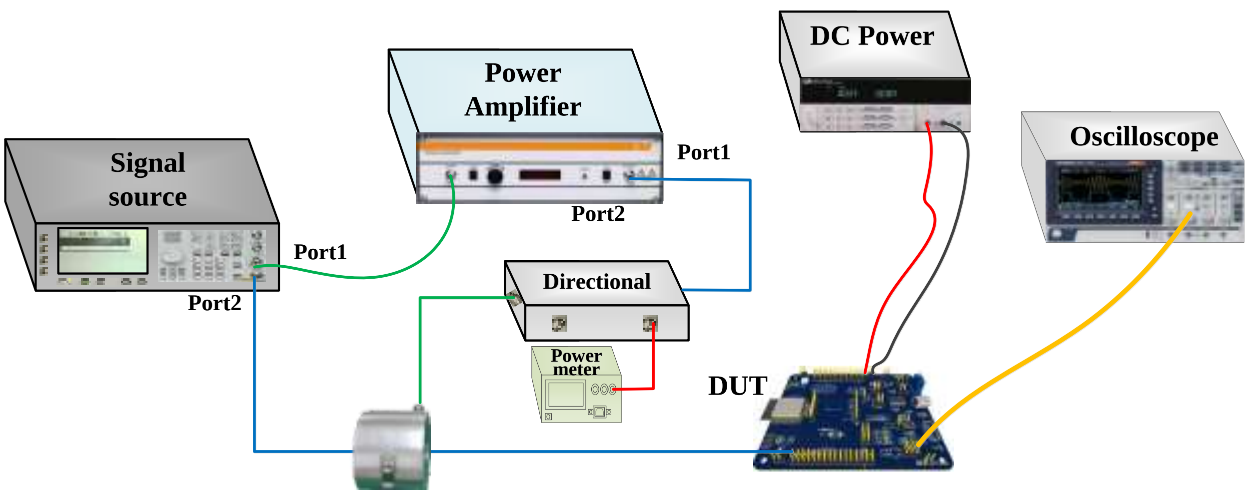

Figure1. Connection Diagram of the Chip Bulk Current Injection Conducted Electromagnetic Susceptibility Testing Device.

The test method and procedure for chip bulk current injection conducted electromagnetic susceptibility involves several steps. First, the bulk current injection probe, other test instruments, and the device under test (DUT) are connected as shown in Figure 1. The DUT is then powered on and its normal operating status is verified. At each test frequency point, the amplitude of the interference signal connected to the injection probe is gradually increased until the test meets the specified requirements. During this process, it is monitored whether the measured output power and frequency reach the limits supplied to the injection probe. If the DUT (integrated circuit) exhibits susceptibility phenomena or reaches the target levels of frequency and amplitude, then the electromagnetic immunity level of the DUT is determined. In all cases, the monitored frequency and power values are recorded.

Methods for Chip Bulk Current Injection Conducted Electromagnetic Susceptibility Testing

The methods for chip bulk current injection conducted electromagnetic susceptibility testing include the substitution method and the closed-loop method. For the substitution method, forward power is used as the benchmark parameter for calibration and testing. The specific test level (electric field, current, voltage, or power) should be calibrated before the actual test. Apply the interference signal to the DUT according to the predetermined calibration value in the test plan. Both forward and reflected powers should be recorded during the calibration and testing process. When using the substitution method for testing, the wire harness length is 1700 (+300/-0) mm. The distance between the current injection probe and the DUT is (150±50) mm, (450±50) mm, or (750±50) mm. If a current monitoring probe is needed, it should be placed at a distance of (50±10) mm from the DUT.

For the closed-loop method, a calibration device is used in actual tests to measure the test level, such as electric field, voltage, current, or power, and provide feedback to the signal generator to increase or decrease the test level until the predetermined level is reached. When using the closed-loop method for testing, the wire harness length is 1000 (+200/-0) mm. The distance between the current injection probe and the DUT is (900±10) mm. A current monitoring probe must be placed using the closed-loop method, and it should be positioned at a distance of (50±10) mm from the DUT connector.

Waveform Injection Protocols

The waveform injection protocols involve setting the system parameters for the BCI conducted electromagnetic susceptibility test process and then conducting the BCI conducted electromagnetic susceptibility test on the device under test (Fu et al., 2023). The testing mainly includes single-frequency sine wave interference conducted susceptibility testing, single-frequency square wave interference conducted susceptibility testing, and single-frequency triangular wave interference conducted susceptibility testing (Badini et al., 2017; Spadacini et al., 2018; Toscani et al., 2018).

The sine wave is one of the most common waveforms and is widely present in nature and electronic devices, such as AC power sources and radio waves. In the simulation of electromagnetic interference, the sine wave can represent continuous and stable electromagnetic radiation sources.

The square wave has a steep waveform and contains rich harmonic components, which can simulate the electromagnetic interference generated by rapid switching actions in digital circuits (such as clock signals and data signals).

The triangular wave has a relatively smooth waveform but also contains harmonic components. Its harmonic content is less than that of a square wave but more than that of a sine wave. The triangular wave can simulate certain electromagnetic interference sources with gradual characteristics.

For single-frequency sine wave interference conducted susceptibility testing, injection susceptibility testing is conducted on the signal cable harness of the DUT within the frequency range of 10 kHz to 400 MHz where the type of injected interference signal is a single-frequency sine wave with an adjustable signal source output power of 0 to 5 dBm; if susceptibility phenomena still occur at 0 dBm, the test continues to reduce the signal source output power, and a 75W power amplifier is used to amplify the signal source power by 70% before injecting the signal into the signal cable of the DUT through the injection probe.

For single-frequency square wave interference conducted susceptibility testing, injection susceptibility testing is conducted on the signal cable harness of the DUT within the frequency range of 10 kHz to 400 MHz where the type of injected interference signal is a single-frequency square wave with an adjustable signal source output power of 0 to 5 dBm; if susceptibility phenomena still occur at 0 dBm, the test continues to reduce the signal source output power, and a 75W power amplifier is used to amplify the signal source power by 70% before injecting the signal into the signal cable of the DUT through the injection probe.

For single-frequency triangular wave interference conducted susceptibility testing, injection susceptibility testing is conducted on the signal cable harness of the DUT within the frequency range of 10 kHz to 400 MHz where the type of injected interference signal is a single-frequency triangular wave with an adjustable signal source output power of 0 to 5 dBm; if susceptibility phenomena still occur at 0 dBm, the test continues to reduce the signal source output power, and a 75W power amplifier is used to amplify the signal source power by 70% before injecting the signal into the signal cable of the DUT through the injection probe.

Results and Discussion

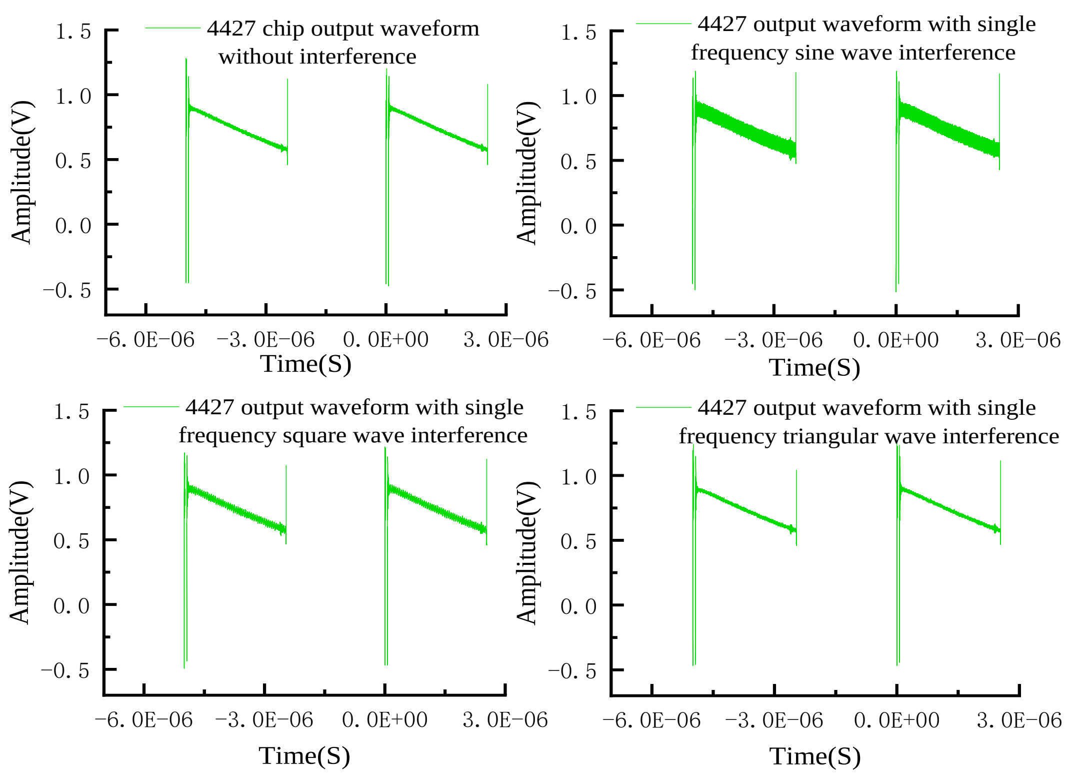

Figure 2. Output waveforms of TC 4427 at 100 MHz under conditions both without interference and with the influence of three types of waveform interference signals.

The test results indicate that the chip's conducted electromagnetic susceptibility is more easily induced when subjected to sinusoidal interference signals of the same amplitude and frequency. This study systematically investigates the impact patterns of different types of interference signals on the conducted electromagnetic susceptibility of integrated circuits, with a particular focus on conducting comparative experiments on the conducted susceptibility of typical chips to sine, square, and triangular wave signals using the bulk current injection method. The experimental results indicate that, under the same interference amplitude and frequency conditions, the sine wave interference signal exhibits a stronger ability to induce conducted electromagnetic susceptibility in the tested chips compared to other waveforms, as shown in Figure 2. The methodological framework and analytical structure established in this study are universal and can be extended to a broader range of conducted electromagnetic susceptibility research on integrated circuits, providing a reliable technical pathway for further in-depth exploration.

Conclusion

In conclusion, the BCI method proves to be a robust and efficient technique for assessing the conducted EMS performance of chips. It facilitates early detection of design weaknesses, supports EMC optimization, and ultimately contributes to the development of more resilient and compliant electronic systems. Future work will explore the integration of BCI-based EMS analysis with simulation models to predict susceptibility with greater accuracy and to reduce the cost and time of physical testing.

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References

Badini, L., Spadacini, G., Grassi, F., Pignari, S. A., & Marliani, F. (2017). A rationale for statistical correlation of conducted and radiated susceptibility testing in aerospace EMC. *IEEE Transactions on Electromagnetic Compatibility*, *59*(5), 1576–1585. https://doi.org/10.1109/TEMC.2017.2678762

Fu, C., Yan, Z., Liu, Y., Wang, Z., & Su, D. (2023). Broadband pulse injection probe with improved injection efficiency for conducted electromagnetic susceptibility test. *IEEE Sensors Journal*, *23*(5), 4763–4775. https://doi.org/10.1109/JSEN.2023.3237133

International Electrotechnical Commission. (2004). *Integrated circuits – Measurement of electromagnetic immunity, 150 kHz to 1 GHz – Part 3: Bulk current injection (BCI), 10 kHz to 1 GHz* (IEC Standard No. 62132-3). https://cdn.standards.iteh.ai/samples/11850/f49da267d4cf4a40a02b65616cc485a8/IEC-62132-3-2007.pdf

International Electrotechnical Commission. (2013). *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields* (IEC Standard No. 61000-4-6). https://webstore.iec.ch/en/publication/4224

Leong, W. Y., Leong, Y. Z., & Leong, W. S. (2024a). Miniature THz antenna design. In *2024 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM)* (pp. 1–2). IEEE. https://doi.org/10.1109/iWEM59914.2024.10649329

Leong, W. Y., Leong, Y. Z., & Leong, W. S. (2024b). System-on-chip (SoC) medicine. In *2024 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM)* (pp. 1–2). IEEE. https://doi.org/10.1109/iWEM59914.2024.10649387

Spadacini, G., Grassi, F., Pignari, S. A., & Arianos, S. (2018). Bulk current injection as an alternative radiated susceptibility test enforcing a statistically quantified overtesting margin. *IEEE Transactions on Electromagnetic Compatibility*, *60*(5), 1270–1278. https://doi.org/10.1109/TEMC.2018.2810074

Toscani, N., Grassi, F., Spadacini, G., & Pignari, S. A. (2018). Circuit and electromagnetic modeling of bulk current injection test setups involving complex wiring harnesses. *IEEE Transactions on Electromagnetic Compatibility*, *60*(6), 1752–1760. https://doi.org/10.1109/TEMC.2018.2794823