Intel® Pentium® 4 Processor in the 423-pin package

EMI Guideline

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Revision History

Rev 1.0 — Initial release.
Rev 2.0 — Final release

1.0 Introduction

As microprocessor amperage and speeds increase, the ability to contain the corresponding electromagnetic radiation becomes more difficult. Frequencies generated by the Pentium ® 4 processor will be in the low gigahertz (GHz) range, which will impact both the system design and the electromagnetic interference (EMI) test methodology.

This document is intended to provide electrical and mechanical design engineers with information in regards to developing a Pentium® 4 processor based system to meet government EMI regulations. Heat sink grounding, processor shielding, differential and spread spectrum clocking and the test methodology impact to FCC Class B requirements are discussed.

Designers should be aware that implementing all the recommendations in this guideline will not guarantee compliance to EMI regulations. Rather, these guidelines may help to reduce the emissions from processors and motherboards and make chassis design easier.

1.1 Terminology

Electromagnetic Interference (EMI) - electromagnetic radiation from an electrical source that interrupts the normal function of an electronic device.

Electromagnetic Compatibility (EMC) - the successful operation of electronic equipment in its intended electromagnetic environment.

1.2 References

Intel Pentium 4 Processor and 850 Chipset Platform Design Guide.
Intel Pentium 4 Processor in the 423-Pin Package Datasheet.
Intel Pentium 4 Processor Thermal Design Guidelines.
`*CK00 Clock Synthesizer Design Guidelines*.

1.3 Brief EMI Theory

Electromagnetic energy transfer can be viewed in four ways: radiated emissions, radiated susceptibility, conducted emissions and conducted susceptibility. For PC system designers, reduction of radiated and conducted emissions is the way to achieve EMC compliance. Susceptibility is typically not a major concern in the desktop PC environment although it may be more important in an industrial environment.

The main component of EMI is a radiated electromagnetic wave, which consists of both electric (E-fields) and magnetic (H-fields) waves traveling together and oriented perpendicular to each other. Although E and H fields are intimately tied together, they are generated by different sources. E-fields are created by voltage potentials while H-fields are created by current flow. In a steady state environment (where voltage or current is unchanging), E and H fields are also static and of no concern to EMI. Changing voltages and currents are of concern since they contribute to EMI. If a dynamic E-field is present then there must be a corresponding dynamic H-field, and vice versa. Motherboards with fast processors will generate high frequency E and H fields from currents and voltages present in the component silicon and signal traces.

Two methods exist for minimizing E and H field emissions from a system: prevention and containment. Prevention is achieved by implementing design techniques that minimize the ability of the motherboard to generate EMI fields. Containment is used in a chassis environment to contain radiated energy within the chassis. Careful consideration of board layout, trace routing and grounding may significantly reduce the motherboards radiated emissions and make the chassis design easier.

1.4 EMI Regulations and Certifications

Personal Computer Original Equipment Manufacturers (PC OEMs) ensure EMC compliance by meeting EMI regulatory requirements. PC designers must ensure that their computer systems do not exceed the emission limit standards set by applicable regulatory agencies. Regulatory requirements referenced in this document include:

United States Federal Communication Commission (FCC) Part 15 Class B

International Electrotechnical Commission's International Special Committee on Radio Interference (CISPR) Publication 22 class B limits.

The FCC rules are viewed to require any PC OEM who sells an "off-the-shelf" motherboard in the United States to pass an open chassis test. Open chassis testing is defined as removing the chassis cover (or top and 2 sides) and testing for EMI compliance (although permitted emission levels are allowed to be higher). Removing the cover greatly reduces the shielding provided by the chassis and increases the amount of EMI radiation. The purpose of this regulation is to ensure that system boards have reasonable emission levels since they are one of the main contributors to EMI.

2.0 EMI Design Considerations

The following sections discuss design techniques that may be applied to minimize EMI emissions. Some ideas have been incorporated into Intel enabled designs (differential clock drivers, selective clock gating, etc) and some must be implemented by motherboard designers (trace routing, clocking schemes, etc).

2.1 Spread Spectrum Clocking (SSC)

Spread Spectrum Clocking is defined as continuously ramping (or modulating) the processor clock frequency over a predefined range, Figure 1. SSC reduces radiated emissions by spreading the radiated energy over a wider frequency band, Figure 2. Thus, instead of maintaining a constant system frequency, SSC modulates the clock frequency along a predetermined path (or modulating profile, Figure 1) with a predetermined modulation frequency. The modulation frequency is usually selected to be larger than 30 kHz (above the audio band) while small enough not to upset the PC system's timings (less than 0.8% of the clock frequency). SSC has been demonstrated to effectively reduce peak radiation levels, making EMC compliance easier to achieve.

To conserve the minimum period requirement for bus timing, the SSC clock is modulated between f_{nom} and $(1-\delta)\ f_{nom}$ where f_{nom} is the nominal frequency for a constant frequency clock. δ specifies the total amount of spreading as a relative percentage of f_{nom}. The modulation percentage is always a function of $1-\delta$ and not $1+\delta$, as increasing the clock frequency above the rated speed of the processor will cause unpredictable operation.

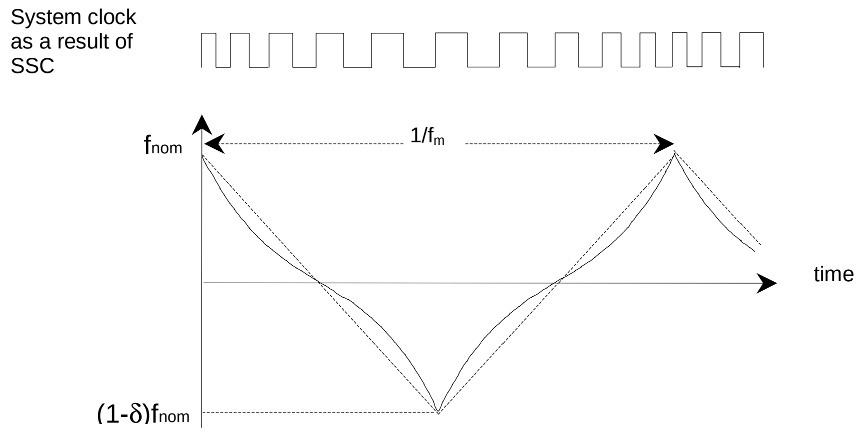

Figure 1. Spread Spectrum Modulation Profile

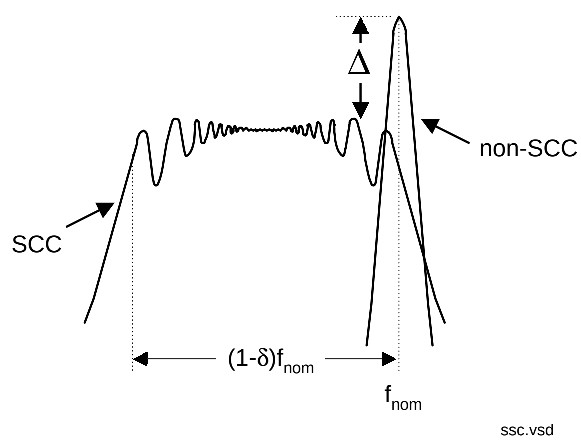

Figure 2. Impact of Spread Spectrum Clocking on Radiated Emissions
Radiated emissions are typically confined in a narrow band centered around clock frequency harmonics. By uniformly distributing the radiation over a band of a few MHz, regulatory measurement levels will be reduced.

2.2 Differential Clocking

Differential clocking requires that the clock generator supply both clock and clock-bar traces. Clock-bar has equal and opposite current as the primary clock and is also 180 degrees out of phase. To maximize the benefit of differential clocking, both clock lines must be routed parallel to each other for their entire length. Devices connected to the clock must also be designed to accept both the clock and clock-bar signals.

EMI reduction due to differential clocking is caused by H-field cancellation. Since H-field orientation is generated by and is dependent upon current flow, two equal currents flowing in opposite directions and 180 degrees out of phase will have their H-fields cancelled, Figure 3. Lower H-fields will result in reduced EMI radiation.

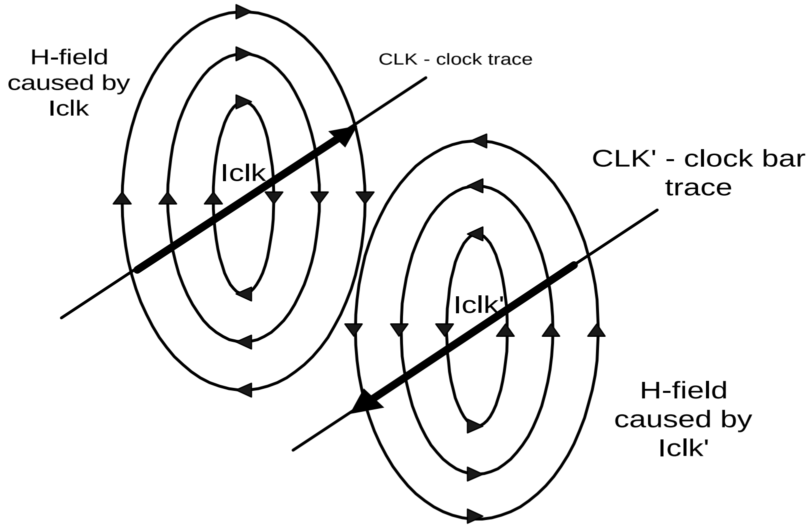

Figure 3. Cancellation of H-fields Through Inverse Currents

Differential clocking can also reduce the amount of noise coupled to other traces, which improves signal quality and reduces EMI. I/O signals are particularly important because they often leave the system chassis (serial and parallel ports, keyboards, mouse, etc) and will radiate noise that has been induced onto them. A single-ended clock's return path is usually a reference plane, which is shared by other signals/traces. When noise is created on a single-ended clock, the noise will appear on the reference plane and may be coupled to I/O traces. A differential clock's return path is the clock-bar signal/trace, which is more isolated than the reference plane and minimizes potential I/O trace coupling.

For best results, the trace lengths and routing of the clock lines must be closely matched and spacing between the two traces should be kept as small as possible. This will minimize loop area and maximize H-field cancellation. In addition, the real and parasitic terminations of each signal of a differential pair should be the same. Also, the skew between the signal level transitions on the two lines must be small compared to the rise time of the level transitions.

Placing ground traces on the outside of the differential pair may further reduce emissions. Intermediate vias to ground may be needed to reduce the opportunity for re-radiation from the ground traces themselves. Distance between vias should be less than ¼ of a wavelength of the 5^{th} harmonic of the processor core frequency.

2.3 PCI Bus Clock Control

Experimental data has indicated a reduction in EMI may be possible by disabling the clocks to unused (and therefor unterminated) PCI slots. CK00, the clock chip that has been specified and designed for Pentium® 4 processors, supports individual control of the various PCI clocks. Designers have the option to enable or disable individual PCI clocks depending upon their specific system configuration requirements. Refer to the CK00 Clock Synthesizer Design Guidelines for details on how to configure the PCI clocks.

2.4 Heatsink Effects

Heatsink grounding may be an effective way to reduce system EMI emissions. Noise coupled from the processor package to the heatsink may cause it to act as an antenna and re-radiate the noise. Heatsink size, shape, fin pattern, orientation and material may all impact its ability to reradiate the high frequency signals. Designers will have to experimentally investigate the behavior of a particular heatsink to determine its EMC performance.

Grounding of the heatsink through the Intel processor package is not possible with the current package implementation but may be an option at some time in the future. As such, OEMs must design their own heatsink grounding solution.

When designing a grounding mechanism for the heatsink care must be taken to minimize the impedance and distance between the ground paths. Typical guidelines suggest ground points should be separated by less than ¼ wavelength of the 3^{rd} harmonic of the processor core frequency.

Grounding materials should be selected to eliminate galvanic action between the various metals with which they will be in contact. Oxidation of the various materials should also be considered as some oxides are non-conductive (for example, aluminum oxide) and will degrade EMC performance over time. Manufacturing process residue or coatings to prevent oxidation should also be checked for conductivity, especially at high frequencies.

2.5 Faraday Cages

Grounding of heatsinks may reduce EMI, but that alone may not be sufficient to pass the required tests. Additional shielding of the processor itself may be necessary. A faraday cage placed around the processor may provide a reduction in radiated noise and make chassis design easier.

A true faraday cage would completely surround the source of radiation and contain all radiated energy. Within the limitations of processor packaging and motherboard assembly it is not possible to create a true faraday cage around the processor. By using the heatsink and motherboard ground plane as two sides of the cage and a metal frame to enclose the remaining four sides, a reasonable approximation of a faraday cage can be achieved.

Intel has designed a 'picture frame' type of grounding device that fits between the processor and heatsink, Figure 4. With this implementation, it is unnecessary to design a separate heatsink grounding mechanism as the frame will provide this capability. OEMs who choose to use the Intel designed grounding frame will need to provide ground pads on the top layer of the motherboard around the processor socket. These pads will provide the necessary ground continuity to complete the faraday cage. Exact physical dimensions of the frame, materials used and the required motherboard ground pad descriptions are provided in the Mechanical Assembly and Design Guidelines listed above.

Investigations on a variety of Pentium® 4 processor motherboards indicates a ground frame is not necessary to meet FCC or CISPR regulations. Based on this data, the ground frame depicted in Figure 4 will remain at the prototype stage, although further development may take place if greater EMI containment is needed. It may be wise for motherboard designers to implement the ground pads mentioned in the previous paragraph, in the event the ground frame does become necessary. Intel will make every effort to assist OEMs who are interested in developing the faraday cage for their particular application, but it should be noted that each OEM is ultimately responsible for ensuring their systems meet the EMC regulations.

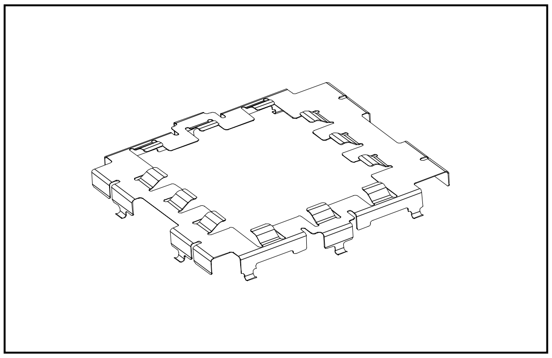

Figure 4 Prototype Ground Frame

2.6 EMI Test Capabilities

FCC regulations in the United States specify the maximum test frequency for products with clocks in excess of 1GHz is 5 times the highest clock frequency or 40 GHz, which ever is lower. Pentium® 4 processors are expected to initially be available at 1.4 GHz and 1.5 GHz, which means the maximum frequency which must be scanned is 7.5 GHz. OEMs are advised to enquire into the capabilities of their preferred EMC test lab to ensure they are able to scan up to 7.5 GHz.

History indicates that processor performance and frequency double approximately every 2 years. With this in mind, it would be advisable to be prepared for the frequencies that will need to be scanned in the next few years.

Since the FCC Rules ultimately require testing to 40 GHz, commercial test equipment has been developed which is capable of making measurements to that frequency. Although it will be some time before processors require testing at this frequency, it may be cheaper to upgrade to 40 GHz now rather than making several intermediate steps.

It is also possible to upgrade various parts at different times. The spectrum analyzer may be upgraded to 40GHz today while only obtaining the necessary antennas to support the initial processor frequencies. As processor speed increases, the necessary antennas and cables could be purchased which would support testing to the higher levels. Cost flexibility in antenna selection is probably the greatest, as different antenna designs are necessary for different frequency ranges.

3.0 Summary

High speed clock frequencies within the Pentium® 4 processor will make EMI compliance more challenging. In order to facilitate successful chassis and motherboard designs, Intel has developed a number of components and techniques to reduce or contain EMI emissions. OEMs are advised to verify that their preferred EMC test facility is capable of measuring the required frequencies.

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