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Literature Review on Emc in Integrated Circuits

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Abstract: This paper introduces key concepts related to Electromagnetic Compatibility (EMC) of Integrated Circuits (ICs). A brief description of Electric and magnetic field coupling, conducted and radiated mode emissions, as well as susceptibility, are also discussed in this paper.

Key words: Electromagnetic compatibility · Electric field · Magnetic field · Simultaneous switching noise · Radiated emission · Conducted Emission

INTRODUTION

Integrated Circuit EMC: Integrated circuits (ICs) are most important in the electromagnetic compatibility of an electronic system. Preferably, ICs are the source of signals, disturbance that produce interference [1-6]. These parameters converts the D.C. power supplied to them into the high-frequency currents and voltages that are responsible for unintentional emissions or coupling. The major issues of electromagnetic interference are also, very often, ICs. Of all the components in a typical electronic system, ICs tend to be the most susceptible to damage caused by over-voltage or over-current conditions. Even if they are not damaged, noise coupled to the input or power pins of ICs may cause them to malfunction. Although ICs are generally the ultimate source of an EMC problem, the major area of most EMC-related research and problem solving has been external to the IC package. EMC engineers have traditionally focused their efforts on the design of printed circuit boards, enclosures, and cabling. With a few notable exceptions (e.g. over-voltage protection and slew rate control), EMC has not played a major role in the design of the integrated circuit itself. EMC problems associated with integrated circuits can generally be classified as ***intra-chip*** **or** ***externally-coupled.***

Intra-chip EMC problems result when a signal or noise created in one or more circuits interferes with the operation of another circuit on the same chip. Externally-coupled EMC problems result when signals or noise generated on an IC interfere with circuits or devices off the chip; or conversely when noise generated externally interferes with the proper operation of IC. The two most common intra-chip EMC problems are 1. Crosstalk 2. Simultaneous switching noise Crosstalk results when voltages or currents in one circuit are unintentionally coupled to another circuit [2-7]. If the coupling is strong enough, the coupled signal can affect the amplitude and/or timing of the signal received by the victim circuit, causing it to malfunction.

Crosstalk: The crosstalk between two circuits is generally defined as "the ratio of the unintentional voltage appearing across the load in the victim circuit to the signal voltage in the source circuit". It is normally expressed in dB.

Since the coupled voltage is normally smaller than the source voltage, crosstalk expressed in dB is usually a negative value.

In integrated circuits, there are generally three types of coupling that can result in crosstalk:

- Common-Impedance Coupling,
- Electric Field Coupling,
- Magnetic Field Coupling.

Common Impedance Coupling: (also called conducted coupling) occurs when parts of the current paths in two circuits share the same conductor (e.g. the same ground metallization). An example of this is illustrated in Fig. 1-1, where two circuits with sources Vsl and VS2 share a common conductor that has a resistance, RRET. Note that

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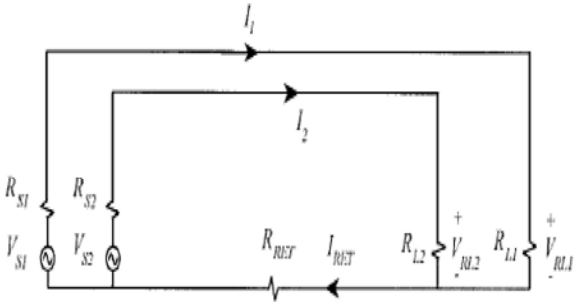

Fig 1-1:

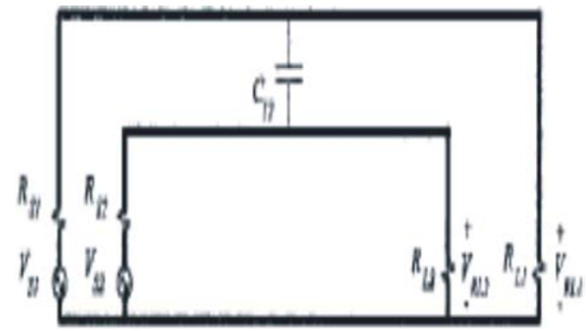

Fig. 1-2:

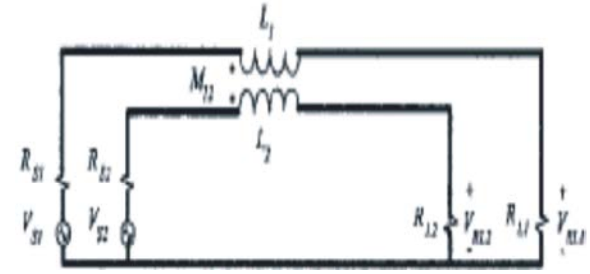

Fig. 1-3:

Table 1:

Coupling	Conditions	Remeidies
Common Impedance Coupling	Low-Frequency	Isolate Current Path
	Low-impedance	Reduce impedance of common path
Electric Field Coupling	High-Frequency	Separate circuits
	High-impedance	Isolate the circuits with grounded conductor
	source	Reduce signal voltage

the finite impedance associated with the shared conductor results in a voltage drop that appears across both circuits [3-8]. Generally Speaking, the coupled voltage is proportional to the product of the shared impedance and the current in the source circuit.

Electric Field Coupling: (also called capacitive coupling) occurs when electric field lines begins from a conductor in one circuit and ends on a conductor in another circuit. This can be represented schematically by a Parasitic capacitance between the two conductors. A known example of this is the coupling between two closely spaced signal conductors as illustrated in Fig. 1-2. Usually, electric field coupling produces a current in the nearby circuit that is proportional to the time derivative of the source signal (i.e.$C.dV/dt$).

Magnetic Field Coupling: (or inductive coupling) can also be a significant source of crosstalk in ICs. This type of coupling occurs when magnetic fields produced by the time-varying currents in a source circuit "couple" (i.e. penetrate the loop area) of a second circuit. This is similar to the coupling between the primary and secondary of a transformer.

Fig. 1-3 illustrates magnetic field coupling between two circuits that have overlapping loop areas. Magnetic field coupling generates a voltage in the victim circuit that is proportional to the derivative of the signal current in the source circuit (i.e. $L.di/dt$).

Table 1-1 lists the 3 basic coupling mechanisms that can result in crosstalk between circuits in an IC as well as the conditions likely to produce each type and possible courses of action. Crosstalk problems in ICs can generally be avoided by following basic guidelines for routing circuits on a chip. It is important to keep track of the current paths associated with each signal as well as the voltages.

Simultaneous Switching Noise: Simultaneous switching noise is the most infamous EMC problem associated with integrated circuit design. Also known as ground bounce, power bounce or delta-I noise; *simultaneous switching noise* has been the source of many IC failures some of which we cannot find the reason, after the design was in full production [4-9]. It is once again a common impedance coupling problem that arises due to the fact that various circuits in an integrated circuit share the same power distribution bus. When a circuit draws current from the power bus, a small voltage is dropped across the bus. The drop in power bus affects the voltage in the circuits connected to the bus. Fig. 1-4 illustrates the basic concept. Suppose that there are two totem pole output stages in a CMOS circuit that share the same power distribution path and resistance power path back to the source is Rdd + Rss. If the first circuit output, Vs1Gl, is in the high state, then Vs1Gl=VDD-VSS. When the second

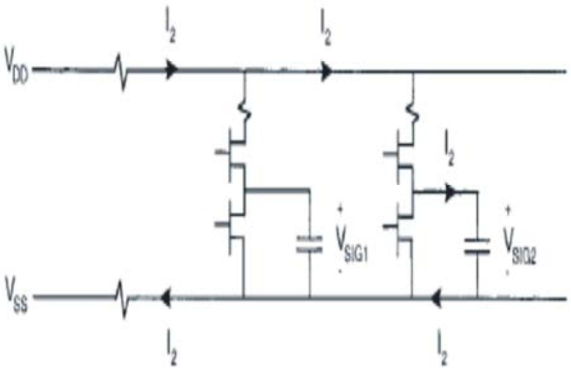

Fig. 1-4:

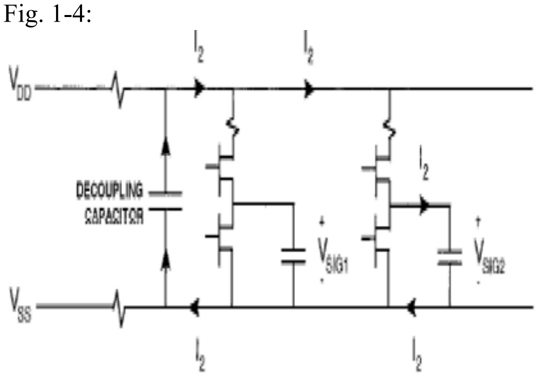

Fig. 1-5:

circuit switches from low to high, a current I2 is drawn from the VDD side of the power bus and flows to the Vss side of the power bus. The current I2 only flows long enough to charge the capacitance associated with signal 2. However as I2 is pulled through the resistance of the power bus, there is a momentary drop in the voltage seen by both circuits. The voltage VsIGl takes on a new value:VslGl = VDD - VSS – I 2 (RDD + Rss). If the resistance is a few milliohms and the peak current is on the order of an ampere, the voltage fluctuation is only a few millivolts. Similarly if the number of circuits and the switch at the same time is high, the peak current taken through the power bus which is also high and it cause outputs to fluctuate by several volts causing changes in the state of outputs that are supposed to be stable. Simultaneous switching noise can be reduced by providing low impedance power distribution on the IC. More speed VLSI designs also have *on-chip decoupling capacitance* to protect against problems due to simultaneous switching. On-chip decoupling capacitors are capacitors connected between VDD and Vss that provide a temporary source of charge for the instantaneous switching currents required by nearby circuits. Fig. 1-5

Describes how a nearby decoupling capacitor prevents instantaneous switching currents from being drawn from the power bus. When a circuit switches, the peak current required to start charging the signal capacitance is drawn primarily from the larger nearby decoupling capacitor instead of being drawn through the power bus resistance. After the initial peak demand for current has passed.

Externally-Coupled EMC: Most integrated circuit designs are thoroughly tested before being mass-produced and intra-chip EMC problems are generally resolved before devices are placed in a real product. However, semiconductor devices that exhibit no intra-chip problems can still be the source (and victim) of EMC problems due to disturbance that is coupled in or out of the chip package There are four possible mechanisms for coupling of electromagnetic noise to or from an integrated circuit. Like crosstalk within a device, externally-coupled disturbance can be conveyed via a conducted path, an electric field or a magnetic field. This also creates radiate energy directly from the chip or package [10].

Conducted Coupling: Perhaps the most obvious way to couple noise in to or out of an integrated circuit is via the package leads or pins. Crosstalk between a high-frequency input/output and a low-frequency input/output is one way that noise is coupled conductively. Simultaneous switching noise is another common source of high-frequency noise. Since simultaneous switching noise is a fluctuating voltage on the power bus, all of the device pins referenced to a corresponding power bus may have high-frequency voltage fluctuations if there is improper decoupling on the chip or package. Voltage drops across an IC's substrate can also result in voltage differences between pins connected to different areas of the chip. The magnetic fields are strongest just above the lead frame where the currents are the strongest [11]. The strongest currents are flowing in the VCC and GND pins. The high-frequency currents conducted off the chip via these pins can result in significant radiated emissions from any printed circuit board that uses this particular device. It is not uncommon to observe harmonics of internal clocks on all of the pins connected to an integrated circuit. This can be a difficult problem to address at the board level, since it becomes necessary to route all traces connected to that IC as if they were high-frequency traces. On the other hand, noise problems such as this can be reduced relatively inexpensively through the use of effective on-chip decoupling techniques.

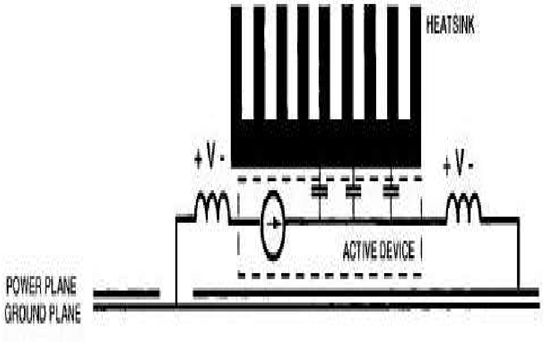

Fig-1-6

Electric Field Coupling: It is also possible to couple energy from or to an IC through an electric field. Electric field coupling occurs when a voltage that is produced across a device create a voltage to appear between two external conductors. Usually, this type of coupling occurs when a heat sink or a cable is placed very near the surface of the chip package. Large heat sinks can become relatively efficient [12-13]. When boards with heat sinks are located in shielded enclosures, the heat sinks can facilitate the coupling of energy that drives enclosure resonances The average voltage on the surface of the semiconductor device can be different than the voltage on the surface of the PCB due to the signal voltages themselves or the voltage dropped across the connections between the device and the board as illustrated in Fig.1-6. One possible solution to this problem is to fix heat sink to the PCB. Another possible solution is to attempt to shift the resonances of the PCB/heat sink structure so that they don't correspond to enclosure resonant frequencies Both of these solutions will create cost effectiveness..

A much better solution is to design the chip and package to prevent significant coupling to the heat sink. This can be done by reducing the inductance between the chip and the PCB. Although the field is ultimately radiated in this example, we don't refer to this as *radiation* from the integrated circuit itself. The coupling between the IC and the heat sink was through an electric field. The coupling between the IC and the board was conducted. The radiation came from the board and the heat sink. The integrated circuit was the source, but the heat sink/board structure was the antenna.

Magnetic Field Coupling: When a device package contains high-frequency current loops, energy can also be coupled out of the device through a magnetic field. It is possible for the magnetic flux from a current loop in the device to link to circuit loops outside the device. This mutual inductance can produce an unwanted voltage in the external loop. Likewise, an external magnetic flux can induce an unwanted voltage across an interior circuit loop. Magnetic field coupling can be minimized by keeping power and signal loop areas as small as possible.

Radiated Field Coupling: Radiation coupling is the transfer of electromagnetic energy over distances generally greater than a few wavelengths at these distances, fields drop off more slowly With distance than they do very near the source. Both the electric field and the magnetic field are needed to propagate the energy. Objects that are much smaller than a wavelength do not make very efficient antennas. Most integrated circuit packages are too small to radiate effectively at frequencies below about 10 GHz. At frequencies where the packages are large enough to radiate efficiently, the thin metallic structures in the package tend to be very lossy. As a result, radiation of electromagnetic energy directly from an integrated circuit is not usually a significant Problem. when they actually mean noise coupled out of an integrated circuit and then radiated by something else. If the conductors that make up the antenna are located within the integrated circuit or its package, then we say that the device *radiates.* However, if a device merely couples to an effective antenna located outside the package, we should describe that coupling as conducted, electric field, or magnetic field coupling. By clearly stating and understanding the coupling mechanism, we are in a much better position to deal with any problems resulting from this coupling. The best way to deal with radiated electromagnetic noise from integrated circuits is usually to start by identifying the structures that are acting as the effective *antenna.* If the radiation is significant, the conducting surfaces or wires that form the antenna will generally be one-tenth to one-quarter of a wavelength in size or larger. Generally, two large structures are required along with a noise source that drives one of them relative to the other.

Once the antenna has been identified, steps can be taken to either:

- Reduce the amplitude of the noise source
- Decouple the noise source from the antenna
- Eliminate part of the antenna.

For example, consider the heat sink radiation problem illustrated in Fig. 1-6. The IC is the source. The heat sink is one half of the antenna and the circuit board power/ground plane pair is the other antenna half. The coupling mechanism is partly conducted (power pins connecting to plane pair) and partly electric field coupling (chip surface to heat sink). We could reduce the amplitude of the source by providing better on-chip or on-package decoupling, which would reduce the high-frequency current drawn through the power pins. We could decouple the source from the antenna by decreasing the capacitance between the IC and the heat sink or by filtering the connection between the power plane pair and the IC power pins. Alternatively, we could eliminate part of the antenna by shrinking the heat sink or bonding it to the Power/ground plane pair.

CONCLUSION

This paper has presented in a general way the issues involved in the electromagnetic compatibility of integrated circuits. The concepts of intrachip and externally-coupled EMC have been introduced. The main mechanisms for conducted and radiated mode parasitic emissions from integrated circuits have been described. .

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