
A Primer on Transient Voltages...and their effects on microchips

Origin of Transient Voltages

Lightning, inductive load switching, and electrostatic discharge (ESD) are the most common sources of electrical overstress which produce transient voltages. Transients are narrow spikes of voltage ranging from less than 100 nanoseconds in duration for ESD, to greater than a thousand microseconds for lightning and load switching transients. Transient voltage magnitudes range from tens of volts up to more than 10kV.

Direct lightning hits have typical peak currents of 25kA but can exceed 200kA. Most damage results from the lesser amounts of transient voltage and current that bypasses any existing up-front suppression. The many parallel circuits in most distribution systems help in sharing the transient current, thus minimizing its effects at any one point. Other lightning related threats include ground potential rise and electromagnetic coupling. Lightning is predictably unpredictable, so you don't know where the next strike will hit.

When an inductive load is switched off, the stored energy in the inductor is dumped into the energizing line creating a voltage spike according to Faraday's law of induction: $V = -L(di/dt)$. These loads can be a transformer, motor or perhaps the solenoid in a copy machine. Poor electrical wiring practices aggravate load switching transients.

Inductive load switching produces the broadest range of transient conditions: 50ns duration for electrical fast transients (EFT, essentially high

voltage noise), up to 100 plus milliseconds for a generator load dump, when a fully loaded heavy vehicle generator has its load abruptly disconnected.

Static electricity is produced when two dissimilar materials are rubbed together. Your shoe soles and the floor, or just normal body movements while sitting in a chair are typical examples. On dry days, static charges increase because dry materials become good insulators. Seven to twelve kV are typical values of voltage buildup. When the humidity is high, moist skin becomes conductive, continually draining off charges and minimizing ESD effects.

Transient Entry

Transients gain entry to wiring and circuit traces by conduction or radiation. Examples of conduction include a direct hit by lightning or a resulting side-flash, inductive load switching across a power source, and contact by an ESD spark. Radiated energy, transferred by electromagnetic coupling and magnetic induction is picked up by conductive material in close proximity to a discharge channel of lightning or ESD, or from nearby wiring carrying a hefty transient of any origin.

Power lines are prime targets for direct lightning hits. Although surge suppression is provided by the power company to protect transformers, up to 10kV can still get through to the service entry of a building. Any other load in close proximity to an inductive load being switched feels the sting of the transients produced. The energy of an inductive source transient is

often consumed by other parallel loads. The greater the number of parallel loads, the lesser the effects of the transient. Conducted ESD normally enters a system through the touch of a fingertip or hand held metal tool.

Systems which are interconnected with long wires such as telephones, oil field and automated factory instrumentation and distributed computer systems are efficient collectors of radiated lightning energy. Close proximity strikes can induce voltages of 300V or more on signal lines. Power lines adjacent to computer data lines have been reported to induce both destructive and upsetting transient voltages. Lines switching high current inductive loads are the most disruptive. The exceedingly fast rise time of ESD, in the nanosecond range, produces efficient coupling into nearby wiring. A 7kV spark to a nearby metal desk was observed to upset a PC from a distance of four feet.

Effects on Microchips

Failure of silicon based electronic equipment is manifested in several modes, but can be generally classified in one of the three following categories: 1) hard failure, 2) upset, and 3) latent.

Hard failures are those sustaining permanent damage and must be replaced to restore normal circuit operation. If some components are shorted, they may be vaporized when they become part of the driving current path. Failures resulting from latch-up often char the component and a small part of the underlying circuit board. At

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the other extreme are ESD related component failures which produce exceedingly small failure sites, down into the micron range. These can be very difficult to diagnose without sophisticated equipment.

Upset is a temporary malfunction which may automatically reset or require manual reset to restore the system to normal. If a microprocessor overwrites a memory, serious problems may occur, depending on the computer use. Upsets are caused by many factors including conducted and radiated ESD, radiated EFT, and low level conducted and radiated lightning.

Latent failures are parts that have been zapped only once but did not fail nor significantly degrade. These become the "walking wounded" and without further transient stress fail at a later, unpredictable date. Some fail within hours, while others may perform for several years. These long term latent failures may be too often blamed on poor quality while the real culprit is latent failure syndrome.

Failure levels

The small geometries of individual components on integrated circuits (ICs) make them susceptible to transients although there is some level of on-chip protection for most devices in the form of a thyristor or diode resistor network.

Nevertheless, ICs which interface with the outside world, such as line drivers and line receivers, still fail at 40V to 50V for 8/20us simulated lightning pulses. Although many of these components have been hardened to 10kV of ESD, most microchips fail below 2kV.

Failure threshold levels vary among vendors depending on the amount of

built-in protection. Also, survival of a single event does not ensure against a latent failure at some later date. Adequate protection at signal line entry points can ward off commonly encountered threats.

Summary

Lightning, load switching and ESD are sources of transient voltages which can gain entry into sensitive electronic equipment by conduction or radiation. The very small geometries of components on ICs makes them vulnerable to low energy levels of voltage spikes.