

MicroNote 101

Transient Voltages and Their Effects on Microchips

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Origin of Transient Voltages

Lightning, inductive load switching, and electrostatic discharge (ESD) are the most common sources of electrical overstress that produce transient voltages. Transients are narrow spikes of voltage ranging from less than 100 nanoseconds in duration for ESD, to greater than 1,000 microseconds for lightning and load switching transients. Transient voltage magnitudes range from tens of volts up to more than 10 kV.

Direct lightning hits have typical peak currents of 25 kA but can exceed 200 kA. Most damage results from the lesser amounts of transient voltage and current that bypass any existing upfront 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 energy stored in the inductor is dumped into the energizing line. This creates a voltage spike according to Faraday's law of induction: $V = -L(di/dt)$. This load can be a transformer, a 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: 50-nanosecond duration for electrical fast transients (EFT, or high voltage noise), up to <100 milliseconds for a generator load dump and when a fully-loaded vehicle generator has its load abruptly disconnected. Static electricity is produced when two dissimilar materials are rubbed together. Good examples include the soles of your shoes and the floor, or normal body movements while sitting in a chair. On dry days, static charges increase because dry materials become good insulators. Typical values of voltage buildup can range from 7 kV to 12 kV. 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 direct hits 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, can be picked up by conductive material in close proximity to a discharge channel of lightning—or ESD, and also from nearby wiring carrying hefty transients of any origin.

Power lines are prime targets for direct lightning hits. Although the power company provides surge suppression to protect transformers, even up to 10 kV of lightning can still get through to the service entry of a building. The transients produced can also affect any other load in close proximity to inductive loads being switched. 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 handheld metal tool.

Systems that are interconnected with long wires such as telephones, oil fields, automated factory instrumentation, and distributed computer systems are primary collectors of radiated lightning energy. Close-proximity strikes can induce voltages of 300 V 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 PC was affected when a 7 kV spark hit a metal desk at a distance of four feet.

Effects on Microchips

Failure of silicon-based electronic equipment manifests in several modes, but can be generally classified in one of the three following categories: hard failure, upset, or latent.

Hard failures are those sustaining permanent damage and must be replaced to restore normal circuit operation. If some components are shorted, they may become part of the driving current path and be vaporized. Failures resulting from latch-up often char the component and a small part of the underlying circuit board. On the other hand, ESD-related component failures produce exceedingly small failure sites, down to the micron range. These can be very difficult to diagnose without sophisticated equipments.

Upsets are temporary malfunctions that may automatically reset or require a 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 neither failed nor degraded significantly. These become the “walking wounded,” and do not experience further transient stress fail at a later, unpredictable time. Some fail within hours, while others may perform for several years. These long term latent failures may be too often blamed on poor quality, when the real culprit is latent failure syndrome.

Failure Levels

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

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

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 a later time. Adequate protection at signal-line entry points can ward off commonly encountered threats.

Summary

Lightning, load switching, and ESD are sources of transient voltages that 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.

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