# Noise Effects

## 1 Introduction

This short treatise discusses how AC EXTEST technology may be affected by noise sources. These sources are categorized as “single-ended” and “common mode” sources. A single-ended source will affect single-ended signals, or half of a differential pair of signals. A common mode source will affect both signals of a differential pair equally. Figure 1shows two symbols used here to depict noise sources. Noise sources are zero-impedance voltage sources that produce voltage pulses in either polarity of a specified amplitude and frequency. In this document, the frequency will be either “low” meaning with a period longer than the time constant of the coupling circuitry present, or “high” meaning with a period shorter than the coupling time constant (if any).

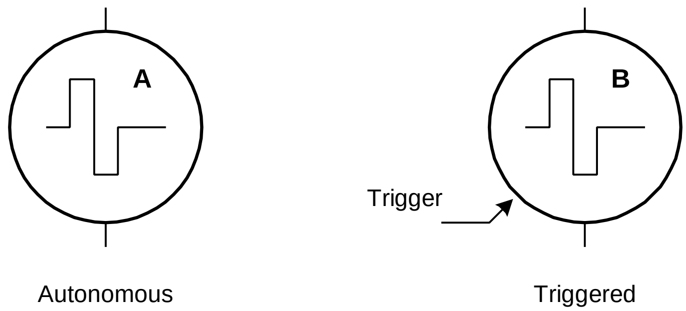


**Figure 1: Noise source symbols.**

An autonomous source produces noise pulses repetitively via some internal “program” that may be periodic or random. Such sources will be called periodic or random. A triggered noise source will produce some form of pulse train determined by an internal program which starts synchronously with a trigger event. Multiple triggered sources can be started synchronously with a common trigger event. The two sources shown are labeled A and B. Sources with the same label behave identically.

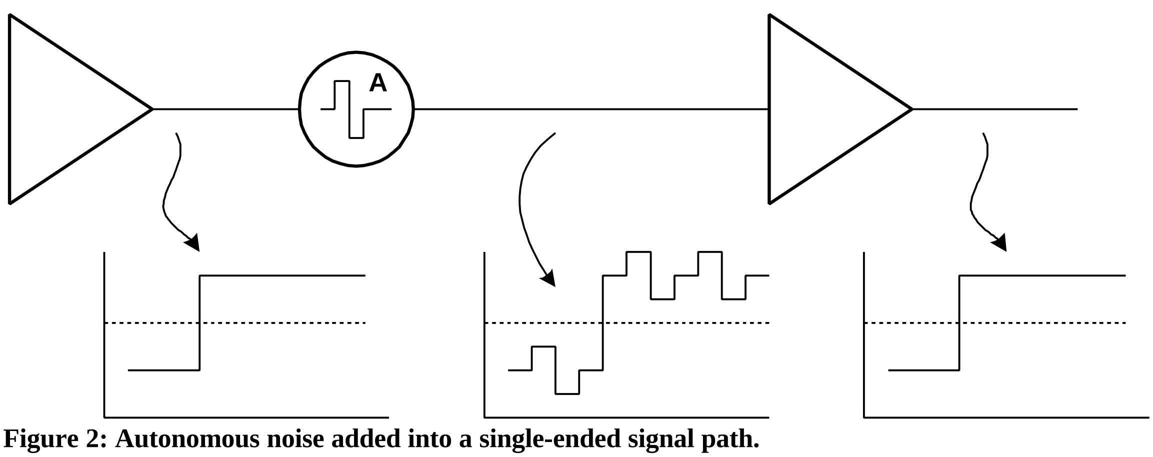


**Figure 2: Autonomous noise added into a single-ended signal path.**

A single-ended noise source adds noise to a single-ended signal signal path, or ½ of a differential pair. Figure 2 shows a single-ended signal path with an autonomous noise source of ¼ the amplitude of the signal inserted. The driver transmits its signal and the receiver sees the signal with added noise. In this case the noise does not cross the receiver’s threshold for determining the data signal, so the noise has no effect.

However, if the noise amplitude is higher, than the result in Figure 3 can occur, where the data has been destroyed by the noise.

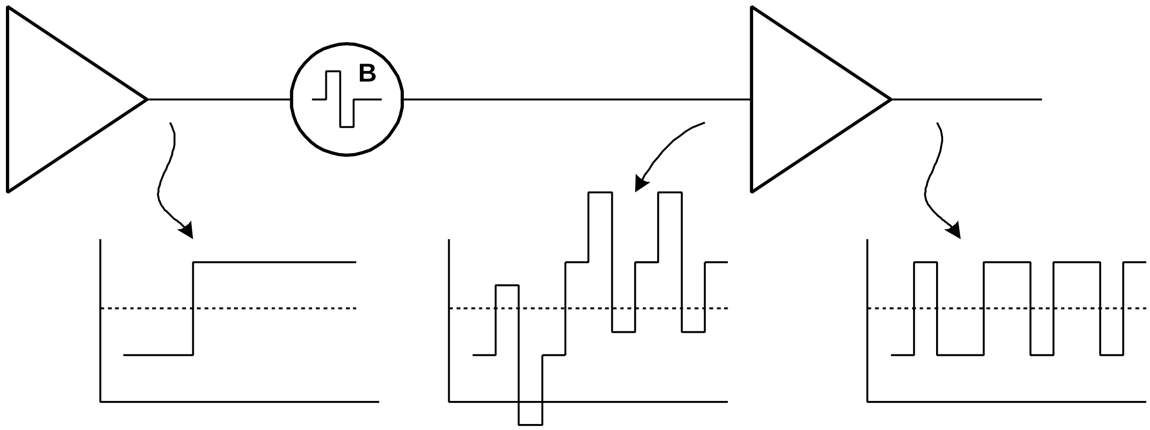


**Figure 3: Single-ended noise with enough amplitude to affect the received signal.**

In differential signaling, noise is often common mode coupled meaning it affects both legs of a differential pair equally, as shown in Figure 4. Here a large-amplitude noise burst is added into each leg of the pair. The differential receiver subtracts the two signals canceling the common mode noise. The receiver output is noise free. The fact that the noise caused the signal on an individual leg to cross the common mode threshold is immaterial.

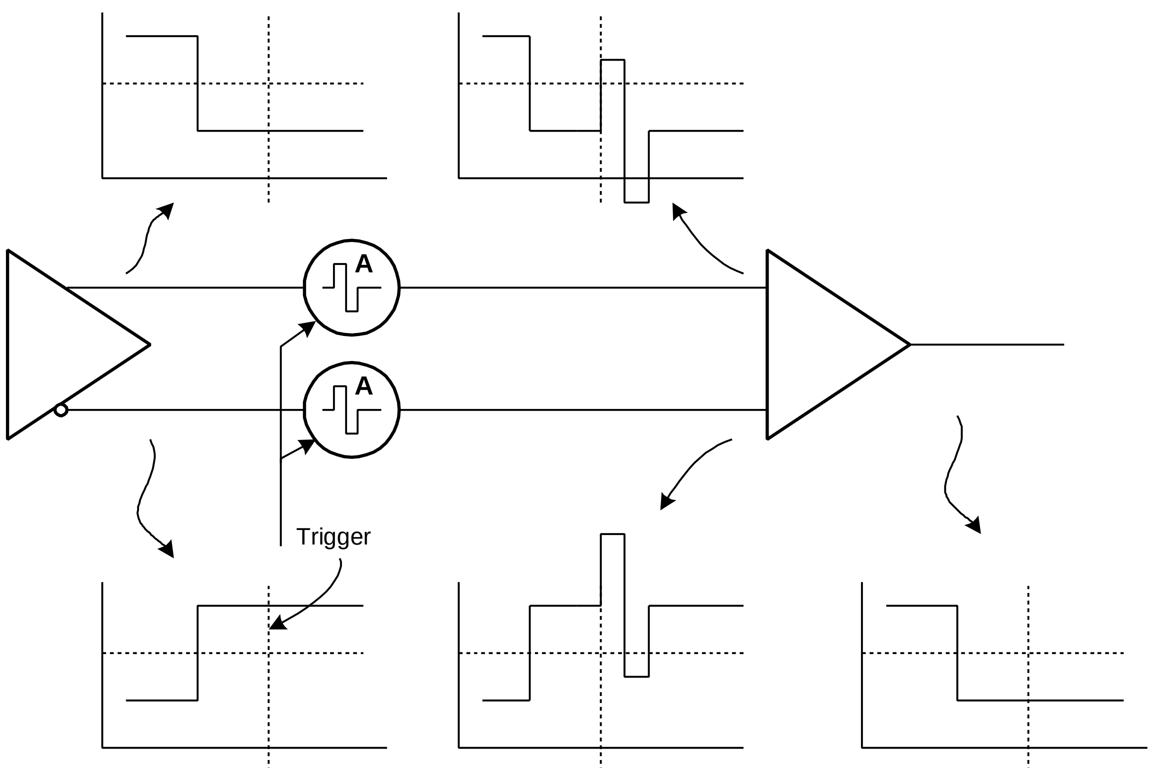


**Figure 4: Differential signals with a common mode noise burst added.**

# 2 Noise Sources

There are numerous sources of noise that may be encountered during test.

## 2.1 Power Distribution

The power distribution network may be a source of either conducted or radiated noise. This is particularly true in high-power consuming boards and boards where a number of slightly different power supplies are required. In either case, power may be distributed in a two-tiered system. A primary power source may provide a single (probably elevated) voltage. This keeps the amperage delivered to the board relatively low. Then on board, the second tier generates, via DC-DC conversion, lower supply voltages as needed in various localities. Because modern silicon processes are proliferating the number of Vdd supplies needed on a board, and because newer ICs may have large current requirements, we could in the limit see a converter near every major IC. Each of these will create some amount of constant (but uncorrelated) switching noise and they will also be reacting to load changes as a function of board activity.

It is possible that board activity that occurs during testing may not have been thoroughly anticipated and thus could stress the ability of these converters to react to load changes. This could lead to variations in converter output rather than the desired static output. Another effect could be Ground-Bounce. In either case the amount of local energy storage (bypassing) should cause these variations to be lower in frequency.

## 2.2 Ground-Bounce

Ground-bounce occurs when the ground reference in one point of a circuit moves relative to the ground reference in another point. This implies some impedance between the two “ground” points such that when there is a current flow between the two points a voltage is generated.

The “bounce” part of the name implies a transient response. The response could be due to non-reactive or reactive impedances. In the non-reactive case, the ground-bounce will reflect a step-function change to a change in current flow. In the reactive (usually inductive) case, the bounce will be related to di/dt and will then decay to zero. These effects will often be observed in combination.

A common place for ground-bounce to occur is between a board ground and the ground point on a die inside an IC package (see Figure 5). There may be a significant resistive voltage drop between them and significant inductance, particularly when loads can switch in subnanosecond time frames. The effect is to add a noise source to the die’s ground lead which then appears equally on all of the outputs, relative to board ground. The inputs will also see this noise added to the voltages appearing equally on them.

Ground-bounce is also a symptom of poor power/ground distribution on a board. Ideally, power distribution is done by nearly intact power planes. Any signals that pass over these planes have mirrored power return signals. Significant breaks in these planes (with signals traveling over these breaks) add impedance to the return paths, leading to ground-bounce opportunities.

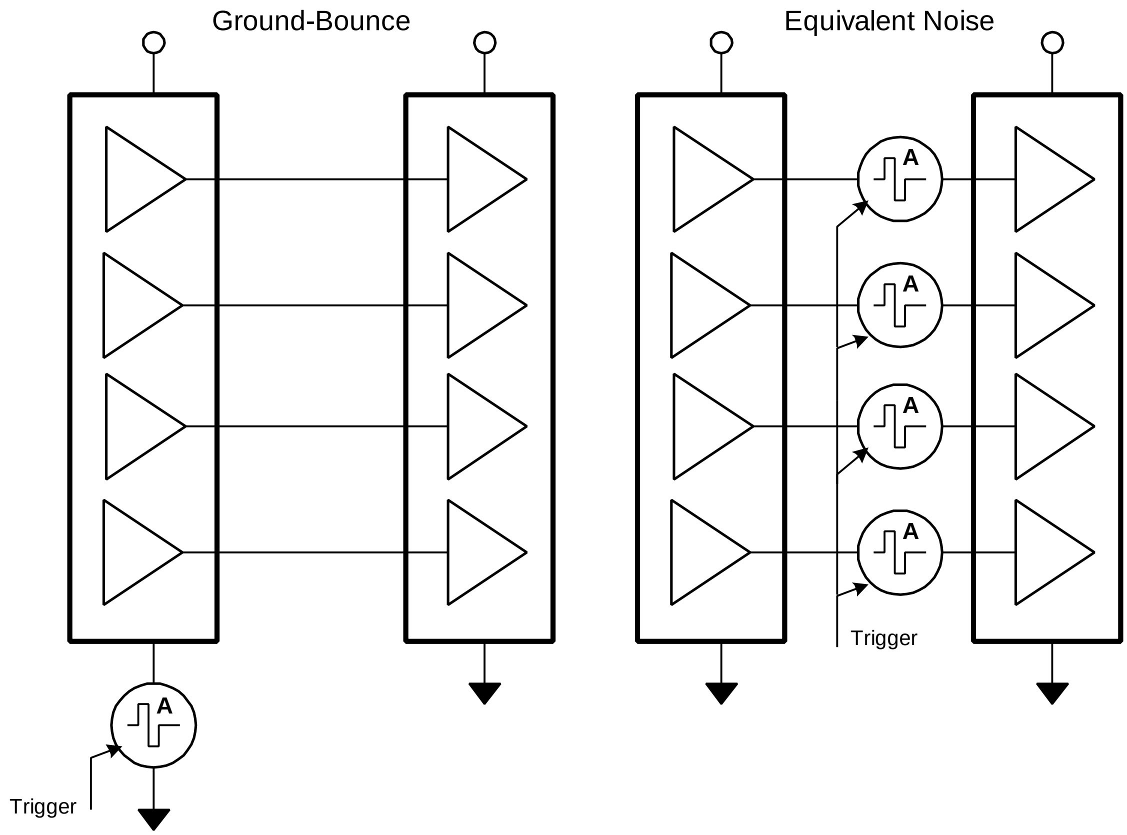


**Figure 5: Intrapackage ground-bounce and its common mode effect on transmitted signals.**

## 2.3 Signal Switching

When a signal switches states, it may generate a noise impulse. This is particularly true when the signal driver is working into a heavier load. The effect of the state change may show up in the power and ground distribution paths of an IC. For example, if an IC has a number of single-ended drivers that change state in the same direction at the same time, the summed power delivered to the loads all comes from the power leads. This can lead to ground bounce. However, differential drivers have little net change in total power when they change state. (In effect they switch power from one leg to the other.) Thus differential switching will generate little or no ground-bounce in the power distribution paths.

In a Boundary-Scan test, large numbers of outputs may change state in synchrony across a board. This is because, at the falling edge of TCK in the Update-DR (or Update-IR) state, drivers in many IC (all performing EXTEST) can change state. In the worst case, they are all single-ended drivers, driving significant loads, and all changing in the same direction. This can lead to ground bounce and transient stress on power converters.

## 2.4 Rogue Signals

"Rogue" signals are those that are not controllable during testing. These signals may or may not react to the signal activity seen during testing, which to these signals, is likely to be unnatural activity.

A rogue signal may cause trouble when it generates signal noise during a test. This can be autonomous noise (for example, a free-running oscillator) or it may be triggered by testing events at some point(s) in the test. The signal noise can add to simultaneous switching, and/or may contribute to ground-bounce. In some cases the signal may (unnaturally) participate in driver conflicts which may lead to abnormally high current flow, exacerbating switching noise and ground-bounce.

A cross between triggered and autonomous noise from rogue signals occurs when a complex event such as downloading data from a EEPROM occurs in response to a trigger. This event may be self-clocking and last a long time, looking like a free-running oscillator.

## 2.5 Crosstalk

Crosstalk can couple a time-varying signal between signal paths, as shown in Figure 6. In this example, single-ended noise is injected into a differential pathway. Crosstalk is a strong function of signal slew rates, signal trace geometry and the proximity of their layout.

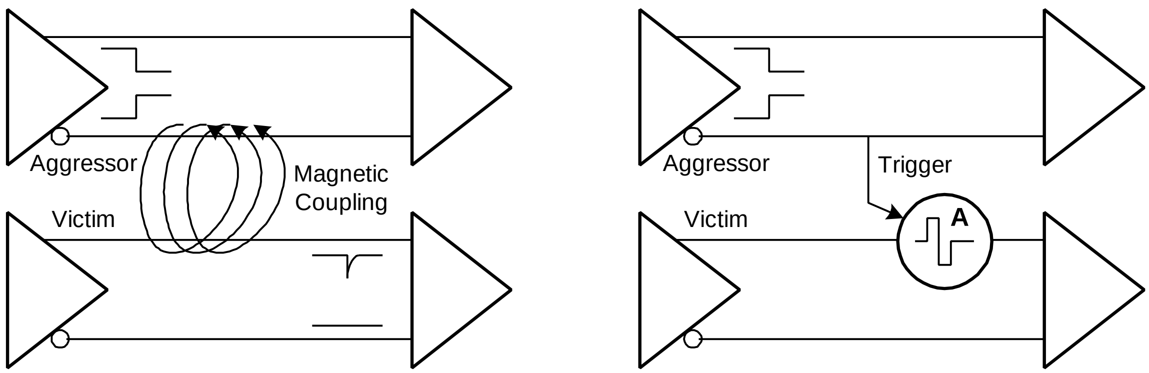


**Figure 6: Magnetic coupling can couple noise from an 'aggressor' signal into a 'victim' signal.**

## 2.6 EMI

Electro-magnetic interference (EMI) is conducted or radiated interference from an aggressor to a victim signal. Conducted implies it comes through signal or power distribution paths. Radiated means it is conducted through the atmosphere. Conducted EMI may be the aggregate name given to the other phenomena already listed. Radiated EMI implies that the victim line has become an “antenna” for the aggressor signal. High impedance inputs to circuits are candidates for radiated EMI. On boards, these are often unterminated IC inputs; they may be unterminated due to the partitioning that placed those ICs on a board without their associated drivers or terminations.

Victim signal inputs may then process the noise signals, leading to switching activity and related power consumption, and the potential for rogue signal activity.

## 2.7 Transmission Line Effects

Higher-speed signal paths are typically implemented with transmission lines to preserve signal quality. These lines are terminated to prevent signals (or inverted versions) from being reflected back and forth along a path. However a board, containing a partition of a circuit, may contain unterminated or other non-ideal structures. This will have the effect of adding noise (delayed, possibly inverted, and attenuated copies of the original signal) to the path.

A second cause of reflections may be the very defects we are trying to detect. For example (see Figure 7) a short at the negative leg of a differential driver may cause a reflection seen at the positive input of the differential receiver. Depending on the size of the reflection, it may affect the outcome of the test.

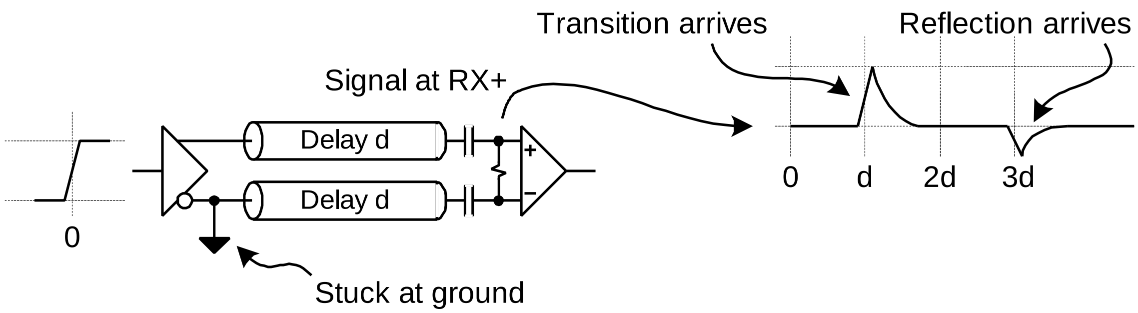


**Figure 7: A defect that causes a signal reflection.**

## 2.8 ATE Interfaces

Large production ATE board testers (known as 'bed-of-nails' testers) must be applied carefully to avoid noise sources. The principle noise source is ground-bounce. Figure 8 shows an example of an board sitting on a bed-of-nails and how the ATE ground system is not the same as the board ground do to fixture impedances.

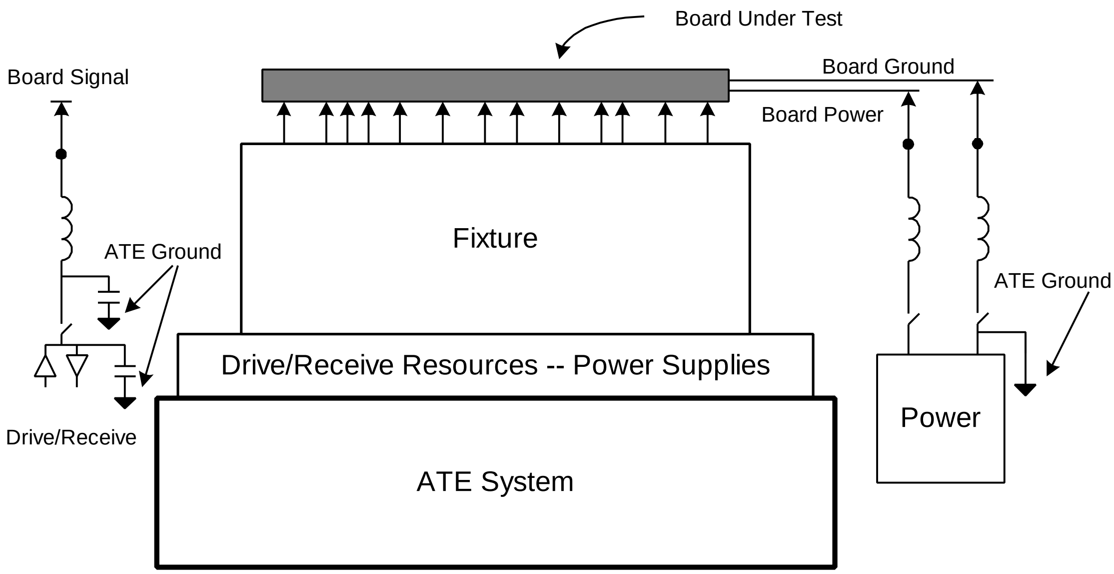


**Figure 8: An ATE system, fixture and board. The equivalent circuitry for signal and power paths is shown.**

There are two problems. First, the testers drive/receive electronics (even when the connection relay is open) present a significant load to board signals. This will cause drivers on the board to switch more current which adds to switching noise and power supply demand. This can cause board and IC-level ground-bounce. Then when many drivers on the board switch synchronously, the can lead to ground-bounce between the board ground and ATE system ground. This can cause Boundary-Scan tests to fail due to extra pulses being seen on TCK on the board, usually following the falling edge of TCK in the Update-DR state. Again, care must be taken when interfacing large ATE systems to boards.