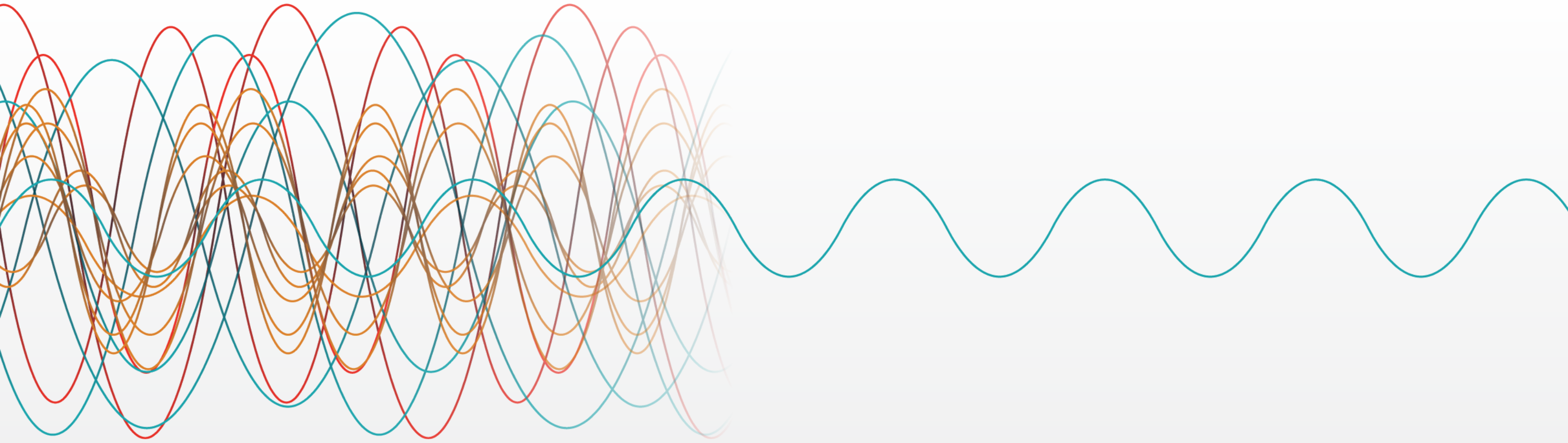
A Practical Approach to Understanding External Noise

Methods to identify and mitigate external noise



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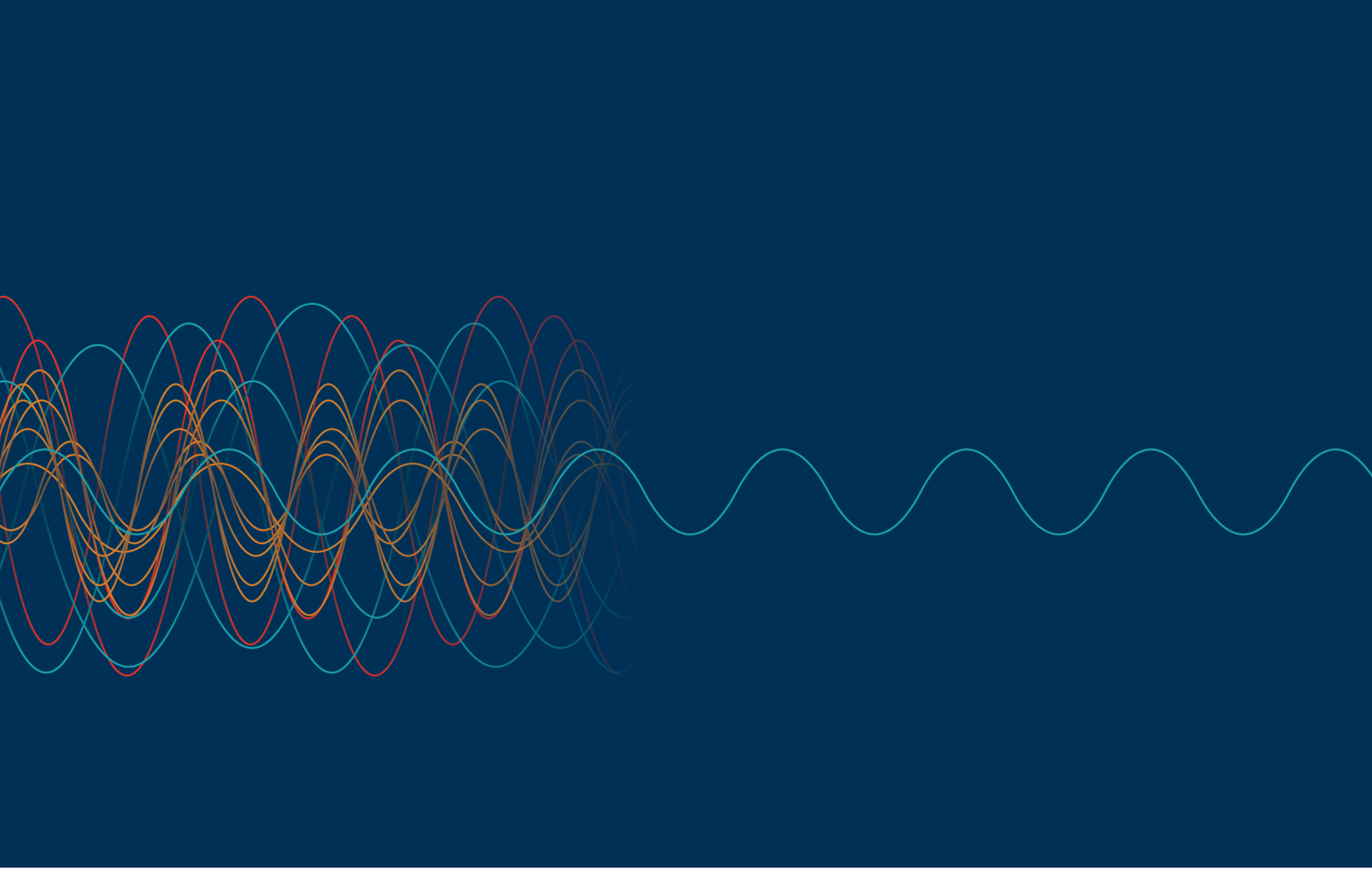


Why learn about external noise?

External noise, also known as interference, introduces error into instrument setups. For numerous research and industrial applications, high measurement precision is required. However, the complex function of external noise often makes it difficult to understand and mitigate. A practical approach to understanding the function of external noise ensures the best practice for noise mitigation, enabling the lowest possible noise levels for an instrument.

Learn to take measurements
without the noise

What is noise?

Noise is the total unwanted electromagnetic signal that can affect a measurement. It is continuous, random, and present everywhere at all times; it can never be completely removed. Typically, noise is observed as voltage or current, represented with the units V/√Hz or A/√Hz. Noise can be categorized into two main types: intrinsic and external.

Intrinsic noise

Intrinsic noise is noise inherent within any material, device, instrument, or particle. This includes the device under test (DUT). Generally, intrinsic noise describes a physical phenomena and is categorized into different types based on the behavior and origin of that phenomena.

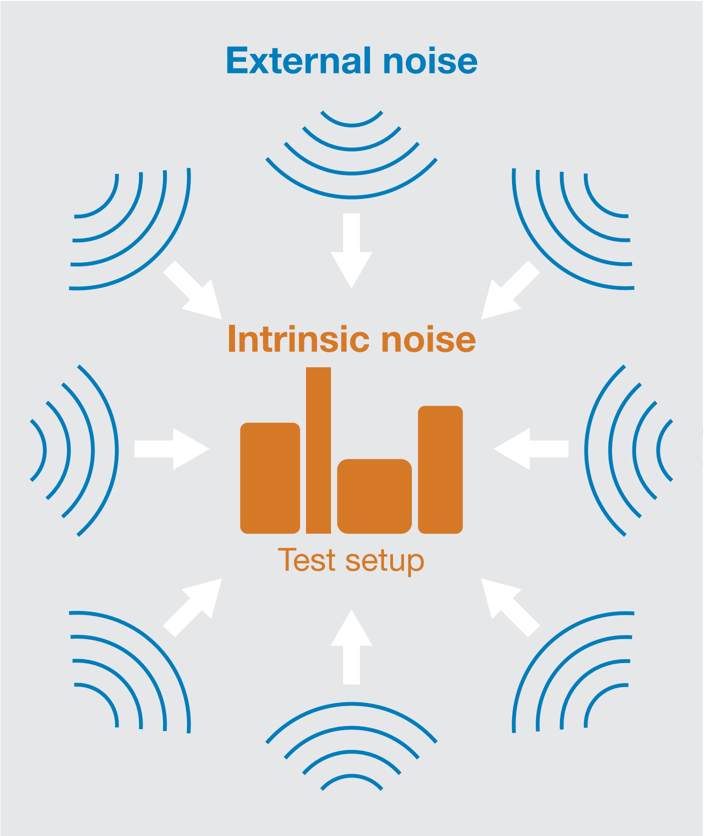
In the context of an experiment, intrinsic noise refers to the noise always present within the components of a test setup, including measurement instruments, cables, wires, and the DUT. Theoretically and in practice, intrinsic noise is unavoidable, but it can be significantly reduced by optimizing the setup. This includes using well-designed instruments, cables, wires, and fixturing.

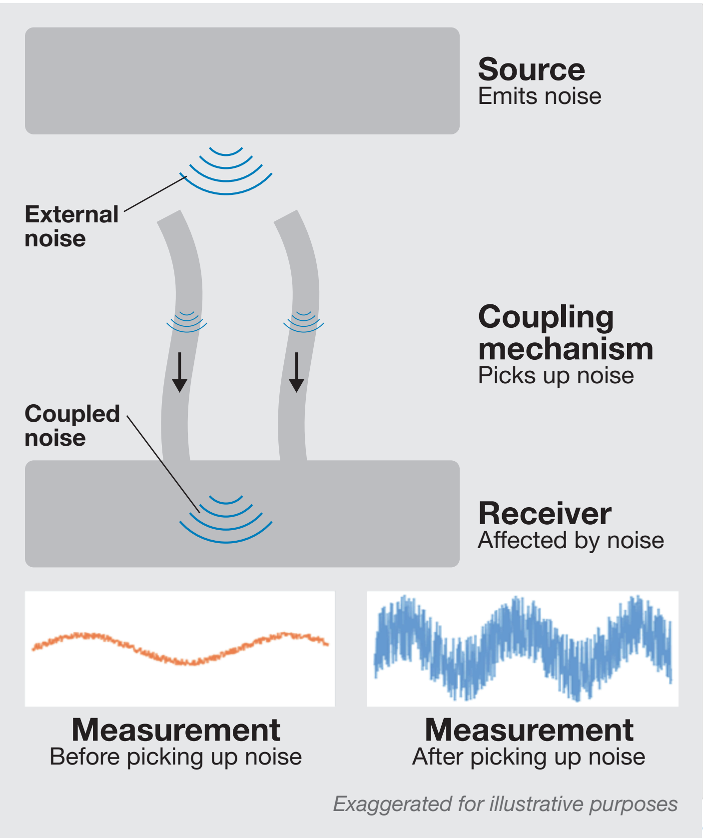
External noise

External noise is noise that comes from sources outside of a test setup. In order for external noise to manifest, there must be a source, receiver, and coupling mechanism. The source is the cause of the noise, the receiver is what is affected by the noise, and the coupling mechanism is what picks up the noise from the source and allows it to affect the receiver.

When external noise is coupled into a receiver, the measurement will be affected. In the context of an experiment, the receiver is the test instrument, and the coupling mechanism is often the wires, cables, or fixturing. The effect on the measurement generally occurs as an experimental error or measurement uncertainty error.

External noise is theoretically fully preventable; however, in practice it cannot be fully prevented from coupling into a setup. When external noise has coupled into a setup, it is referred to as **coupled noise**. Steps can be taken to help minimize the influence of coupled noise through mitigation strategies that reduce the amount of external noise that couples into a system.





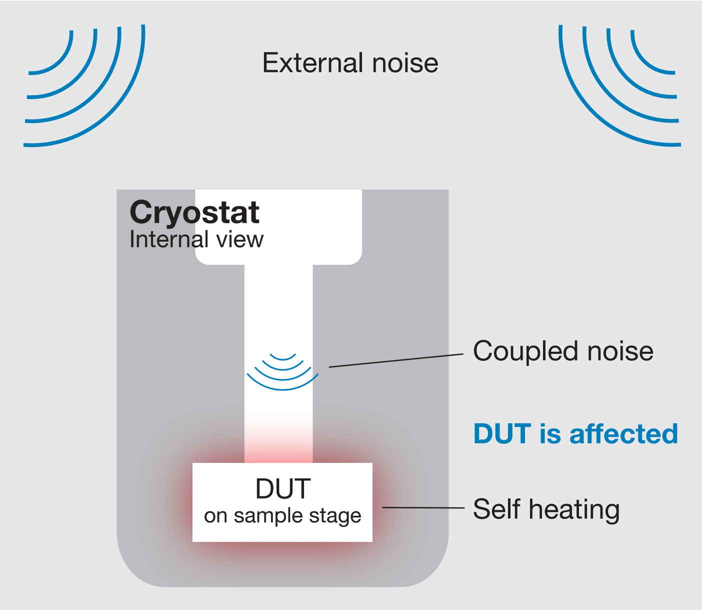
Exaggerated for illustrative purposes

Impact on measurements

The receiver is the component(s) of the test setup that is affected by the noise. When external noise is coupled into a receiver, it also impacts the measurement. The coupled noise can cause two types of errors to occur: experimental error and measurement uncertainty error. Both errors can occur simultaneously within an experiment.

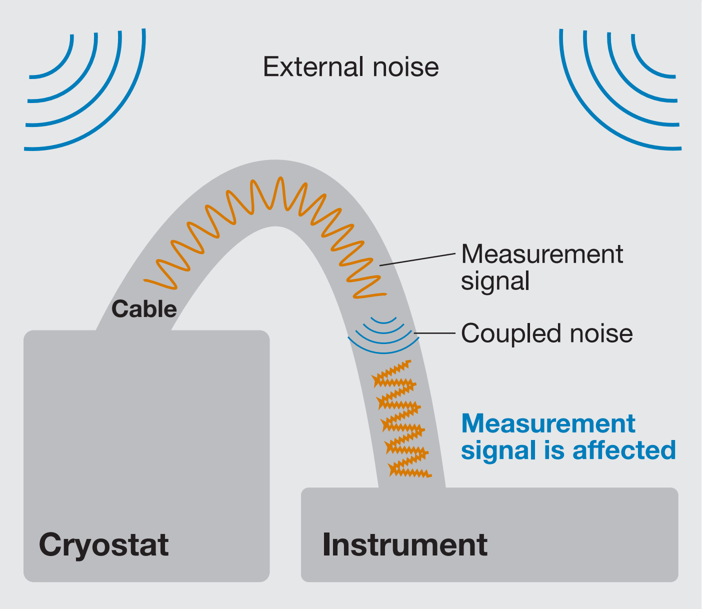
Experimental error

In an experimental error, external noise causes an error to occur in the experiment itself, causing inaccurate test values to be produced. For example, noisy lab equipment, such as chillers and coolers, produces noise that can couple with the wiring connected to a sample in a cryostat. This coupled noise can cause sample self-heating within the test chamber. The values produced from the experiment could change as a result of this self-heating. This scenario typically applies to experiments with delicate samples in ultra-low power—millikelvin range—environments.

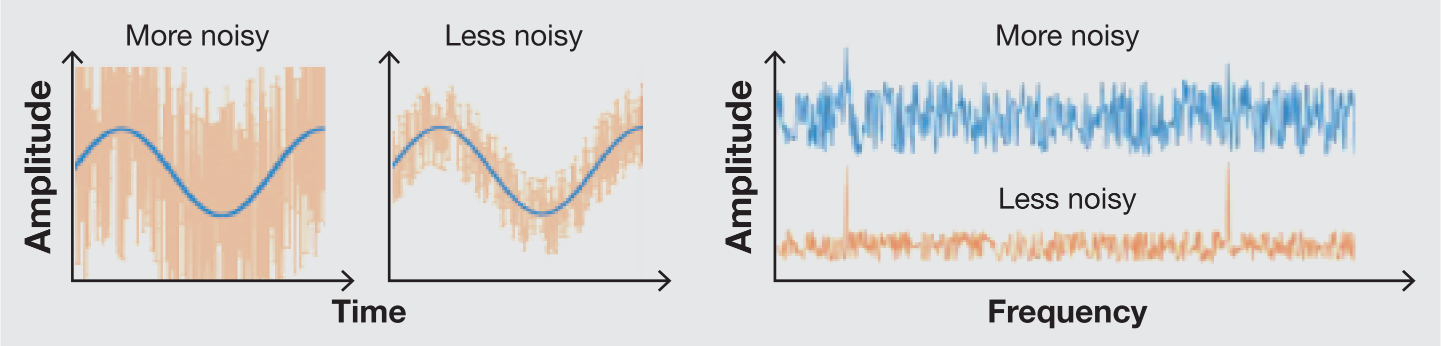


Measurement uncertainty error

More often, a measurement uncertainty error occurs, which describes how external noise increases the uncertainty of a measurement. Continuing the example above, when noise from lab equipment interferes with measurement signals, the values produced from the experiment are not altered, but the ability to measure it with a certain degree of accuracy becomes more difficult. In this scenario, external noise interferes with the measurement signal, causing the reading to be less certain. In a statistical representation, the standard deviation of the measurement would increase. Uncertainty is further explained in the graphic below.



Uncertainty is the margin of values of a measurement. A common representation of a measured signal is a graph of amplitude over time and amplitude over frequency. In amplitude over time, the blue line represents the theoretical signal in an ideal world with no noise. The orange oscillations represent what would be seen in reality. In an amplitude over frequency graph, the peak at which the measured signal appears becomes less prominent when more noise is present. In both cases, more noise makes it more difficult to discern where the measured signal would appear on the graph.



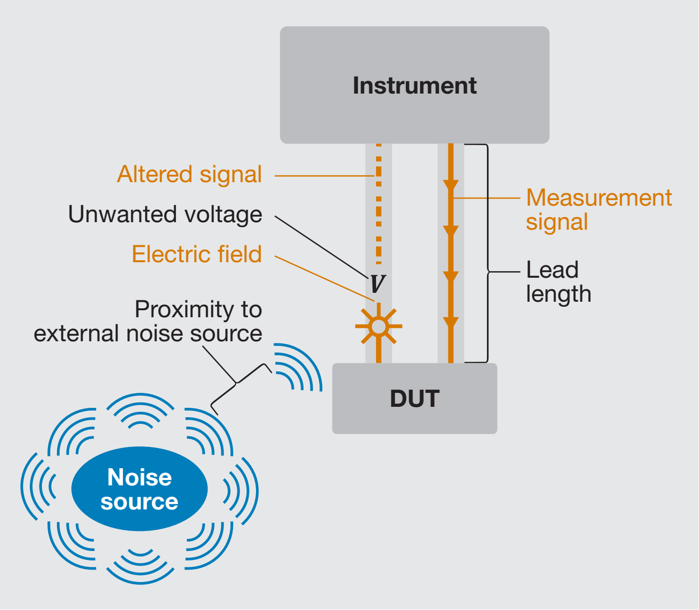
Common types of coupling

The coupling mechanism is the component that serves as a pathway for noise to travel from the source to the receiver. It is typically wires, cables, or fixturing but can vary case by case. The method of how noise enters the coupling mechanism is the coupling type. In a lab setting, the most common types of coupling are capacitive coupling (electrostatic), inductive coupling (electromagnetic), and radiated coupling. Other types of coupling occur less often in a lab environment.

Capacitive coupling

Capacitive coupling occurs when external noise interferes with the voltage being transmitted within a coupling mechanism. The disruption to the voltage generates an electric field, altering the measurement signal. Typically, the coupling mechanism is the signal leads connecting the DUT to the instrument. The DUT itself is also highly susceptible to capacitive coupling.

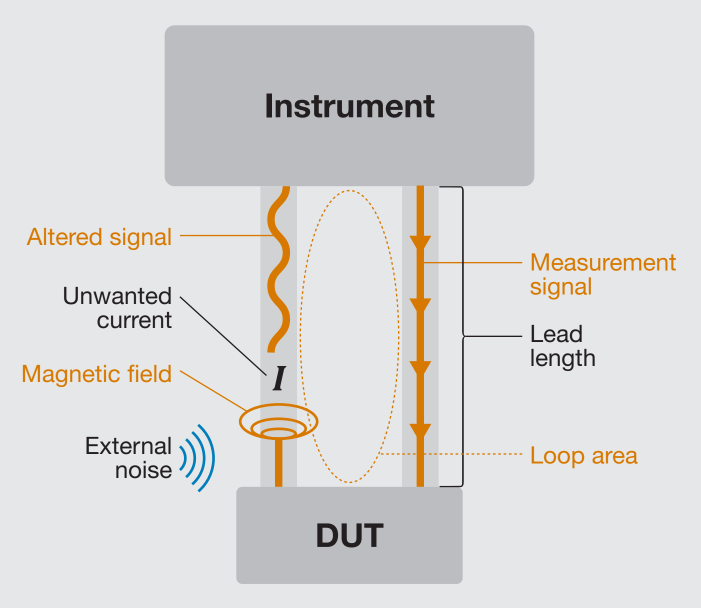
Components in a setup with higher impedances, greater than 1 MΩ, are generally more susceptible to capacitive coupling. The amount of coupling that occurs is affected by the voltage change of the instrument (receiver), the length of the lead—when it is the coupling mechanism—between the DUT and instrument, and the distance in the air between the leads and the noise source.



Inductive coupling

Inductive coupling occurs when external noise interferes with the current being transmitted within a coupling mechanism. The disruption to the current creates a fluctuating magnetic field, altering the measurement signal. Typically, the coupling mechanism is the leads in a setup connecting the DUT to the instrument.

Components in a setup with lower impedances, less than 1 MΩ, are generally more susceptible to inductive coupling. The amount of coupling that occurs is affected by the field change from the external noise source and the size of the current loop (area of the measurement circuit).



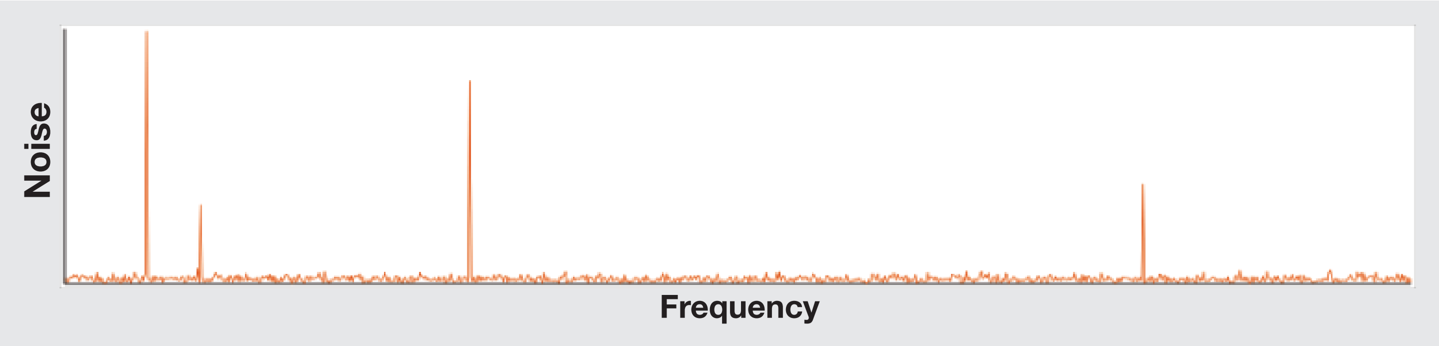
Radiated coupling

In most scenarios, capacitive and inductive coupling occur simultaneously. This is referred to as radiated coupling. When a single noise source emits a signal, it most often causes both capacitive and inductive coupling at the same time. Some noise sources cause only capacitive or inductive coupling, but if sources that emit both types are close to a test setup, radiated coupling will still occur.

Major external noise sources

The source is what releases noise into an environment. Described at right are five common sources of external noise. These can be identified by observing the behavior displayed by taking an FFT. An FFT, or fast Fourier transform, is an algorithm that computes and graphs complex data. When applied to a test setup, an FFT plot shows the noise levels at varying frequencies.

Power lines	**The most common perpetrator of noise** Frequency range: 50 Hz to 60 Hz Identify: likely when FFT contains multiples of 50 Hz or 60 Hz
RF and AM radio stations	Frequency range: 100 kHz to 300 kHz Identify: likely when FFT contains spikes in the 100 kHz to 300 kHz range; DC bias would be higher than expected
Wi-Fi signals and cell phones	Frequency range: 800 MHz to 5 GHz Identify: likely when FFT contains major spikes in the 800 MHz to 5 GHz range
LED or fluorescent screens and lights	Frequency range: 100 kHz to 300 kHz Identify: likely when FFT contains spikes in the 100 kHz to 300 kHz range; troubleshoot by turning lights off
Switching power supplies	Frequency range: 100 kHz to 500 kHz Identify: likely when FFT contains spikes in the 100 kHz to 500 kHz range



Mitigation scope

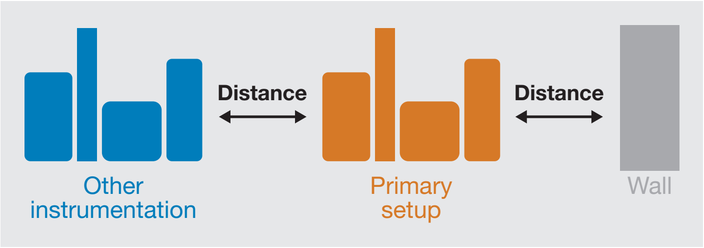
Keep in mind that both intrinsic and coupled noise can never be fully removed from a measurement. Even the most detailed and expensive mitigation strategies and test setup will allow noise to penetrate. Additionally, it is often difficult to identify the primary receiver(s), coupling mechanism(s), and source(s) contributing to coupled noise, as well as the type(s) of error that results from it. In most scenarios, multiple noise sources will impact a test setup. For the most practical and effective solution, it is recommended to implement mitigation strategies that prioritize preventing external noise from coupling into a system. When multiple are used together, these strategies protect receivers highly susceptible to noise and reduce the effect of all coupling mechanisms and sources described previously.

The significance of noise also varies based on the temperature range of the application. In low power environments, small amounts of noise can be significant, requiring more extensive mitigation strategies. In high power environments, more noise may be tolerated due to the higher relative signal strength, sometimes requiring less extensive mitigation strategies. Be aware of an experiment's significant figures to determine the optimal scope of noise mitigation strategies to implement.

Mitigation strategies

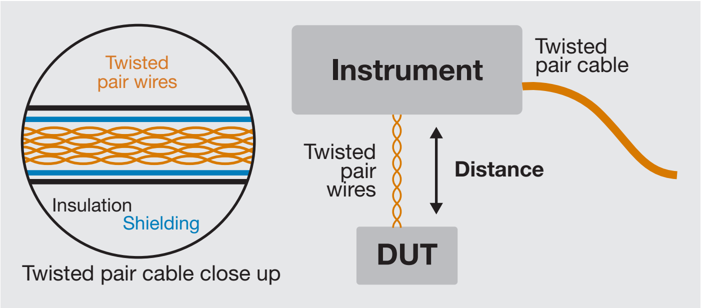
Isolate the setup

- Increase distance of primary setup from other instrumentation
- Increase distance of primary setup from walls to mitigate power line coupling



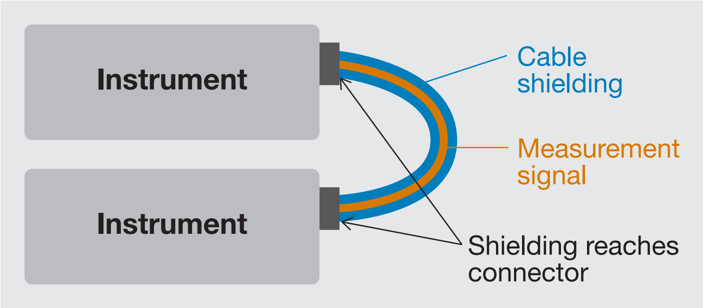
Decrease the loop area

- Use shortest possible cables
- Use twisted pairs for all wires and cables



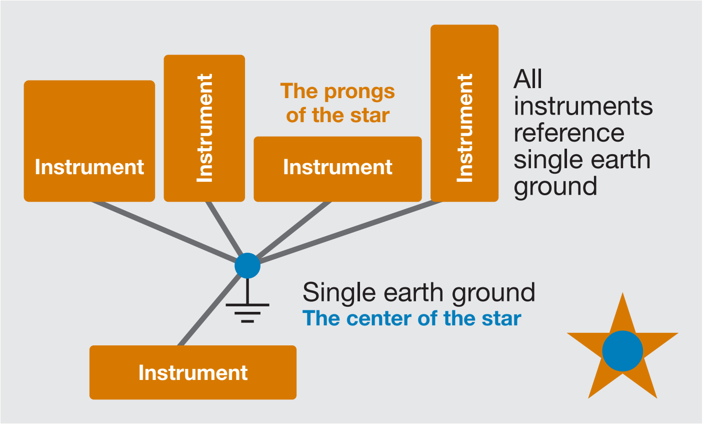
Shielding

For best practice, use instruments with built-in shielding. Used individually, these instruments do not require any additional mitigation. However, when multiple instruments are used together or combined with a system, noise can often penetrate the leads, wires, and cables connecting each instrument. Ensure that shielding completely covers all wires and cables, surrounding any area with low-level signals, and is brought all the way to the sensitive connectors. For example, the cable shielding should touch both triaxial or BNC connectors between two instruments.



Grounding

Always reference the instrument manual for grounding suggestions. Generally, star grounding to earth ground is the most reliable solution for low noise requirements but can be difficult to implement with certain setups. When star grounding is unfeasible, minimize the number of earth grounds installed to reduce the size of the ground loop. Star grounding is the only method to prevent ground loops. **Never remove a safety ground.**



Filtering and lock-in amplifiers

Filters are practical and well suited for most applications but can alter data if not applied properly. **Hardware filters** typically function as high-pass or low-pass filters and can come pre-installed in an instrument or connected by the user later. Hardware filters are ideal when the external noise affecting a setup occurs at a different frequency than the signal of interest. **Software filters** may come pre-installed in an instrument and can be adjusted by the user to optimize measurements for a specific application. Reference the instrument manual for best practice suggestions. **Lock-in amplifiers** may also come pre-installed in an instrument. When using a lock-in, avoid setting the reference frequency as a multiple of any common noise source, particularly power line frequencies (50 or 60 Hz).

Take measurements without the noise

The MeasureReady™ M81-SSM (Synchronous Source and Measure) system provides a confident and straightforward approach for advanced measurement applications. It eliminates the complexity of multiple function-specific instrumentation setups, combining the convenience of DC and AC sourcing with DC and AC measurement, including a lock-in's sensitivity and measurement performance.

This ultra-low noise synchronous source and measure system ensures inherently synchronized measurements from 1 to 3 source channels and from 1 to 3 measure channels per half-rack instrument—while also being highly adaptable for a range of material and device research applications.

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