Apply optimal measurement conditions with Eynocs Analyzers

Complete Guide

Rev. 1.05

Eynocs GmbH · Hauptstr.12 · 56412 Daubach · Tel.: +49 2602 6866460 · www.eynocs.de · mail@eynocs.de

Contents

1 Introduction

Simply connecting the power and communication cables, verifying that the instrument is properly detected, and then clicking "Start Measurement" may be enough to obtain measurement results. However, obtaining reliable and optimal results requires more than simply operating the instrument. It is important to be well prepared and to have a thorough understanding of the instrument, its operating principles, and its measurement capabilities.

Proper preparation helps ensure that the instrument is configured correctly and that the measurement conditions are appropriate. This includes checking all power and communication connections, confirming that the instrument is recognized by the measurement system, selecting the appropriate measurement settings, and verifying that the instrument is operating within its specified limits.

A good understanding of the instrument also helps the user recognize potential sources of measurement error and avoid incorrect or unreliable results. By becoming familiar with the instrument's specifications, limitations, measurement range, accuracy, and recommended operating conditions, measurements can be performed more efficiently and with greater confidence.

Therefore, although starting a measurement may require only a few simple steps, achieving the best possible results requires adequate preparation, proper configuration, and a good understanding of the instrument. This allows the instrument to be used effectively while ensuring that measurements remain within its specified capabilities and limitations.

2 Verifying the Analyzer

The first and most important step before starting any measurements is to make sure that the analyzer itself is functioning correctly. This initial verification may take some time and, at first glance, may seem like an unnecessary step because it does not directly bring us closer to obtaining measurement results. Nevertheless, it is an essential part of the measurement process.

Before connecting the analyzer to materials or samples, it is important to verify that the instrument is operating as expected and is ready to perform measurements. This includes checking the general condition of the analyzer, ensuring that all required components and connections are properly installed, and confirming that the instrument starts up without errors or warnings.

Spending time on this initial verification can prevent much larger problems later. If the analyzer is not functioning correctly, measurement results may be inaccurate, inconsistent, or difficult to reproduce. In the worst case, measurements may be performed on valuable samples without realizing that the instrument was not operating within its specified conditions.

Therefore, this first step should not be considered a delay or an unnecessary additional task. Rather, it establishes the foundation for all subsequent measurements. Only when the analyzer has been confirmed to be functioning correctly and is in a suitable operating condition should the measurement of materials and samples begin.

A reliable measurement starts with a reliable instrument. Taking the time to verify the analyzer at the beginning helps ensure that the results obtained later can be trusted and interpreted with confidence.

2.1 Warm-Up

After switching on the analyzer, the instrument should be given sufficient time to warm up before measurements are started. Although the analyzer may appear to be ready shortly after power-up, its internal components and measurement systems may require additional time to reach a stable operating condition.

The warm-up period is important because many measurement systems are sensitive to changes in temperature, electrical conditions, and other environmental factors. Immediately after startup, internal components may still be reaching their normal operating temperature. During this period, the instrument's response can change gradually, which may lead to measurement drift or reduced repeatability.

During the warm-up period, it is also useful to check whether the analyzer reports any warnings, error messages, or abnormal behavior. Communication with the controlling software should be confirmed, and the instrument should be allowed to complete any automatic initialization procedures.

It is important not to shorten or skip the warm-up period simply to start measurements more quickly. Doing so may save a few minutes at the beginning but can result in unstable measurements, additional repetitions, or unreliable data later. Allowing the analyzer to reach a stable operating condition provides a better basis for accurate and reproducible measurements.

For Eynocs analyzers and interfaces, the recommended warm-up time is typically **30 minutes**. This period allows the instrument and its internal components to reach a stable operating condition before measurements are performed.

During the warm-up period, it is recommended to simply allow the analyzer to stabilize. If measurements are necessary during this time, only **non-sensitive or preliminary measurements** should be performed. These measurements should not be considered final or used when high measurement accuracy is required, as the instrument may still be subject to thermal and measurement drift.

In particular, **calibration should not be started during the warm-up period**. Performing a calibration while the analyzer is still warming up can result in calibration values that no longer represent the instrument's stable operating condition. As the instrument continues to warm up, its characteristics may change, potentially reducing the accuracy and reliability of subsequent measurements.

Once the 30-minute warm-up period has been completed, measurements can normally be started. However, when a high level of accuracy and confidence in the measurement results is required, it is recommended to perform a complete calibration after the warm-up period.

Depending on the analyzer and measurement configuration, this calibration may include **Short, Load, Open, and Reference** measurements. After completing the calibration, the results should be checked against the appropriate calibration standards to confirm that the analyzer is performing as expected and that the calibration is valid.

Only after the calibration has been successfully completed and verified should the actual measurement of the material or sample be started.

The overall sequence can therefore be summarized as:

Power on → 30-minute warm-up → Calibration (if required) → Check calibration against standards → Start measurement

Following this sequence helps minimize measurement drift, improves repeatability, and provides greater confidence that the obtained results reflect the actual properties of the material or sample rather than changes in the analyzer itself.

2.2 Measurement Wire Configuration

Before performing any calibration, the **measurement wire configuration must be selected and verified**. If the analyzer and interface support more than two wires, calibration must always be performed using the **same 2-, 3-, or 4-wire measurement mode that will subsequently be used for the actual sample measurement**. In other words, a system calibrated in 2-wire mode must be used for measurements in 2-wire mode, while a system intended for 3-wire or 4-wire measurements must be calibrated in the corresponding 3-wire or 4-wire configuration. Switching the wire configuration after calibration can change the electrical measurement path and therefore invalidate the calibration for the new configuration. This is particularly important because 3- and 4-wire configurations use separate current and voltage connections to reduce the influence of cable impedance, contact resistance, and electrode-interface effects.

The appropriate configuration depends on the type of sample and measurement cell. **2-wire measurements** are the standard and simplest configuration and are appropriate for most conventional dielectric, conductivity, and impedance measurements where the sample is connected between two electrodes and electrode/contact effects are not dominant. In this configuration, the same two connections are used for applying the excitation and sensing the resulting electrical response. It is therefore particularly suitable for standard parallel-plate dielectric measurements and for sample cells designed specifically for two-electrode operation.

3-wire measurements can be useful when the measurement setup provides separate voltage sensing and requires improved control of the voltage measurement relative to the current path. **4-wire measurements** provide separate current and voltage connections and are particularly useful for low-impedance samples or samples where electrode contact impedance, cable impedance, or electrode polarization can significantly influence the result. In a 4-wire configuration, the outer connections carry the measurement current while separate voltage-sensing electrodes measure the voltage across the relevant portion of the sample. Because very little current flows through the voltage-sensing connections, the voltage measurement is less affected by the resistance or impedance of those connections.

The choice between 2-, 3-, and 4-wire operation should therefore be made **before calibration**, based on the sample, sample cell, electrode arrangement, and expected impedance range. For a conventional parallel-plate dielectric sample with good electrode contact and no significant electrode polarization, 2-wire operation is normally the most straightforward choice. For low-impedance materials, significant contact resistance, conductive or ionic samples, or measurements where electrode-interface effects are important, a 3- or 4-wire configuration may provide a more appropriate measurement method. The analyzer/interface must, of course, support the selected configuration. For example, Eynocs HZx interface and Lamda Analyzer support software-selectable 2-, 3-, and 4-wire configurations, whereas other interfaces are designed specifically for 2-wire measurements. Zeus supports hard non selectable 4-wire configuration.

The most important rule is: calibrate in exactly the same wire configuration in which the sample will be measured. The user should therefore check the selected wire mode in UniLab before starting **Short, Load, Open, and Reference calibration**. If the sample measurement will be performed in 4-wire mode, the calibration must be performed in 4-wire mode; if the sample measurement will be performed in 3-wire mode, the calibration must be performed in 3-wire mode; and if the sample measurement will be performed in 2-wire mode, the calibration must be performed in 2-wire mode. This applies to the complete calibration sequence, not only to the Short calibration. Changing from one wire configuration to another after calibration should be treated as a change of measurement configuration requiring the calibration procedure to be checked or repeated.

This requirement is especially important when using analyzers with multiple selectable wire configurations because the additional voltage-sensing connections in 3- and 4-wire operation change the measurement circuit. The calibration therefore needs to characterize the electrical behavior of the configuration that will actually be used. A calibration performed in one configuration cannot automatically be assumed to compensate the effects of another configuration.

Before continuing with the calibration procedures, verify the following:

- The required **2-, 3-, or 4-wire measurement mode** has been selected.
- The physical sample-cell wiring corresponds to the selected software configuration.
- All cables are connected to the correct analyzer/interface terminals.
- The calibration standards are connected using the same measurement configuration intended for the sample.
- **Short, Load, Open, and Reference calibrations are performed in the same wire configuration as the subsequent sample measurement.**
- The wire configuration is not changed between calibration and measurement without checking whether a new calibration is required.

Once the wire configuration has been confirmed and the analyzer has completed its required warm-up period, the calibration sequence can be started. This ensures that the calibration represents the actual electrical measurement configuration rather than a different connection mode.

2.3 Performing the Short Calibration

The **Short calibration** is used to characterize the analyzer's response when the measurement impedance is effectively **0 Ω**. During this calibration, the analyzer measures the impedance spectrum of a known calibration condition. This condition is created either by short-circuiting the electrodes of the sample cell or, for configurations without a sample cell, by using the dedicated **Short calibration standard** supplied with the system.

The purpose of this calibration is to determine the residual impedance and frequency-dependent behavior of the measurement system under short-circuit conditions. This provides the analyzer with a reference that can subsequently be used to compensate for effects originating from the measurement setup itself rather than from the material or sample being measured.

2.3.1 Starting the Short Calibration

The Short calibration can be started in **UniLab** by navigating to:

Measurement Setup → Preparation Phase → Analyzer → Analyzer Calibrations

In the Analyzer Calibrations section, locate the **Short calibration** and click the green **Start** button next to it. Once started, UniLab will initiate the calibration procedure and display a countdown while the analyzer performs the required measurements. The procedure should be allowed to run until the analyzer confirms that the calibration has been completed successfully.

It is important not to interrupt the calibration procedure while it is running. The calibration data should only be considered valid once the analyzer has reported that the procedure has been completed.

2.3.2 Verifying the Short Calibration

After the Short calibration has been completed, and the other required calibrations have also been performed, a **frequency sweep** can be carried out to verify the quality and effectiveness of the Short calibration. When checking the result in UniLab, the appropriate measurement parameter should first be selected. For this verification, select **|Impedance Z|**, with the unit displayed as **Ω (ohm)**. This allows the magnitude of the measured impedance to be observed over the complete frequency range and compared with the expected response of a correctly calibrated short.

Before starting this verification measurement, it is recommended to establish the short condition again rather than simply relying on the previous connection. For example, the Short calibration standard can be **removed and reinserted**, or the electrodes of the sample cell can be **opened and closed again** to recreate the short-circuit condition. This provides an additional check that the short connection is properly established and that the calibration result is reproducible.

A correctly calibrated short condition typically produces a very low impedance over the measured frequency range. The measured response will generally show its **highest impedance value at the maximum frequency**, with the impedance decreasing as the frequency is reduced. The exact shape and magnitude of the response depend on the analyzer, interface, cabling, sample-cell configuration, and measurement frequency range.

The resulting frequency sweep should be compared with the expected behavior for the particular analyzer and measurement configuration. For a more reliable assessment, the result can be compared with the corresponding **Performance Demonstration** of the analyzer or the analyzer/interface combination on the website. These Performance Demonstrations provide a useful reference for understanding what constitutes a typical and acceptable response.

It is recommended to become familiar with the expected appearance and magnitude of a successful Short measurement. Keeping previous successful measurements as references can be particularly useful for future comparisons. If a new Short measurement deviates significantly from the established reference, this may indicate a problem with the calibration, the short connection, the sample cell, cabling, or the analyzer/interface itself.

The Short calibration should therefore be regarded not only as a required calibration step but also as a useful **diagnostic check of the complete measurement chain**. A successful and reproducible Short response provides confidence that the analyzer and its associated measurement hardware are operating as expected before measurements are performed on actual materials or samples.

2.4 Performing the Load Calibration

The **Load calibration** is used to characterize the analyzer's response when a known impedance is connected to the measurement system. For this calibration, usually a **100 Ω reference standard** is used. Depending on the delivered configuration and available options, the load standard may be provided either as a **Load calibration standard box** or as a **Load calibration standard designed to be inserted directly into the sample cell**. The appropriate standard should always be used according to the configuration and options delivered with the analyzer.

The purpose of the Load calibration is to provide the analyzer with a known impedance reference and to compensate for the characteristics of the complete measurement system. By measuring a precisely known load resistance, the analyzer can determine how accurately the measurement chain reproduces a known impedance over the specified frequency range. This helps to ensure that subsequent measurements of unknown materials or samples are accurate and reproducible.

2.4.1 Starting the Load Calibration

The Load calibration can be started in **UniLab** by navigating to:

Measurement Setup → Preparation Phase → Analyzer → Analyzer Calibrations

In the **Analyzer Calibrations** section, locate the **Load calibration** and click the green **Start** button next to it. Before starting the calibration, make sure that the correct **Load calibration standard** is properly connected. Depending on the delivered configuration, this means either connecting the Load calibration standard box or inserting the Load calibration standard into the sample cell.

Once the calibration has been started, UniLab will initiate the measurement procedure and display a countdown while the analyzer performs the required measurements. The calibration should be allowed to run without interruption until the analyzer confirms that the procedure has been completed successfully.

2.4.2 Verifying the Load Calibration

After the Load calibration has been completed, and the other required calibrations have also been performed, a **frequency sweep** can be carried out to verify the quality and effectiveness of the Load calibration. When checking the result in UniLab, the appropriate measurement parameter should first be selected. For this verification, select **|Impedance Z|**, with the unit displayed as **Ω (ohm)**. This allows the magnitude of the measured impedance to be observed over the complete frequency range and compared with the expected response of the Load reference standard.

The measured impedance should be close to the nominal value of **Load resistor** over the relevant frequency range. Small deviations may occur depending on the analyzer, interface, cables, sample-cell configuration, and frequency range. The measured result should therefore be compared with a known good measurement and, where available, with the corresponding **Performance Demonstration** of the analyzer or analyzer/interface combination on the website.

For a reliable verification, the Load standard should be correctly connected and, where applicable, removed and reinserted before performing the verification measurement. This helps confirm that the standard is making a proper and reproducible electrical connection. If the measured response differs significantly from the expected Load value behavior or from the established reference, the calibration and the complete measurement setup should be checked before proceeding with measurements on actual materials or samples.

Becoming familiar with the typical response of the Load standard is recommended, as previous successful measurements can serve as a useful reference for future calibration checks. A stable and reproducible Load response provides additional confidence that the analyzer and the associated measurement hardware are operating correctly and are ready for accurate measurements.

2.5 Performing the Open Calibration

The **Open calibration** is used to characterize and compensate for the effects of the measurement system when no electrical connection is present between the measurement terminals. Ideally, an open circuit has an infinitely high impedance. In practice, however, the analyzer, interface, cables, connectors, and sample-cell geometry introduce parasitic capacitance and other frequency-dependent effects. The Open calibration allows these effects to be characterized so that they can be compensated for during subsequent measurements.

For systems using a **sample cell with parallel electrode plates**, the electrodes must be opened **completely** before performing the Open calibration. This is a particularly important point. If the electrode plates are not opened far enough and a residual capacitance remains between them, the analyzer will not see a true open circuit. Instead, it will perform the calibration with an unintended capacitive load still present. The resulting Open calibration will therefore be incorrect and can introduce significant errors into subsequent measurements, particularly at frequencies **above 1 MHz**.

The reason for this increased sensitivity at higher frequencies is that the impedance of a capacitance decreases as frequency increases. Consequently, even a relatively small residual capacitance between the electrode plates can result in a significantly lower impedance at high frequencies. This means that the analyzer may use lower impedance measurement ranges in this frequency region, making the effects characterized during the Open calibration particularly important.

As an alternative, the **Iin** / **CE terminal** can be left open during the Open calibration. This configuration can be used when the intention is to compensate primarily for the effects of the **analyzer/interface itself**, rather than for the complete sample-cell configuration. The appropriate Open calibration method therefore depends on what part of the measurement system is intended to be characterized and compensated.

2.5.1 Starting the Open Calibration

The Open calibration can be started in **UniLab** by navigating to:

Measurement Setup → Preparation Phase → Analyzer → Analyzer Calibrations

In the **Analyzer Calibrations** section, locate the **Open calibration** and click the green **Start** button next to it.

Before starting the calibration, the measurement configuration must be prepared correctly. When calibrating the complete sample-cell setup, make sure that the parallel electrode plates are **fully open** and that no material, sample, or other conductive object is present between the electrodes. The electrodes must remain in this condition throughout the calibration procedure.

If the purpose of the calibration is instead to characterize only the analyzer/interface, the **Iin / CE terminal can be left open** according to the applicable measurement configuration.

Once the calibration has been started, UniLab will initiate the measurement procedure and display a countdown while the analyzer performs the required measurements. The calibration should be allowed to complete without interruption until the analyzer confirms that the procedure has been successfully finished.

2.5.2 Verifying the Open Calibration

After the Open calibration has been completed, and the other required calibrations have also been performed, a **frequency sweep** can be carried out to verify the quality and effectiveness of the calibration.

When checking the result in UniLab, two parameters are particularly useful:

- **|Impedance Z|**, with the unit displayed as **Ω (ohm)**
- **Parallel Capacitance Cp**, with the unit displayed as **F (farad)**

The impedance response can be used to observe the overall behavior of the open circuit over the measured frequency range. In addition, checking the **parallel capacitance** provides a direct indication of whether there is significant residual capacitance present in the measurement setup.

For a properly performed Open calibration with the measurement terminals genuinely open, the measured parallel capacitance should normally be in the **fF (femtofarad) range** and should not show significantly higher capacitance values. A substantially higher capacitance can indicate that the measurement system is not sufficiently open or that parasitic capacitances are influencing the measurement.

This is particularly important when using a sample cell with parallel electrode plates. If the electrodes are not opened completely, a residual capacitance remains between the plates. Although this capacitance may be relatively small, its impedance decreases as the frequency increases. Consequently, its influence becomes increasingly significant at higher frequencies and can lead to incorrect Open calibration results, especially above **1 MHz**.

Therefore, when verifying the Open calibration, both **|Impedance Z|** and **parallel capacitance Cp** should be inspected. The impedance response should show the expected high-impedance behavior, while the parallel capacitance should remain in the expected **fF range**. The exact values and frequency dependence should be compared with a known good measurement or, where available, with the corresponding **Performance Demonstration** for the analyzer or analyzer/interface combination on the website.

If the measured parallel capacitance is significantly higher than expected, the first step should be to check the physical measurement configuration. For a parallel-electrode sample cell, verify that the electrodes are **fully opened** and that no sample, conductive material, contamination, or other object is present between them. If only the analyzer/interface is intended to be characterized, verify that the **Iin / CE terminal is genuinely left open**.

Learning the typical impedance and parallel-capacitance response of a correctly performed Open calibration is highly recommended. These reference measurements can then be used for future comparisons and can help identify problems with the sample cell, connections, analyzer/interface, or calibration procedure before measurements on actual samples are performed.

2.6 Performing the Reference Calibration

The **Reference calibration** is used to calibrate and verify the different measurement ranges of the analyzer against a known electrical reference. In contrast to the Short, Load, and Open calibrations, which characterize specific known impedance conditions, the Reference calibration provides an additional check that the analyzer measures a known reference value correctly across its available measurement ranges.

A known reference standard is used for this purpose, typically a **100 pF capacitor**. Depending on the analyzer and delivered configuration, the reference may be provided in different ways. For **Omega interfaces**, the reference standard is integrated into the interface. In this case, the appropriate connection for the Reference calibration is established using the **open configuration**, according to the delivered system configuration. For other analyzers, the reference may be supplied either as a **100 pF Reference calibration box** or as a **100 pF Reference calibration standard designed to be inserted directly into the sample cell**. The reference configuration supplied with the analyzer should always be used according to the delivered options and measurement setup.

The purpose of the Reference calibration is not only to obtain a single calibration value. The analyzer uses the known reference to **check the different measurement ranges individually** and verify that each range produces a result within the specified standard or acceptance limits. This is particularly important because an analyzer may use different measurement ranges depending on the frequency and measured impedance or capacitance. A measurement range that is not correctly calibrated or is outside its specified limits can therefore affect only a particular part of the overall measurement spectrum.

2.6.1 Starting the Reference Calibration

The Reference calibration can be started in **UniLab** by navigating to:

Measurement Setup → Preparation Phase → Analyzer → Analyzer Calibrations

In the **Analyzer Calibrations** section, locate the **Reference calibration** and click the green **Start** button next to it.

Before starting the calibration, the appropriate reference configuration must be established. For analyzers supplied with a **100 pF Reference calibration box**, the reference box should be connected correctly according to the system configuration. If a **100 pF reference standard for the sample cell** is supplied, it should be inserted into the sample cell correctly and make proper contact with the electrodes.

For **Omega interfaces**, where the reference is integrated into the interface, the connection should be established using the appropriate **open configuration** as specified for the interface.

Once the calibration has been started, UniLab will perform the required measurements over the applicable measurement ranges. The analyzer may switch between different ranges during this process. The procedure should be allowed to run without interruption until the analyzer confirms that the Reference calibration has been completed.

2.6.2 Checking the Measurement Ranges

An important part of the Reference calibration is the verification of **each individual measurement range**. The analyzer measures the known reference and compares the obtained value with the expected value and the applicable acceptance limits for that range.

A useful check is to perform a frequency sweep using the reference standard and select the appropriate measurement parameters in UniLab. Depending on the measurement being evaluated, parameters such as, **Parallel Capacitance Cp** and **Tan delta (Loss Factor)**. The measured response should be compared with the expected response of the reference and, where available, with the corresponding **Performance Demonstration** of the analyzer or analyzer/interface combination on the website.

2.6.3 Influence of Temperature and Humidity

The Reference calibration is particularly sensitive to the conditions under which it is performed. **Operating temperature, warm-up time, and humidity** can significantly influence the measured values and may cause individual measurement ranges to shift outside their specified standards.

For this reason, the analyzer must be given sufficient time to complete its recommended **warm-up period** before the Reference calibration is started. Performing the calibration while the analyzer is still warming up can result in calibration values that change as the instrument reaches thermal stability. A calibration that initially appears acceptable may therefore no longer be representative once the analyzer has reached its normal operating temperature.

Environmental **humidity** should also be considered. Changes in humidity can influence insulation properties, leakage currents, surface conditions, connectors, sample-cell components, and other parts of the measurement system. These effects can become particularly relevant when measuring very small capacitances or working with high-impedance measurement ranges.

The reference standard itself should also be handled correctly. It should be kept clean and dry, protected from unnecessary environmental exposure. The electrical contacts should not be touched unnecessarily, as contamination from fingerprints, moisture, or other residues can affect the measurement.

For reliable and reproducible calibration results, the following conditions should therefore be maintained as consistently as possible:

- Allow the analyzer to complete its specified **warm-up period** before calibration.
- Perform the calibration under the recommended **operating temperature** conditions.
- Consider the influence of **humidity**, particularly for high-impedance and low-capacitance measurements.
- Use the correct reference standard for the delivered analyzer/interface configuration.
- Ensure that the reference standard and its electrical contacts are **clean, dry, and correctly connected**.
- Avoid unnecessary handling of the reference standard immediately before calibration.

The Reference calibration should therefore be regarded as both a **calibration and a diagnostic check of the analyzer's measurement ranges**. A successful result across all ranges demonstrates that the analyzer is not only calibrated but also capable of measuring the known reference correctly throughout its intended operating range. If one or more ranges fall outside the specified limits, the cause should be investigated before measurements on actual materials or samples are started.

Possible causes include insufficient warm-up, unsuitable temperature or humidity, incorrect connection of the reference standard, contamination or poor electrical contact, an incorrectly performed preceding calibration, or a problem within the analyzer/interface itself. Correctly performing and documenting the Reference calibration is therefore an important final step in establishing confidence in the complete measurement system.

3 Optimal Sample Geometry

The geometry of a dielectric sample has a significant influence on the quality, accuracy, and re-producibility of impedance measurements. For optimal measurement results, the sample geometry should be selected so that the resulting sample capacitance is within a suitable range for the analyzer and the intended frequency range.

For typical dielectric samples, good measurement performance can generally be achieved with sample capacitance between approximately **50 pF** and **200 pF**, with an optimum value of around **100 pF**, particularly in the frequency range from **100 kHz** to **100 MHz**.

At lower frequencies, higher sample capacitance can also be measured with good performance. Depending on the analyzer and measurement configuration, capacitance of up to approximately **1 nF** can provide suitable measurement results at lower frequencies.

It is important to understand that these values represent the **recommended range for optimal measurement performance**, rather than the absolute measurement limits of the analyzer. The analyzers are capable of measuring capacitance over a considerably wider range, depending on the frequency and measurement configuration. However, when the sample capacitance is significantly outside the recommended range, the **relative measurement accuracy generally decreases**.

The sample geometry should therefore be selected with the intended capacitance in mind. For a parallel-plate sample cell, the capacitance is influenced primarily by the dielectric properties of the material, the electrode area, and the sample thickness. In simplified terms, increasing the electrode area or reducing the sample thickness increases the capacitance, while reducing the electrode area or increasing the sample thickness decreases it.

This means that the sample dimensions should not be selected based only on the physical size or availability of the material. Where possible, the geometry should be chosen so that the resulting capacitance falls within the recommended measurement range of the analyzer.

3.1 Why the Sample Capacitance Is Important

The analyzer measures the electrical response of the complete measurement system, not only the ideal electrical properties of the sample. The measured signal is therefore influenced by the sample capacitance, the measurement range selected by the analyzer, the sample-cell geometry, parasitic capacitance, cable and interface effects, and the frequency of the measurement.

When the sample capacitance is within the recommended range, the analyzer can generally operate in a measurement range where the signal level and sensitivity are well suited to the sample. This provides a good balance between measurement resolution, accuracy, and repeatability.

When the capacitance becomes too high or too low, the analyzer may need to use different measurement ranges or may become increasingly influenced by parasitic effects and instrument limitations. Although the analyzer may still provide a numerical result, the relative uncertainty of that result can become larger.

For this reason, a measurement result should not be judged solely on whether the analyzer is technically able to measure it. A result obtained near the optimum sample capacitance range will generally provide greater confidence than a result obtained close to the extreme limits of the analyzer's measurement capability.

3.2 Samples with Significant Electrical Conduction

Samples with a considerable amount of electrical conduction require a different approach to sample geometry than typical dielectric materials. For these materials, it is generally advantageous to use a **thicker sample with a smaller diameter**. This geometry increases the electrical resistance of the sample and helps to bring the measurement into a more favorable range for the analyzer.

As a general guideline, a sample resistance of approximately **1 kΩ** provides an optimum measurement condition over the entire frequency range. At lower frequencies, excellent measurement results can also be obtained over a considerably wider resistance range, approximately from **10 Ω to 10 MΩ**.

The reason for selecting the sample geometry based on its expected resistance is that the analyzer's measurement performance depends strongly on the impedance of the sample. If the sample resistance is very low, the measurement can become increasingly influenced by the limitations of the low-impedance measurement ranges. Conversely, very high sample resistance can make the measurement more sensitive to leakage currents, parasitic effects, environmental influences, and the limitations of the high-impedance measurement ranges.

The sample resistance is strongly influenced by the geometry of the sample. For a given material, increasing the **sample thickness** generally increases the resistance, while increasing the **electrode area or sample diameter** generally decreases the resistance. Therefore, for materials with significant electrical conduction, a thicker and smaller-diameter sample can be used to increase the resistance toward a more favorable measurement range.

The geometry should ideally be selected based on an estimate of the material's electrical conductivity or resistance before the sample is prepared. If the approximate conductivity or resistivity is known, the expected sample resistance can be calculated for different combinations of sample thickness and electrode diameter. This makes it possible to optimize the geometry before performing the actual measurement.

The recommended values should be regarded as guidelines for achieving optimum measurement performance rather than strict measurement limits. **Eynocs analyzers are capable of producing high-quality, publishable results outside these recommended resistance ranges as well.** However, when operating outside the optimum range, greater attention should be given to the measurement conditions, calibration, sample geometry, and verification of the obtained results.

For measurements over a broad frequency range, it is particularly important to consider that the apparent impedance of the sample may change significantly with frequency. A geometry that provides an ideal resistance at one frequency may therefore result in a different measurement condition at another frequency. The complete frequency-dependent response should consequently be considered when selecting the sample geometry.

A practical approach is therefore to:

Estimate the electrical resistance → Select sample thickness and diameter → Target approximately 1 kΩ where possible → Verify the measurement response over the required frequency range → Adjust the geometry if necessary

This approach helps the analyzer operate within favorable measurement ranges while maintaining good accuracy and re-producibility for electrically conductive or partially conductive materials.

3.3 Small Capacitances Below 50 pF

In some applications, it is not possible to obtain a sample capacitance within the recommended **50–200 pF** range. This can occur, for example, when the material has a low dielectric constant, when the sample must have a certain thickness, or when the available sample area is limited.

If capacitance below approximately **50 pF** have to be measured, the **stray and parasitic capacitance of the sample cell and measurement setup** becomes increasingly important.

The capacitance measured by the analyzer is then no longer determined solely by the sample. A small additional capacitance originating from the electrodes, sample cell, connectors, cables, interface, and surrounding structures can become a significant fraction of the total measured capacitance.

For example, when the actual sample capacitance is large, a small parasitic capacitance may have only a minor effect on the result. However, when the sample capacitance is only a few picofarads, the same parasitic capacitance can represent a substantial percentage of the measured value.

This is one of the main reasons why the **Open calibration** becomes particularly important when measuring small capacitance. The Open calibration characterizes the capacitive contribution of the measurement setup without the sample present and allows the analyzer to compensate for these effects.

For very small capacitance, the physical configuration of the sample cell should also be kept as consistent as possible. The position of the electrodes, sample thickness, electrode spacing, cables, connectors, and surrounding objects can all influence the measured result. Even small changes in the measurement geometry can become significant when the sample capacitance is very low.

3.4 Practical Recommendation

Whenever possible, the sample geometry should be designed or selected to produce a capacitance close to **100 pF**. This provides a useful target for achieving good measurement performance over the typical frequency range of **100 kHz to 100 MHz**.

If a higher capacitance is required, values up to approximately **1 nF** can still provide good results at lower frequencies, depending on the analyzer and measurement configuration.

If the expected capacitance is below **50 pF**, additional care should be taken. The Open calibration should be performed correctly, the sample-cell geometry should be well defined and reproducible, and the resulting measurement should be evaluated with greater attention to the influence of stray capacitance and the applicable measurement range.

In all cases, the recommended capacitance ranges should be considered together with the **frequency range and the analyzer/interface configuration**. A capacitance that provides excellent measurement performance at one frequency may not provide the same performance at another frequency because the impedance of a capacitor changes with frequency.

The objective is therefore not simply to obtain a measurable signal, but to select a **sample geometry and capacitance that allow the analyzer to operate in a favorable measurement range**, providing the best possible accuracy, stability, and reproducibility for the intended measurement.

3.5 Determining Sample Geometry

The appropriate **sample thickness and diameter** can also be estimated directly in UniLab by changing the relevant variables in the **Sample Properties** window. This provides a practical way to investigate different sample geometries before preparing the actual sample.

By entering or adjusting parameters such as the sample thickness, sample diameter, and material properties, the expected capacitance can be evaluated. Even before the actual dielectric properties of the material are known, the calculation of the **air capacitance** provides a useful first approximation of the expected measurement conditions.

The calculated air capacitance can therefore be used as a **starting point for selecting a suitable sample geometry**. The sample dimensions can be adjusted until the estimated capacitance falls within the recommended measurement range—for typical dielectric measurements, approximately **50–200 pF, with around 100 pF being a useful target**.

Once the actual material properties are known or estimated, the calculation can be refined further. The dielectric constant of the material will change the expected capacitance compared with the air-filled geometry, allowing the sample dimensions to be optimized more accurately.

This approach is particularly useful when planning a measurement because it allows different combinations of **sample diameter and thickness** to be evaluated before the sample is physically prepared. It can help avoid producing samples that result in capacitance that are unnecessarily low or high for the intended measurement range.

The calculated value should, however, be regarded as an **initial estimate rather than a guarantee of the final measured capacitance**. The actual result can be influenced by the real sample dimensions, electrode geometry, surface quality, air gaps, dielectric properties, stray capacitance, and other characteristics of the complete measurement setup.

A practical workflow is therefore:

Define sample dimensions → Calculate air capacitance → Adjust thickness/diameter → Target a suitable capacitance range → Prepare the sample → Measure and verify the actual capacitance

Using the Sample Properties calculation in this way provides a useful first step for designing the sample geometry and can serve as the basis for further optimization once more information about the material is available.

4 Stray Capacitance Correction

The **Stray Capacitance Correction** is used to compensate for the additional capacitance introduced by the sample cell, spacers, and other parts of the measurement geometry that are not part of the actual sample. This correction becomes particularly important when measuring materials with relatively small capacitance, where the stray capacitance of the measurement setup can represent a significant fraction of the total measured capacitance.

The procedure determines the difference between the **theoretical air capacitance** of the intended sample geometry and the **actual capacitance measured with air** in the sample cell. This difference can then be entered into UniLab so that it is automatically taken into account when calculating the dielectric properties of the sample.

4.1 Creating a Defined Air Gap

The first step is to create an air capacitor with a well-defined geometry corresponding as closely as possible to the geometry that will be used for the actual sample measurement.

For sample cells where the sample thickness is defined using spacers, the air capacitor can be created by placing **two parallel spacers** between the electrodes. The spacers should have the same thickness as the intended sample thickness and should be positioned so that the electrode separation is clearly defined.

Alternatively, if the sample cell is equipped with a **micrometer adjustment**, the electrode spacing can be set directly by turning the micrometer to a known height. The selected electrode diameter and electrode separation should correspond to the geometry that will subsequently be used for the sample measurement.

The objective is to create an air-filled capacitor with the **same electrode diameter and electrode separation** as the intended sample geometry.

4.2 Measuring the Air Capacitance

Once the air capacitor has been established, a frequency sweep should be performed to measure its capacitance. The measured capacitance should be observed over the relevant frequency range.

For the stray-capacitance correction, the capacitance should be evaluated in the relatively **flat region between approximately 100 Hz and 100 kHz**, where the measured capacitance is stable and does not show significant frequency-dependent effects. A representative value from this stable region should be recorded.

It is important that the measurement is performed with the same electrode configuration and geometry that will be used for the actual sample measurement. Changes in electrode spacing, spacer thickness, electrode position, cables, or other parts of the measurement setup can change the measured stray capacitance.

4.3 Calculating the Theoretical Air Capacitance

The next step is to calculate the theoretical capacitance of an ideal air capacitor having the same electrode diameter and thickness as the measured configuration.

This can be done in UniLab using the **Sample Properties** window. Enter the corresponding electrode/sample diameter and thickness. UniLab will then calculate the expected theoretical C0 air capacitance for the defined geometry.

The calculated value represents the capacitance expected from the ideal parallel-plate geometry. The experimentally measured value, however, also contains contributions from the actual measurement cell, spacers, electrode configuration, and other parasitic effects.

4.4 Determining the Stray + Spacer Capacitance

The correction value is obtained by comparing the **theoretical air capacitance** with the **measured air capacitance**.

The difference between these two values represents the additional capacitance that must be considered for the measurement setup:

Stray + Spacer Capacitance = Measured Air Capacitance − Theoretical Air Capacitance

The resulting difference can then be entered into the **Sample Stray + Spacer Capacity** field in UniLab.

Once this value has been entered, UniLab can automatically apply the correction during subsequent sample measurements. The software subtracts the defined stray and spacer capacitance from the measured response when calculating the dielectric properties of the sample, including the real and imaginary parts of the permittivity, **ε’ and ε”**.

4.5 Important Considerations

The correction should be determined using the **same sample-cell geometry** that will be used for the actual measurements. In particular, the electrode diameter, electrode separation, spacers, and relevant cell configuration should remain unchanged. The correction value is specific to the measurement geometry and should not automatically be transferred to a substantially different electrode spacing or sample-cell configuration.

The air-capacitance measurement should also be performed only after the analyzer has completed its required warm-up and calibration procedures. This ensures that the measured capacitance represents the stable measurement system rather than changes caused by instrument drift.

It is also important to ensure that the electrodes and spacers are clean, dry, and correctly positioned. Small changes in electrode spacing can have a noticeable effect on the capacitance, particularly when working with small gaps.

The Stray Capacitance Correction is therefore a useful method for improving the accuracy of dielectric measurements when the sample capacitance is relatively small. By first measuring the actual air capacitance, comparing it with the theoretical value calculated from the sample geometry, and entering the resulting correction into UniLab, the influence of the measurement cell and spacers can be compensated for automatically.

A practical workflow is:

Define sample geometry → Create the equivalent air capacitor → Measure air capacitance → Identify the stable capacitance region → Calculate theoretical air capacitance in Sample Properties → Determine the difference → Enter the value into Sample Stray + Spacer Capacity → Measure the sample with automatic correction

This procedure provides a traceable and reproducible way of accounting for the additional capacitance introduced by the sample cell and spacer arrangement, particularly when measuring low-capacitance dielectric samples.

5 Accuracy of Measurement

The **accuracy of measurement plots** are an important part of the specifications of the Eynocs impedance analyzers because they show not only the nominal measurement range of an instrument, but also **how accurately the analyzer is expected to perform at a given combination of frequency and impedance**. This is particularly important when selecting an analyzer or deciding whether a particular sample geometry is suitable for a planned measurement.

The Eynocs analyzers use different precision configurations. **Omega is supplied with High Precision as its standard precision configuration**, whereas **Zeus and Lamda are available with a Normal Precision configuration and can be upgraded to High Precision**. This makes the Normal Precision versions of Zeus and Lamda particularly attractive for users who require a capable and versatile analyzer but do not routinely need the highest available accuracy, for example when measurements of extremely low-loss dielectric materials are not the primary application. The choice should nevertheless be made according to the required measurement uncertainty rather than price alone.

For every analyzer variant and precision option, Eynocs provides corresponding **accuracy plots**. These plots describe the expected measurement performance over frequency and impedance and indicate regions in which different levels of accuracy can be expected. The plots are presented on a **logarithmic frequency/impedance scale**, which allows the very large operating range of the analyzers to be displayed in a single diagram.

5.1 How to read an accuracy plot

The vertical axis of the plot represents the magnitude of impedance,

$$|Z|\ [\Omega]$$

while the horizontal axis represents frequency,

$$f\ [\mathrm{Hz}]$$

The diagonal lines represent constant values of capacitance or inductance. For a capacitor,

$$|Zc| = 1\ /\ 2\pi fC'$$

and therefore a particular capacitance follows a diagonal line across the frequency/impedance diagram.

For example, a **10 pF capacitor** has the following approximate impedance values:

Frequency	Impedance of 10 pF
1 kHz	15.9 MΩ
100 kHz	159 kΩ
1 MHz	15.9 kΩ
10 MHz	1.59 kΩ
100 MHz	159 Ω

Thus, when a 10 pF sample is measured, its operating point moves along the **10 pF diagonal line** as the frequency is changed. The accuracy that can be expected at each frequency is therefore determined by where this line passes through the different accuracy regions of the analyzer.

The same principle applies to a **330 pF capacitor**. Its approximate impedance values are:

Frequency	Impedance of 330 pF
1 kHz	482 kΩ
100 kHz	4.82 kΩ
1 MHz	482 Ω
10 MHz	48.2 Ω
100 MHz	4.82 Ω

The 330 pF capacitor therefore follows the **330 pF diagonal** on the accuracy diagram. Compared with the 10 pF capacitor, it occupies a substantially lower impedance region at the same frequency.

5.2 Example: 10 pF sample

Consider a 10 pF dielectric sample measured from 1 kHz to 100 MHz. At low frequencies, its impedance is relatively high. At 1 kHz, for example, the analyzer sees approximately 15.9 MΩ. As the frequency increases, the impedance decreases continuously until it reaches approximately 159 Ω at 100 MHz.

This illustrates why it is not sufficient to state that an analyzer can simply "measure 10 pF." The **same 10 pF capacitor presents very different measurement conditions at different frequencies**.

At 100 kHz the impedance is approximately 159 kΩ, while at 100 MHz it is only approximately 159 Ω. Consequently, the measurement may pass through several different measurement regions as the frequency is swept.

For example of one of Eynocs Analyzers: **Lamda** specification sheet provides separate accuracy plots for the **NO-PR (Normal Precision)** and **HI-PR (High Precision)** configurations. The Normal Precision plot specifies regions including approximately **0.5 % / 0.03**°, **1 % / 0.25**°, **5 % / 2.5**°, and **10 % / 5**°, while the High Precision configuration provides tighter accuracy regions in parts of the operating range, including approximately **0.5 % / 0.03**°, **1 % / 0.25**°, and **2.5 % / 1**°. These values should be interpreted together with the boundaries in the actual accuracy plot rather than as a single accuracy value applicable to the entire frequency range.

Note that each analyzer is delivered with its own Measurements Accuracy Plot in the User Manual (directly in the USB-Stick / Analyzer Folder). It can also be found online in the Specifications File at the last page.

5.3 Example: 330 pF sample

The same analysis can be made for a 330 pF sample. At 100 kHz, the impedance is approximately 4.82 kΩ, whereas at 1 MHz it has decreased to approximately 482 Ω. At 100 MHz, the impedance is only approximately 4.82 Ω.

Consequently, the 330 pF sample occupies a considerably lower impedance region than the 10 pF sample at the same frequency. When the 330 pF diagonal is followed across the accuracy plot, it can therefore enter different accuracy regions from those encountered by the 10 pF sample.

This is particularly useful when planning dielectric measurements. A sample that has an apparently suitable capacitance at one frequency may move into a less favorable measurement region at another frequency. **Capacitance alone therefore does not determine measurement accuracy; capacitance, frequency, and the resulting impedance must always be considered together.**

5.4 Relation to sample geometry

This also explains why the recommended sample capacitance discussed in the previous sections is important. For a parallel-plate dielectric sample,

$$C = \varepsilon 0 * \varepsilon r * A / d$$

so the sample diameter/electrode area and thickness determine the capacitance, while the measurement frequency determines the corresponding impedance.

For example, increasing the electrode area or reducing the sample thickness increases the capacitance. At a given frequency this also reduces the magnitude of the impedance. Conversely, a smaller electrode area or thicker sample produces a lower capacitance and therefore a higher impedance.

The **accuracy plot should consequently be considered during sample preparation**, not only after the sample has been measured. By estimating the expected capacitance of the sample and converting it to impedance over the intended frequency range, it is possible to determine whether the planned measurement will remain within a favorable accuracy region.

5.5 Normal Precision versus High Precision

The distinction between Normal Precision and High Precision is particularly relevant for practical instrument selection.

For **routine impedance, capacitance, conductivity, and dielectric measurements**, Normal Precision may provide more than adequate performance, particularly when the measured signal is well inside the favorable region of the accuracy diagram. This can make a Normal Precision Zeus or Lamda an attractive solution where instrument cost is an important consideration.

High Precision becomes increasingly valuable when the measurement requires very small relative errors, accurate phase information, or reliable characterization of **very low-loss materials**. In dielectric spectroscopy, this is especially important because a small dielectric loss can correspond to a very small dissipative component compared with the much larger capacitive component. An error in phase or loss measurement can therefore become significant even when the absolute impedance measurement itself appears reasonable.

The decision should therefore not simply be based on the maximum advertised impedance or capacitance range. Instead, the expected operating point of the actual sample should be plotted against the analyzer's accuracy diagram.

5.6 Practical use of the accuracy plots

Before beginning a new measurement series, the following procedure is recommended:

1. **Estimate the expected sample capacitance, resistance, or inductance.**
2. **Calculate or estimate the corresponding impedance** at the frequencies of interest.
3. Locate the expected operating points on the analyzer's accuracy plot.
4. Follow the corresponding capacitance, resistance, or inductance line across the frequency range.
5. Check which accuracy region the measurement occupies at each frequency.
6. If the measurement enters an unfavorable region, consider changing the **sample geometry, measurement frequency, analyzer configuration, or precision option**.
7. Perform the appropriate calibration and verify the system using known standards before measuring the actual sample.

For Lamda, for example, the specification document explicitly provides separate **Normal Precision (NO-PR)** and **High Precision (HI-PR)** accuracy plots. The document also specifies an operating temperature of 10–40 °C, with the stated specification limits applying at 20–25 °C and humidity below 50 %, which is another reminder that the plotted accuracy values apply under defined measurement conditions.

The plots should therefore be regarded as a **planning and specification tool**, rather than simply a graphic showing the absolute limits of the analyzer. They allow the user to determine whether a particular sample is being measured in a region where the analyzer can provide the required accuracy.

For comparison, Eynocs' Lamda performance demonstrations also show measurements of very small capacitors, including **5 pF and 0.6 pF**, illustrating that the instrument can operate in regions well beyond the typical sample-capacitance range discussed earlier. However, the fact that an analyzer can measure a value does not automatically mean that the measurement has the same relative accuracy as a measurement made in its optimum operating region.

In practice, the best measurement is therefore obtained by matching the sample geometry to the analyzer's accuracy map, rather than simply choosing a geometry that falls somewhere inside the analyzer's headline measurement range. This is one of the most important considerations when preparing a dielectric or impedance measurement for high-quality and reproducible results.

5.7 Faraday Cage and Proper Earthing

The accuracy specified in the analyzer's performance and accuracy plots can only be achieved when the measurement is performed under suitable electrical conditions. In particular, **electrostatic and electromagnetic interference from the surrounding environment can have a significant effect on sensitive impedance and dielectric measurements**. This becomes especially important when measuring **low capacitances, high impedances, low-loss dielectric materials, very small dielectric-loss values, or samples with a large capacitive component compared with their loss component**. For these measurements, the use of a properly connected **Faraday cage or electrically shielded measurement enclosure** is strongly recommended.

A Faraday cage provides an electrically conductive enclosure around the sensitive measurement region and helps shield the sample, sample cell, and measurement connections from external electric fields and electromagnetic interference. Without adequate shielding, signals from mains wiring, electrical equipment, computers, motors, switching power supplies, and other sources can couple capacitively or inductively into the measurement system. The resulting unwanted signal can appear as additional capacitance, conductance, or noise and can therefore influence the measured impedance and calculated dielectric properties.

The importance of shielding is particularly high for **low-loss materials**. In a low-loss dielectric, the current associated with dielectric loss is very small compared with the reactive capacitive current. The analyzer must therefore distinguish a relatively small loss component from a much larger capacitive signal. Even a small amount of external interference, leakage current, parasitic conductance, or unwanted capacitive coupling can consequently produce a significant relative error in the measured loss. A measurement can therefore have a reasonable total capacitance while still requiring excellent shielding because the quantity of interest is the much smaller loss component.

This means that the need for a Faraday cage cannot be determined from capacitance alone. A relatively large sample, for example several hundred picofarads or even nanofarads, can still require excellent shielding if the material has a very low dielectric loss. Conversely, a higher-loss sample may be less sensitive to a given level of environmental interference. **The lower the loss being measured, the more important it becomes to control the complete electrical environment of the measurement.**

The effectiveness of the shielding depends not only on the presence of a metal enclosure but also on its **electrical connection and earthing**. The external metal case of the Faraday cage should have a proper, low-impedance connection to the appropriate **protective earth (PE)** or laboratory grounding system, following the analyzer, sample-cell, and laboratory electrical-safety requirements. The cage should not simply be placed around the sample without an intentional electrical connection. A properly earthed shield provides a defined electrical reference and allows interference coupled onto the enclosure to be conducted away rather than coupling into the sensitive measurement circuit.

Particular attention should be paid to the connection between the Faraday cage and earth. The connection should be **short, secure, and electrically reliable**, with good electrical contact to the conductive enclosure. Painted, oxidized, or otherwise poorly conducting surfaces should not be used for the grounding connection unless a suitable grounding point is provided by the enclosure manufacturer. The protective-earth connection of the laboratory installation should be used in accordance with the applicable electrical-safety requirements. **Signal ground, protective earth, and the Faraday-cage connection must not be interconnected arbitrarily**, since an incorrect grounding arrangement can create ground loops or introduce additional interference.

The sample cell should also be positioned consistently inside the shielded environment, with unnecessary cables and conductive objects kept away from the sensitive measurement region. Cable routing is important because cables can act as antennas and can capacitively couple environmental interference into the measurement system. The shielding should therefore enclose the sample cell and relevant measurement connections as far as practical while still allowing normal operation of the cell.

The effect of parasitic capacitance is particularly easy to understand with a small-capacitance sample. For example, when measuring a **10 pF sample**, an additional parasitic capacitance of only 1 pF represents 10 % of the sample capacitance. For a **330 pF sample**, the same 1 pF contribution represents only about 0.3 %. However, the same numerical comparison does **not** mean that a 330 pF sample is automatically insensitive to interference. If the 330 pF material is extremely low-loss, a very small unwanted conductance or loss current can still be large compared with the actual loss signal being measured.

For low-loss measurements, it is therefore useful to consider not only the magnitude of the impedance or capacitance, but also the **ratio between the loss component and the reactive component**. A sample with a large capacitance and a very small loss tangent can be more demanding than a smaller but substantially more lossy sample. This is why low-loss measurements require careful attention to shielding, earthing, Open calibration, stray-capacitance correction, sample-cell cleanliness, cable arrangement, and environmental conditions.

The Faraday cage does **not replace Open calibration or stray-capacitance correction**. Instead, these measures address different sources of measurement error. The Faraday cage reduces external electromagnetic and electrostatic interference, while Open calibration characterizes the electrical behavior of the measurement system in the open configuration and stray-capacitance correction accounts for known parasitic contributions from the sample cell, spacers, and measurement geometry. All of these measures should be used together when high measurement accuracy is required.

For high-accuracy and particularly low-loss measurements, the recommended arrangement is therefore:

Analyzer → correctly connected measurement cables → calibrated sample cell → sample inside a shielded/Faraday-cage environment → Faraday cage properly connected to protective earth.

Before starting a sensitive measurement, verify that:

- The Faraday cage is electrically continuous and properly closed around the sensitive measurement area.
- The external case/enclosure has a **secure connection to the appropriate protective earth**.
- The grounding connection is clean, secure, and mechanically stable.
- Measurement cables are routed consistently and kept away from unnecessary sources of interference.
- The sample cell and sample are positioned consistently inside the shield.
- Open calibration has been performed with the same shielding and measurement configuration used for the actual sample.
- Stray-capacitance correction, where required, has been determined using the same physical measurement arrangement.
- The sample cell, electrodes, and insulating surfaces are clean and dry.
- No unnecessary grounded or floating conductive objects are introduced near the sample cell during measurement.

A properly implemented Faraday cage is therefore an important part of the **measurement system**, particularly when the objective is to determine very small dielectric-loss values. It should not be regarded as a solution only for measurements below a particular capacitance. **Low-loss measurements of both small and large capacitance samples can require excellent shielding and grounding**, because the relevant limitation is often the size of the loss signal rather than the absolute capacitance of the sample.

The overall principle is:

Good calibration removes known measurement-system errors; good geometry provides a suitable measurement signal; and good shielding and earthing prevent the electrical environment from becoming part of the measurement.