Characterizing the Parasitic Capacitance in a Test Fixture

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Internal Parasitic Capacitance

- Parasitic capacitance in a test instrument arises from two sources:
  - Capacitance between circuit traces and wires internal to the tester.
  - Capacitance between electrical paths external to the tester.

- The internal parasitic capacitance of a test system can be measured but running hysteresis tests with the system in the intended amplification level but with no external connections to the test system.
  - Averaging may be necessary to reduce noise effects.

Internal Parasitic Capacitance

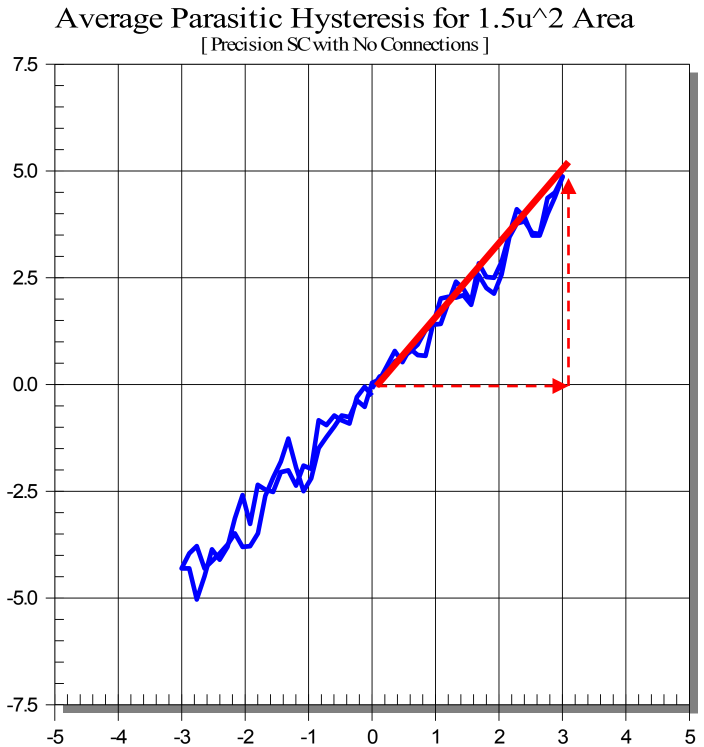
- Radiant testers have the following internal parasitic capacitance values:

– RT66A and RT6000	1pF
– Precision Premier	1.5pF
– Precision Workstation	1.5pF
– Precision LC	0.5pF
– Precision SC	17fF

Internal Parasitic Capacitance

- Example:
  - Precision LC with no connections.
  - Area set to 1.5μ^2
  - Vmax = 3V
  - Pmax = 5.0 $\mu C/cm^2$
- Parasitic Capacitance

(5.0 $\mu C/cm^2$ * 1.5μ^2) / 3V = 17fF



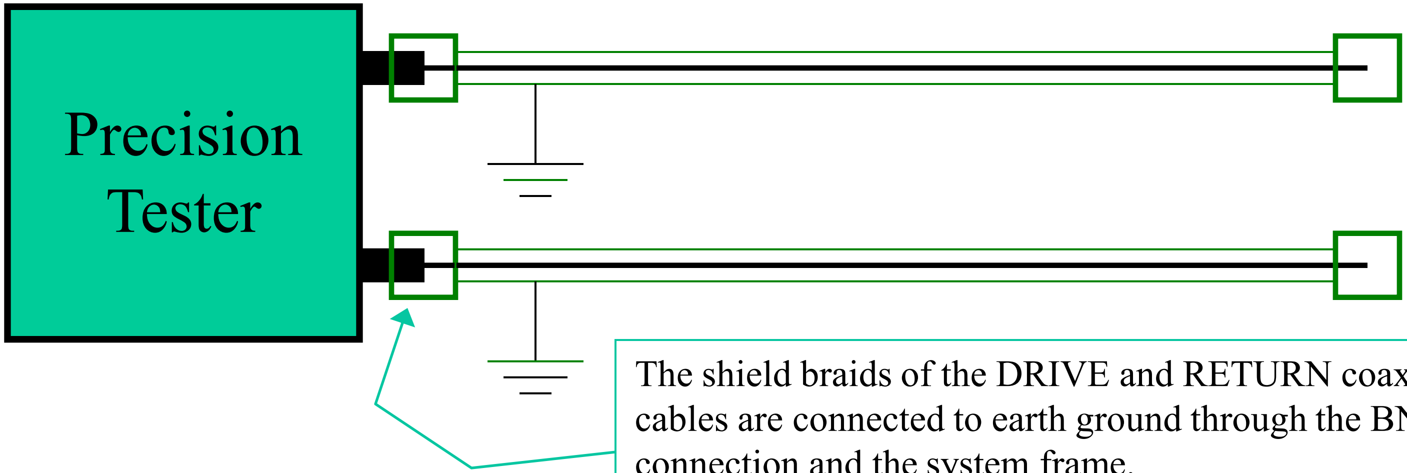
External Parasitic Capacitance

- Test systems with Virtual Ground measurement circuits eliminate the effects of all external parasitic capacitance not connected directly between the DRIVE and RETURN leads.

- All Radiant testers use Virtual Ground measurement circuits.

External Parasitic Capacitance

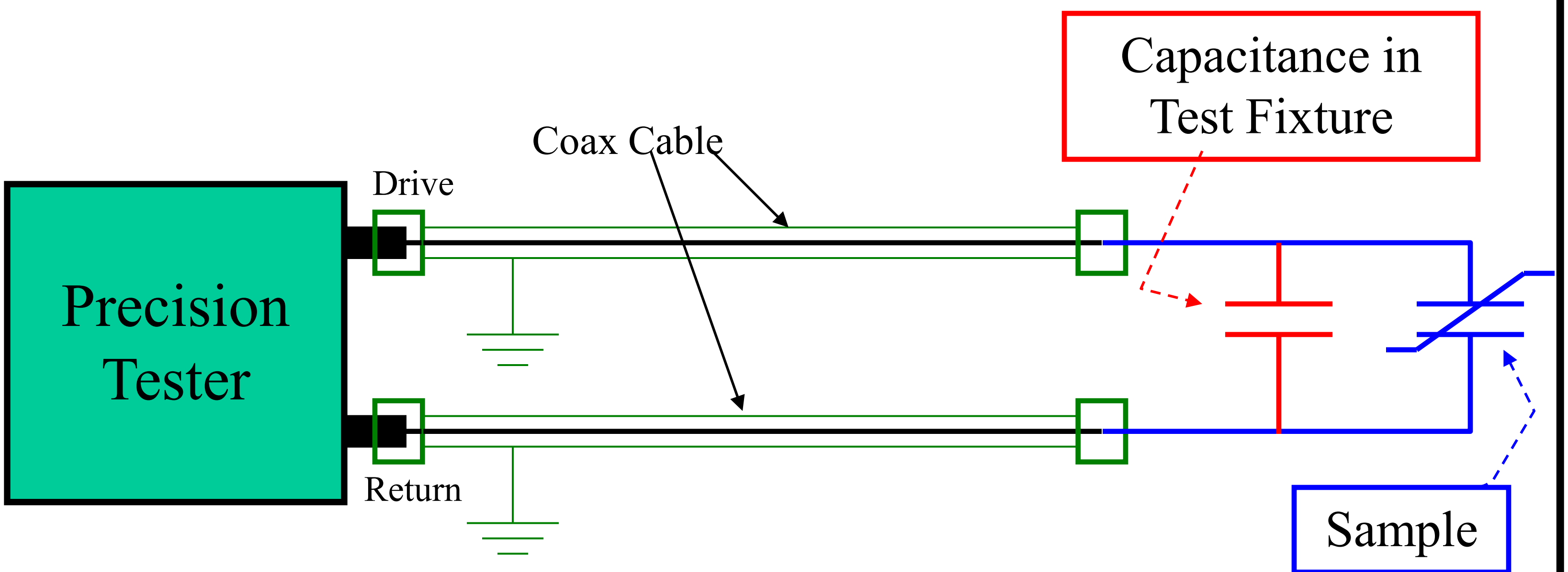
- Example: If two 3 meter coax cables are attached to the DRIVE and RETURN connections but to nothing else on the other end, the Virtual Ground ignores all capacitance from the RETURN lead to the shield braid of its coax cable. The grounded shield braid on both coax cables prevents any electric field lines from connecting between the DRIVE and RETURN leads inside the two cables. Hence, no parasitic capacitance occurs on coax cables connected to a Virtual Ground test system!



The shield braids of the DRIVE and RETURN coax cables are connected to earth ground through the BNC connection and the system frame.

External Parasitic Capacitance

- If coax cable is used to connect to the sample, the only external parasitic capacitance occurs at the test fixture after the signal path leaves the protective sheath of the coax shield braid.



Typical External Parasitic Capacitance Values

- Probe station needles at 45º angle to each other and roughly 200µ apart at the tips = ~170fF
- Probe station needles tip-to-tip almost co-linear to each other and roughly 200µ apart at the tips = ~70fF
- AFM cantilever capacitance to large area electrode under the cantilever = ~100fF
- Two unshielded wires several centimeters long and roughly 1cm apart = ~1pF

Typical Capacitance of PZT

- A typical PZT capacitor from 1000Å to 2000Å thick has approximately 1pF of equivalent capacitance for every 10 square microns.
  - C_{EQ} => Pmax / Vmax
- If you have 1pF total parasitic capacitance, it becomes a problem for capacitors smaller than 30µ x 30µ:

Capacitor Dimensions	Area	% Contribution of Parasitic Capacitance
100µ x 100µ	10,000μ^2	0.1%
30µ x 30µ	900μ^2	>1%
10µ x 10µ	100μ^2	10%
1µ x 1µ	1μ^2	1000%

Conclusion About Parasitics

- Parasitic capacitance arises from two locations:
  - Inside the tester
  - Inside the test fixture
- Always use coaxial cable from the tester to as close as possible to the sample as possible.
- Typical parasitic values are such that parasitics begin to significantly affect the measured data if the sample capacitor is less than $1000\mu^2$ in area.
- Because parasitic capacitance is in parallel with the sample being measured, we can subtract it directly from the measured data once we know its value.

The Three Step Plan

- To eliminate parasitic capacitance from the measured data, we must follow the Three Step Plan!
  - Minimize capacitance intrinsic in the test fixture.
  - Measure or calculate the remaining internal and external parasitic capacitance in parallel with the sample.
  - Subtract the polarization of the total parasitic capacitance from the measured data.
    - Parasitic capacitance is in parallel with the sample so its charge response adds to that of the sample during the test.

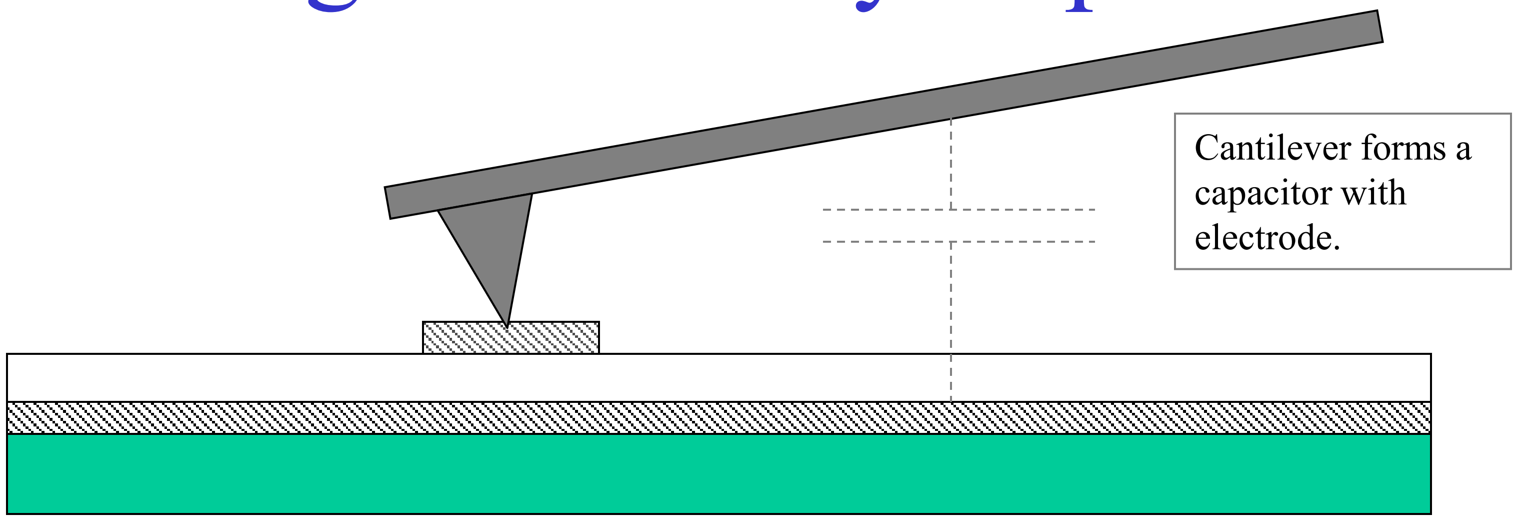
Minimizing External Parasitics

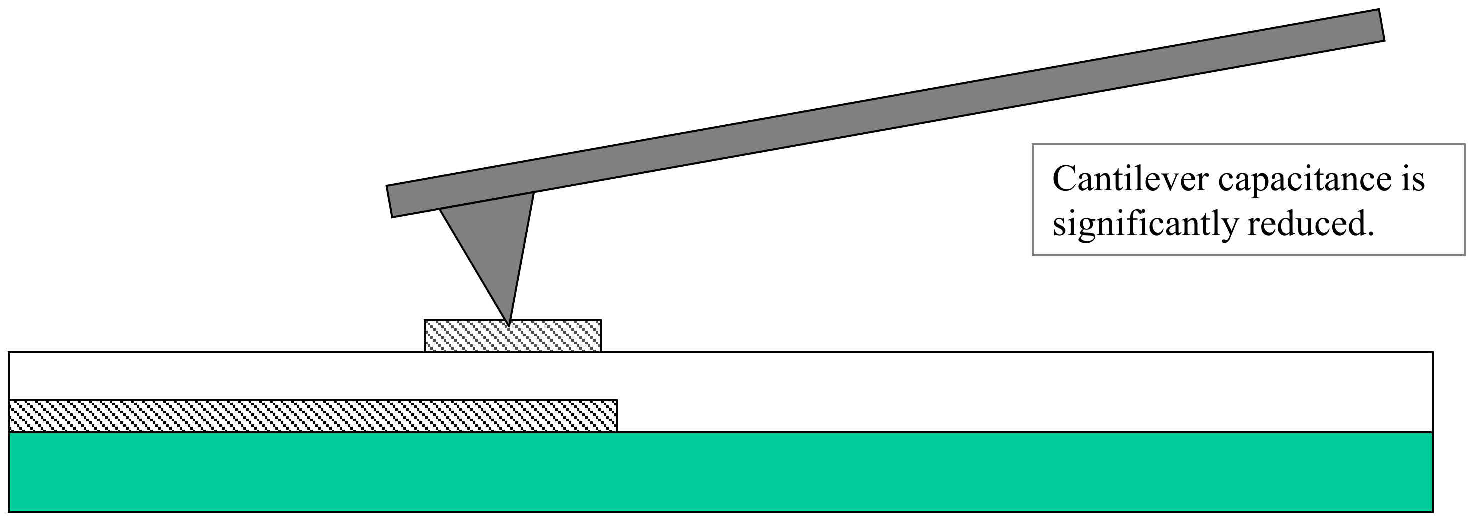
- Use coaxial cable to a point as close as possible to the sample.
- Where unshielded wire must be used, keep the DRIVE and RETURN leads as far apart as possible and run them anti-parallel as much as possible.
- Connect all pieces of metal in the test fixture to earth ground.
  - Any electric field path from the DRIVE lead to the RETURN lead forms a capacitor.
  - Floating metal parts in an electric field act as receiving antennas and re-radiators. Electric field lines can connect between the DRIVE and RETURN leads via a circuitous collection of floating metal parts in the test fixture. Grounding the parts interrupts the field connections.

AFMs

- Atomic Force Microscopes are particularly prone to parasitic capacitance because of the cantilever.
- If the sample has a global electrode, one that is larger than the cantilever of the AFM, then the cantilever body will form a capacitor with the electrode. Due to the large size of the cantilever compared to sub-micron ferroelectric capacitors, it will have a capacitance significantly larger than the sample.
- To eliminate the parasitic capacitance, use a cantilever with the longest tip possible and pattern both electrodes of the sample to minimize the area of parasitic capacitance.

Reducing AFM Stray Capacitance



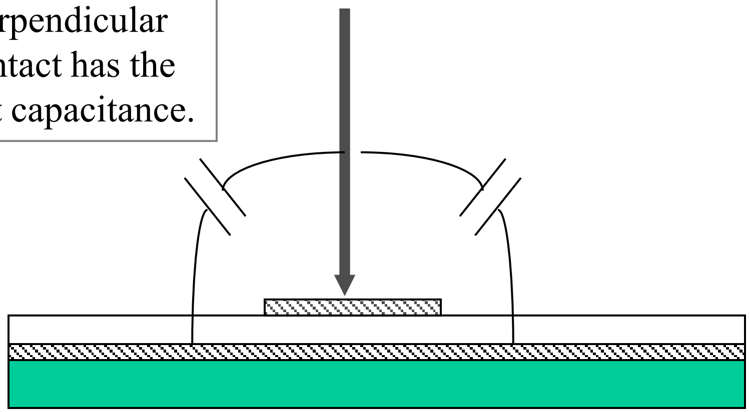


Probe Stations

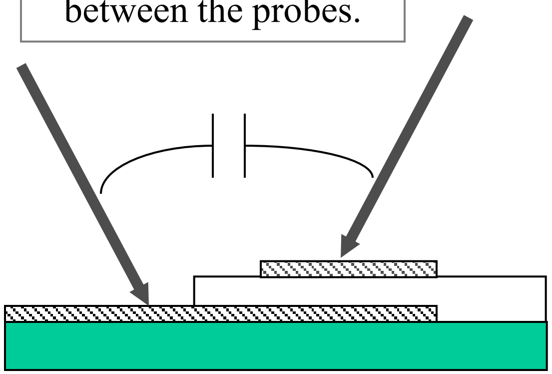
- Manual probe stations represent the most economical approach for minimizing parasitic capacitance.
- The parasitic capacitance of a probe station can be reduced to less than that of an AFM while the probe station costs less than an AFM.
- The parasitic capacitance of a probe station comes from the probe needles. Control their geometry to control their stray capacitance.

Probe Stations

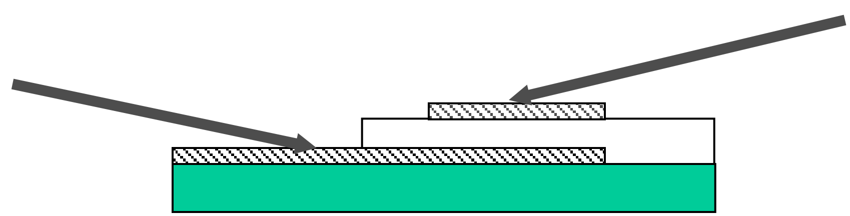
For global electrodes, a perpendicular contact has the least capacitance.



For patterned electrodes, there is stray capacitance between the probes.



Increasing the angle between the probe tips can reduce the stray capacitance to extremely low levels.



Conclusions about Minimizing Parasitics

- Careful layout of the test fixture can reduce built-in parasitic capacitance significantly.

- Pay attention to the geometry of the test fixture and the electrical conduction paths.

- Probe stations are the best environment for reducing parasitic capacitance to a minimum.
  - Probe stations are better than AFMs when practical.
  - There are manual probe stations capable of probing submicron capacitors.

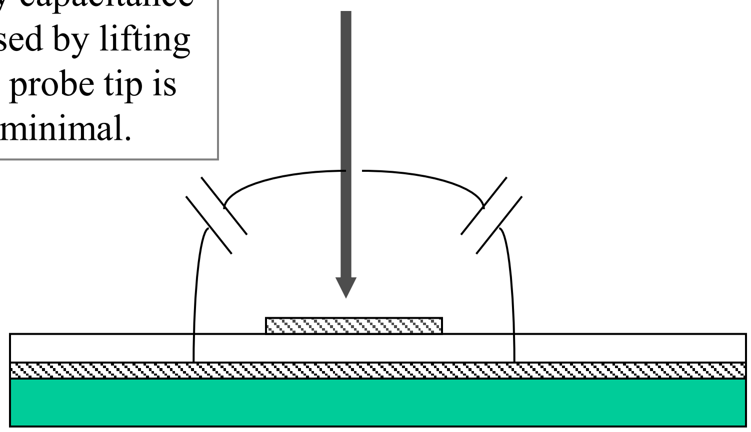
Subtracting Parasitics

- The effect of parasitic capacitance on measured data may be eliminated by two different methods:
  - Capture the parasitics in the same format as the intended measurement and subtract them point-by-point from the measured data.
  - Measure the actual capacitance value of the parasitics and use a mathematical technique to remove that capacitance value from the measured data.
- Measuring the parasitics and subtracting them point-by-point can only be done if the parasitics are fixed.
- If the parasitics are sensitive to small changes in geometry, then a mathematical technique must be used to eliminate their effects from the data.

Eliminating Fixed Parasitic Capacitance

- There are situations where the parasitic capacitance of the test fixture is immune to changes in geometry and distances.

The change in stray capacitance caused by lifting the probe tip is minimal.



When parasitic capacitance is constant, it can be measured by disconnecting the probe from the sample and making the measurement.

Eliminating Fixed Parasitic Capacitance

- In Vision, subtracting measured parasitics is a relatively simple program:

Task 1: Pause (Message = Lower probe to sample)

Task 2: Hysteresis of sample

Task 3: Pause (Message = Raise probe from sample slightly)

Task 4: Hysteresis of test fixture and tester parasitics.

Task 5: Two Trace Math Filter: Subtract Parasitic from Data

Eliminating Fixed Parasitic Capacitance

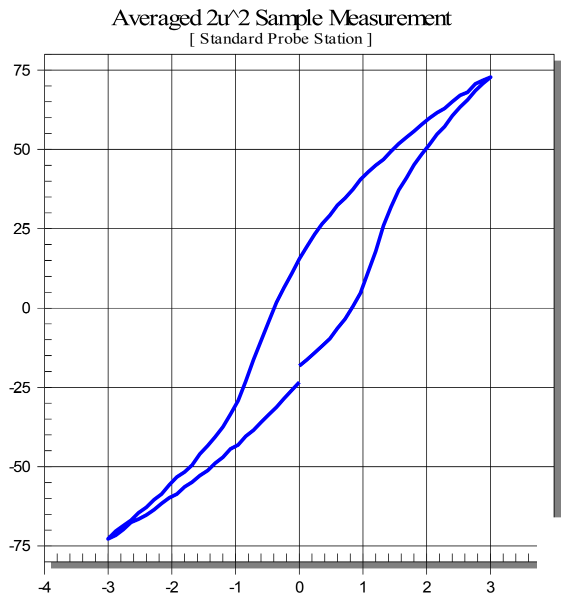
- For very small samples, noise becomes an issue and averaging is necessary.

Pause - "Load Sample"
Sample Hysteresis
Accumulate/Average Filter
Branch to Sample Hysteresis

Pause - "Unload Sample"
Parasitic Hysteresis
Accumulate/Average Filter
Branch to Parasitic Hysteresis

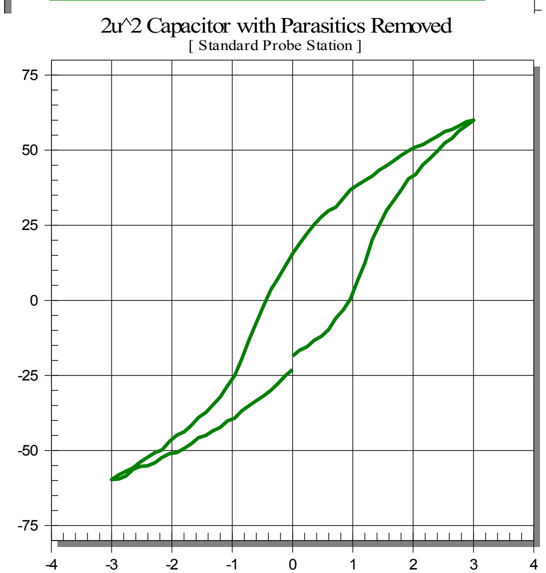
Two Trace Math Filter to subtract parasitics from measurement .

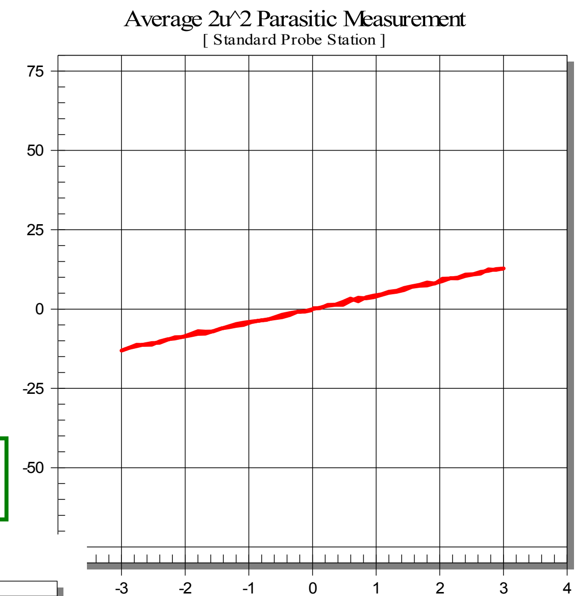
Example of Parasitic Subtraction



Measured Sample

Corrected Data





Measured Parasitics

In this case, the probe station added 13µC/cm^2 of polarization to the 60 µC/cm^2 of the sample, an error of +17%!

The number of Branch loops determines the amount of averaging.

Calculating Polarization from Capacitance

- In the case where the parasitic capacitance is measured as a capacitance, it must be translated into the expected polarization values to be subtracted from the measured data.

- To calculate the polarization profile generated by the parasitic capacitance, the capacitance may be integrated over the intended voltage profile of the test.

$$P(v)_{parasitic} = \int C_{parasitic}\, dv + P_{initial}$$

New Vision Parasitics Tasks

> Radiant is developing two parasitics tasks for the Vision Library:

The Parasitics Task measures and stores polarization of the parasitic capacitance using the selected test format (Hysteresis, PUND, etc.).

– The task will apply averaging if requested.

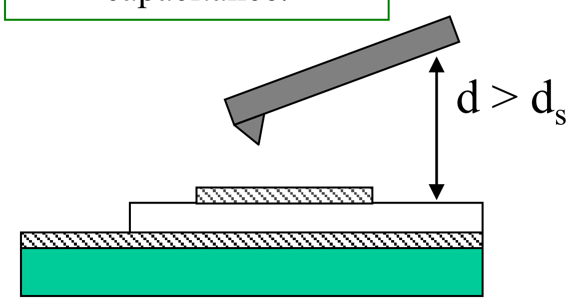
The Compensation Filter will subtract the selected parasitic polarization file from measured data:

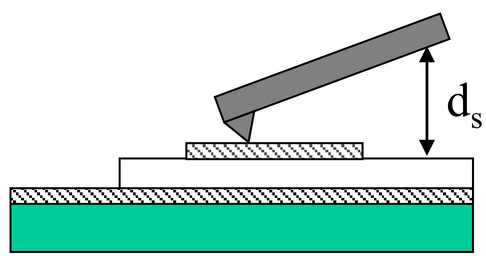
– The Compensation Filter will also allow the user to enter parasitic capacitance and resistance values. The filter will then calculate and subtract out their contributions to the measured polarization using the voltage profile of the specified measurement.

Eliminating Variable Parasitic Capacitance

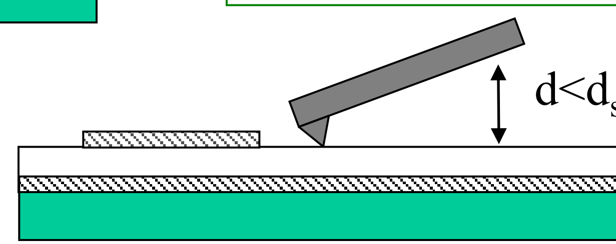
- In some situations, especially AFMs, the amplitude of the parasitic capacitance is exquisitely sensitive to position of the probe relative the sample
  - In other words, the probe cannot be “moved” from the sample without changing the value of the parasitic capacitance it generates.

Lifting the cantilever lowers the parasitic capacitance.





Moving the cantilever to the side reduces the thickness of the parasitic capacitance by the top electrode thickness.



Deriving Variable Parasitic Capacitance from Measured Data

- When parasitic capacitance cannot be measured directly, it can be derived directly from the data .

Step 1: Measure hysteresis on the sample

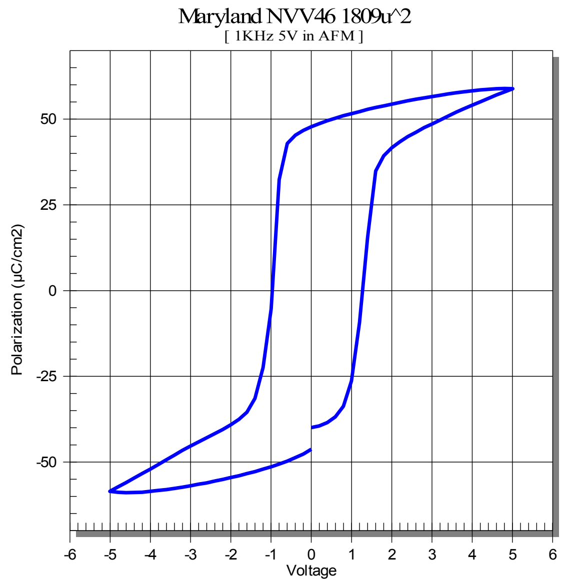
Step 2: Measure a much larger capacitor on the sample for which the parasitics will be miniscule.

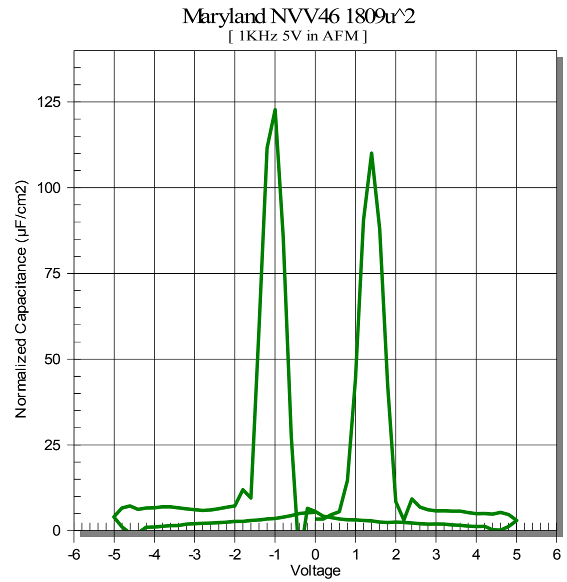
Step 3: Compare the derivatives of the hysteresis loops to derive the capacitance of the test fixture.

Step 4: Calculate the parasitic polarization and subtract it from the measured data.

The Power of the Derivative

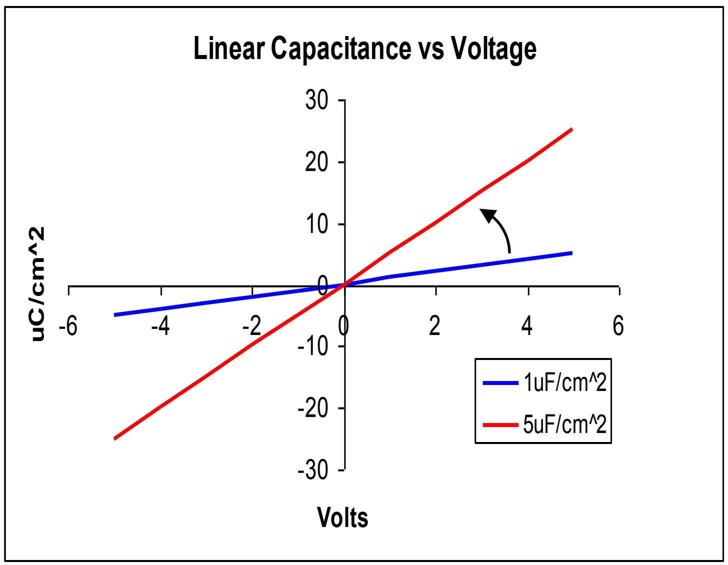
- The derivative of the hysteresis with respect to voltage is the large signal C(V) of the capacitor. The values must be normalized to area.
  - $C(V)_{LS} = [\ \delta P(V) / \delta V\ ] / \text{Area}$

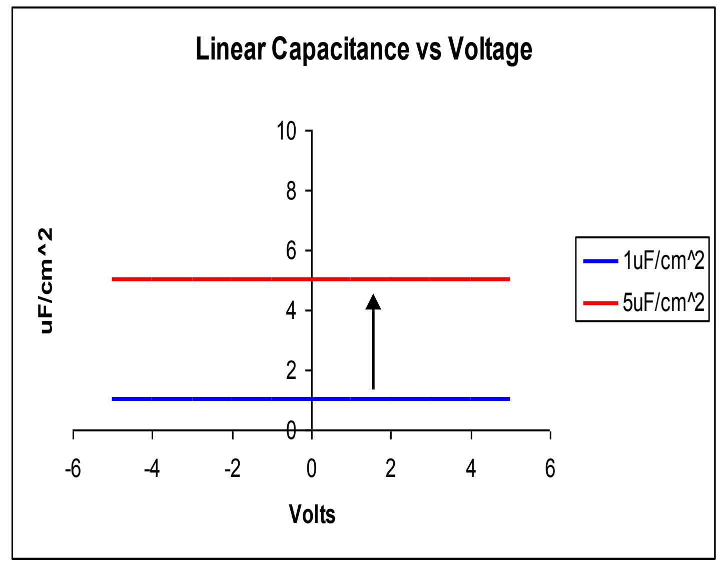




The Power of the Derivative

- On the capacitance vs voltage plot, vertical displacement is linear capacitance.

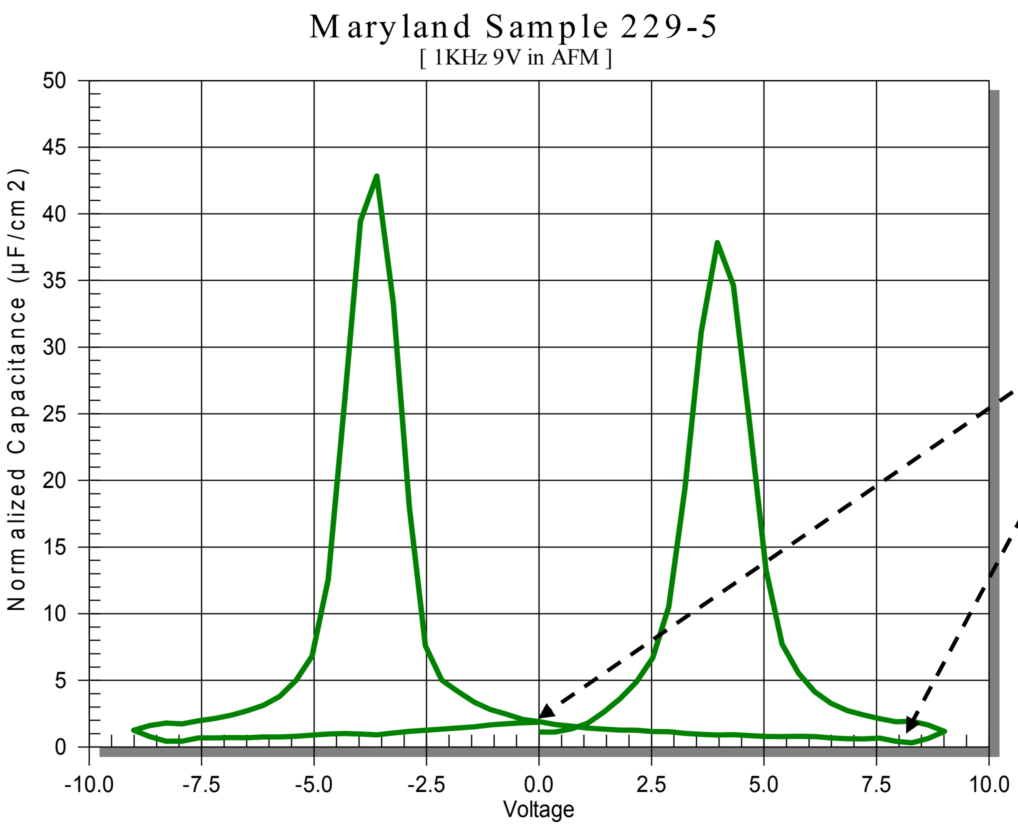




- Parasitic capacitance will show up as vertical displacement of the normalized C(V) of the sample.

The Power of the Derivative

- The intrinsic dielectric constant of the sample can be measured from the derivative of the hysteresis loop of a large area capacitor.

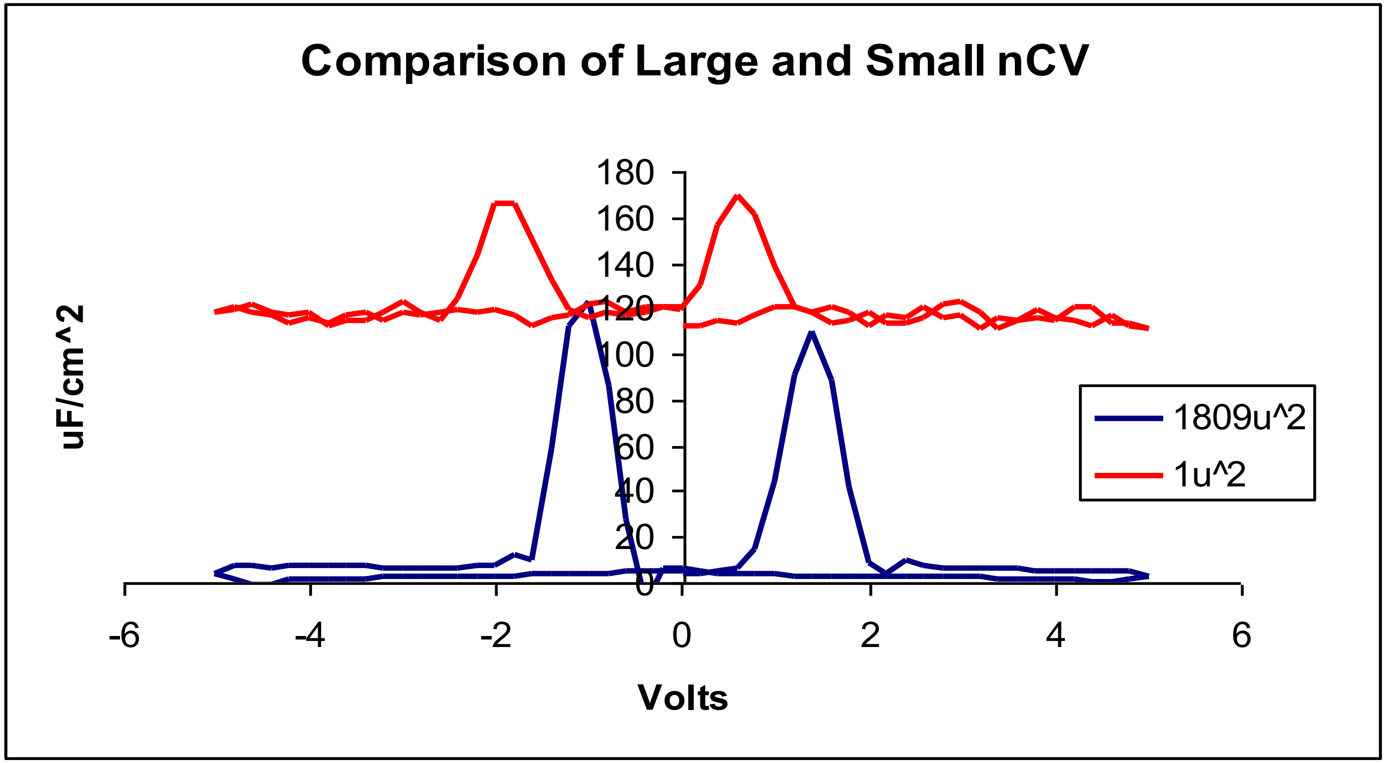


Potential reference points for intrinsic capacitance.

- Location of crossing point. ("X" marks the spot!)
- Location of minimum value of derivative.

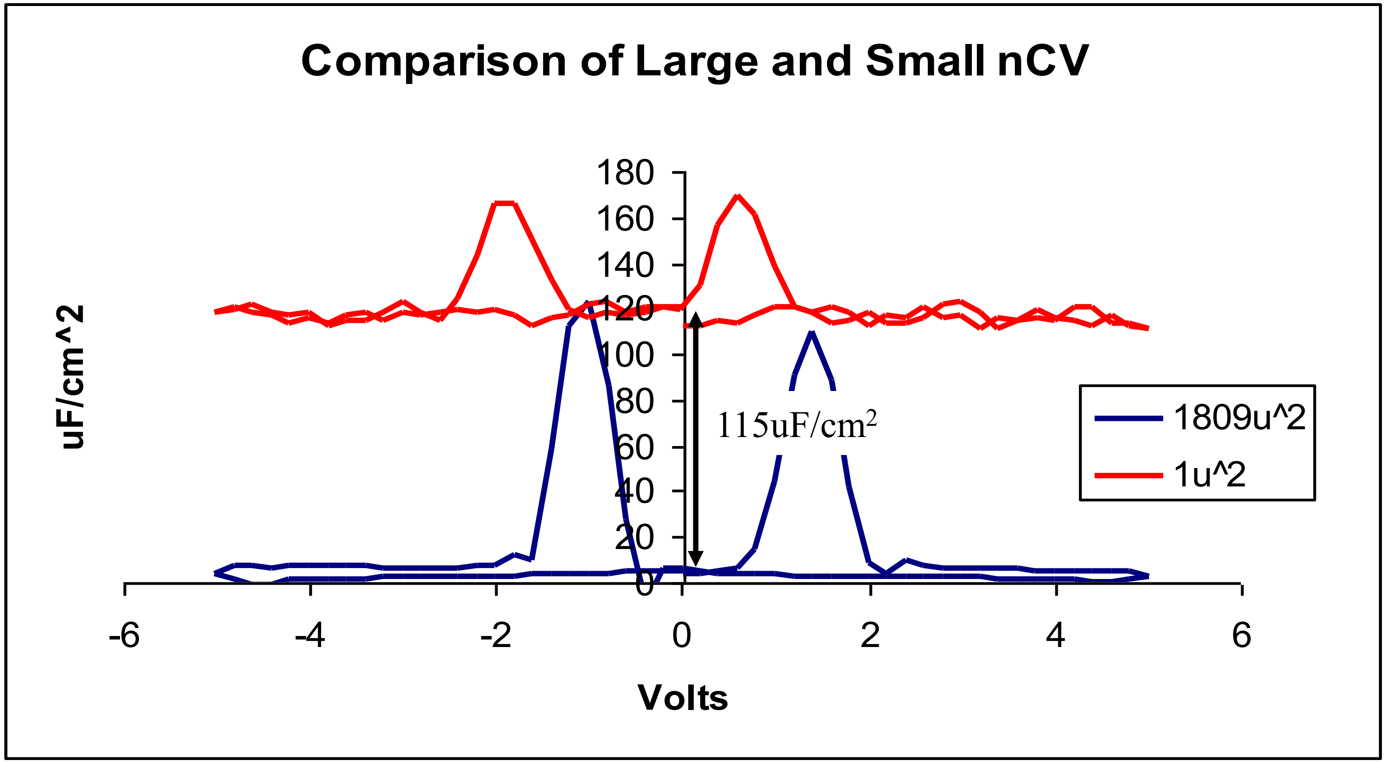
Case Study

- Plots of the normalized C(V) of the of two different capacitor sizes on the same substrate.   The samples were measured on an AFM at the University of Maryland.



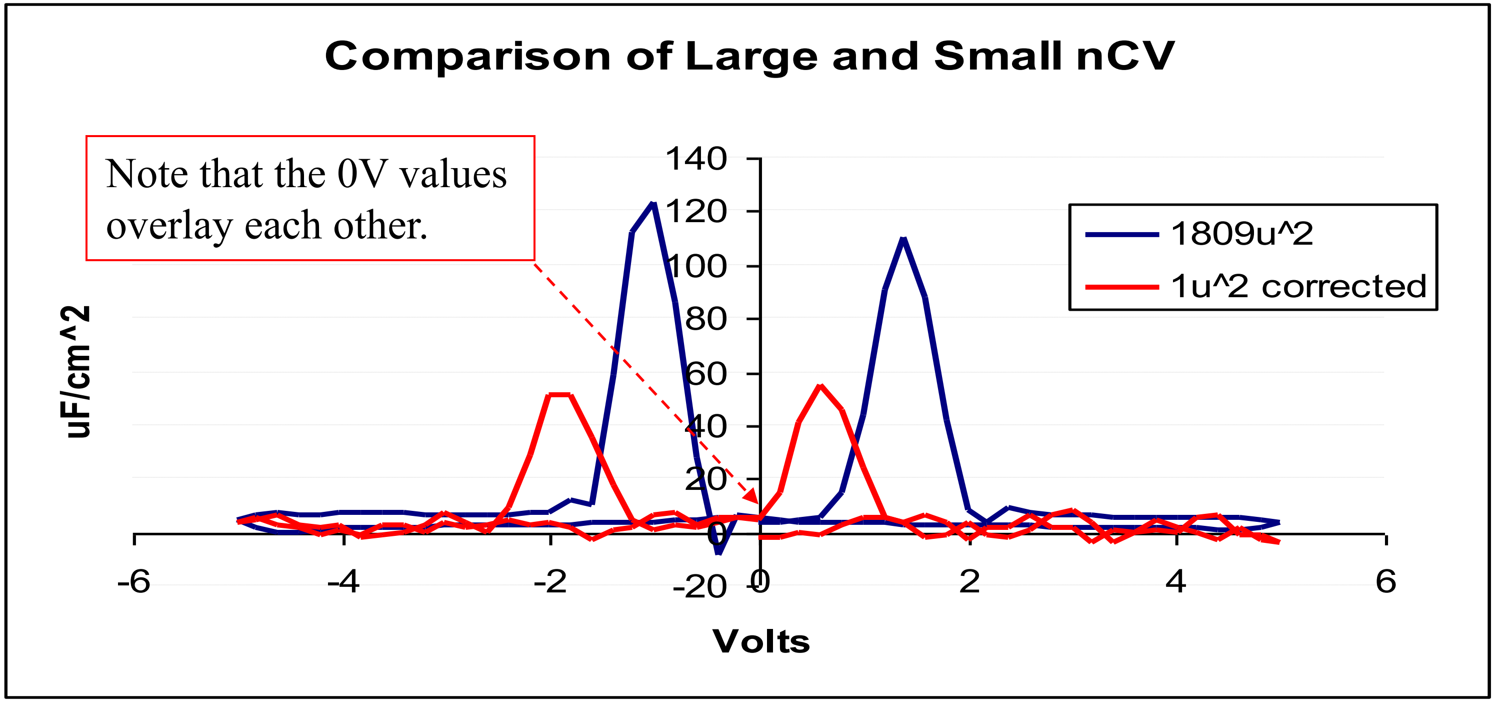
Case Study

- Parasitic capacitance appears to be 115µF/cm^2.



Case Study

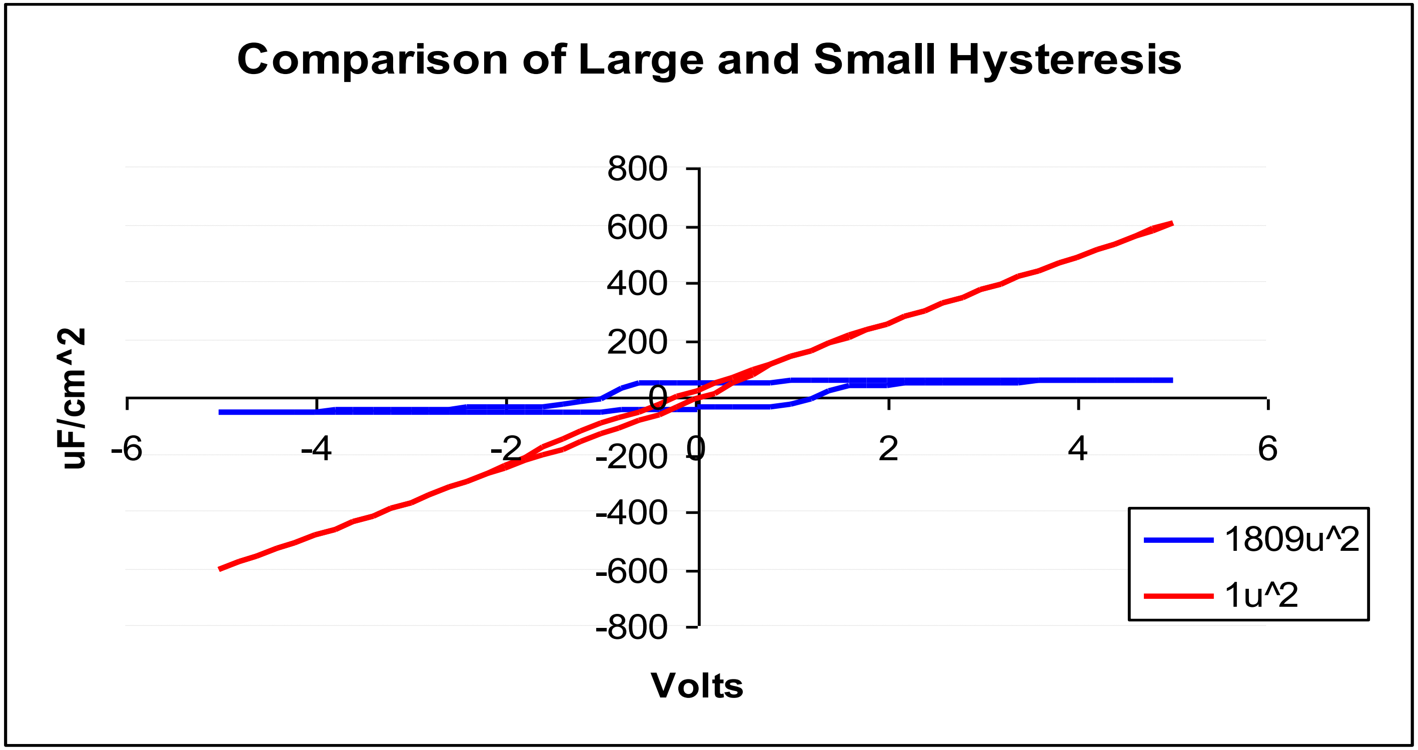
- The two derivatives with the parasitic taken out.



- The two capacitors are shifted in coercive voltage with respect to each other.

Case Study

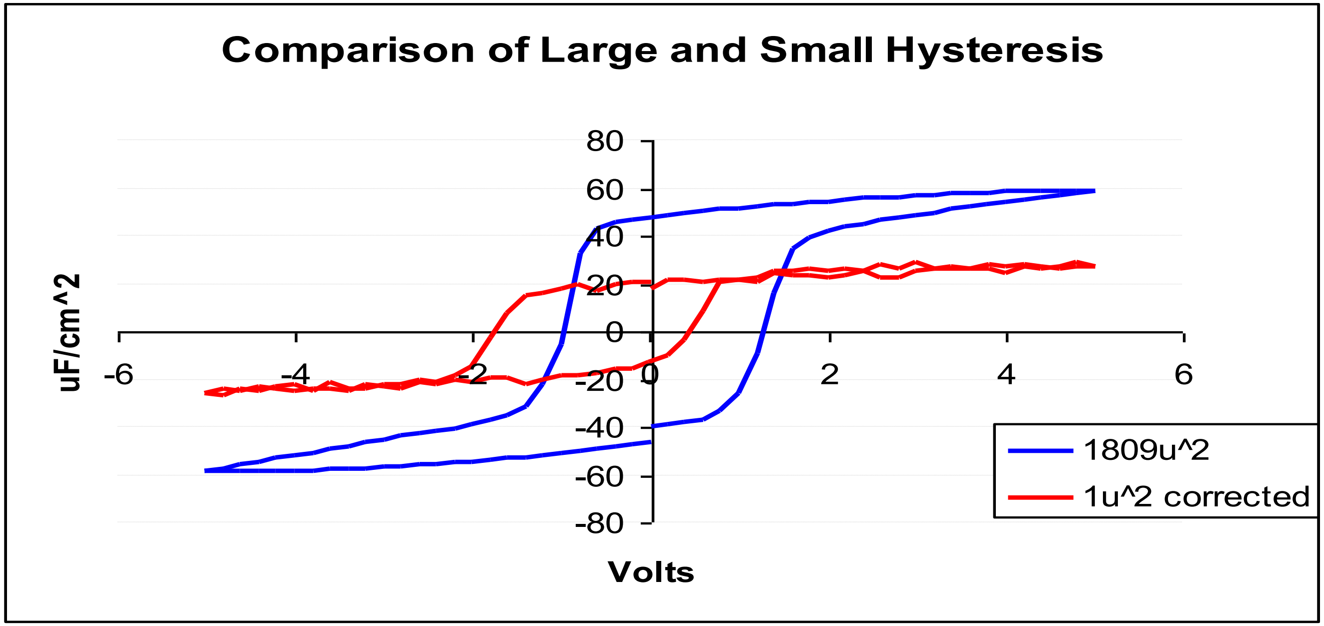
- The original hysteresis loops.



- The effect of the parasitic capacitance of the AFM is readily apparent.

Case Study

- The small capacitor hysteresis loop corrected for the 115µF/cm^2 of parasitic capacitance.



- There was an uncertainty in the actual area of the small capacitor during this experiment. The differences in the maximum polarization values in the hysteresis plots could be due either to an error in our estimate of the area of the small capacitor or a real effect occurring from the fabrication of the small capacitor.

Conclusion

- Parasitic capacitance arises from both the internal characteristics of the tester being used as well as the test fixture in which the sample is mounted.
- Normally, parasitic capacitance is not a factor in measurements of capacitors larger than $1000\mu^2$.
- The best test fixture for minimizing parasitic capacitance is the manual probe station.
- For very small sample capacitors, correcting measured data for the impact of parasitic capacitance can be very complex, especially when an AFM is used as the test fixture.
- The parasitic capacitance can be derived directly from the measured data and then subtracted out.

Acknowledgements

Radiant would like to thank Dr. Ramesh of the University of Maryland and the MRSEC at the University of Maryland for allowing the use of their equipment and capacitors. I personally would also like to thank Dr. Ramesh's graduate students for their enthusiastic assistance.