Hewlett-Packard

Electronic Materials Measurement Seminar

LF and RF Parallel Plate Measurement Technique for Dielectric Substrates

Kobe Instrument Division

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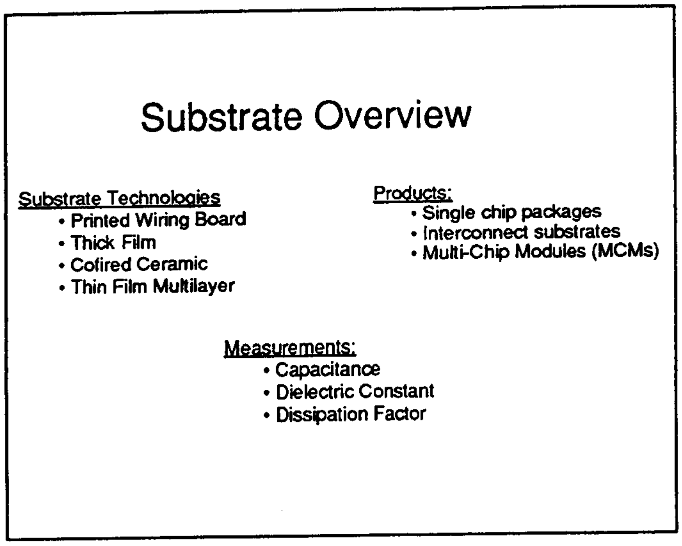
Electronic Materials Measurement Seminar

Substrate Materials Application Session

LF and RF Parallel Plate Measurement Technique for Dielectric Substrates

Agenda

- *Substrates Overview*
- Parameters to Evaluate Dielectric Substrates
- LF Parallel Plate Technique
- Sources of Measurement Errors and Solution
- RF Parallel Plate Technique



Substrate Overview

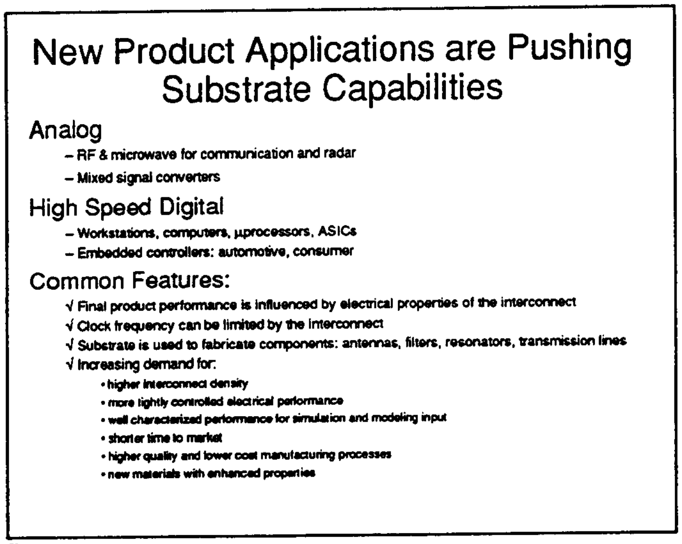
Substrate Technologies
- Printed Wiring Board
- Thick Film
- Cofired Ceramic
- Thin Film Multilayer

Products:
- Single chip packages
- Interconnect substrates
- Multi-Chip Modules (MCMs)

Measurements:
- Capacitance
- Dielectric Constant
- Dissipation Factor

These substrates all consist of patterned conductor layers separated by dielectric layers with conducting vias between them. The differences are in the materials used and their manufacturing processes. All of these technologies are used to produce interconnect substrates for packaged devices, for single chip packages and for multichip modules. The only difference is in the specific shape and layer count.

We will look at how capacitance and dielectric constant measurements can be used to look into these structures with an electrical eye and gain useful information about process conditions, and performance related information.



New Product Applications are Pushing Substrate Capabilities

Analog
- – RF & microwave for communication and radar
- – Mixed signal converters

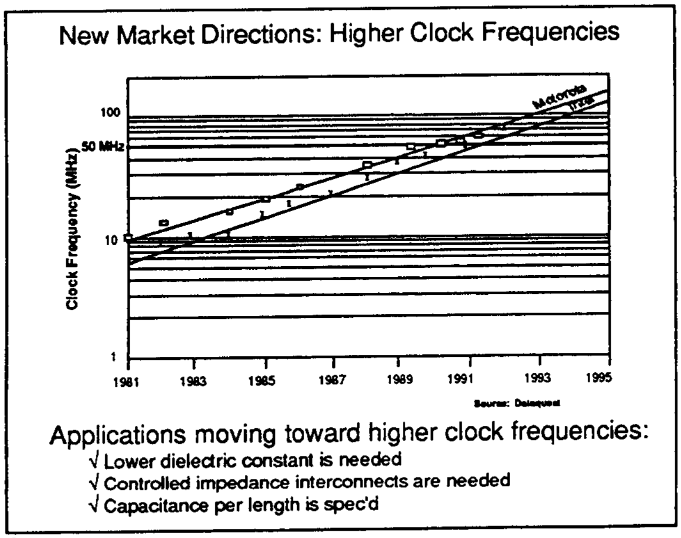
High Speed Digital
- – Workstations, computers, µprocessors, ASICs
- – Embedded controllers: automotive, consumer

Common Features:
- √ Final product performance is influenced by electrical properties of the interconnect
- √ Clock frequency can be limited by the interconnect
- √ Substrate is used to fabricate components: antennas, filters, resonators, transmission lines
- √ Increasing demand for:
  - higher interconnect density
  - more tightly controlled electrical performance
  - well characterized performance for simulation and modeling input
  - shorter time to market
  - higher quality and lower cost manufacturing processes
  - new materials with enhanced properties

The world of electronics is progressing at an incredible rate. This is primarily driven by the increasing expectations from the end users who expect more features, and by the IC Industry who is able to supply it. Caught in between is the packaging and interconnect industry who must supply all the infrastructure technology to integrate systems.

Substrate technologies must also advance to keep up with the requirements of the new applications. New personal communicators are driving rf and microwave products. The tidal wave of computers is driving the digital revolution.

Both types of applications have the same requirements on boards: shorter time to market, lower cost and higher quality manufacturing require more efficient R&D and more use of process monitoring. The interconnect now plays more of a role as a circuit element, and must be factored into the system level performance equation. This means dielectric constant is an important performance parameter.



New Market Directions: Higher Clock Frequencies

Source: Dataquest

Applications moving toward higher clock frequencies:
- √ Lower dielectric constant is needed
- √ Controlled impedance interconnects are needed
- √ Capacitance per length is spec'd

RF and microwave applications have always been operating at high bandwidths in the hundreds of megahertz range. In the last few years, digital applications have begun to catch up. Off the shelf digital products have clock frequencies over 50 MHz, and analog bandwidths in the 250 MHz range.

This trend is on an exponentially increasing track. In a few years, the bandwidth of signals in digital applications will be just as high as for rf and microwave applications. In this regime, electrical aspects of the interconnect substrates, such as time of flight and characteristic impedance are important terms in both analog and digital applications.

Impact on Substrate Technologies

State of the art is continually being pushed:
- New materials are being developed
- New processes are being developed

R&D: shorter development cycle times
- √ More efficient evaluation of materials and processes needed

Manufacturing: lower cost, higher quality
- √ Tighter process control and SPC a must
- √ More use of incoming and outgoing QC testing
- √ 100% open/short testing on tighter than 100 mil centers common

Users want more performance related information:
- Trace capacitance
- Dielectric Constant
- Full SPICE Deck, transmission line parameters

This advance in IC technology and product features means substrates must continually advance as well. The three big issues are higher performance, faster time to market and lower cost, higher quality manufacturing.

In addition, the end users of the substrates, who are responsible for integrating them into products need more information about their electrical performance so that accurate simulations can be performed, and to verify that the substrates meet the electrical specs.

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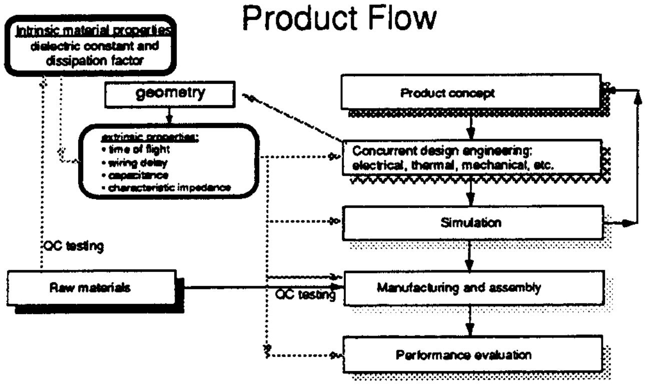
Intrinsic Material Measurements in the Product Flow



Intrinsic material properties
dielectric constant and dissipation factor

geometry

extrinsic properties:
- time of flight
- wiring delay
- capacitance
- characteristic impedance

QC testing

Raw materials

QC testing

Product concept

Concurrent design engineering: electrical, thermal, mechanical, etc.

Simulation

Manufacturing and assembly

Performance evaluation

There are two types of properties: intrinsic and extrinsic. Dielectric constant and dissipation factor are intrinsic properties in that these are properties of the material independent of the sample size of the material. As a fundamental property of the material, these two parameters act as a window into the state of the materials. They can be used as quality control terms to evaluate the reproducibility of the material and its state during the manufacturing processing.

All of the performance related properties are extrinsic in that these properties depend also on the geometry.

In the product evolution flow, the geometry and material properties are important ingredients to simulations of the system performance. These performance related properties are often monitored along the manufacturing path to verify that the final product has the specified properties.

How the intrinsic material properties are factored into the extrinsic performance properties is explored in the following slides.

Permittivity

Describes the interaction of a material with an electric field

$$K = \varepsilon_r = \frac{\varepsilon''}{\varepsilon_o}$$

$$K' = \varepsilon'_r = \frac{\varepsilon''}{\varepsilon_o} = \underset{\text{(storage)}}{\varepsilon'_r} \text{-j } \underset{\text{(loss)}}{\varepsilon''_r} = \left(\frac{\varepsilon'}{\varepsilon_o}\right) \text{-j } \left(\frac{\varepsilon''}{\varepsilon_o}\right)$$

K = dielectric constant

ε'_r = relative permittivity

ε_o = permittivity of free space $= \frac{1}{36} \times 10^{-9}$ Farad/meter

$\approx$ 8.854 pF/m

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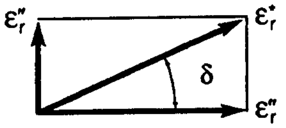
Permittivity (ε) describes the interaction of a material with an electrical field. Dielectric constant (K) is equivalent to relative permittivity (ε_r) or the absolute permittivity (ε) of free space (ε_o). The real part of permittivity (ε'_r) is a measure of how much energy from an external electric field is stored in a material. The imaginary part of permittivity (ε''_r) is called the loss factor and is a measure of how dissipative or lossy a material is to an external electric field.

Loss Tangent



$$\tan\delta = \frac{\varepsilon''_r}{\varepsilon'_r} = \frac{\varepsilon''}{\varepsilon'} = \frac{K''}{K'}$$

$\tan\delta$ = D (Dissipation Factor)

$= \frac{1}{Q}$ (Inverse Quality Factor)

$\propto \frac{\text{Energy Lost per Cycle}}{\text{Energy Stored per Cycle}}$

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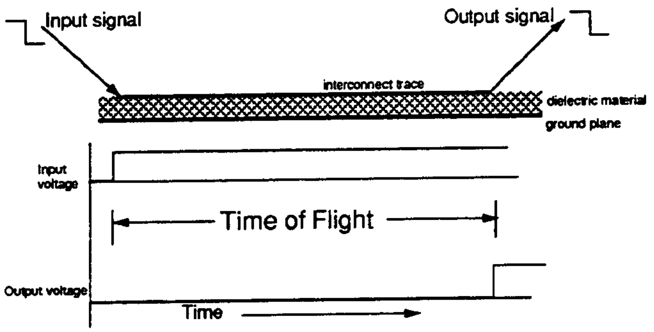
When complex permittivity is drawn as a simple vector diagram, the real and imaginary components are 90 degrees out of phase. The vector sum forms an angle δ with the real axis (ε'_r). The relative "lossiness" of a material is the ratio of the energy lost to the energy stored.

Time of Flight



Toward Higher Clock Frequencies:
Lower Dielectric Constant and Shorter Time of Flight

Time of Flight $\propto \sqrt{\varepsilon_r}$

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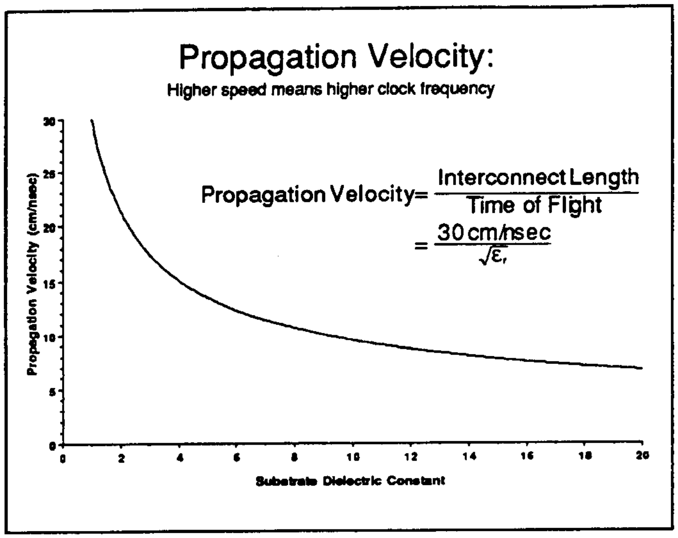
In digital applications, higher clock frequency means shorter clock periods. The time it takes for a signal to propagate from one chip to the next on the board can limit how short a period is possible. To get shorter periods, a shorter time of flight is required.

The time of flight for a signal how long it takes to get from the output on one chip to the input of another. It depends on the length of the interconnect, and the dielectric constant of the material surrounding the signal trace.

Merely by changing the dielectric constant of the insulation, the time of flight will change. The lower the dielectric constant, the shorter the time of flight.

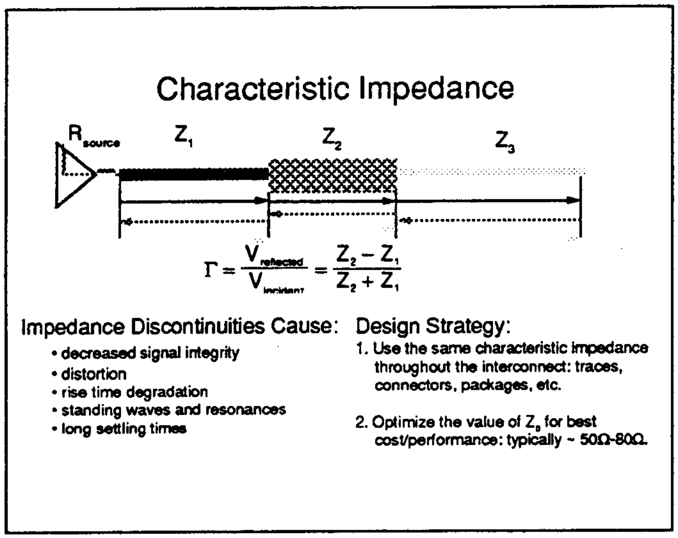


Propagation Velocity:

Higher speed means higher clock frequency

$$\text{Propagation Velocity} = \frac{\text{Interconnect Length}}{\text{Time of Flight}} = \frac{30\,\text{cm/nsec}}{\sqrt{\varepsilon_r}}$$

A related term is the speed of a signal, or propagation velocity. This is directly related to the sqrt of the dielectric constant. The faster the signals move in the substrate, the better chance there will be for a higher clock frequency. This is why it is so important to move toward lower dielectric constant materials.



Characteristic Impedance

$$\Gamma = \frac{V_{reflected}}{V_{incident}} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

Impedance Discontinuities Cause:

- decreased signal integrity
- distortion
- rise time degradation
- standing waves and resonances
- long settling times

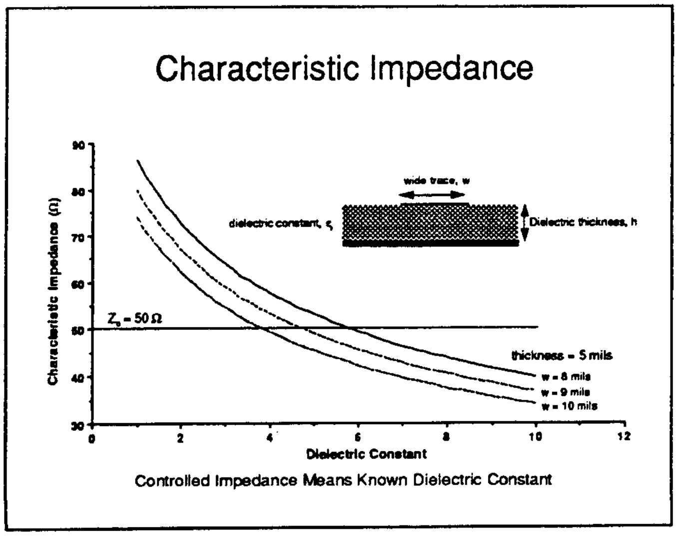
Design Strategy:

1. Use the same characteristic impedance throughout the interconnect: traces, connectors, packages, etc.
2. Optimize the value of Z_0 for best cost/performance: typically ~ 50Ω-80Ω.

Characteristic impedance is perhaps the most commonly used term in high speed circuits, and the most confused term. It is a property of the interconnect and relates how the voltage and current signals interact as its moves down the interconnect trace. The key feature is that when the characteristic impedance changes, either by a geometry change or material change, some of the signal will be reflected.

At each interface, there will be a series of reflections. These will result in a decrease in overall signal integrity.

The way to get around this problem is to use controlled impedance interconnects. Every section of trace, connector and package should have the same characteristic impedance. Most systems use a value of 50Ω to 80Ω. The precise value is a trade off between manufacturability, cost, noise sensitivity and power dissipation.



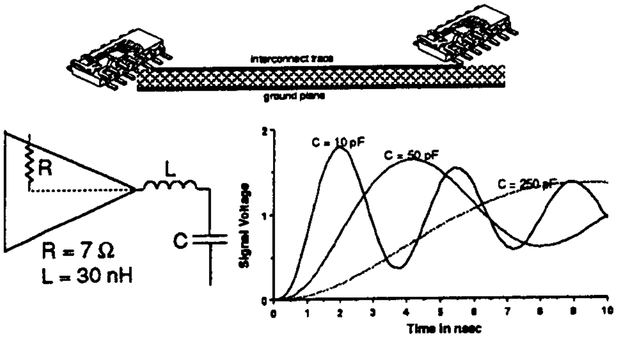
Characteristic Impedance

Controlled Impedance Means Known Dielectric Constant

Characteristic impedance depends on the intrinsic material property of dielectric constant, and the cross sectional geometry. For the specific case of microstrip, the line width and dielectric thickness influence the characteristic impedance.

In the particular case analyzed here, the dielectric thickness is 5 mils. For a dielectric constant of 4.9 and a target of 50Ω, a 9 mil wide trace will do it. If the line width should vary by ±1 mil, the characteristic impedance would vary by about ±10%. If the dielectric constant were to vary by ±10%, the characteristic impedance would vary by about ±5%. It is not as sensitive to characteristic impedance as the line width.

Capacitance of Traces and Signal Integrity Simulation



Accurate simulations require accurate capacitance values of packages and interconnect traces

The last example of a performance property is the capacitance of the interconnect. It is one of a number of parasitic properties that must be used in simulations.

In this example, the wave form seen at the end of an interconnect is simulated. It depends on the chip driver features, the package the chip is in, and the capacitance of the interconnect. If the interconnect capacitance changes, the simulated waveform will change.

End Users are Demanding More Characterization Information

√ Dielectric constant, propagation velocity, wiring delay
√ Capacitance per trace

- Resistance per trace
- Inductance per trace
- Characteristic impedance of traces
- Cross talk coupling coefficients

In high speed applications, the substrate electrical properties influence circuit performance. This means that in order to simulate the product performance, the interconnect electrical circuit parameters are required. All high speed system designers are demanding more of this type of information.

The terms that will be measured in this seminar are related to dielectric constant and capacitance. Other parameters such as resistance, inductance, characteristic impedance and cross talk can also be measured with similar techniques, but not described here.

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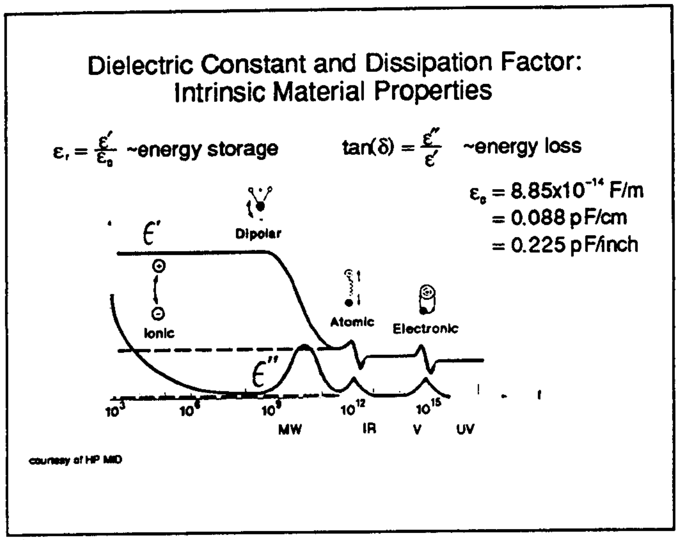


Dielectric Constant and Dissipation Factor: Intrinsic Material Properties

$\varepsilon_r = \frac{\varepsilon'}{\varepsilon_0}$ ~energy storage

$\tan(\delta) = \frac{\varepsilon''}{\varepsilon'}$ ~energy loss

$\varepsilon_0 = 8.85\text{x}10^{-14}$ F/m
= 0.088 pF/cm
= 0.225 pF/inch

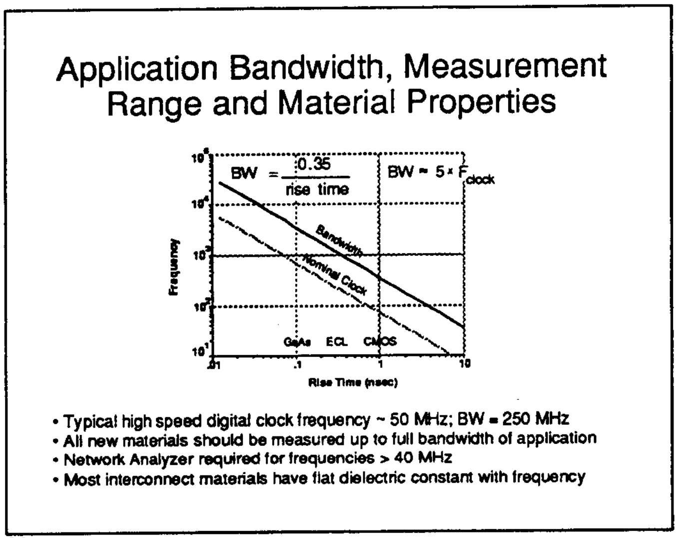
courtesy of HP MID

The dielectric constant of a material is actually a complex number. The real part of it is often what we call the dielectric constant. It relates to the energy storage in electric fields by the material. We often normalize it to the permittivity of free space so that we deal with small, dimensionless numbers. Often we refer to the "relative" dielectric constant.

The imaginary component relates to the energy dissipated in the material by the electric fields. The ratio of the imaginary to the real is what we refer to as the dissipation factor or the tangent of the loss angle.

Neither of these terms are actually constant. They both vary with the frequency of the electric field. At frequencies below 1 GHz, typical for most electronic applications, these terms are generally flat with frequency, and drop off at higher frequencies.

With this frequency dependence, it is important to address the question, at what frequency should the dielectric constant measurements be performed?



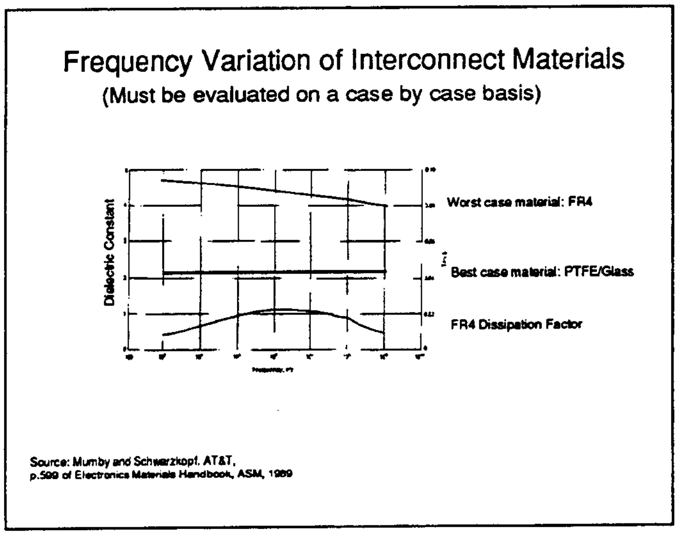
Application Bandwidth, Measurement Range and Material Properties

- Typical high speed digital clock frequency ~ 50 MHz; BW = 250 MHz
- All new materials should be measured up to full bandwidth of application
- Network Analyzer required for frequencies > 40 MHz
- Most interconnect materials have flat dielectric constant with frequency

Material and performance related measurements should always be performed up to at least the bandwidth of the application. In analog applications, the bandwidth is often the clear.

In digital applications, the bandwidth can be found from either the rise time or the clock frequency, depending on which is known. With a clock frequency of 50 MHz, the bandwidth is about 250 MHz.

For all new materials that have no prior data base, measurements should be made up to the full bandwidth. If this is over about 40 MHz, it will require the use of a network analyzer, and is more complicated than an impedance analyzer. However, most interconnect materials have a dielectric constant that is relatively flat with frequency, so that low frequency measurements can be used to relate to high frequency performance.



Frequency Variation of Interconnect Materials

(Must be evaluated on a case by case basis)

Source: Mumby and Schwarzkopf, AT&T,
p.599 of Electronics Materials Handbook, ASM, 1989

Here is an example of the actual frequency variation in dielectric constant for the most varying material, FR4, and the most constant material, Teflon.

Even as worst case, FR4 varies only about 10% from 100 kHz to 1 GHz. For some applications, this can be considered flat. All other interconnect dielectrics vary much less than this.

This means that a measurement done at 1 MHz, for example, has relevance at 100 MHz.

However, until it is established that the dielectric constant is constant over frequency, high frequency measurements are still needed at some point for all new materials.

The frequency variation must be analyzed for all materials on a case by case basis.

Why Impedance Analyzer/LCR Meter** and Parallel Plate Technique

1. Simple sample preparation for thin, flat structures
2. Simple fixturing
3. Simple instrument
4. Low cost
5. Adequate for most materials that are constant over frequency
6. IDEAL for *fast, routine* measurements

** Impedance analyzers use a synthesized frequency source and can sweep in frequency.
LCR meters use fixed frequency values

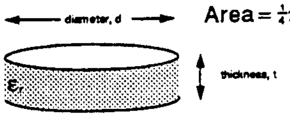
If low frequency measurements are acceptable, an impedance analyzer can be used. The chief value of the impedance analyzer is its ease of use and low cost compared to a network analyzer.

Samples are typically in sheet form and can be measured using a parallel plate technique, often with no special preparation at all.

This combination is ideal for fast, routine measurements, and may open up a few applications that did not exist before because it was too complicated.

Parallel Plate Technique

Measuring Dielectric Constant from Capacitance and Geometry



$\text{Area} = \frac{1}{4}\pi d^2$

Ideal parallel plate capacitor:

$$C = \varepsilon_0 \varepsilon_r \frac{\text{Area}}{t} \qquad \varepsilon_r = \frac{Ct}{\varepsilon_0 \text{Area}}$$

$$\varepsilon_0 = 8.85\text{x}10^{-14}\ \text{F/m} = 0.088\ \text{pF/cm} = 0.225\ \text{pF/inch}$$

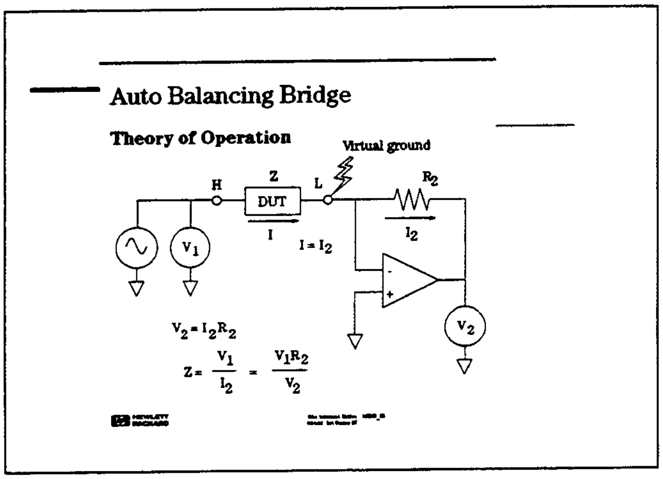
Non-ideal effects:

- stray parasitics with the cabling
- fringe fields around the edges (for less than 3%, need d >100 t)

The basis of measuring dielectric constant is from measuring the capacitance of a pancake sample of the material made with electrodes on opposite sides. The capacitance is related exactly to the geometry and dielectric constant when the sample is in this parallel plate configuration.

From the measured capacitance, surface area of electrodes and plate separation, the dielectric constant can be calculated. The measured dissipation factor is the actual material dissipation factor.

However, there are two artifacts which make this simplified analysis too simple. One is stray parasitics from the cabling and the other is fringe fields. These are compensated for with the four terminal impedance analyzer and the HP 16451B fixture.



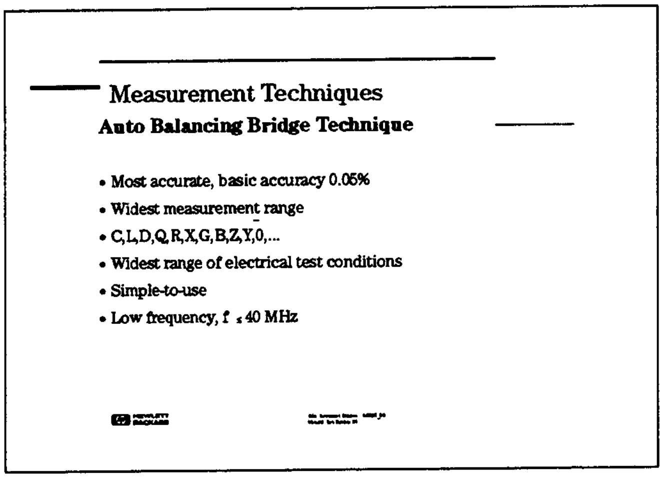
Auto Balancing Bridge

Theory of Operation

$V_2 = I_2R_2$

$Z = \frac{V_1}{I_2} = \frac{V_1R_2}{V_2}$

For low frequency, the four terminal or auto balancing bridge technique is very effective for measuring dielectric substrates using the parallel plate fixture. The auto balancing bridge can be conceptionilized as an optional amplifier: V=I*R.



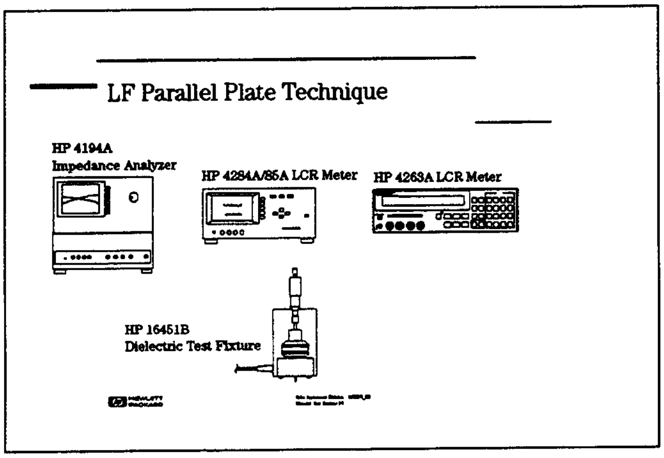
Measurement Techniques

Auto Balancing Bridge Technique

- Most accurate, basic accuracy 0.05%
- Widest measurement range
- C,L,D,Q,R,X,G,B,Z,Y,θ,...
- Widest range of electrical test conditions
- Simple-to-use
- Low frequency, f ≤ 40 MHz

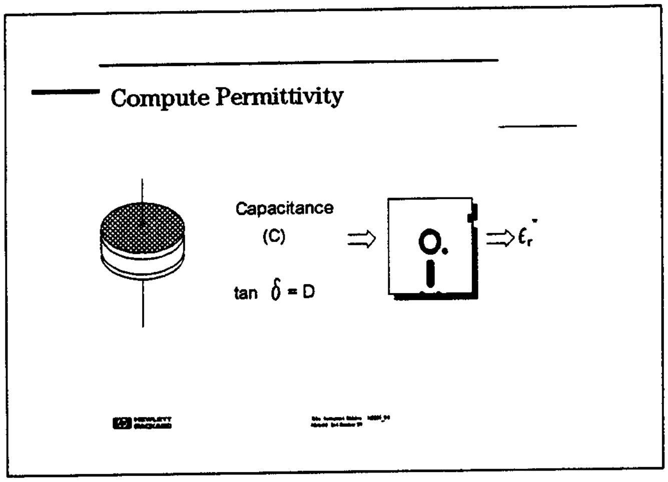
The auto balancing bridge technique is by far the best technique for measurements below 40 MHz. It provides the most accurate measurements possible and the widest impedance measurement range. Both of these are critical for accurate material analysis.

A wide range of AC and DC stimuli can be applied to the material. In addition, this low frequency technique is the simplest measurement technique to use.



LF Parallel Plate Technique

Hewlett-Packard offers several LCR meters and Impedance Analyzers plus the HP 16451B Dielectric Test Fixture for LF Parallel Plate solutions.

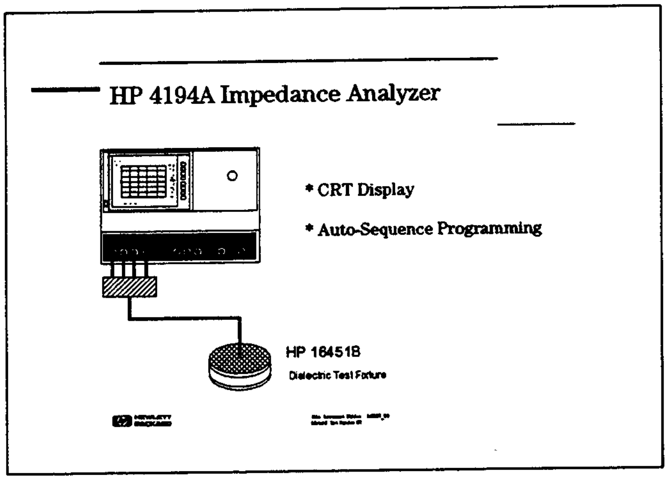


Compute Permittivity

Capacitance (C) $\Rightarrow$ $\Rightarrow \varepsilon_r'$

tan δ = D

The parallel plate method involves sandwiching a thin sheet of material between two electrodes to form a capacitor. An LCR meter or impedance analyzer is used to measure the loaded fixture. ε_r' is computed from the measurement of capacitance and ε_r'' is computed from the measurement of dissipation factor (D).

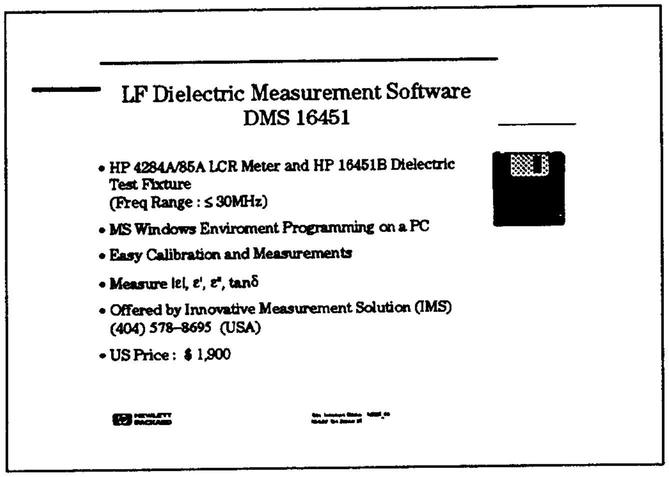


HP 4194A Impedance Analyzer

- * CRT Display
- * Auto-Sequence Programming

HP 16451B
Dielectric Test Fixture

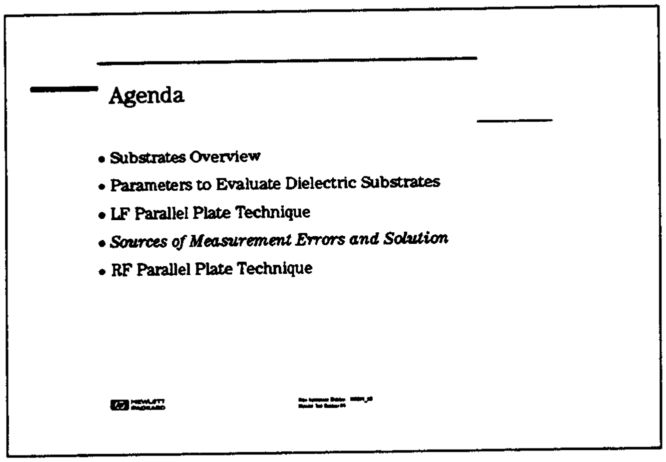
The HP 4194A Impedance Analyzer can display the capacitance and dissipation factor frequency response from 100 Hz to 40 MHz on its color CRT. In addition, the HP 4194A can compute and display permittivity vs frequency using the built-in programming capability called "Auto-Sequence Programming."



LF Dielectric Measurement Software
DMS 16451

- HP 4284A/85A LCR Meter and HP 16451B Dielectric Test Fixture
  (Freq Range : ≤ 30MHz)
- MS Windows Enviroment Programming on a PC
- Easy Calibration and Measurements
- Measure $|\varepsilon|$, ε', ε'', tanδ
- Offered by Innovative Measurement Solution (IMS)
  (404) 578–8695 (USA)
- US Price : $ 1,900

Innovative Measurement Solution (IMS) has just introduced the DMS 16451 (LF Dielectric Measurement Software). It works on a PC MS windows environment, and it's applicable for the HP 4284A/HP 4285A with the HP 16451B. It allows you to perform the easy calibration and auto calculation for permittivity, and loss tangent.



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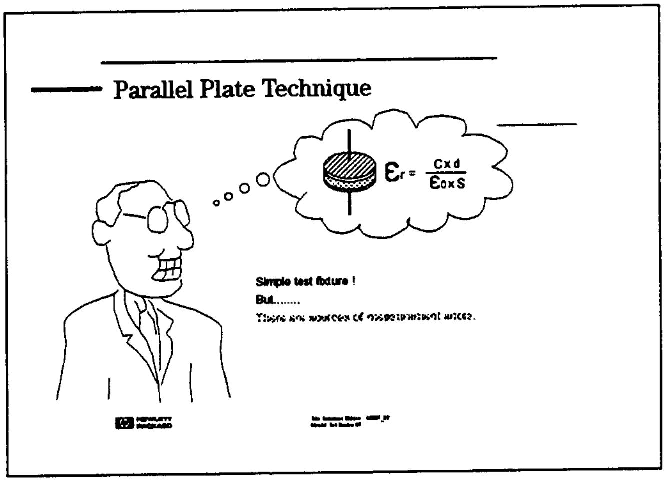

Parallel Plate Technique

$\varepsilon_r = \frac{C \times d}{\varepsilon_0 \times S}$

Simple test fixture !

But.......

There are sources of measurement errors.

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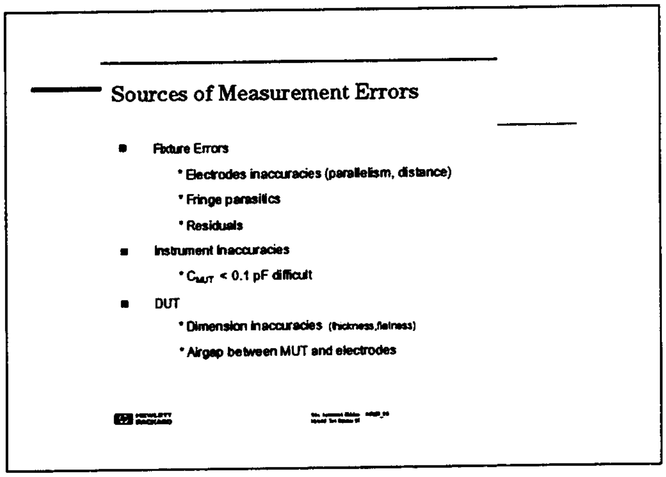

Sources of Measurement Errors

- Fixture Errors
  - Electrodes inaccuracies (parallelism, distance)
  - Fringe parasitics
  - Residuals
- Instrument Inaccuracies
  - $C_{MUT} < 0.1$ pF difficult
- DUT
  - Dimension inaccuracies (thickness,flatness)
  - Airgap between MUT and electrodes

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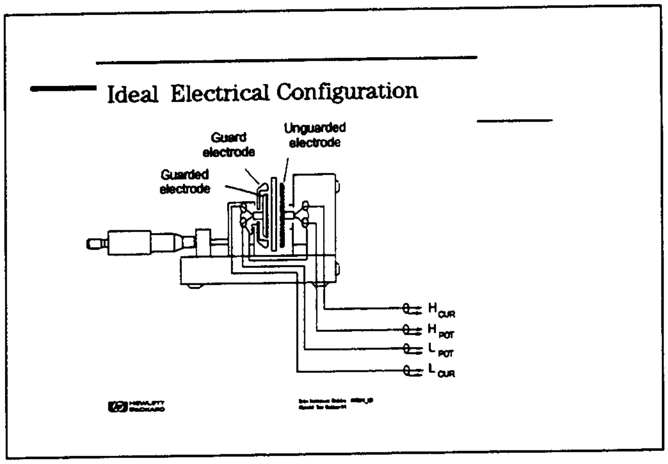
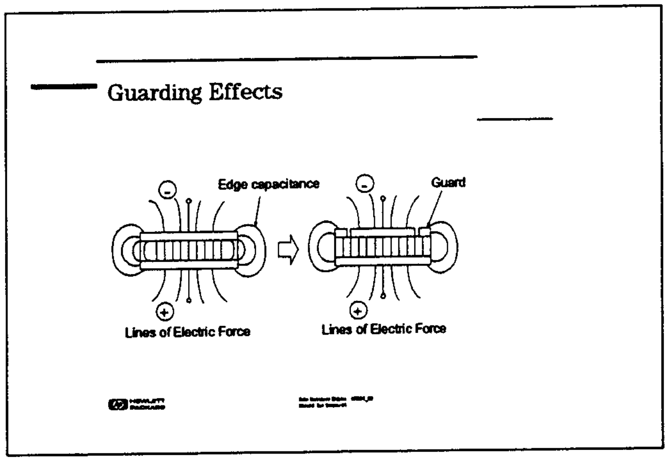
To measure dielectric constant accurately, we have to consider the sources of measurement errors. We will learn how we can minimize these errors in the following slides.



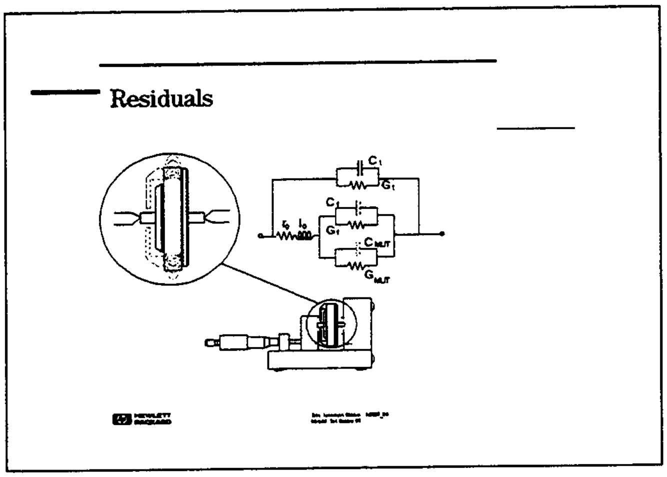
Ideal Electrical Configuration

This is the ideal electrical configuration of dielectric test fixture. It has three electrodes; a unguarded electrode which connects to high terminal, guarded electrode which connects to low terminal, and guard electrode which connects to guard terminal.



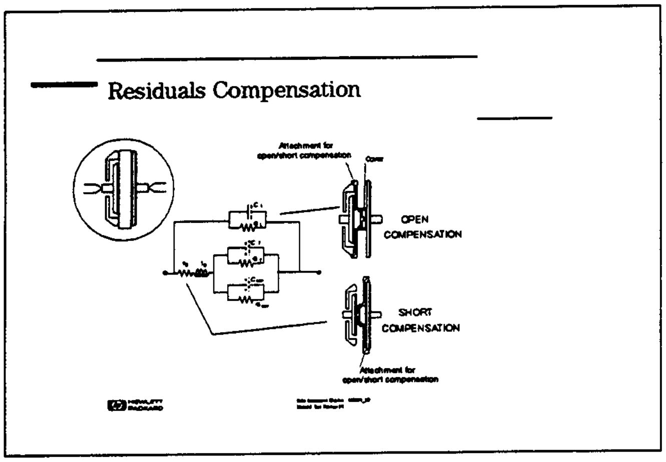
Guarding Effects

Guard electrode eliminates the error comes fringe parasitics. When we don't have a guard electrode, the current that flows through the stray capacitance causes measurement error. But when we guard electrode, it eliminates the current flowing perpendicular to the material. The current flows to the guard electrode eliminating measurement error because the current is not measured.



Residuals

All test fixtures have residuals such as residual impedance(r0, I0) and stray admittance(Ct, Gt). This slide shows where residuals exist on the dielectric test fixture. Note that Cmut and Gmut is what we want to measure.



Residuals Compensation

To remove errors from residuals, we have to perform open/short compensation. Open compensation eliminates the error from stray admittance. Short compensation eliminates the error from residual impedance. An attachment for open/short compensation are necessary for accurate compensation.

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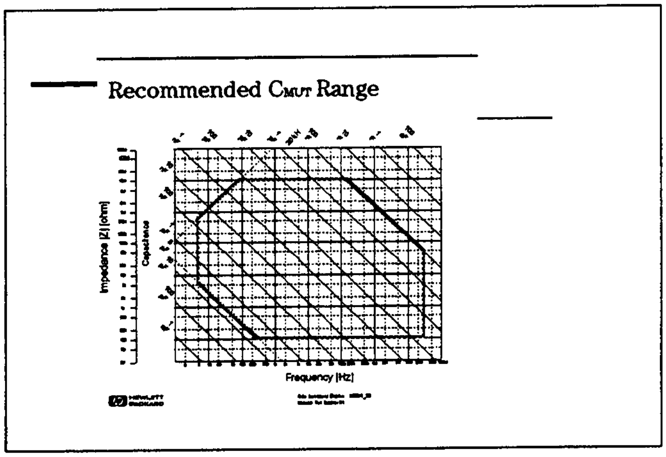

Recommended C_{MUT} Range

It is important to select the size of the material such that its capacitance value is within range of the measurement equipment. For example it is difficult to measure 0.1pF or smaller because of instrument inaccuracies. Since the capacitance value is decided by the size of sample material, we have to select the sample size in order to have the sample material impedance enter appropriate impedance range in the slide.

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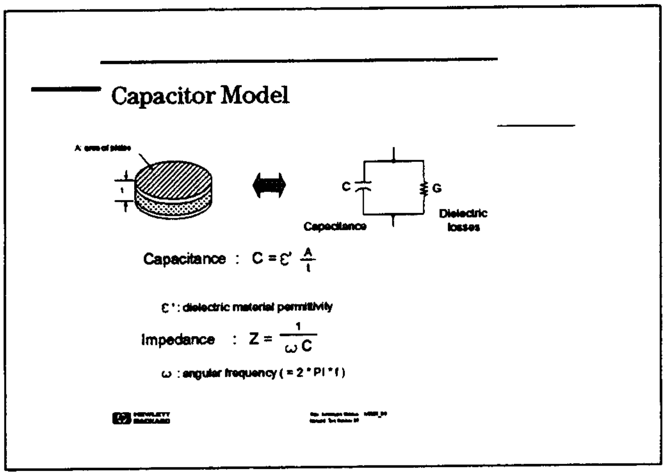

Capacitor Model

Capacitance : $C = \varepsilon' \frac{A}{t}$

ε' : dielectric material permittivity

Impedance : $Z = \frac{1}{\omega C}$

ω : angular frequency (= 2 * PI * f)

The capacitance of the material is calculated by the dielectric constant and sample size. And impedance of material is calculated by the capacitance of material and measurement frequency. When we measure the material at a certain frequency, we can estimate the measured impedance value by assuming the dielectric constant value of material. It is better that the impedance value is medium range(1kohm - 1Mohm), which LCR Meter and Impedance Analyzers can measure accurately.

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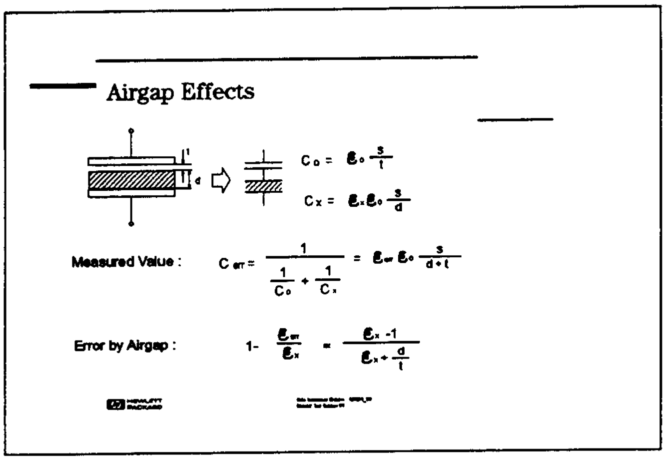


Airgap Effects

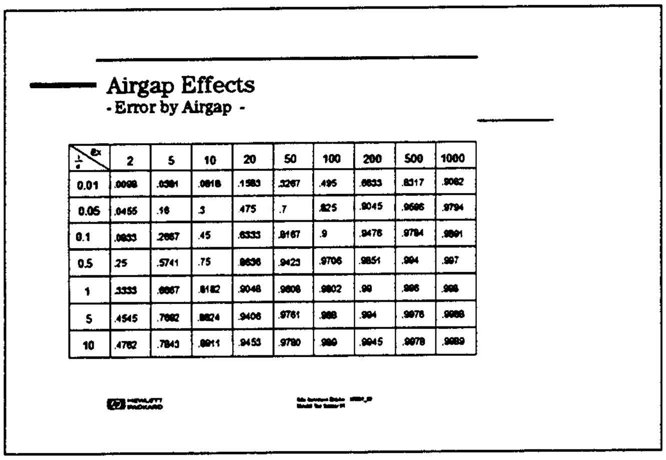
$C_0 = \varepsilon_0 \frac{s}{t}$

$C_x = \varepsilon_x \varepsilon_0 \frac{s}{d}$

Measured Value : $C_{err} = \frac{1}{\frac{1}{C_0} + \frac{1}{C_x}} = \varepsilon_{err} \varepsilon_0 \frac{s}{d+t}$

Error by Airgap : $1 - \frac{\varepsilon_{err}}{\varepsilon_x} = \frac{\varepsilon_x - 1}{\varepsilon_x + \frac{d}{t}}$

Airgap between the material and electrodes causes measurement error. When there is airgap thickness between material and electrode, the LCR meter and impedance analyzer measures the sum of capacitances by the dielectric material (MUT) and air. The airgap error calculation is shown in the slide.

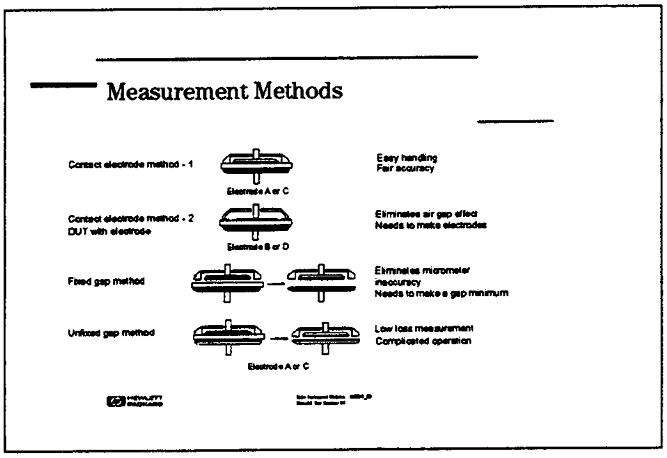


Airgap Effects

- Error by Airgap -

$\frac{t}{d}$ \ ε_x	2	5	10	20	50	100	200	500	1000
0.01	.0098	.0381	.0818	.1583	.3267	.495	.6633	.8317	.9082
0.05	.0455	.16	.3	.475	.7	.825	.9045	.9596	.9794
0.1	.0833	.2667	.45	.6333	.8167	.9	.9476	.9784	.9891
0.5	.25	.5741	.75	.8636	.9423	.9706	.9851	.994	.997
1	.3333	.6667	.8182	.9048	.9608	.9802	.99	.996	.998
5	.4545	.7692	.8824	.9406	.9761	.988	.994	.9976	.9988
10	.4762	.7843	.8911	.9453	.9780	.989	.9945	.9978	.9989

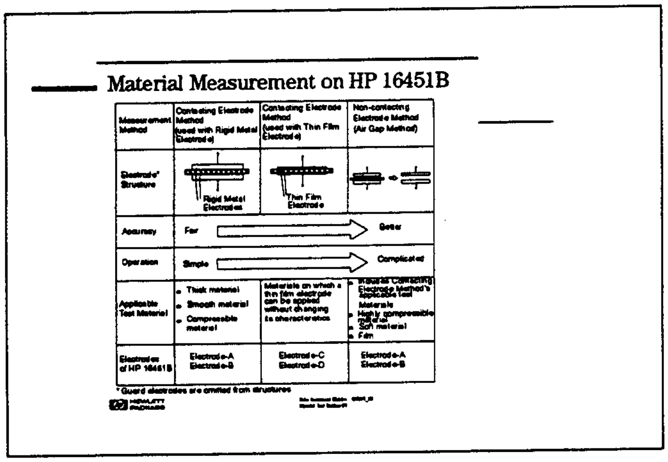
The table shows how much error there is for a given airgap between the material and electrode. Note that the airgap is more serious when we measure high dielectric constant materials.



Measurement Methods

Contact electrode method - 1	Electrode A or C	Easy handing Fair accuracy
Contact electrode method - 2 DUT with electrode	Electrode B or D	Eliminates air gap effect Needs to make electrodes
Fixed gap method		Eliminates micrometer inaccuracy Needs to make a gap minimum
Unfixed gap method	Electrode A or C	Low loss measurement Complicated operation

There are a couple of measurement methods available by the parallel plate technique. Each technique has an advantage and disadvantage. Please refer to the HP Application Note 380-1, "Dielectric constant measurement of solid materialsusing the HP16451B test fixture".



Material Measurement on HP 16451B

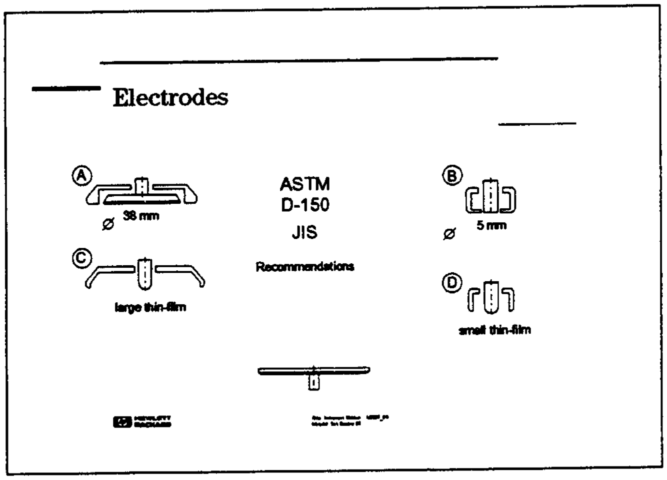
Measurement Method	Contacting Electrode Method (used with Rigid Metal Electrode)	Contacting Electrode Method (used with Thin Film Electrode)	Non-contacting Electrode Method (Air Gap Method)
Electrode* Structure	Rigid Metal Electrodes	Thin Film Electrode	
Accuracy	Fair ⇒ Better		
Operation	Simple ⇒ Complicated		
Applicable Test Material	• Thick material • Smooth material • Compressible material	Materials on which a thin film electrode can be applied without changing its characteristics	• Contacting Electrode Method's Applicable Test Materials • Highly compressible material • Soft material • Film
Electrodes of HP 16451B	Electrode-A Electrode-B	Electrode-C Electrode-D	Electrode-A Electrode-B

* Guard electrodes are omitted from structures

There are three applicable measurement methods for the HP 16451B.

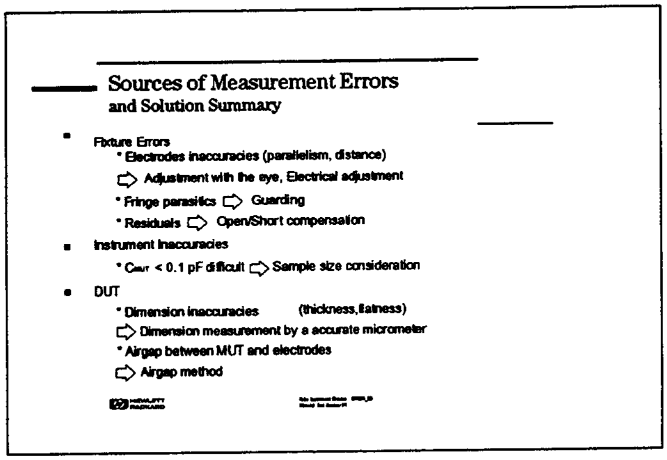
There is the Contacting Electrode method(rigid metal electrode), the Contacting Electrode method(with thin film electrode) and the Non-Contacting Electrode method. These three methods are different in operation and measurement accuracy. The contacting electrode method is the simplest method of all while the contacting method with the thin film electrode is effective for thin materials.

The non-contacting method is the most accurate method of all.A suitable measurement method and electrode for your test material can be selected to measure any material accurately.



Electrodes

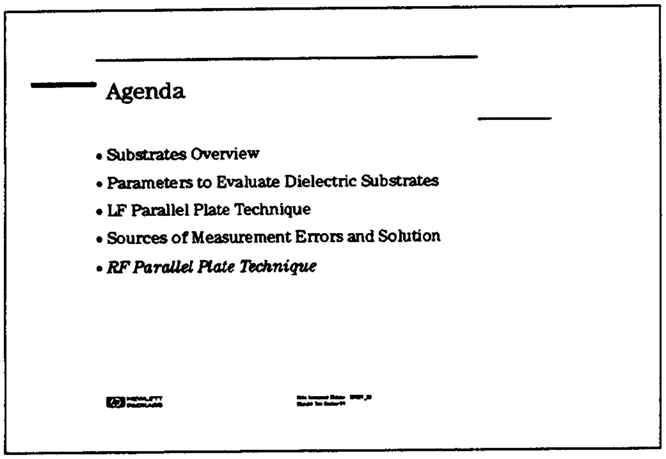
To measure many types of material shape, we need many types of electrodes. For exapmpe, Electrode-A and Electrode-B are the electrodes for materials which don't have electrode on the surface. Electrode-C and Electrode- D are the electrodes for material which have thin film electrodes on the surface.



Sources of Measurement Errors
and Solution Summary

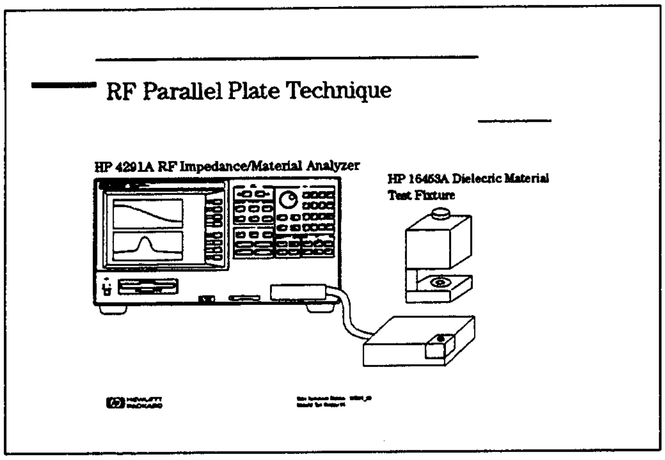
- Fixture Errors
  - * Electrodes inaccuracies (parallelism, distance)
  - ⇨ Adjustment with the eye, Electrical adjustment
  - * Fringe parasitics ⇨ Guarding
  - * Residuals ⇨ Open/Short compensation
- Instrument Inaccuracies
  - * C_{MUT} < 0.1 pF difficult ⇨ Sample size consideration
- DUT
  - * Dimension inaccuracies (thickness,flatness)
  - ⇨ Dimension measurement by a accurate micrometer
  - * Airgap between MUT and electrodes
  - ⇨ Airgap method

We must follow these procedures to minimize measurement errors.



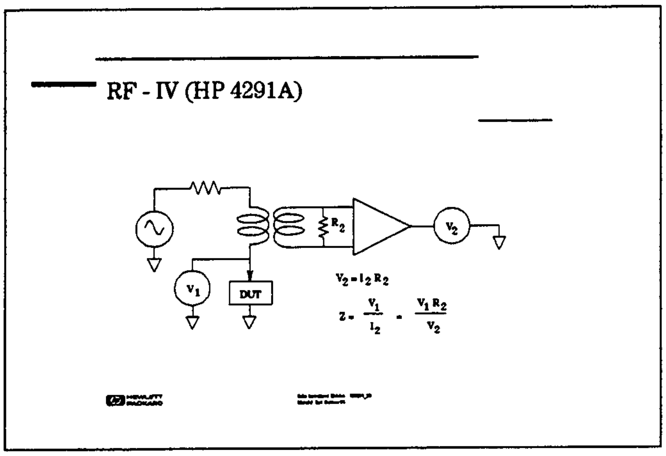
Agenda

- Substrates Overview
- Parameters to Evaluate Dielectric Substrates
- LF Parallel Plate Technique
- Sources of Measurement Errors and Solution
- *RF Parallel Plate Technique*



RF Parallel Plate Technique

The RF parallel plate technique uses the new HP 4291A Impedance/Material Analyzer and the HP 16453A Dielectric Material Test Fixture. The HP 4291A with opt 002 will automatically calculate and display permittivity and loss tangent vs frequency. (You don't need an external computer!) This solution uses the RF-IV measurement technique.

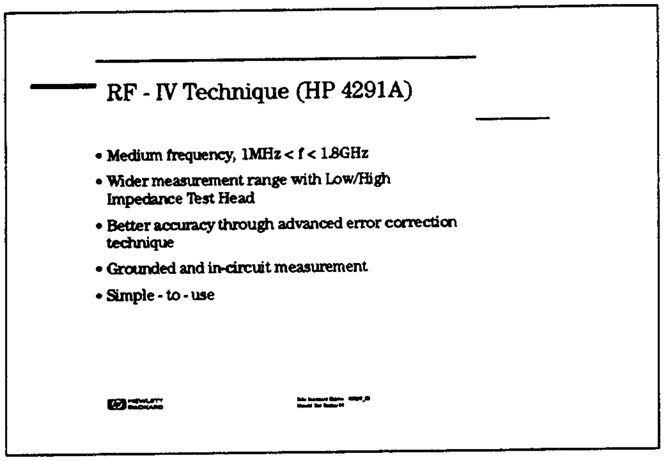


RF - IV (HP 4291A)

$V_2 = I_2 R_2$

$Z = \frac{V_1}{I_2} = \frac{V_1 R_2}{V_2}$

The RF - IV technique measures two voltages; V1 is measured across the DUT and V2 across a low-loss transformer. This technique is bandwidth-limited because of pick-up transformer, however the HP 4291A expands frequency range up to 1.8GHz by using a wide bandwidth balun transfomer.

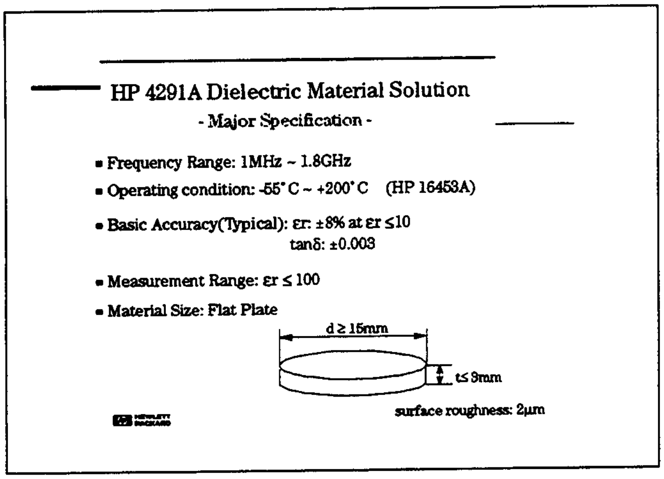


RF - IV Technique (HP 4291A)

- Medium frequency, 1MHz < f < 1.8GHz
- Wider measurement range with Low/High Impedance Test Head
- Better accuracy through advanced error correction technique
- Grounded and in-circuit measurement
- Simple - to - use

The RF - IV technique provides very good mid-frequency range performance, extending up to 1.8GHz.

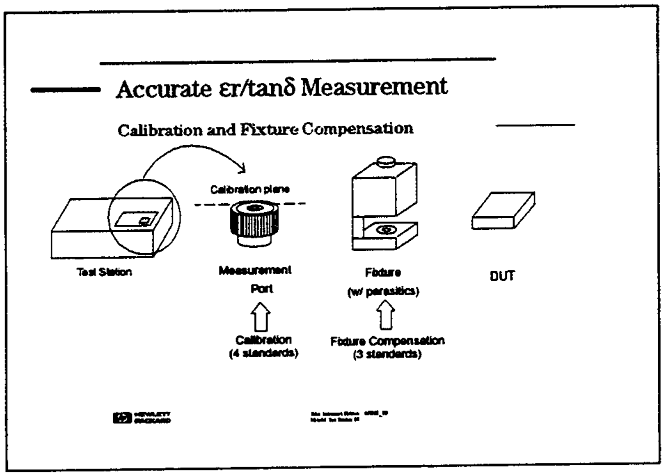
This technique has a very good impedance measurement range with quite good accuracy, since the HP 4291A uses advanced error correction technique like the Open/Short/Load/Air Capacitor Calibration and Open/Short/Load Compensation.



HP 4291A Dielectric Material Solution

- Major Specification -

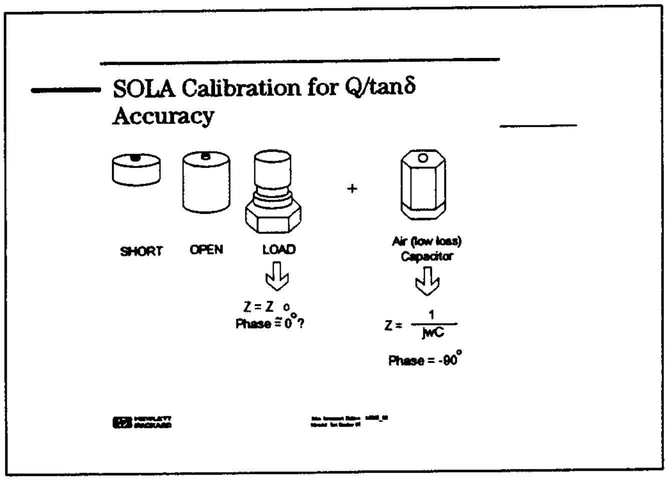
- Frequency Range: 1MHz ~ 1.8GHz
- Operating condition: -55°C ~ +200°C (HP 16453A)
- Basic Accuracy(Typical): εr: ±8% at εr ≤10
  tanδ: ±0.003
- Measurement Range: εr ≤ 100
- Material Size: Flat Plate



Accurate εr/tanδ Measurement

Calibration and Fixture Compensation

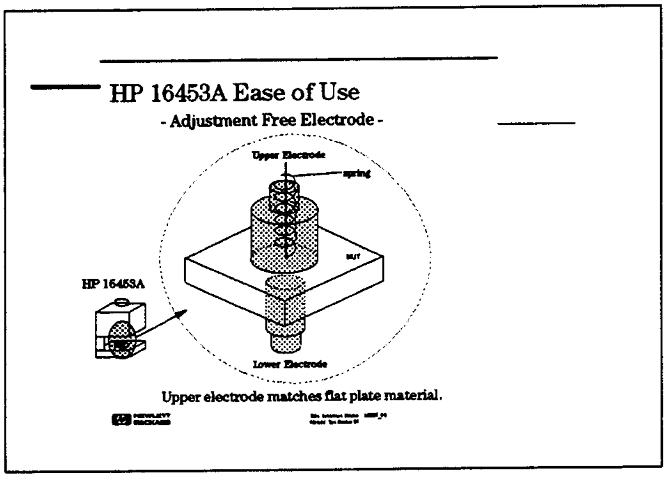
The new HP 16453A uses the parallel plate method, and its upper electrode has a spring inside that pushes the material to fit in the fixture easily. You don't need to adjust the flatness of the electrode like an HP 16451B. (LF Parallel Plate fixture).



SOLA Calibration for Q/tanδ Accuracy

$Z = Z_0$
Phase ≅ 0°?

$Z = \frac{1}{j\omega C}$
Phase = -90°

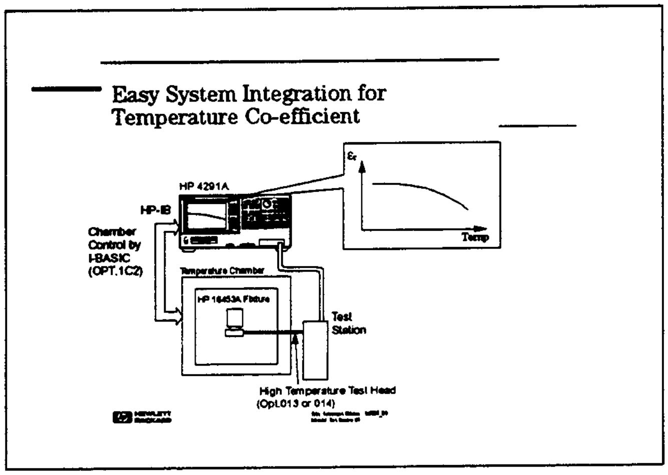


HP 16453A Ease of Use

- Adjustment Free Electrode -

Upper electrode matches flat plate material.

The HP 4291A accurately measures relative permittivity and loss tangent up to 1.8 GHz with the operating codition from -55 degree C to 200 degree C. The required material size is less than 3 mm in thickness.

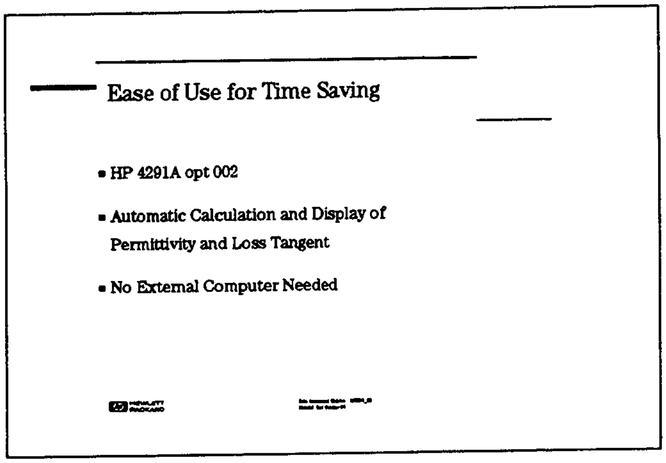


Easy System Integration for Temperature Co-efficient

The HP 4291A provides the following features and options to simplify evaluating temperature characteristics.

1. 1.8 error-free cables
2. High temperature test head option
3. Built-in HP-IB
4. Optional I-Basic
5. Application Program (I-BASIC) Available

Tabai Espec Corporation offers a temperature chamber (SU-240-Y) compatible with the HP 4291A.



Ease of Use for Time Saving

- HP 4291A opt 002
- Automatic Calculation and Display of Permittivity and Loss Tangent
- No External Computer Needed

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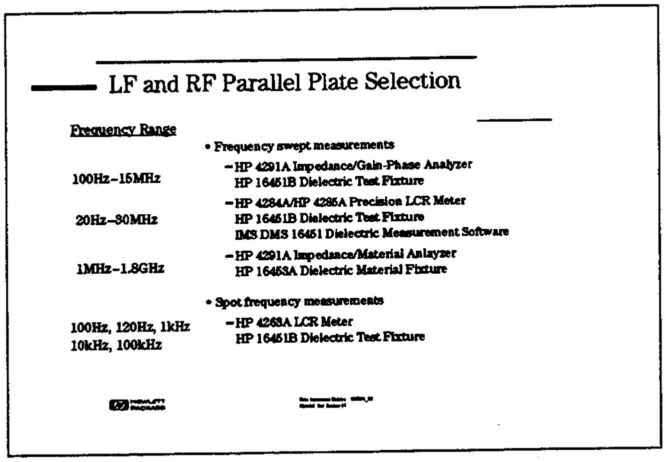
The HP 4291A with Option 002 will automatically calculate and display the relative permittivity values eleminating the need to calculate the parameters using an external computer.



LF and RF Parallel Plate Selection

Frequency Range	
	• Frequency swept measurements
100Hz–15MHz	– HP 4291A Impedance/Gain-Phase Analyzer HP 16451B Dielectric Test Fixture
20Hz–30MHz	– HP 4284A/HP 4285A Precision LCR Meter HP 16451B Dielectric Test Fixture IMS DMS 16451 Dielectric Measurement Software
1MHz–1.8GHz	– HP 4291A Impedance/Material Anlayzer HP 16453A Dielectric Material Fixture
	• Spot frequency measurements
100Hz, 120Hz, 1kHz 10kHz, 100kHz	– HP 4263A LCR Meter HP 16451B Dielectric Test Fixture

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This slide shows the HP selection of LF and RF Parallel Plate solutions for dielectric substrates. You should pick the solution that meets your swept or spot frequency needs.