WORKSHOP WFHI

Microwave Applications of Ferroelectric Ceramics

Friday, May 19, 1995
Orlando, Florida

Development of Thin Film Ferroelectrics for Microwave Applications at The Naval Research Laboratory

Presented at:

Workshop on Microwave Applications of Ferroelectric Ceramics

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by:

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Collaborative Development Effort Involving:

Microwave Technology Branch

Code 6850

Ferroelectric microwave device design and fabrication

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Ferroelectric thin film deposition and characterization

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Sponsoring Organizations:

Superconducting Core Technologies

Office of Naval Research

SPAWAR

Ferroelectrics Exhibit Spontaneous (Permanent) Polarization

Gauss's Law	$\nabla \cdot \mathbf{D} = 4\pi\rho$	Dielectrics
	$\mathbf{D} = \varepsilon_o \mathbf{E} + \mathbf{P}$	Polarization
	$\mathbf{P} = \chi\, \varepsilon_o\, \mathbf{E}$	Susceptability
	$\chi = \text{Constant}$	Linear
	$\varepsilon = \varepsilon_o (1 + \chi)$	Dielectric Constant

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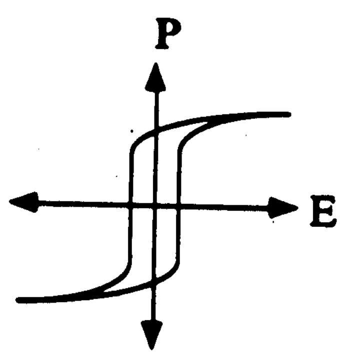
Ferroelectrics	$\chi = \chi(\mathbf{E})$	Nonlinear
	$\chi \neq \text{Constant}$	



Why Ferroelectrics for Microwave Applications?

- Voltage controlled capacitance
  - varactor (variable reactance)
    - tunable oscillator
    - frequency agile filter
  - variable phase velocity transmission line
    - phase shifter
    - tunable delay line
- Very low drive currents - minimum conduction in a dielectric
  - small, light weight power supplies
  - low prime power requirements
- Intrinsically fast mechanism
  - fast switching speeds

Objective:

Demonstrate the advantages of replacing existing devices with devices based on ferroelectric thin films

Approach:

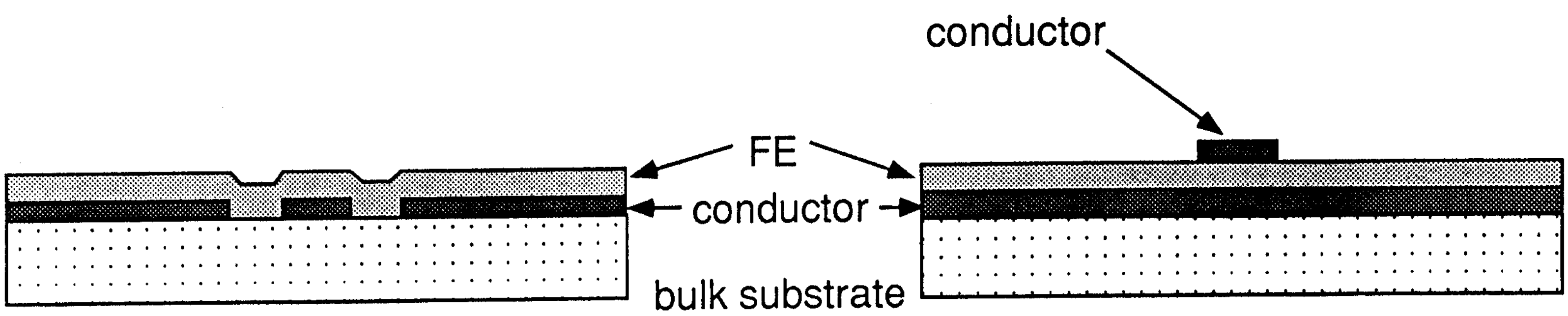
- Deposit high quality low loss ferroelectric films which exhibit electric field controlled dielectric constants
- Characterize the dielectric constant and loss tangent as a function of
  - material composition and phase
  - electric field dependence
  - temperature dependence
- Design and fabricate devices with performance superior to existing technologies

Ferroelectric Materials

- Examples
  - $Sr_xBa_{1-x}TiO_3$ *
  - $K_xTa_{1-x}NbO_3$
  - $LiNbO_3$
  - $(Pb_{1-x}La_x)(Zr_{1-y}Ti_y)O_3$ *
  - $Sr_xBa_{1-x}Sr_2O_6$
- Complex, multicomponent metal oxides
- Many thin film applications have been difficult to implement because of the unavailability of high quality thin films
- Recently developed thin film processing technologies makes these applications possible

* Materials having common crystallographic structures with HTS

Possible Approaches to Thin-Film Ferroelectric Circuits



Coplanar Waveguide

Practical devices using either normal metal or HTS

Less tunability range since field is not confined to FE

More difficult to determine FE properties from measurements

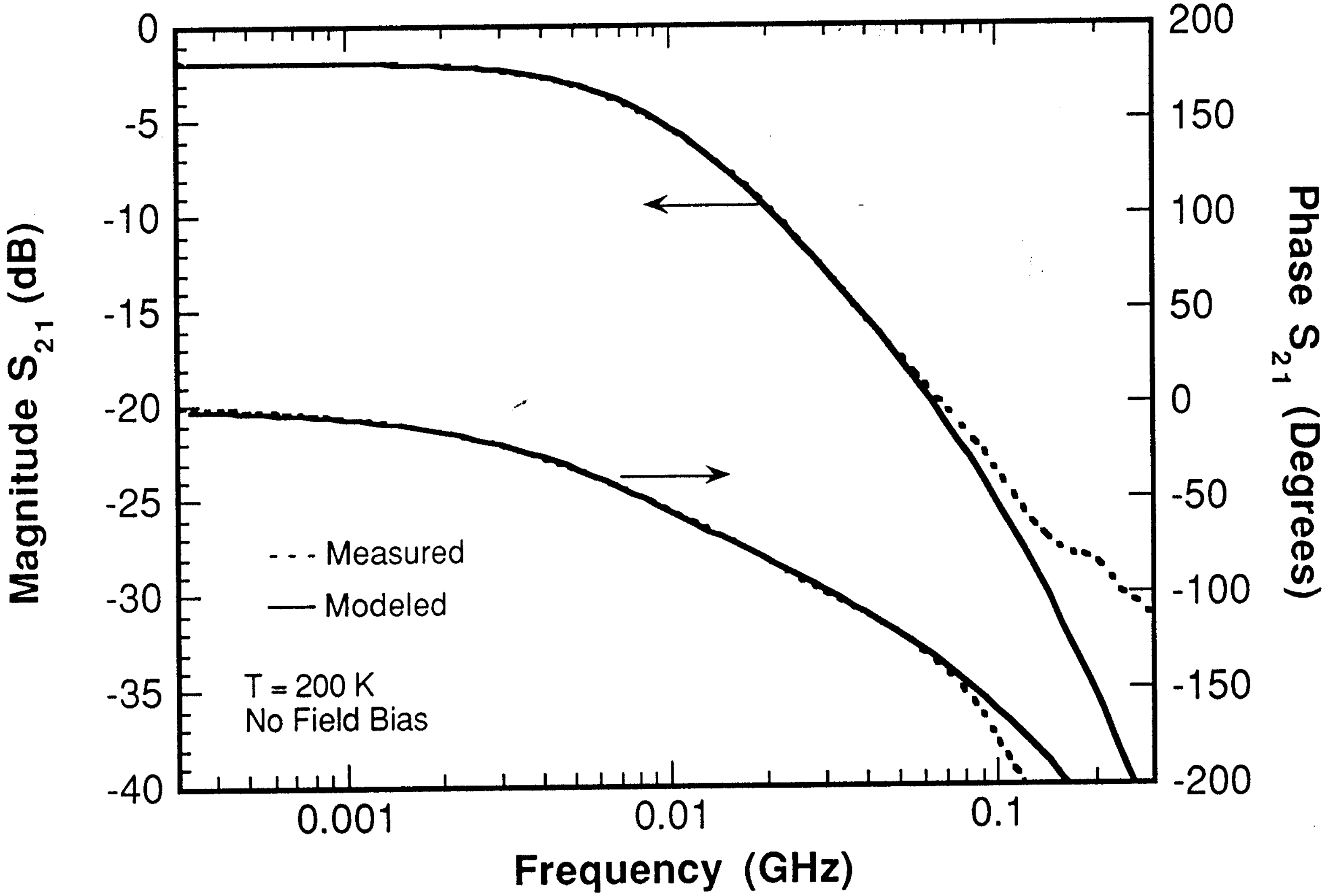
Microstrip Trilayer

Practical devices requires HTS for low loss

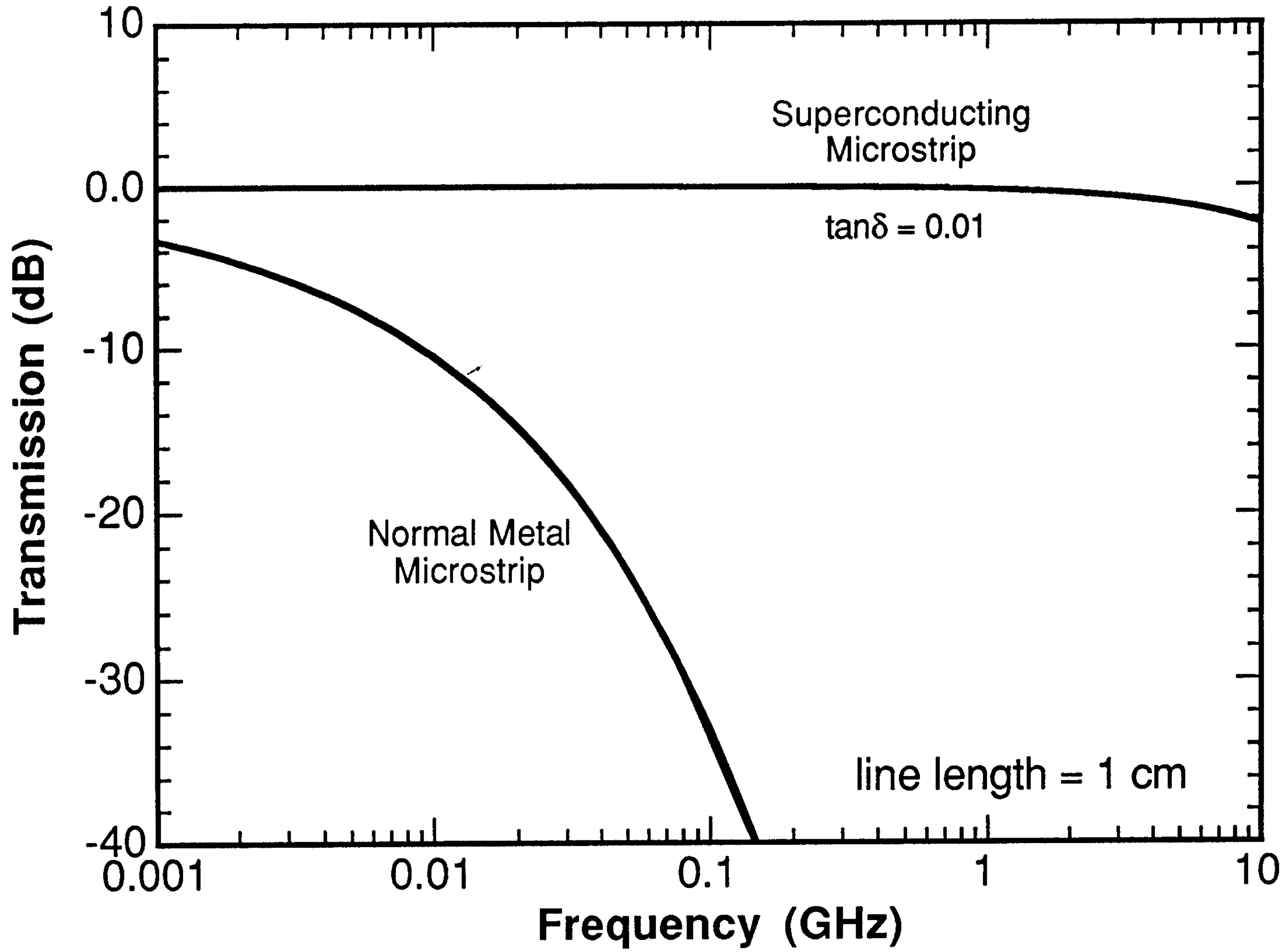
Large tunability range since field is well confined to FE

Much easier to analyze and determine FE and FE/HTS

Measured and Modeled Response of a Ag/SBT/Pt Microstrip Transmission Line

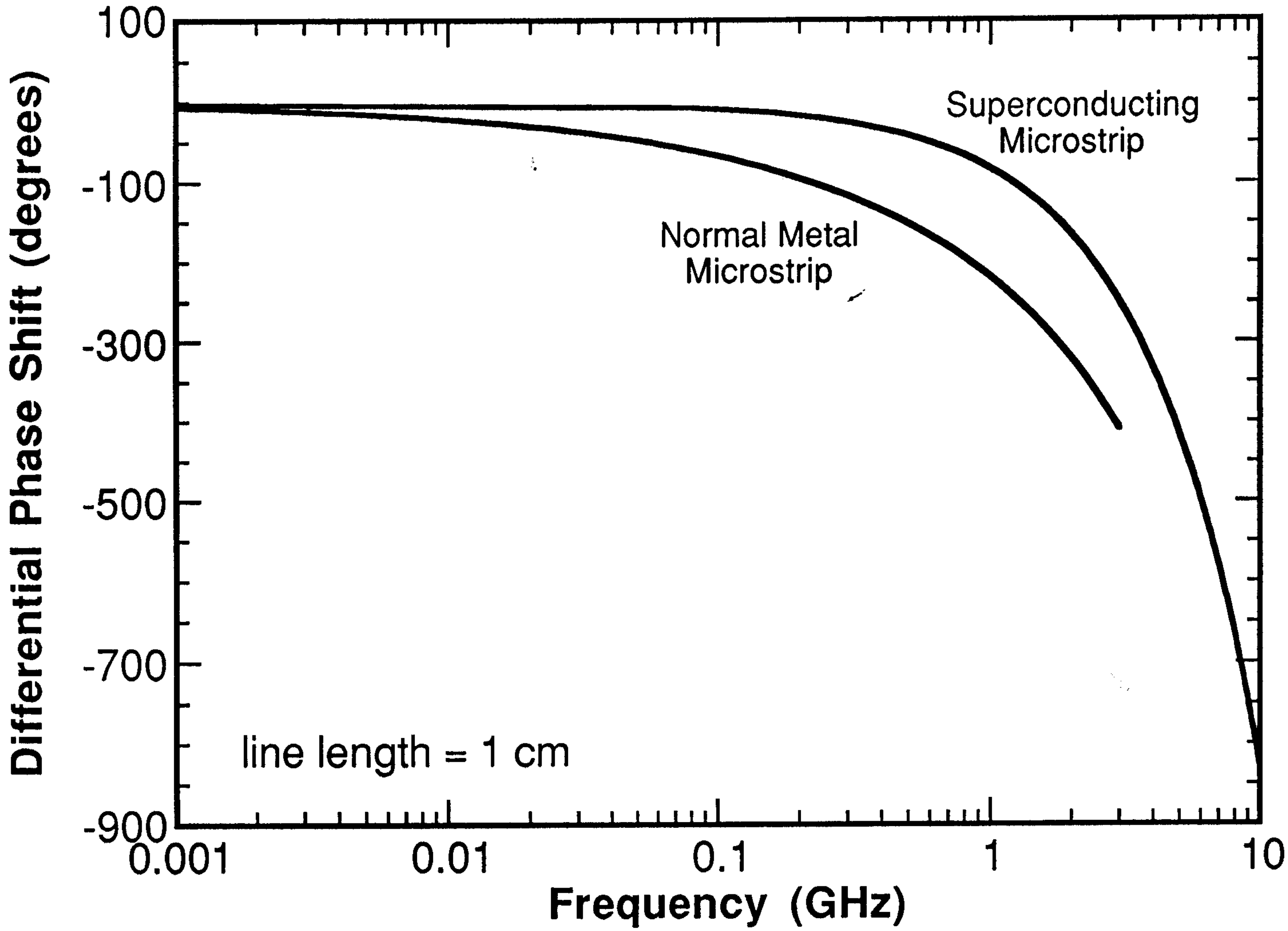


Calculated Transmission in a Thin Film Ferroelectric Microstrip with Normal Conductor (metal loss limited) and Superconductor (ferroelectric loss limited)

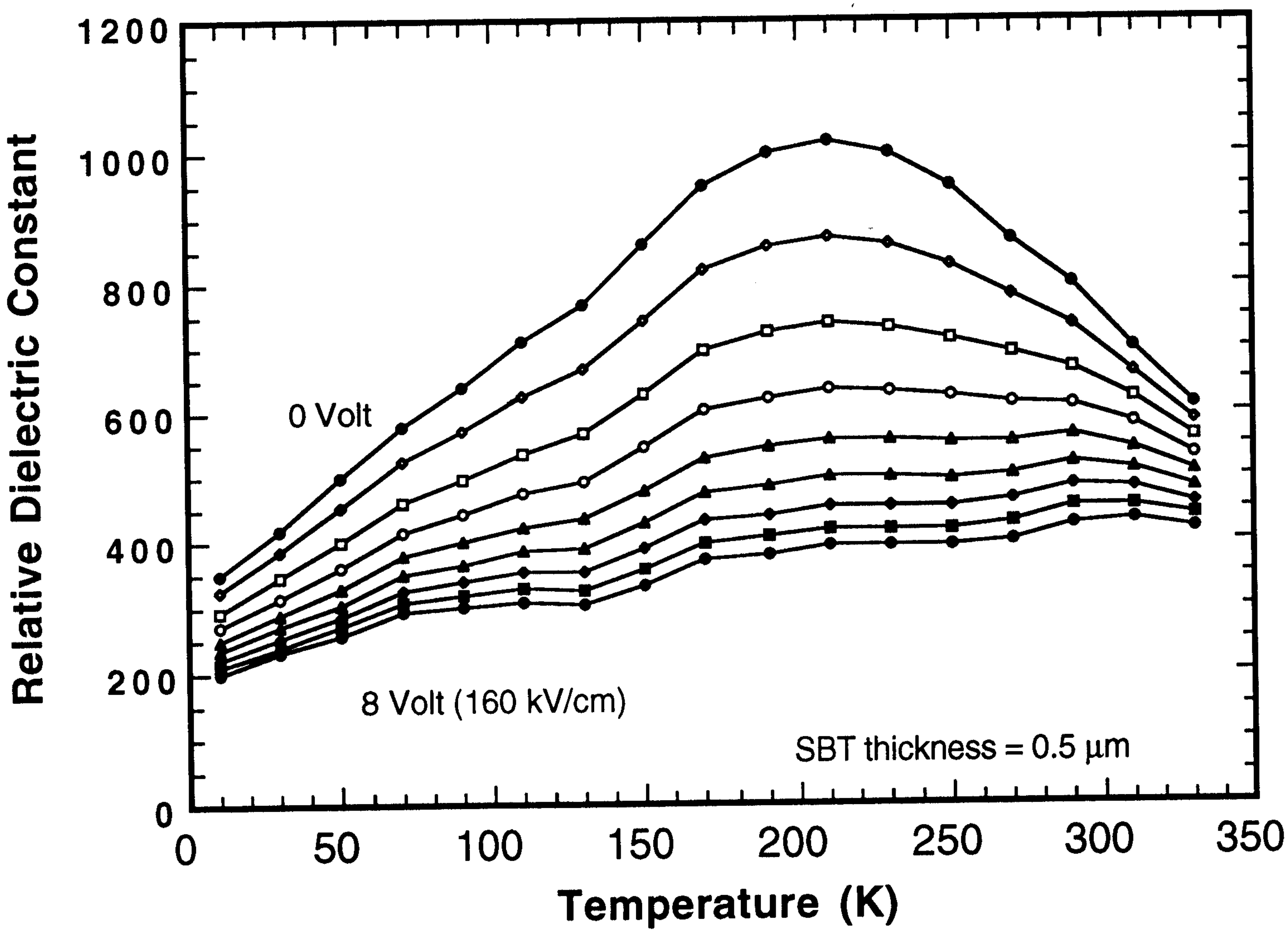


Differential Phase Shift for a 1-cm Thin-Film Ferroelectric Microstrip with Normal Metal Conductors and Superconductors

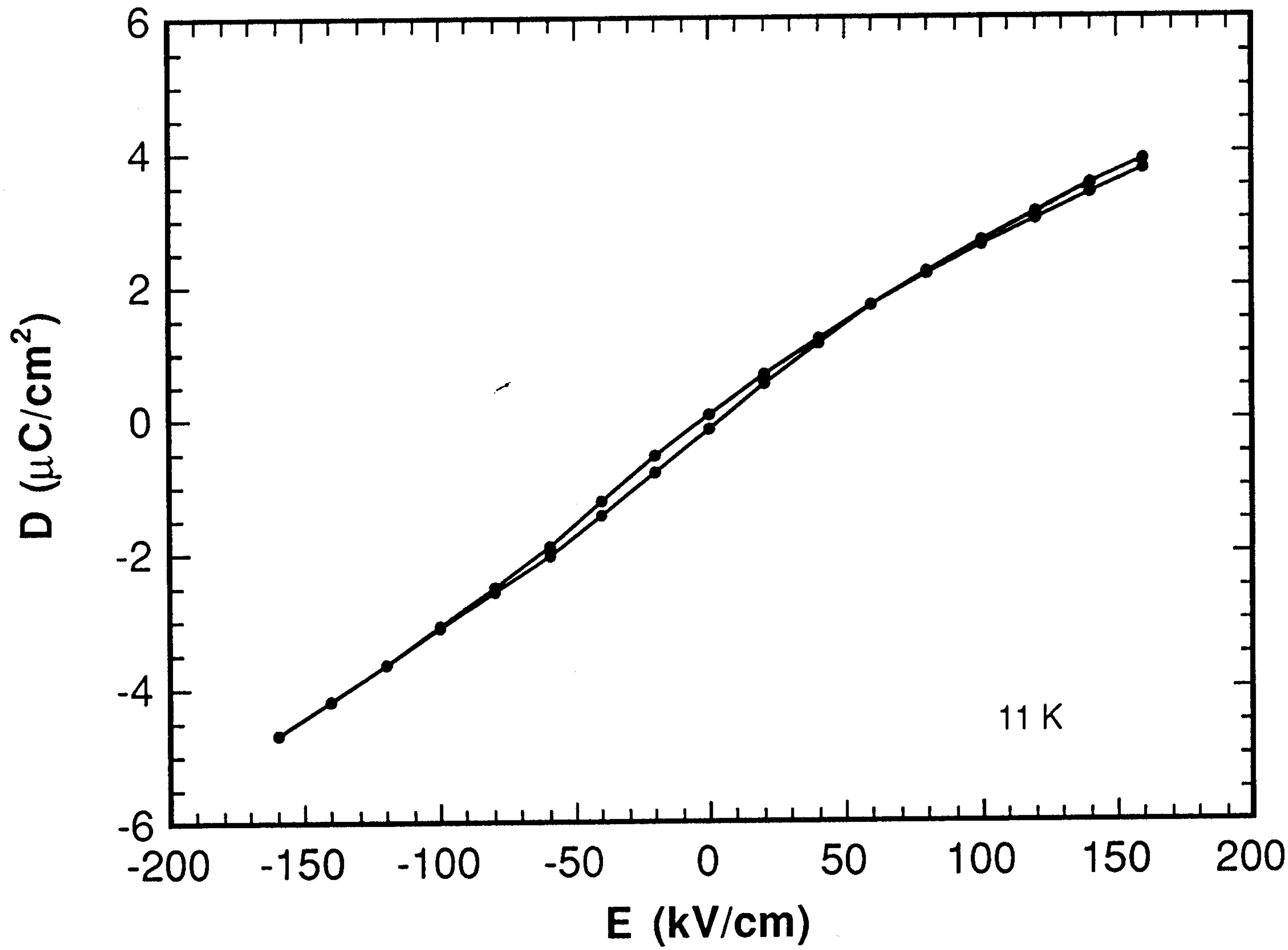
$\Delta\Phi = \Phi(0\ \text{Volts}) - \Phi(8\ \text{Volts})$



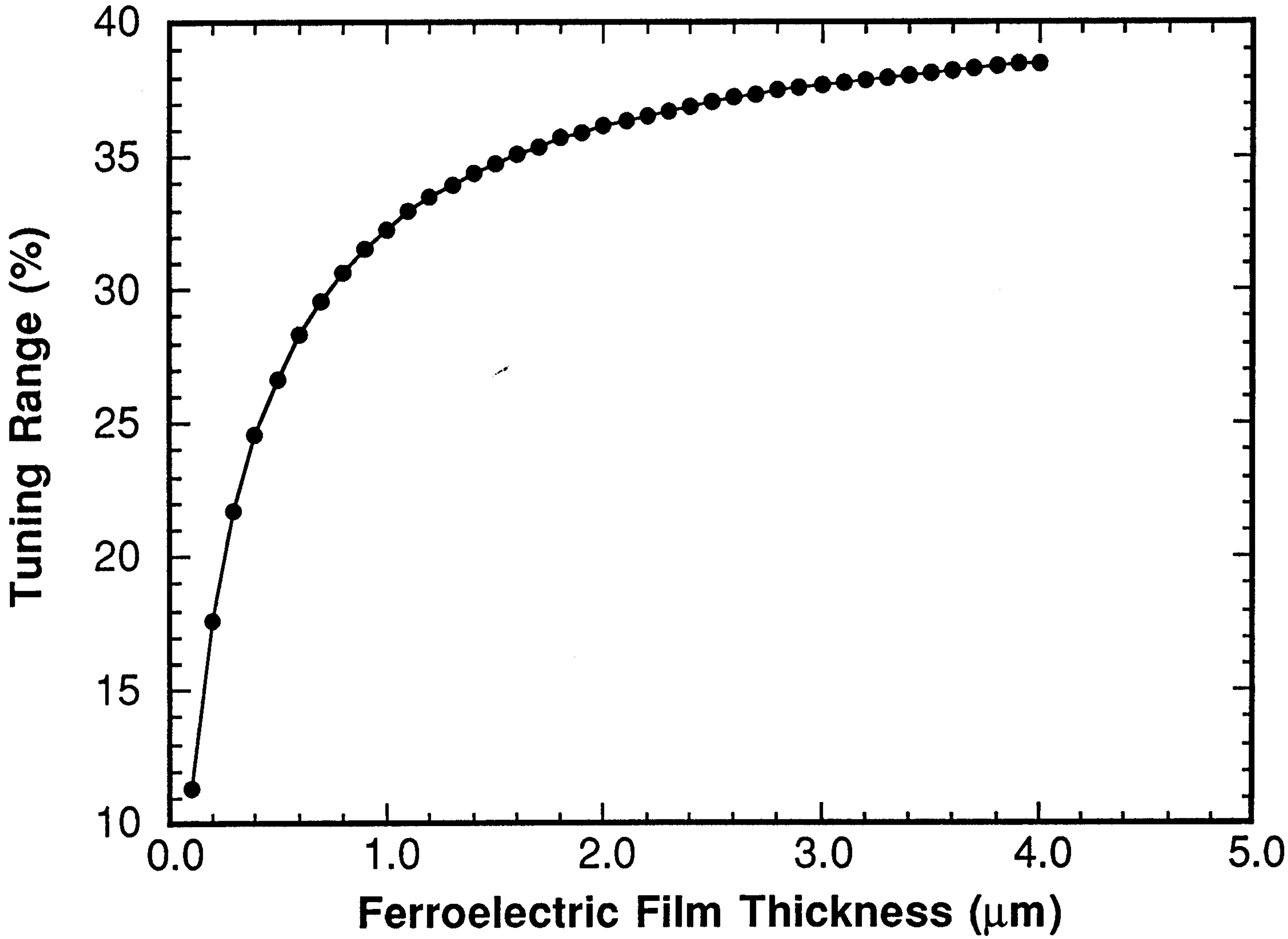
Relative Dielectric Constant of SBT Thin Film Using a YBCO Ground Plane / SBT Dielectric / Ag Strip Microstrip Trilayer



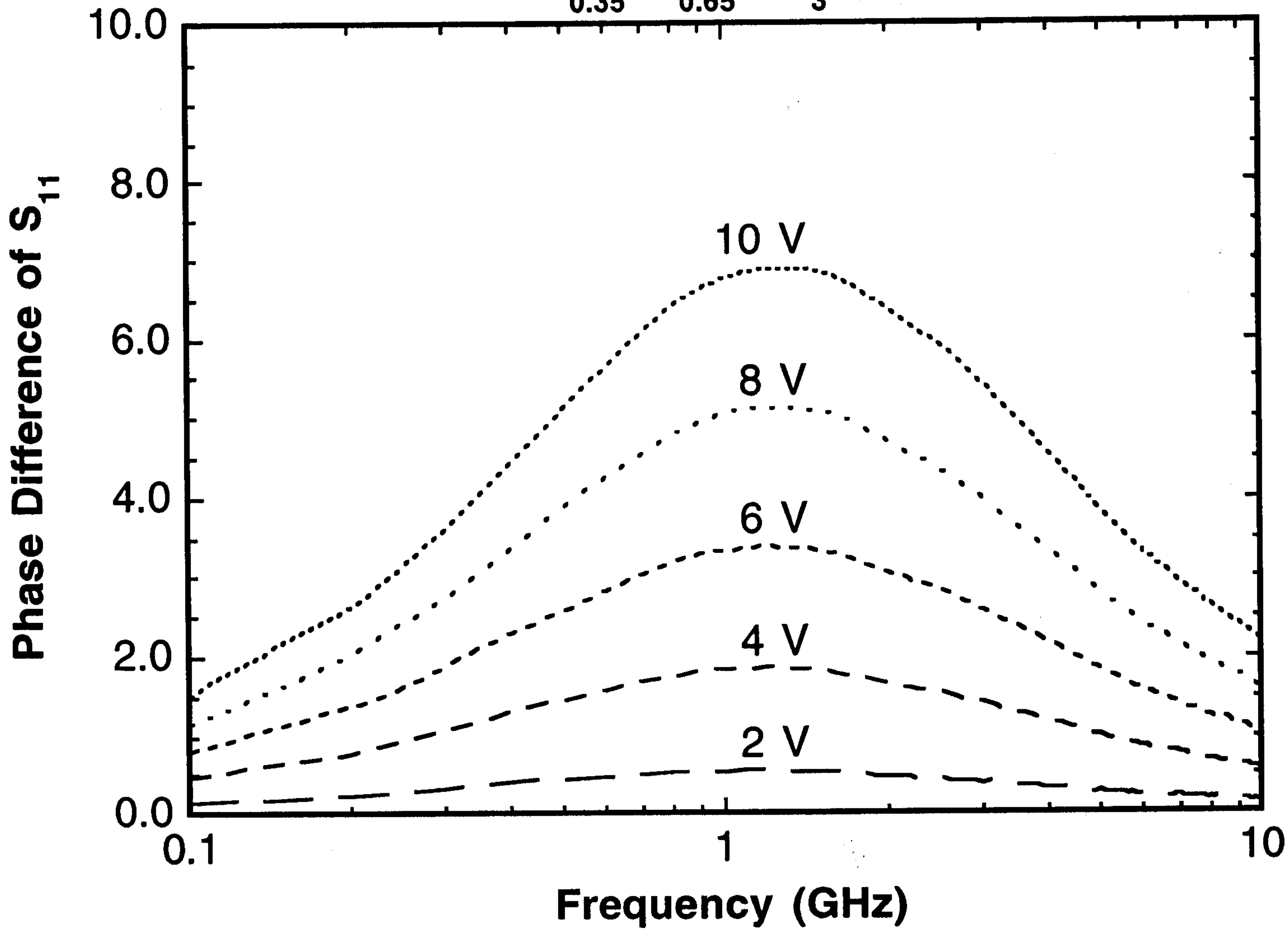
Hysteresis Curve for a Microstrip Trilayer with YBCO Ground Plane / SBT dielectric / Ag strip



Coplanar Waveguide with Ferroelectric Thin-Film Underlayer Tuning Range Assuming a Relative Dielectric Constant Range from 400 to 800



Measured Phase Difference at 300 K for a Gold Interdigital Capacitor on a $Sr_{0.35}Ba_{0.65}TiO_3$ Thin Film



Ferroelectric Varactor Technology

- Demonstrated interdigital tunable capacitor in the 2.5 pF range at room temperature with non-optimized gold electrodes
- Q should be limited by loss tangent of the ferroelectric layer with preliminary results indicating 1000 > Q > 100
- Initial modeling indicates that losses are consistent with conduction in the gold electrodes
- Several processing modification planned for second set of devices
- Excellent agreement with circuit model consisting of variable capacitor shunted by resistor (dielectric losses) and series resistor (metal losses)