Nanocomposite Modelling for Microwave Propagation Using a Spectral Domain Code

Cliff Krowne

Microwave Technology Branch
Electronics Science & Technology Division
Naval Research Laboratory
Washington DC

α and β Effects

- Small currents can result in finite α
- Finite α can result from local dissipative action
- Electronic functions generally rely on β properties
- Often $\beta/k_0 >> \alpha/k_0$, a desirable relation

Conversion of Microscopic Action into Macroscopic Tensor

- Tensors may be developed to describe dielectric, ferroelectric, magnetic, ferromagnetic, chiral, or other properties
- Tensors may correspond to non-Hermitian properties - critical for characterizing lossy media
- Tensors have been used successfully in a recent Green's function based self-consistent code

Nanocomposites and Media Tensors

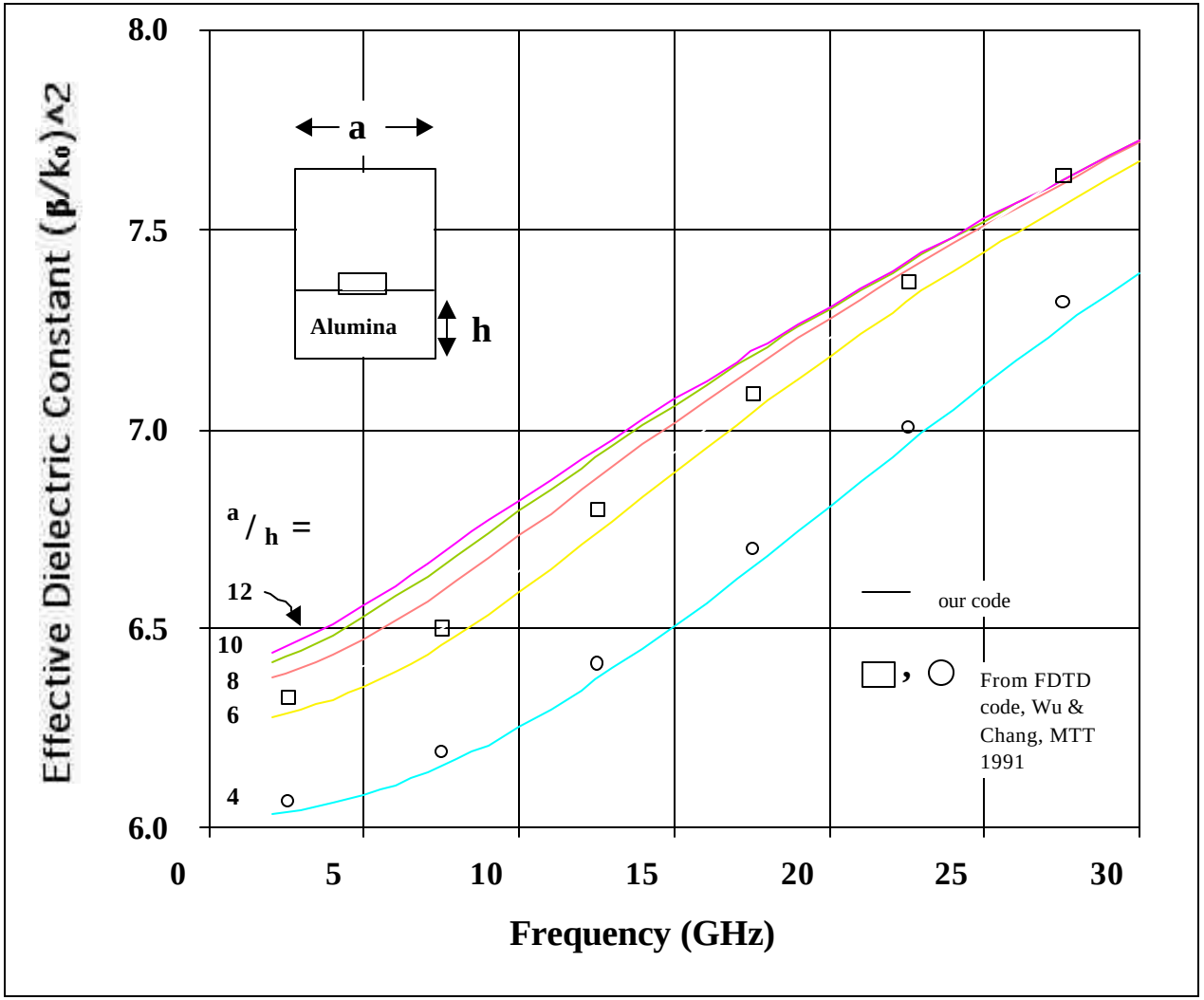
- For nanostructures with size $a << \lambda$ and $a << l$, where l is the characteristic layer or surface area size, a macroscopic tensor reduction can be made
- For a " λ and $a << l$, a local detailed field description is required
- For $a << \lambda$ and a " l, a tensor is possible, with its affects needed in partitions Δl
- For $a >> \lambda$ and $a << l$, a geometric optics approach is acceptable

Nanocomposite Inclusions

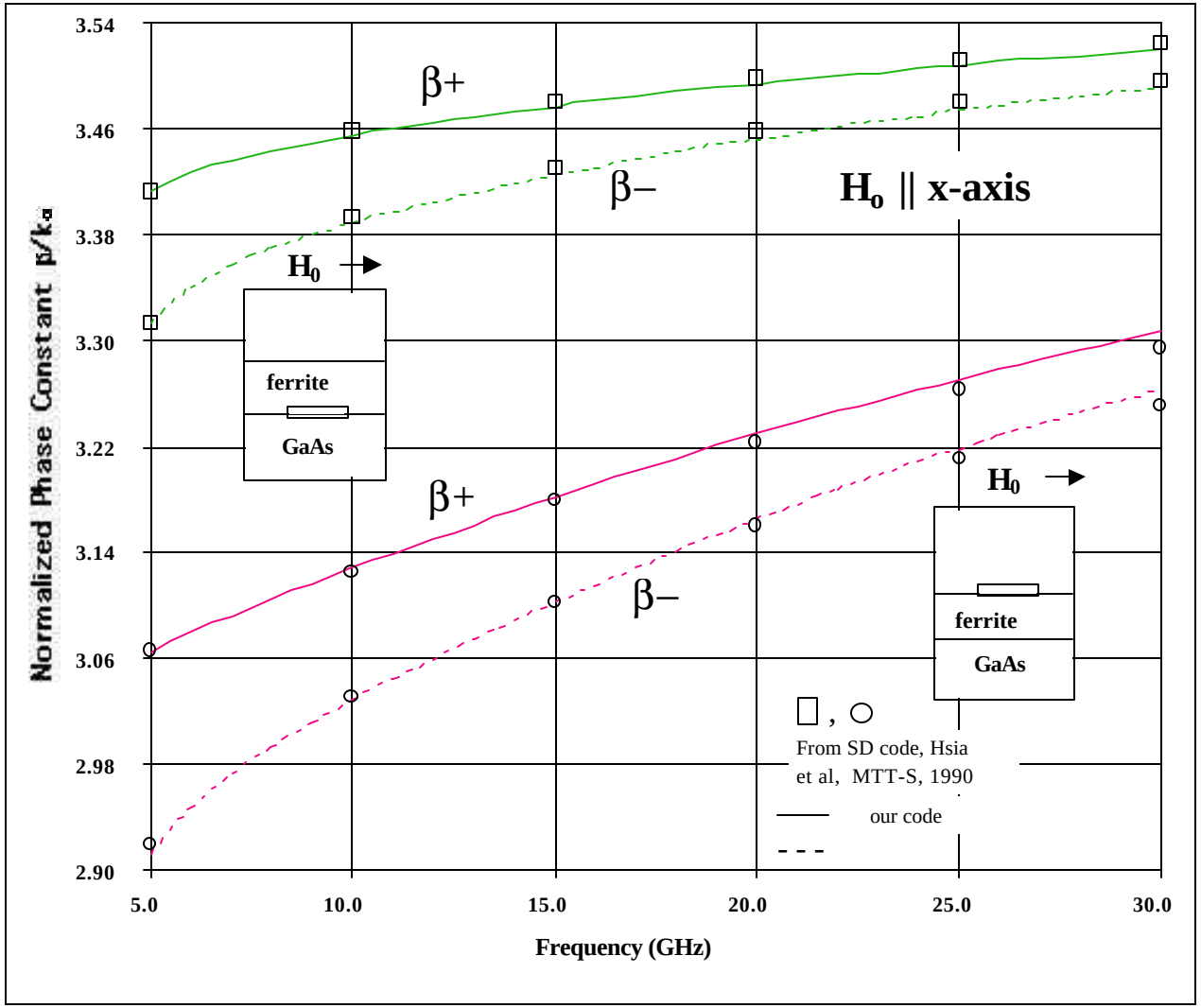
- Particles or voids, thin wire structures, shaped metallic surfaces, ellipsoids of revolution and other volumetric objects

- Specific structures could include helicoidal bianisotropic material crystal inclusions, mobius wire and surface coils of various periods, chiral omega objects, high μ permeability particles, split ring-post objects for simultaneous $\varepsilon < 0$ and $\mu < 0$

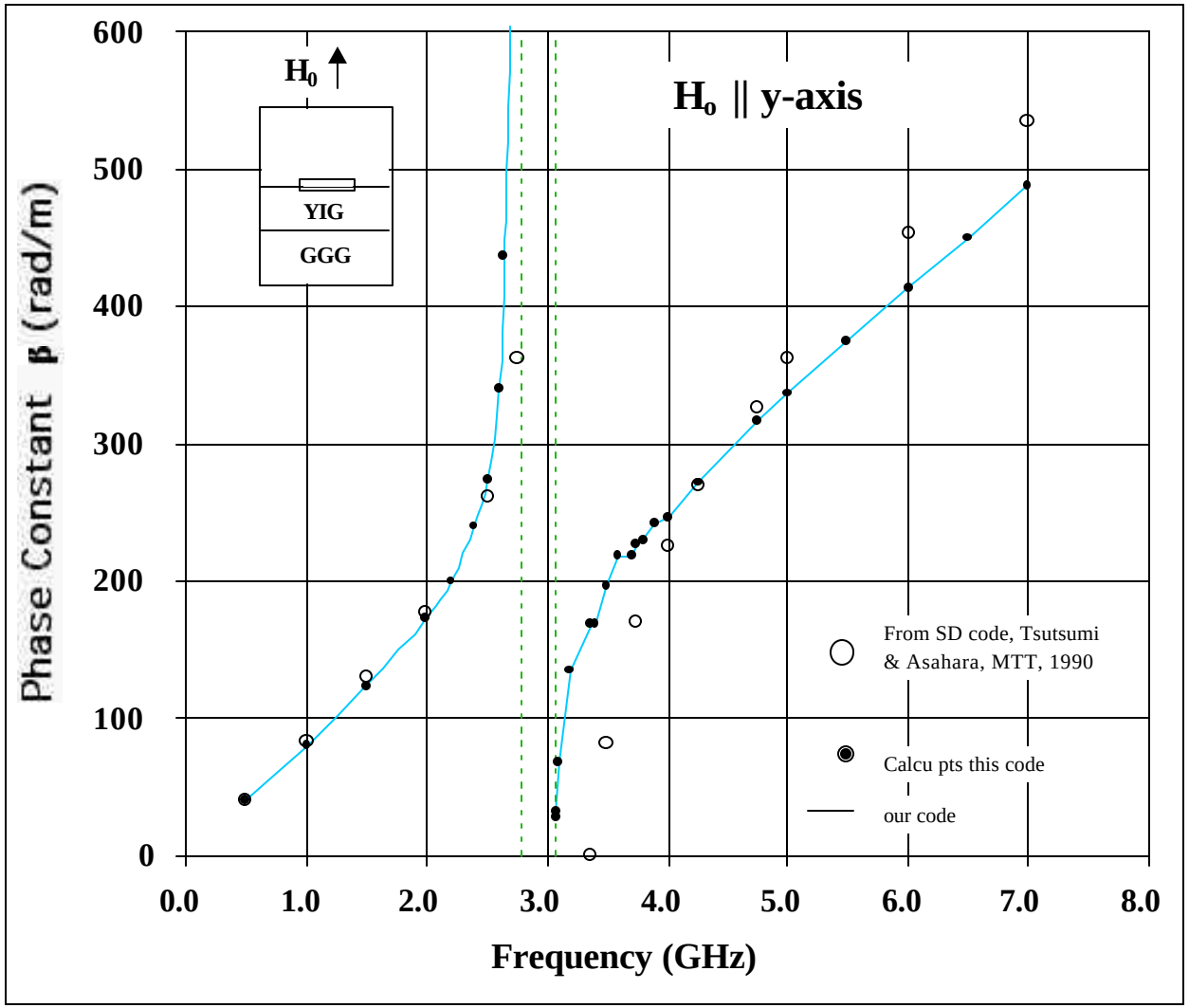
Propagation - Box Width Effect: γ for Dielectric Substrate



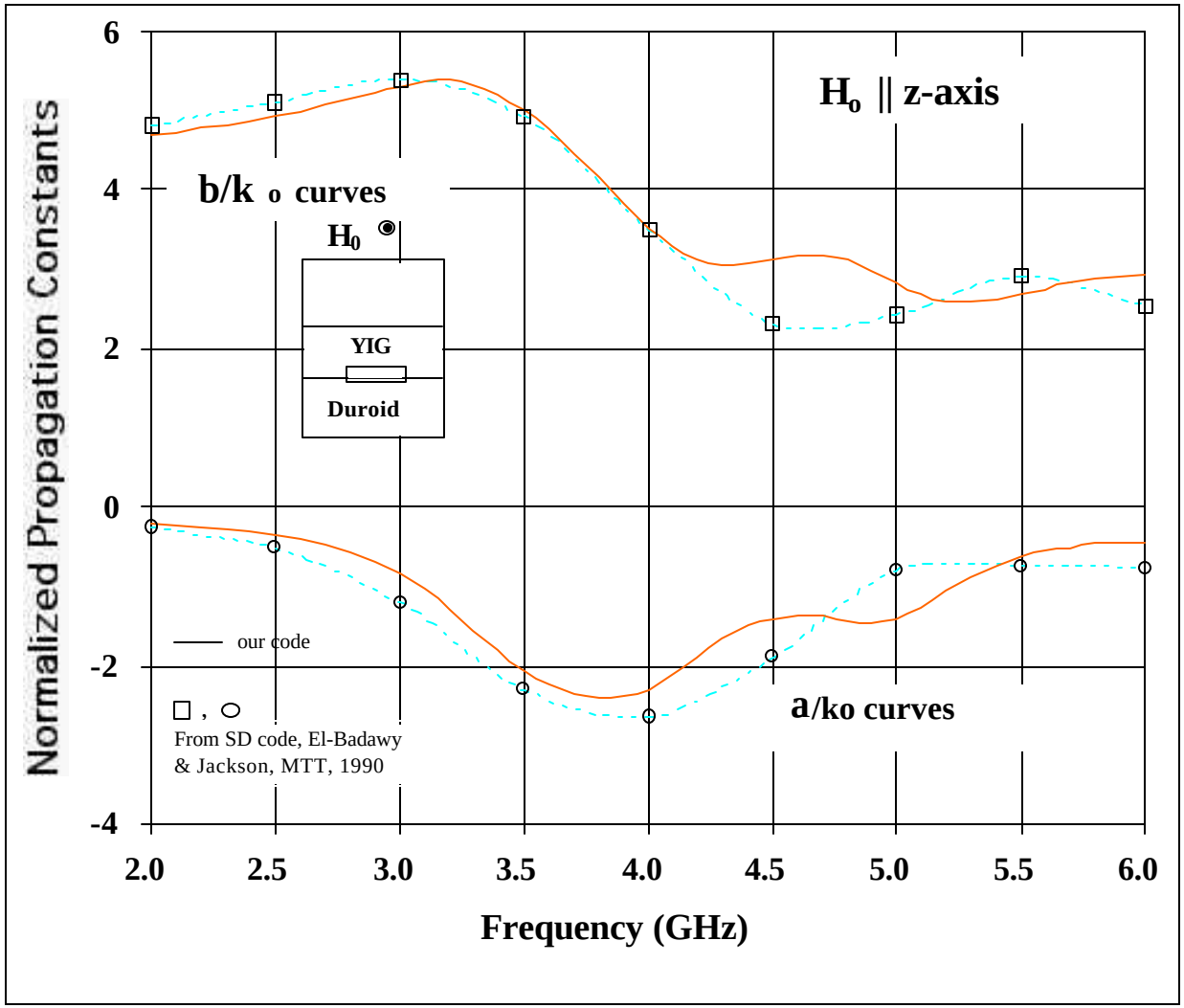
Nonreciprocal Propagation - H_0 In Surface & Normal to γ



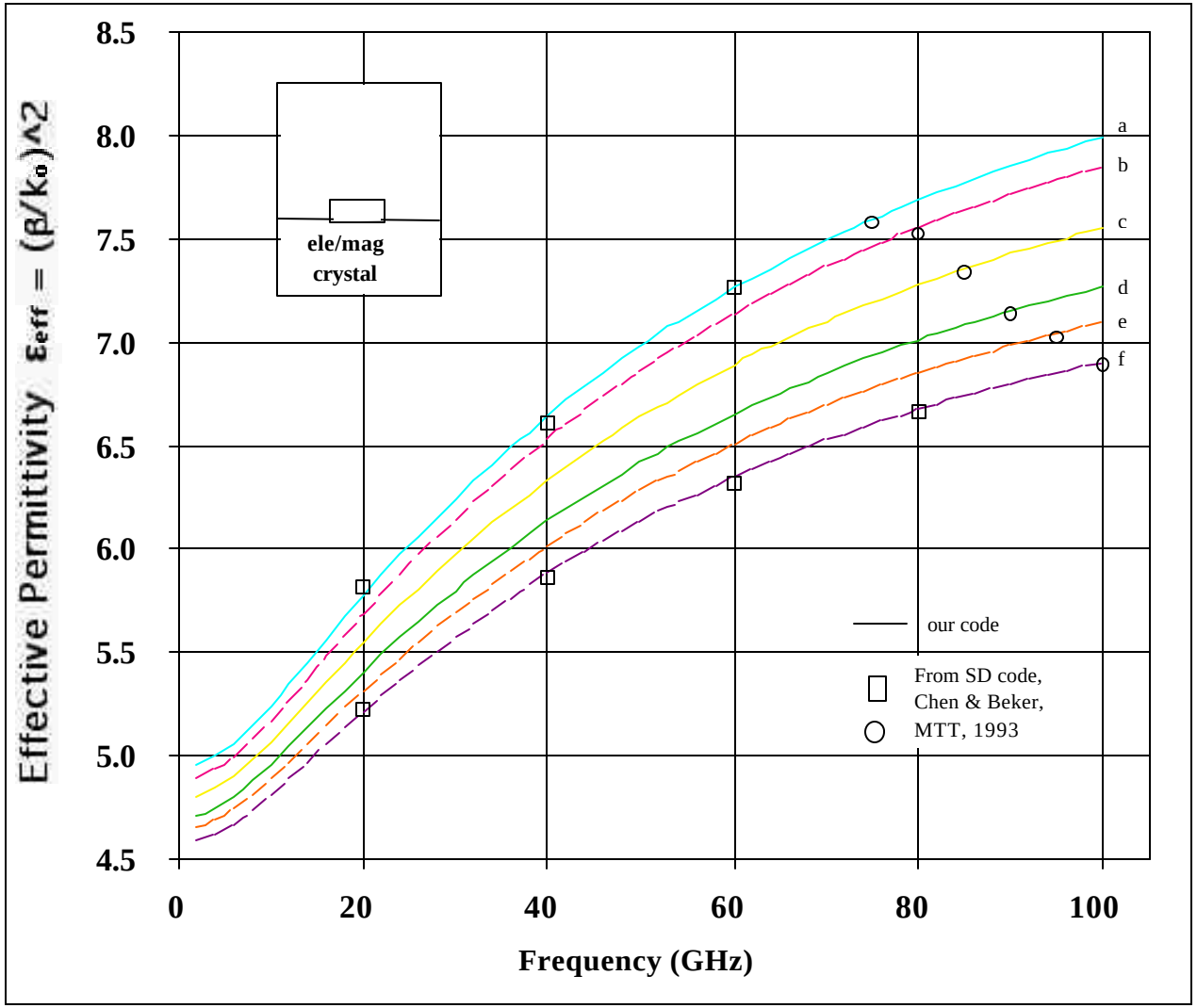
Nonreciprocal Propagation - H_0 Normal to Surface



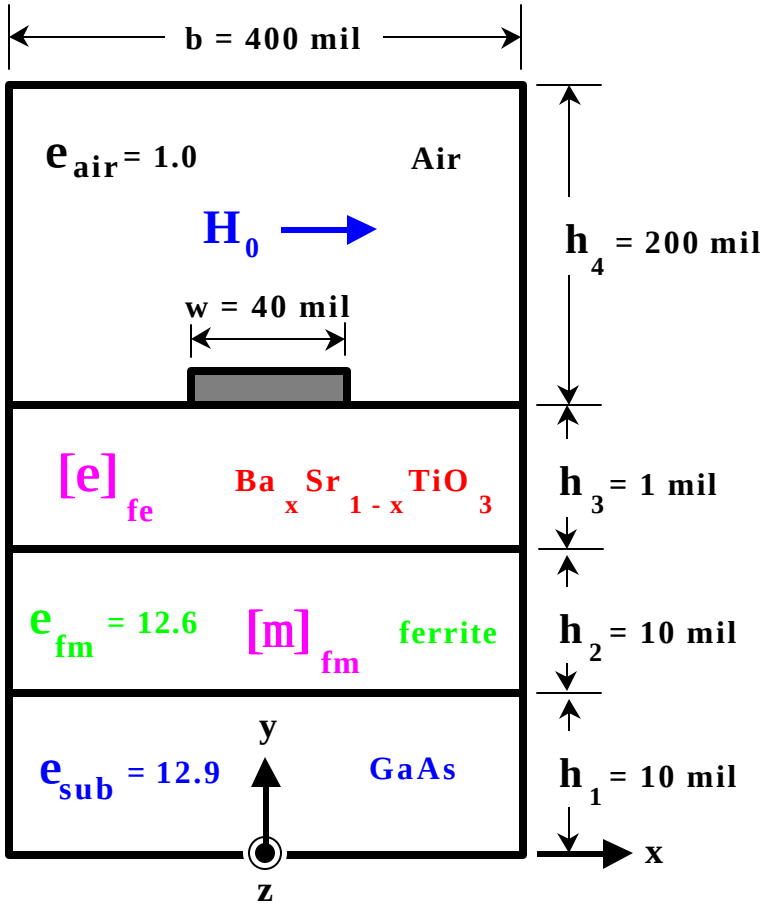
Nonreciprocal Propagation - H_0 Parallel to γ



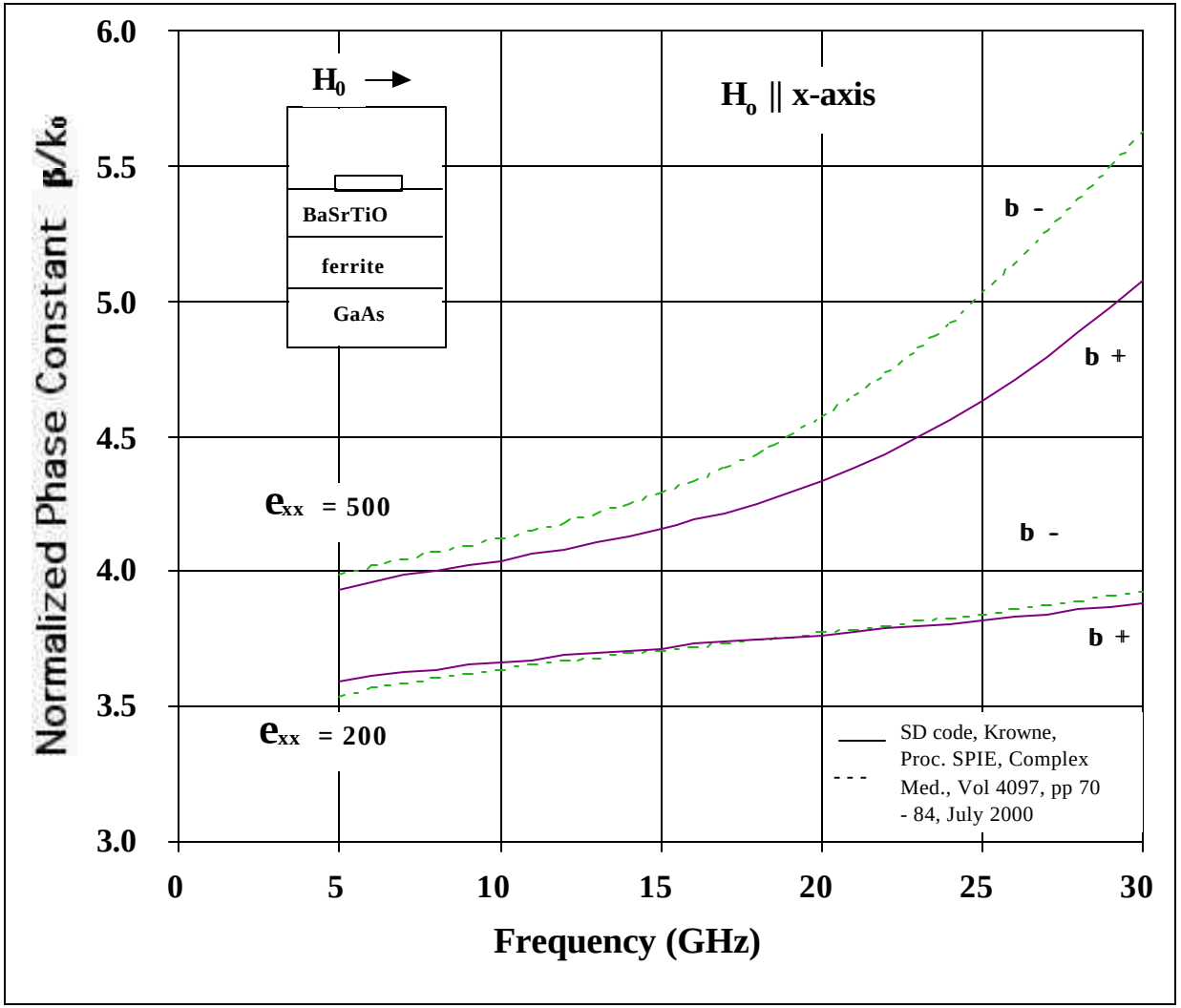
Propagation in Simultaneous Magnetic & Electric Crystal



Structure with Simultaneous Ferro - Magnetic & Electric Layers



Propagation in Simultaneous Ferro - Magnetic & Electric Layers



Permeability Transformation for Ferrite Tensor

Arbitrary H_0 Orientation

See: C. M. Krowne, "Theoretical Considerations for Full-Wave Electromagnetic-Media Interactions in Layered Structures with Ferroelectric or Ferromagnetic Materials," Invited paper, Proc. SPIE, Vol. 4097, pp. 70-84, July 2000.

$$\bar{\bar{m}}'' = \begin{bmatrix} m + (m_z - m)\sin^2\theta\cos^2\phi & \frac{m_z - m}{2}\sin^2\theta\sin 2\phi - jk\cos\theta & \frac{m_z - m}{2}\sin 2\theta\cos\phi + jk\sin\theta\sin\phi \\ \frac{m_z - m}{2}\sin^2\theta\sin 2\phi + jk\cos\theta & m_z + (m_z - m)\sin^2\theta\sin^2\phi & \frac{m_z - m}{2}\sin 2\theta\sin\phi - jk\sin\theta\cos\phi \\ \frac{m_z - m}{2}\sin 2\theta\cos\phi - jk\sin\theta\sin\phi & \frac{m_z - m}{2}\sin 2\theta\sin\phi + jk\sin\theta\cos\phi & m_z - (m_z - m)\sin^2\theta \end{bmatrix}$$

Permittivity Transformation for Electric Crystal Tensor

Arbitrary Crystal Orientation

See: C. M. Krowne, "Theoretical Considerations for Finding Anisotropic Permittivity in Layered Ferroelectric/Ferromagnetic Structures from Full-Wave Electromagnetic Simulations," Invited paper, Microwave & Optical Technology Letters, to be published, Jan. 5, 2000.

$$\bar{\bar{e}}'' = \begin{bmatrix} e_{xx}\sin^2 f + \left(e_{yy}\cos^2 q + e_{zz}\sin^2 q\right)\cos^2 f & \frac{1}{2}\left(-e_{xx} + e_{yy}\cos^2 q + e_{zz}\sin^2 q\right)\sin 2f & \frac{e_{zz} - e_{yy}}{2}\sin 2q\cos f \\ \frac{1}{2}\left(-e_{xx} + e_{yy}\cos^2 q + e_{zz}\sin^2 q\right)\sin 2f & e_{xx}\cos^2 f + \left(e_{yy}\cos^2 q + e_{zz}\sin^2 q\right)\sin^2 f & \frac{e_{zz} - e_{yy}}{2}\sin 2q\sin f \\ \frac{e_{zz} - e_{yy}}{2}\sin 2q\cos f & \frac{e_{zz} - e_{yy}}{2}\sin 2q\sin f & e_{yy}\sin^2 q + e_{zz}\cos^2 q \end{bmatrix}$$

Permittivity Ferroelectric Tensor
Principal Axis Crystal Orientation

See: C. M. Krowne, "Theoretical Considerations for Finding Anisotropic Permittivity in Layered Ferroelectric/Ferromagnetic Structures from Full-Wave Electromagnetic Simulations," Invited paper, Microwave & Optical Technology Letters, to be published, Jan. 5, 2000.

$$\bar{\bar{e}}\left(\mathbf{E}_0\right) = \begin{bmatrix} e_{xx}\left(\mathbf{E}_0\right) & 0 & 0 \\ 0 & e_{yy}\left(\mathbf{E}_0\right) & 0 \\ 0 & 0 & e_{zz}\left(\mathbf{E}_0\right) \end{bmatrix}$$

Dispersion or Extraction

- Tensors can be used for direct calculations, obtaining dispersions diagrams, impedances, fields

  C. M. Krowne, "Full-Wave Spectral Green's Function Integral Equation Calculation of Coplanar Ferroelectric Thin Film Transmission Structures," Microwave Optical Technology Letts., Vol. 26, no. 3, pp. 187-192, Aug. 5, 2000.

- Tensors may also may be used for reverse calculations, obtaining from $\gamma = \alpha + j\beta$, permittivity, permeability, and other parameters

  1. C. M. Krowne, S. W. Kirchoefer, and J. M. Pond, "Anisotropic Permittivity Extraction from Phase Propagation Measurements Using an Anisotropic Full-Wave Green's Function Solver for Coplanar Ferroelectric Thin Film Devices," IEEE Microwave Theory & Techniques Dig., pp. 1193-1196, June 14, 2000.

  2. C. M. Krowne, "Theoretical Considerations for Full-Wave Electromagnetic-Media Interactions in Layered Structures with Ferroelectric or Ferromagnetic Materials," Invited paper, Proc. SPIE (Soc. Photo-Optical Instrum. Engin.), Complex Mediums, Microwave Materials, Vol. 4097, pp. 70-84, July 30, 2000.

  3. C. M. Krowne, "Theoretical Considerations for Finding Anisotropic Permittivity in Layered Ferroelectric/Ferromagnetic Structures from Full-Wave Electromagnetic Simulations," Microwave Optical Technology Letts., Jan. 5, 2001.

Extraction of ε and α

- ε tensor can be found by doing the calculations in the reverse direction

- α is obtained from the s-parameter measurements and a direct calculation from the SD code.

C. M. Krowne, M. Daniel, S. W. Kirchoefer, and J. M. Pond, "Anisotropic Permittivity and Attenuation Extraction from Phase Propagation Measurements Using an Anisotropic Full-Wave Green's Function Solver for Coplanar Ferroelectric Thin Film Devices," IEEE Trans. Microwave Th. & Tech., submitted Sept. 2000.

- Surface resistivity may be extracted if the dyadic Green's function modification is established uniquely for the structure under consideration.

Summary

- Tensors can be obtained for the different microscopic descriptions of the meta - materials
- These tensors can be inserted into the spectral domain code to allow direct and reverse calculations of propagation behavior
- Device design or diagnosis can then occur