RF laminate shielding and transmission

CDS theory chapter sample

This chapter explains how an effective dielectric property becomes an input to a planar laminate transmission calculation. The models are intended for RF screening and teaching. A useful first result is the reflected, transmitted and absorbed fraction of incident power. Shielding effectiveness alone does not reveal which mechanism stopped transmission.

1 Material data and sign convention

Use dielectric measurements at the relevant frequency. Mechanical modulus, fiber strength and the material name do not determine complex permittivity. The calculation assumes passive, positive-permittivity, nonmagnetic phases and uses an exp(-i omega t) time convention.

$$\varepsilon_r = \varepsilon_r' + i\left(\varepsilon_r' \tan\delta + \frac{\sigma}{\omega\varepsilon_0}\right) \tag{1}$$

Relative permittivity is dimensionless. The real part describes electric-field storage. The loss tangent describes dielectric loss, conductivity sigma is in S/m, omega is angular frequency in rad/s and epsilon zero is vacuum permittivity. With this convention, a positive imaginary component represents absorption. If measured complex permittivity already includes conductive loss, do not add that conductivity again.

2 Dilute spherical inclusions

$$\varepsilon_{eff} = \varepsilon_h \frac{\varepsilon_i + 2\varepsilon_h + 2v(\varepsilon_i - \varepsilon_h)}{\varepsilon_i + 2\varepsilon_h - v(\varepsilon_i - \varepsilon_h)} \tag{2}$$

In Equation 2, h denotes the host, i the inclusion and v the inclusion volume fraction. Maxwell-Garnett treats small spherical inclusions embedded in a continuous host. Its algebra remains evaluable at large fractions, but that does not validate it for connected particles or percolating conductive networks. For example, a host permittivity of 2, inclusion permittivity of 8 and volume fraction of 0.2 give an effective value of 8/3.

3 Choose a model for the physical structure

Standard studies include the series and parallel Wiener constructions, Looyenga mixing, Maxwell-Garnett and normal-incidence laminate transmission. Looyenga and Landau-Lifshitz-Looyenga refer to one cube-root mixing law in CDS. Series and parallel values are ordered bounds only for positive, real, lossless dielectric phases. For complex lossy phases, treat them as directional estimates, not ordered complex bounds.

Advanced studies add Bruggeman symmetry, scalar principal-axis Mori-Tanaka and self-consistency, differential mixing, coated spheres, multiphase Bruggeman and oblique TE/TM transmission. A principal-axis approximation is not a full anisotropic constitutive tensor. The spherical self-consistent case reduces to Bruggeman; these should not be interpreted as independent experimental confirmations.

For a coated sphere, first specify core volume divided by total coated-particle volume. Separately specify the volume fraction of coated particles in the host. The coating law is electrostatic and assumes a concentric subwavelength particle. It does not solve dynamic Mie scattering. Differential mixing compares two numerical refinements; multiphase Bruggeman must reach its residual tolerance before returning a property.

4 Convert layer properties into power fractions

The coherent laminate calculation tracks waves reflected between planar interfaces. The implementation uses a scattering-stable recursion equivalent to the transfer-matrix formulation, avoiding exponentially growing terms inside absorbing layers. Air occupies both exterior half-spaces. Each layer is isotropic and nonmagnetic.

$$R + T + A = 1 \tag{3}$$

$$SE = -10 \log_{10}(T) \tag{4}$$

R, T and A denote reflected, transmitted and absorbed power fractions. SE is shielding effectiveness in dB. A high SE may result mainly from reflection rather than absorption. The numerical energy-balance check rejects nonpassive or inconsistent results. Sections 8 and 9 describe the additional lossless one-dimensional TLM and Floquet-Bloch studies.

5 Worked quarter wave check

Consider a lossless slab between air regions at 10 GHz. Set relative permittivity to 4, giving refractive index n = 2. Set dielectric loss tangent and conductivity to zero. For a quarter wavelength inside the slab, use Equation 5 with vacuum wave speed c = 299792458 m/s.

$$d = \frac{c}{4fn} \tag{5}$$

The thickness is 3.747405725 mm. The analytic slab result is R = 0.36, T = 0.64 and A = 0. The shielding is approximately 1.9382 dB. This test checks interface interference and power normalization. It is not a measurement of a particular composite or a validation of a fitted effective-medium law.

6 Study setup and handoff

Create an EM field study in the Workbench model browser or start its matching exercise. Run the EM case separately from thermal, moisture and structural cases. Mixing studies use explicit host and inclusion properties. The laminate study uses A and B dielectric layers, explicit thicknesses, AB repeat count and a frequency interval. Advanced transmission adds angle and TE/TM polarization.

The current handoff is manual: transfer effective real permittivity and effective loss tangent into a laminate layer, setting conductivity to zero when it is already included in effective loss. These fields do not alter saved mechanical ply properties. Never substitute one directional property into an isotropic stack without justifying that approximation.

7 Resolution and engineering limits

The frequency sweep contains 101 samples. Narrow the interval to examine sharp resonances; a smooth plotted line does not prove they are resolved. Shielding is displayed up to 300 dB when transmission reaches the numerical display floor. Do not report the floor as a measured performance. Finite edges, seams, roughness, magnetic or negative-permittivity media, anisotropic polarization conversion and thermal feedback are outside this release.

References

Byrnes, Multilayer optical calculations, arXiv:1603.02720. COMSOL 6.4, Effective Relative Permittivity in Effective Media and Mixtures. Catalysts 9 (2019), 626, Electromagnetic Effective Medium Modelling of Composites with Metal-Semiconductor Core-Shell Type Inclusions.

8 Time domain TLM in one dimension

The Advanced TLM study represents each lossless layer as bidirectional delay cells. At each material junction, continuity of electric and magnetic fields scatters the incident voltages into reflected and transmitted voltages. Matched air ports absorb outgoing waves. A unit impulse supplies the excitation; its recorded reflected and transmitted histories are transformed to the requested frequency samples.

Normal incidence, relative permittivity from 1 to 100, isotropic nonmagnetic layers and zero dielectric or conductive loss are required. Layer transit times are rounded to integer cells of a shared time step. The result reports this thickness approximation, delay-cell count and time-step count. This is a one-dimensional wave solution, not an antenna, finite-edge or general three-dimensional field solution.

A second calculation doubles the temporal and spatial resolution. The run rejects a spectral difference greater than two percentage points, unresolved pulse energy, or a spectral power imbalance. Resource caps limit delay cells and time steps. Increase resolution or simplify the stack when a check fails; a failed check does not produce a substitute TMM result. Press Run again after changing an input.

9 Periodic layers with Floquet Bloch conditions

The Advanced Bloch study forms the characteristic matrix of one lossless A/B period. Its determinant is one, and its eigenvalues obey Equation 6. The eigenvalue is exp(iKd), where d is the period and K is the Bloch wave number. Equation 7 identifies the trace criterion for a propagating band or an evanescent stop band.

$$\lambda^2 - tr(M)\lambda + 1 = 0 \tag{6}$$

$$\cos(Kd) = \frac{tr(M)}{2} \tag{7}$$

The displayed phase is folded into the first Brillouin zone. A nonzero imaginary wave number in a lossless stop band is evanescent decay, not absorption. The study does not infer a complete effective material tensor. For quarter-wave layers with refractive indices 2 and 3, the half trace is −13/12 and attenuation per period is ln(3/2). For identical layers, the result reduces to homogeneous-wave dispersion.

Further reading: Clemson Vehicular Electronics Laboratory, The Transmission Line Matrix Method; Efficient Optical Sensing Based on Phase Shift of Waves Supported by a One-Dimensional Photonic Crystal, PMC8512066. These sources explain the numerical method and periodic-layer dispersion; the CDS domain limits above still apply.