Advanced Computation:
Computational Electromagnetics

Parameter Sweeps

What is a Parameter Sweep?

So far, TMM can only simulate a single device at a single frequency, or wavelength.

Suppose this data is calculated as we continuously change one or more parameters? This is called a parameter sweep.

Parameter sweeps are perhaps the most powerful tool in the analysis arsenal.
Block Diagrams of Common Parameter Sweeps

Conventional Sim (No Sweep)
Dashboard → Compute Params. → Build Device → Perform Sim → Show Results

Wavelength or Frequency Sweep
Dashboard → Compute Params. → Build Device → Set \( \lambda_0 \) or frequency → Perform Sim → Record Results → Show Results

Device Parameter Sweep
Dashboard → Compute Params. → Build Device → Set Parameter → Perform Sim → Record Results → Show Results

Convergence Sweep for NRES
Dashboard → NRES → Set NRES → Compute Params. → Build Device → Perform Sim → Record Results → Show Results

Good idea to visualize your results during simulation. You can abort early if something is wrong.

Make a Generic TMM Function

A great way to simplify programming parameter sweeps is to first make a generic function out of the TMM code.

The basic TMM simulation will take as input arguments:

Source: \( \lambda_0, \theta, \phi, \) polarization, etc.
Device: UR, ER, L, etc.

Given these input arguments, a generic TMM function can simulate the device and calculate reflectance, transmittance, fields, etc.

It may return REF, TRN, or whatever else is desired.
Example Header for a Generic TMM Function

```matlab
function DAT = tmm1d(DEV,SRC)
% TMM1D One-Dimensional Transfer Matrix Method
% DAT = tmm1d(DEV,SRC);
% INPUT ARGUMENTS
% ================
% DEV       Device Parameters
%  .er1    relative permittivity in reflection region
%  .ur1    relative permeability in reflection region
%  .er2    relative permittivity in transmission region
%  .ur2    relative permeability in transmission region
%  .ER     array containing permittivity of each layer
%  .UR     array containing permeability of each layer
%  .L      array containing thickness of each layer
% SRC       Source Parameters
%  .lam0   free space wavelength
%  .theta  elevation angle of incidence (radians)
%  .phi    azimuthal angle of incidence (radians)
%  .pte    amplitude of TE polarization
%  .ptm    amplitude of TM polarization
% OUTPUT ARGUMENTS
% ================
% DAT       Output Data
%  .REF    Reflectance
%  .TRN    Transmittance
```

These comments are displayed at the command prompt by typing `>> help tmm1d`.

It is always a good idea to include a help section at the start of your codes.

What Steps are Performed by TMM1D()

- **Step 0** – Define problem
- **Step 1** – Dashboard
- **Step 2** – Describe device layers
- **Step 3** – Compute wave vector components
- **Step 4** – Compute gap medium parameters
- **Step 5** – Initialize global scattering matrix
- **Step 6** – Main loop through layers
- **Step 6.1** – Iterate through layers
  - Compute P and Q
  - Compute eigen-modes
- **Step 7** – Compute reflection side scattering matrix
- **Step 8** – Compute transmission side scattering matrix
- **Step 9** – Update global scattering matrix
- **Step 10** – Compute source
- **Step 11** – Compute reflected and transmitted fields
- **Step 12** – Compute reflectance and transmittance
- **Step 13** – Verify conservation of power
Wavelength or Frequency Parameter Sweep

By far, the most common parameter sweep is calculating the device behavior as a function of frequency or wavelength.

```matlab
for nlam = 1 : NLAM
    SRC.lam0 = LAMBDA(nlam);
    DAT = tmm1d(DEV,SRC);
    REF(nlam) = DAT.REF;
end
```

![Graph showing reflectance and transmittance as functions of wavelength.]

Incorporating Material Dispersion into a Parameter Sweep

Sometimes the material properties change significantly as a function of frequency, or wavelength.

This is called dispersion.

Dispersion can be incorporated into your parameter sweep by:

1. Calculate the material properties at the given wavelength or frequency.
2. Rebuild the device each iteration with the material properties that were just calculated.
Bad Vs. Good Parameter Sweeps

- **BAD**
  - Line Thickness
  - White Space
  - White Space
  - Triangles
- **GOOD**
  - # Digits
  - Label
  - Font Size
  - Scale

Wavelength Response of a Bragg Grating