Week 5: Quarter Wave Transformer with FDTD in 1D Systems

Sankeerth.D
EE13B102
Electrical Engineering

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Abstract

Transmittance can be increased by introducing a qwarter wave plate inbetween the slab and air. Impedance matching, ideally, wil make all the light pass through, reducing back reflection.

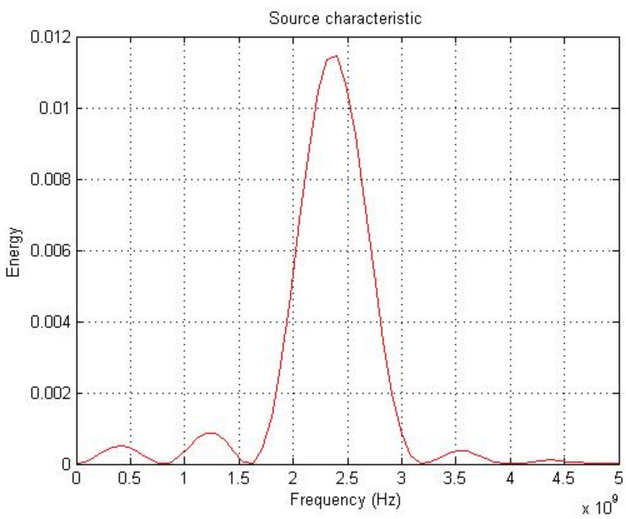
1 Introduction

Again, the normallized equation is solved here, and the units and differential increments are adjusted to fit the problem parameters. QWT's have their refractive index as the geometric mean of the product of the refractive indices of the adjascent media. Here, two of these are used on either side of the slab.

2 Selection of Units

Where H1 and E1 are the scaled E and H. Scale the units of x and t to obtain equations identical to the ones shown above. for the frequency of 2.4 GHz, In the middle layer, it turns out that the ripples are too high for a time step of 0.333e-10 seconds. So, for this case, It's conveniant to choose t to be in multiples of 0.1666e-10, and x to be in multiples of 0.5e-2 metres. Then, the update equations will be identical to the normallized case.

1 foot occupies 30 centimeter, so 60 units of x should do. The length of the quarter wave plate is 1.68 centimeter. 3 units of x, which is 1.5 centimeter, is used here. Frequency of 2.4 GHz is obtained using a sinusoidal source, and source is on for 3 cycles. This creates a frequency spread, roughly between 2.2 and 2.6 GHz. The source spectrum is as shown an follows:

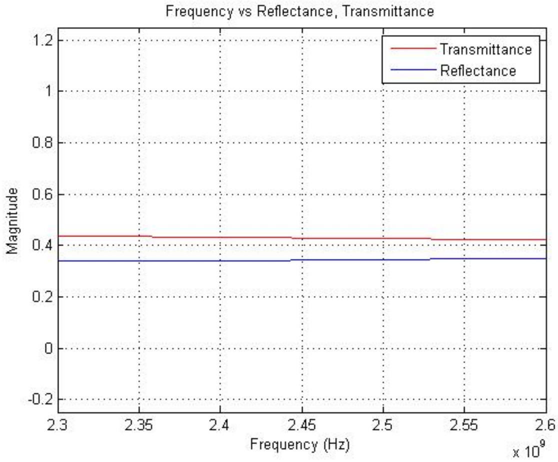


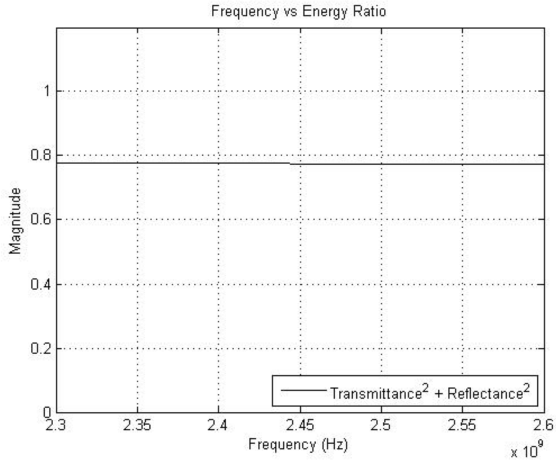
The total length is 300 units, which is 150 centimeter. To record only one time reflection, and provent multiple reflections, the slab is placed at 2*xdim/3 from the source.

3 Observation

On runnning the ssimulation for 700 time units, which is 11.66 nanoseconds, a single reflection and transmission can be captured.

Before introducong the QWT, the reflectance and transmittance are as follows (for epsilon =12, mu = 1):



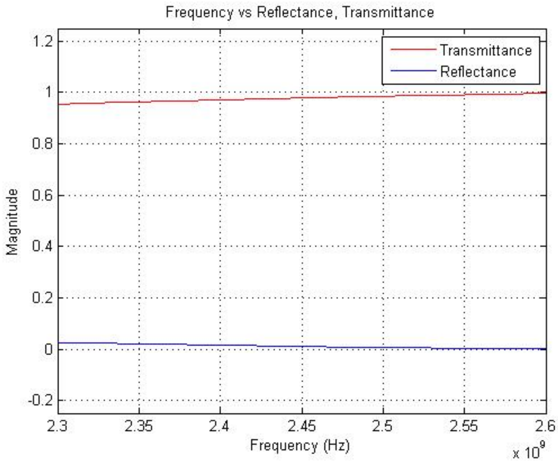


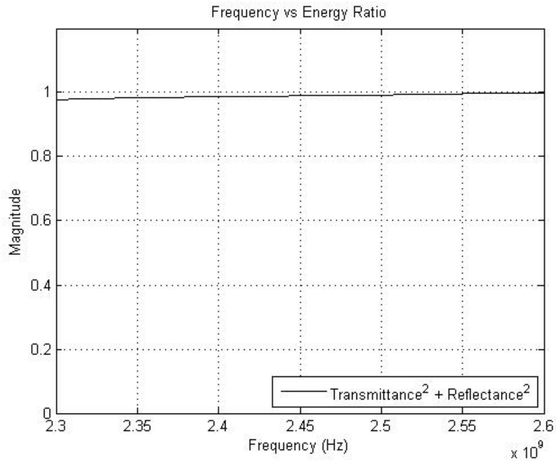
A large portion of the wave got reflected back in this case. Observe that less than 80 percent of the total energy is reflected+transmitted in the first reflection. Also, as expected, as the permittivities are independant of frequency, the characteristics are also independant of frequency (around 2.4 GHz.). Since the medium is nonmagnetic (unlike in the previous case where there's mu = 2) Fresnel's equations can be applied.

$$Reflectance = \frac{(n-1)^2}{(n+1)^2}$$

where n = sqrt(12). Plugging this in, we get reflectance = 0.305, close to whar we get in simulation.

On placing a dielectric across the 1 foot slab, there would be a somewhat slower transition between the media and it is reasonable to expect a higher transmittance. Also, since the QWT is designed such that reflective component destructively interferes across the quarter wave, reflectance reduces sharply, as can be seen below:





One can clearly see thet these lines aren't horizontal. This is because we are measuring the interfered portion of wave (across the QWT). Since there's a frequency spread, and we have used a 1.5 centimeter QWT, the ideal transmission happens at 2.6 GHz. If we were to use a more accurate 1.68 cm, we would've gotten the peak at 2.4 GHz, but this is good enough for a demonstration. As expected, most of the light passes through.

4 Result and Discussion

Note that this probem can be solved using the same update equations and different spacing Δx and Δt. The discretization chosen here is such that in the high refractive index material, the gaussian pulse is not very sharp. If it were to be sharp, Due to courant factor, the inaccuracy and error in simulation increases by multiplee folds, and numerous ripples can be seen in the medium.

As one can see, The medium is not frequency selective, and The reason for the very small slope in the second case is because what we measure is the interfered light, the sum of it's reflected components across 1.68 centimeter. Since defferent frequencies have different powers after this interference, we see this frequency dependnce.