

## Lowpass Filter Design by Circuit-EM Co-simulation

Microwave filter is a two port network providing signal transmission at passband and signal reflection or signal absorption at stopband. Microwave filters are widely used in various microwave systems (radar, radio astronomy systems, base stations...).

The topic of this paper is to present various possible approaches to filter design provided by WIPL-D software on a simple example.

### Filter Designer

Filter Designer (Fig. 1) is a user-friendly, wizard-style application with straightforward two-stage approach to filter design. It is intended for automated design of lowpass, highpass, bandpass and bandstop filters of Chebyshev and Butterworth type. Currently supported filter implementations are microstrip (stepped impedance and stub resonators), ideal transmission line and lumped LC ladder networks. A simulation-ready circuit model in WIPL-D Microwave is automatically generated based on Filter Designer output.

Three models of a low-pass filter, derived from the same specs, are created using Filter Designer. The first model is implemented as a LC ladder (Fig. 2), the second as transmission line (Tx) stubs (Fig. 3). The third model is implemented as a microstrip stub filter (Fig. 4). These three models are simulated in WIPL-D Microwave circuit simulator using closed-form equation components.

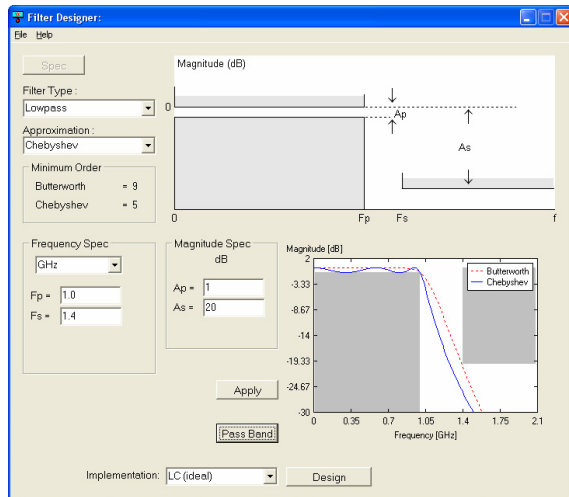


Figure 1. WIPL-D Filter Designer

Filter specs and design parameters are given in Tab. 1. Filter type is lowpass and approximation is Chebyshev.

Table 1. Filter specification (spec) and design parameters

| Spec Parameter        | Value [Unit] | Design Parameter | Value [Unit] |
|-----------------------|--------------|------------------|--------------|
| F pass                | 1 [GHz]      | Filter order     | 5            |
| F stop                | 1.4 [GHz]    | R source         | 50 [Ohms]    |
| Pass-band attenuation | 1 [dB]       | R load           | 50 [Ohms]    |
| Stop-band attenuation | 20 [dB]      | Ripple           | 1 [dB]       |

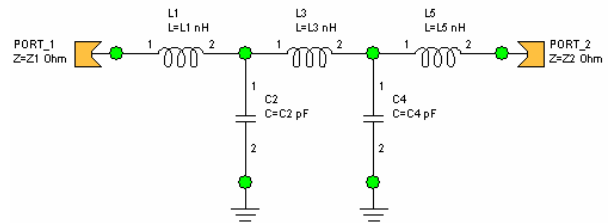


Figure 2. LC ladder filter in WIPL-D Microwave circuit simulator

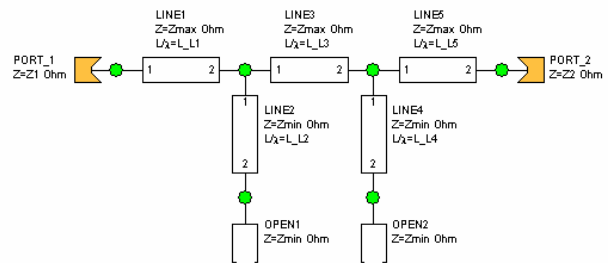
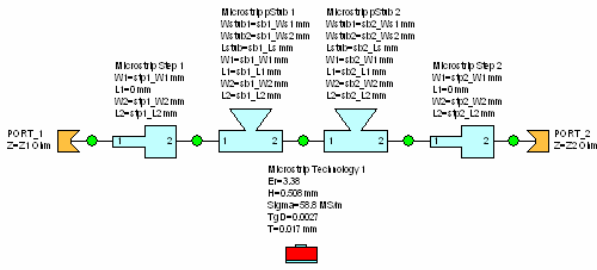
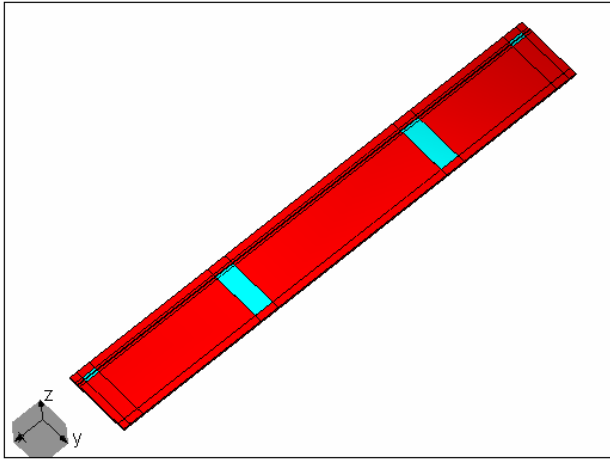


Figure 3. Transmission line ideal filter (stub type) in WIPL-D Microwave circuit simulator



**Figure 4. Microstrip filter in WIPL-D Microwave circuit simulator**

For purposes of verification, full EM simulation in WIPL-D Pro will be performed. The EM model of the complete filter is shown in Fig. 5.



**Figure 5. Microstrip filter in WIPL-D Pro 3D EM solver**

## WIPL-D Simulation

Dielectric characteristics for the microstrip model are given in Tab. 2.  $H$  is substrate height,  $TgD$  is loss tangent, while  $T$  is metallization thickness.

**Table 2. Dielectric characteristics**

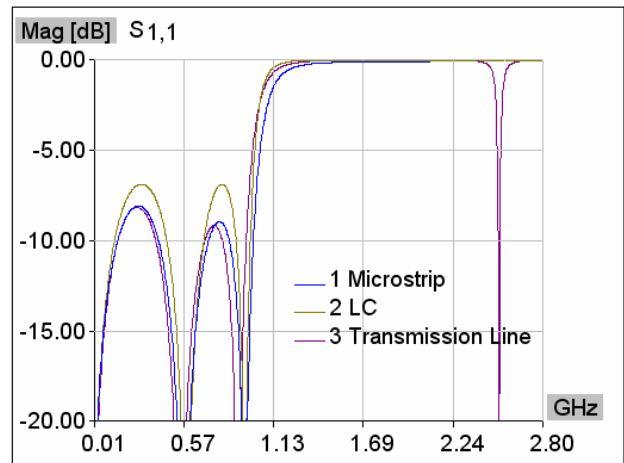
| Parameter | Value [Unit] |
|-----------|--------------|
| $E_r$     | 3.38         |
| $H$       | 0.508 [mm]   |
| $\Sigma$  | 58.8 [MS/m]  |
| $TgD$     | 0.0027       |
| $T$       | 0.017 [mm]   |

Frequency range of interest is from 0.014 GHz up to 2.8 GHz, and it is scanned in 40 points in our simulations except for 3D EM simulation where a more narrow band was 0.014-2.2 GHz was scanned in 20 points. The band was narrowed for EM simulation

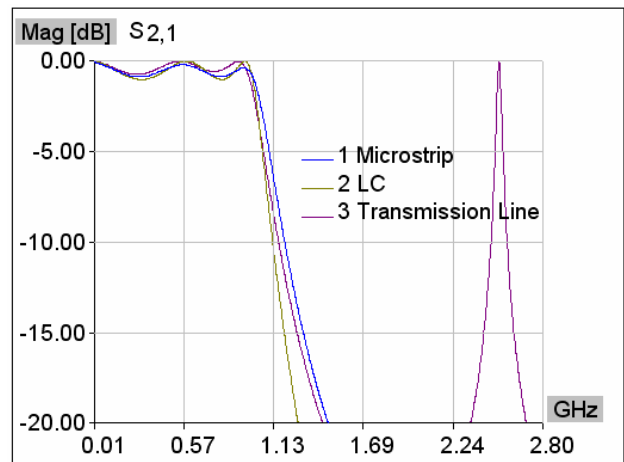
because the closed-form models showed this is enough to capture the dynamics of the filter.

Parameters  $S_{11}$  and  $S_{21}$  of the LC, microstrip and transmission line circuit models are compared in Figs 6-7. Microstrip closed-form component models were used in the corresponding circuit model (Fig. 4). Parameters  $S_{11}$  and  $S_{21}$  of the microstrip circuit model and the full EM model are compared in Figs 8-9.

The 3D EM filter model has the same dimensions as the model in circuit simulator. Differences in the results exist, which is expected because closed-form equations do not take into account all the physical effects that EM simulation does. Some of these effects are mutual EM coupling between discontinuities and radiation of some circuit elements. Simulation times are given in Tab. 3. Computer used for these calculations is Pentium® Dual-Core CPU E5200 @ 2.50 GHz 2 GB RAM, except for 3D EM simulation where Intel® Xeon® CPU E5345 @2.33 GHz with 23.9 GB RAM is used.



**Figure 6.  $S_{11}$  parameter of LC, Tx and microstrip models in WIPL-D Microwave circuit simulator**



**Figure 7.  $s_{21}$  parameter of LC, Tx and microstrip models in WIPL-D Microwave circuit simulator**

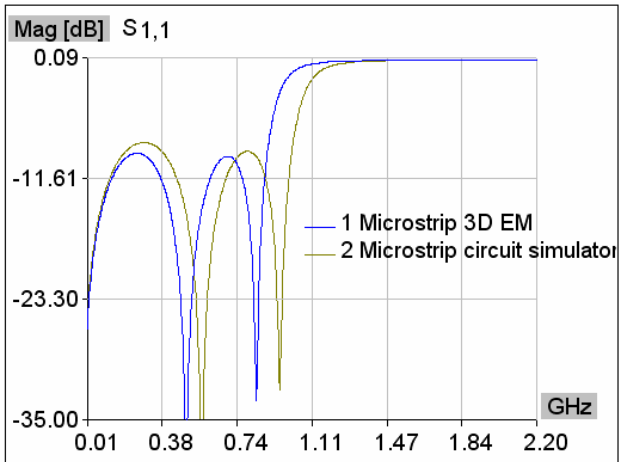


Figure 8.  $S_{11}$  parameter of microstrip model simulated in WIPL-D Microwave circuit simulator and WIPL-D Pro 3D EM solver

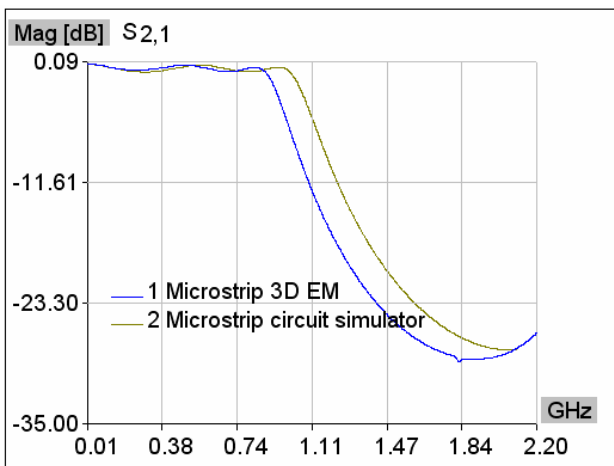


Figure 9.  $S_{21}$  parameter of microstrip model simulated in WIPL-D Microwave circuit simulator and WIPL-D Pro 3D EM solver

Table 3. Analysis characteristics

| Model            | Time @ 0.014-2.8 GHz [sec] |
|------------------|----------------------------|
| LC               | <1                         |
| Tx               | <1                         |
| Microstrip       | <1                         |
| Microstrip/3D EM | 5227                       |

## Conclusion

Using WIPL-D Filter Designer we can easily create initial filter models that approximately satisfy design specs. Circuit models automatically generated in WIPL-D Microwave can be simulated using closed-form component models from library so initial S-parameter results can be obtained in seconds. However, we know that closed-form models have limited validity ranges and don't take into account all the physical effects. Hence, models using closed-form equations can not be considered accurate enough. As a first step, accuracy can be increased if closed-form models are replaced by library EM component models in the circuit simulator. However, EM coupling between circuit components can be taken into account only in the EM model of the entire circuit, so it is important to verify the results in this way.