# Simulation and Analysis of Finned Waveguides

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***Abstract*—This paper focuses on the analysis methods of symmetrical rectangular finned waveguides. Cutoff frequencies are found for different simulation cases in order to prove their validity. Furthermore electromagnetic (EM) fields are studied for geometry changes of the fins (both in width and height).**

***Index Terms*—Finned waveguides, microwave propagation, waveguide analysis, waveguide simulation.**

## I. Introduction

PROPAGATION in waveguides can occur in transverse electric (TE) and transverse magnetic (TM) mode. Waveguides can sustain different modes, each defined by its own cutoff frequency. Our interest is mostly focused on the lowest mode ($TE_{10}$) cutoff frequency, below which no propagation occurs in the waveguide. However higher modes will also be briefly analyzed.

Fins are conductors extending inside the region enclosed by a rectangular waveguide. They can be filled with dielectric or, under appropriate assumptions, the dielectric can be omitted and single conductor fins are used. Finned waveguides are interesting because they can be used to realize converters and filters [2].

In Section II the accuracy of the transmission line matrix (TLM) analysis from [1] is compared with simulations run with COMSOL. The studied waveguide structure does not include a dielectric when TLM comparisons are made.

Section III will cover methods discussed in [2] aimed at finding an equivalent dielectric filled waveguide to the finned structure. The comparisons between equivalent structure and COMSOL simulations are made only for the lowest TE mode ($TE_{10}$).

Section IV of this paper will cover geometry changes in the fin model used in Section III. The objective here is to analyze the electromagnetic field configuration inside the cross sectional area of the waveguide. Some higher propagation modes are also simulated and compared.

## II. Transmission Line Matrix Analysis

Initially the geometry used in this section is a rigged waveguide with zero thickness centered fins in order to cover the case treated in [1]. The geometrical structure is seen in Fig. 1 where the boundary conditions are also shown.

As an extension, cases with copper ridges with different finite thicknesses (1 mm, 3 mm, and 5 mm) have been simulated. Cutoff wavelengths $\lambda_c$ for $TE_{10}$ mode have been recorded and normalized after the simulations. Results are available in Table I. The dimension $a$ is the cross sectional width of the waveguide and $b$ the waveguide height. The gap between the conductors is marked with $d$. The dimensions are equivalent with Fig. 2.

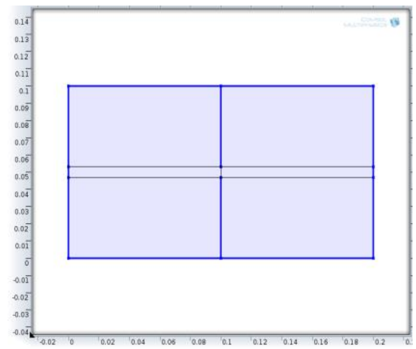

Fig. 1. The domain for the TLM verification of Section II. Blue lines represent perfect electric conductor boundaries.

Results for the boundary condition simulation are within one percent of the TLM estimates for the first three normalized gaps. Thinner fins have a percentage error lower than 2.7 %.

TABLE I
Normalized $TE_{10}$ Cutoff Wavelength $b/\lambda_c$ in Finned Waveguide of Aspect Ratio $b/a = 0.5$ for Several Normalized Gap Widths $d/b$ and Simulation Cases

| Normalized gap width | Boundary condition | 1 mm Cu fin | 3 mm Cu fin | 5 mm Cu fin | TLM method[a] |
|---|---|---|---|---|---|
| 2/3 | 0.2382 | 0.2378 | 0.2361 | 0.2346 | 0.2391 |
| 1/2 | 0.2238 | 0.2231 | 0.2204 | 0.2181 | 0.2253 |
| 1/3 | 0.2036 | 0.2026 | 0.1989 | 0.1958 | 0.2054 |
| 1/4 | 0.1910 | 0.1898 | 0.1855 | 0.1817 | 0.1932 |
| 1/8 | 0.1665 | 0.1649 | 0.1588 | 0.1537 | 0.1697 |
| 1/16 | 0.1482 | 0.1460 | 0.1373 | 0.1304 | 0.1522 |

[a]Data obtained from [1].

The ohmic losses in the copper fin are relevant in the other simulation results. However, the TLM analysis in [1] hasn't covered those cases so a comparison is not possible.

## III. Equivalent Dielectric Filled Waveguide

The second analyzed structure is shown in Fig. 2. In this structure, there are four infinitely thin conductors. The volume bounded by these conductors is filled with the dielectric. The dielectric is marked with the gray color in the middle of Fig. 2 and has relative permittivity $\varepsilon_r$. Otherwise, the inner waveguide is filled with air (light blue parts in Fig. 2).

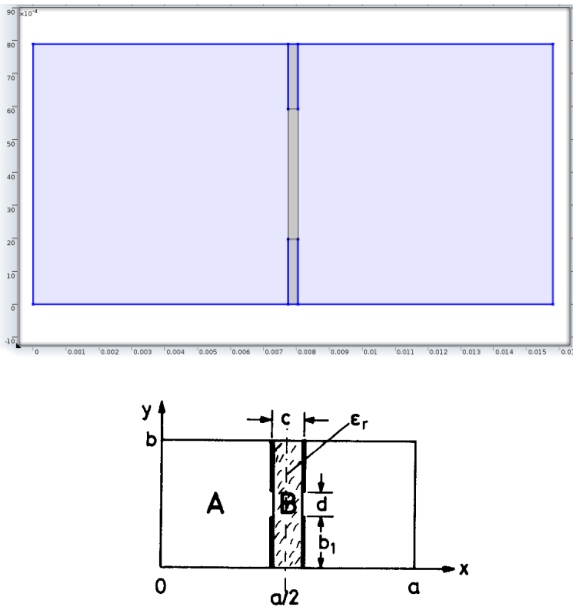


Fig. 2. Cross section of a simulated fin line (above) and physical parameters (below, picture taken from [2]). Blue lines represent perfect electric conductor boundaries. The area A is air filled while B dielectric filled.

Saad and Schünemann present in [2] how to form a simple equivalent model for the waveguide structure seen in Fig. 2. The assumption for that is that the hybrid HE modes might be replaced by their TE parts. In other words, we assume that the TE part is much larger than the TM part. Then, $\varepsilon_r$ is moderate and $c/a \ll 1$. The equivalent structure depends on the used mode. In this paper only the one related to $TE_{10}$ is analyzed. The used dimensions of the fin line are listed in Table II.

TABLE II
FIN LINE PARAMETERS

| Symbol | Description | Value |
|---|---|---|
| $a$ | waveguide width | 15.8 mm |
| $b$ | waveguide height | 7.9 mm |
| $b_1$ | conductor height | 3.16 mm |
| $c$ | dielectric width | 0.3 mm |
| $d$ | distance between conductors in y direction | 1.58 mm |
| $\varepsilon_r$ | dielectric relative permittivity | 2.22 |
| $a_1$ | equivalent waveguide width[a] | 23.7 mm |
| $k_{e10}$ | effective dielectric constant[a] | 1.16 |

[a]Value from [2].

For the lowest mode $TE_{10}$, it is possible to find a cross section width $a_1$ so that we have a simple equivalence for the structure in Fig. 2 without the conductors. So, the equivalence is just a rectangular waveguide which is filled with dielectric and has the original height $b$ and new width $a_1$. The effective dielectric constant $k_{e10}$ is defined according to [2].

From COMSOL simulation, we get the cutoff frequency for $TE_{10}$ mode in the Fig. 2 structure. The value is 6.2822 GHz. When simulated, the equivalent waveguide structure had a value of the cutoff frequency of 5.8724 GHz. These results have a difference of 6.52 %. However, the cutoff frequency gets the value 6.3247 GHz when the same equivalent structure is used but the dielectric has been replaced with air. This value of the air filled equivalent model differs only by 0.677 % from the original structure simulation.

## IV. GEOMETRY CHANGES AND DIFFERENT MODES

The domain used to analyze the way the electromagnetic fields are affected by the geometry of the finned waveguide is the one of Fig. 2. Several parametric simulations have been run with COMSOL, where the fin's thickness $c$ and gap $d$ have been increased twice by a factor of 2. The other fin line parameters are same as in Table II. Cutoff frequencies for the lowest mode are plotted in Fig. 3.

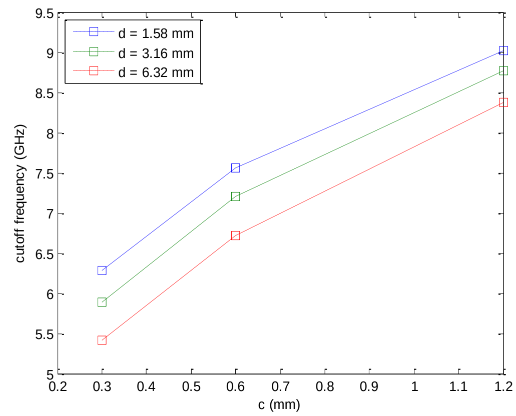


Fig. 3. Cutoff frequencies for lowest mode with different fin parameters.

From Fig. 3 it is clear that, for a given $d$, the cutoff frequencies increase as $c$ increases. Instead, for a fixed $c$, the cutoff frequency is the highest for the smallest $d$ considered. Only nine different cases with different dimensions have been simulated. However, the results seem to be straightforward and quite clear conclusions can be made based on the simulations.

Regarding electromagnetic fields, Fig. 4 shows the field pattern for the lowest mode. It's noticeable how the largest electric field values are present only in the gap between the fins.

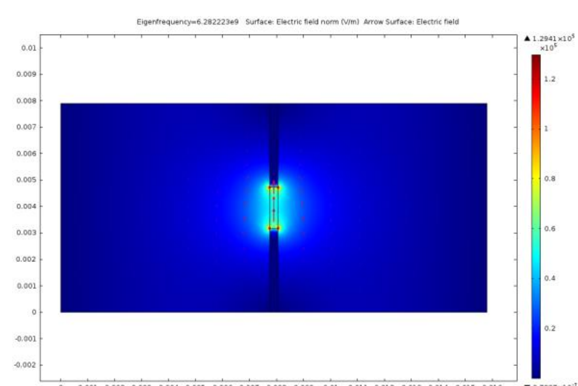

Fig. 4. Electric field pattern for $TE_{10}$ mode.

A very thin and slim fin would mean very intense and centered electric fields in a very small section of the waveguide. This characteristic could be very important for high power waveguides.

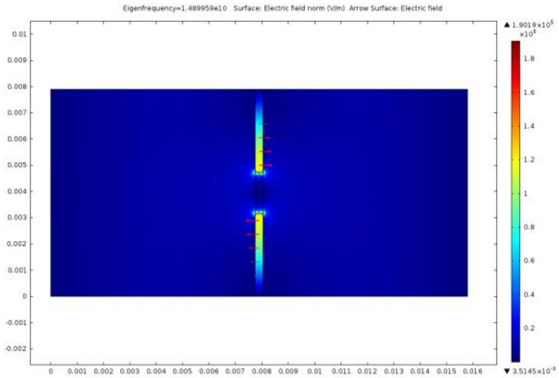


Fig. 5. Electric field pattern for the second lowest propagating mode.

Fig. 5 displays the second order propagation mode. In this case the electric field is present only in the dielectric. The third order mode shows that the E field has the same orientation on both fins. The cutoff frequency is almost the same for the second and third lowest mode.

Fig. 6 concerns the fourth order mode. Now, the largest electric field values don't exist inside the dielectric but in the air region. More advanced modes will not be discussed since they're out the scope of this paper.

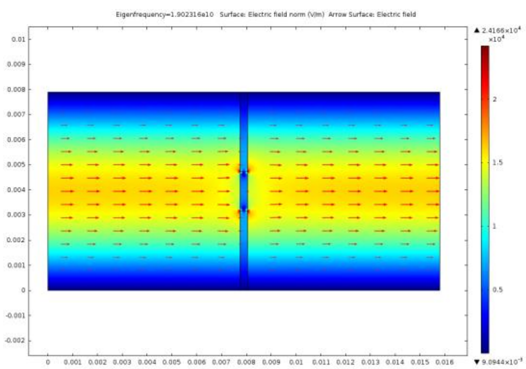


Fig. 6. Electric field pattern for the fourth lowest propagating mode.

## V. Conclusion

Transmission line matrix estimates have been compared with COMSOL simulations. The estimates seem to be precise for the case of infinitely thin conductors. When the conductors become wider the approximations get more inexact.

The equivalent structure for the fin line mode $TE_{10}$ has been studied. It turned out that the approximation wasn't very accurate. However, the difference between the simulation and the equivalent model became more precise when the equivalent dielectric was replaced by air.

The effects of geometry changes were simulated in the fin line structure. It was found out that the cutoff frequency of the lowest mode increases when the gap between the conductors decreases or dielectric width increases. Additionally, four lowest modes of the fin line structure were studied.

## References


[1] Yi-Chi Shih and Wolfgang J. R. Hoefer; "The Accuracy of TLM Analysis of Finned Rectangular Waveguides"; IEEE Trans. Microwave. Theory Tech., VOL. MIT-28, NO. 7, July 1980.

[2] Abdel Megid Kamal Saad and Klaus Schünemann; "A Simple Method for Analyzing Fin-Line Structures"; IEEE Trans. Microwave. Theory Tech., MIT-26, NO. 12, December 1978.