Effective Dielectric Constant

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Part I: Introduction

The effective dielectric constant K_{eff} is somewhat less than the substrate's dielectric constant due to part of the fields from the microstrip conductor existing in air.

Part II: Calculation

When $\left(\frac{W}{H}\right) < 1$:

$$K_{eff} = \frac{K_r+1}{2} + \frac{K_r-1}{2} * \left(\frac{1}{\sqrt{1+12\left(\frac{H}{W}\right)}} + 0.04\left(1-\left(\frac{W}{H}\right)\right)^2\right) \quad (1)$$

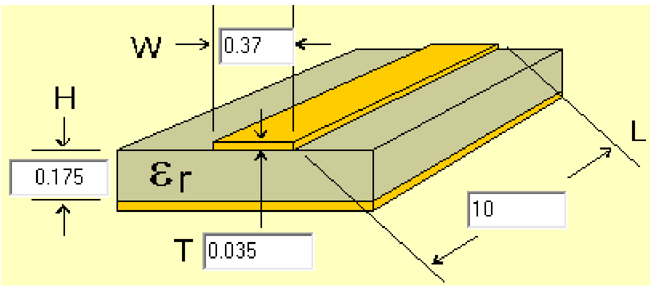
When $\left(\frac{W}{H}\right) \geq 1$:

$$K_{eff} = \frac{K_r+1}{2} + \frac{K_r-1}{2} * \frac{1}{\sqrt{1+12\left(\frac{H}{W}\right)}} \quad (2)$$

All microstrip equations are approximate. The above equations ignore strip thickness, so we wouldn't recommend relying on them for critical designs on thick copper boards [1].

Part III: Using effective dielectric constant

When $\left(\frac{W}{H}\right) \geq 1$:



Length Units: mm $K_r = 4.16$

For the microstrip design in above diagram:

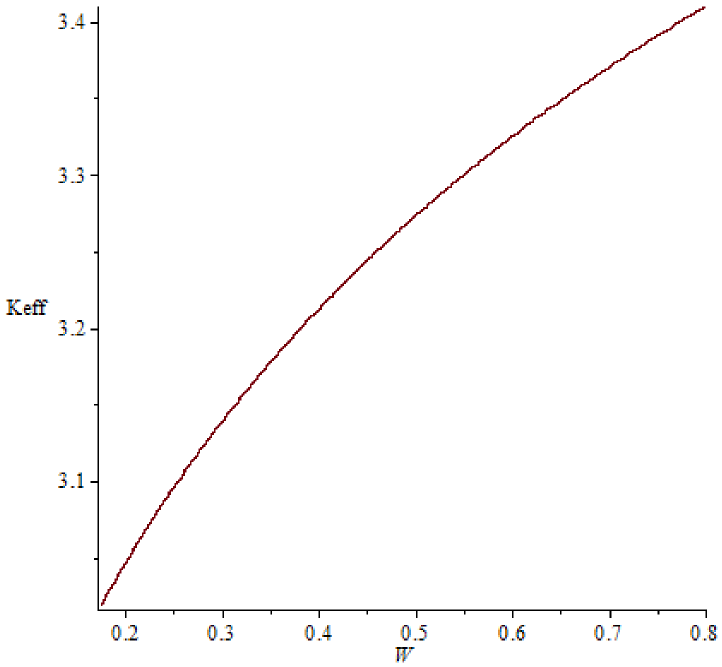
$$\left(\frac{W}{H}\right) = \frac{0.37}{0.175} \approx 2.114285714 \geq 1$$

therefore,

$$K_{eff} = \frac{K_r+1}{2} + \frac{K_r-1}{2} * \frac{1}{\sqrt{1+12\left(\frac{H}{W}\right)}} = \frac{4.16+1}{2} + \frac{4.16-1}{2} * \frac{1}{\sqrt{1+12\left(\frac{0.175}{0.37}\right)}} = 3.19$$

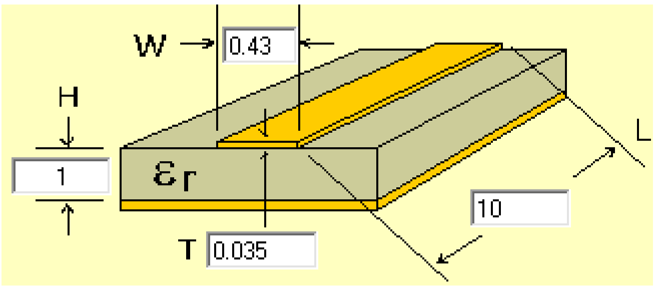
A RF design may use microstrips with different W in a real word design. The effective dielectric constant is plotted in the following chart when W is selected between 0.176mm and 0.8mm.

$$plot\left(\frac{4.16+1}{2} + \frac{4.16-1}{2} \cdot \left(\frac{1}{\sqrt{1+12\left(\frac{0.175}{\mathrm{W}}\right)}}\right), W = 0.176..0.8\right)$$



Finally, the K_{eff} is within [3.01, 3.40] and the average is 3.21. In most cases, the acceptable design can be implemented by using the average as K_{eff}.

When $\left(\frac{W}{H}\right) < 1$:



Length Units: mm $K_r = 4.16$

For the microstrip design in above diagram:

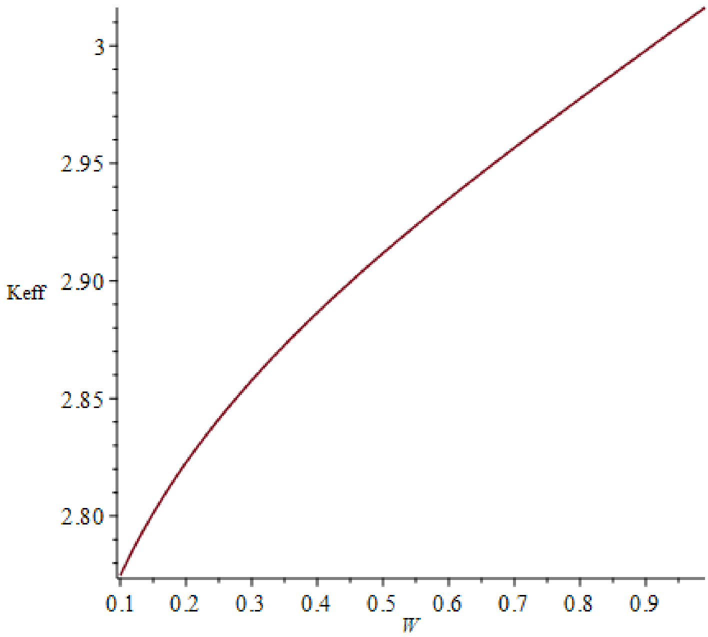
$$\left(\frac{W}{H}\right) = \frac{0.43}{1} = 0.43 < 1$$

therefore,

$$K_{eff} = \frac{K_r+1}{2} + \frac{K_r-1}{2} * \left(\frac{1}{\sqrt{1+12\left(\frac{H}{W}\right)}} + 0.04\left(1-\left(\frac{W}{H}\right)\right)^2\right) = \frac{4.16+1}{2} + \frac{4.16-1}{2} * \left(\frac{1}{\sqrt{1+12\left(\frac{1}{0.43}\right)}} + 0.04\left(1-\left(\frac{0.43}{1}\right)\right)^2\right) = 2.89$$

A RF design may use microstrips with different W in a real word design. The effective dielectric constant is plotted in the following chart when W is selected between 0.1mm and 0.99mm.

$$plot\left(\frac{4.16+1}{2} + \frac{4.16-1}{2} \cdot \left(\frac{1}{\sqrt{1+12\left(\frac{1}{W}\right)}} + 0.04\left(1-\frac{W}{1}\right)^2\right), W = 0.1..0.99\right)$$



Finally, the K_{eff} is within [2.77, 3.01] and the average is 2.89. In most cases, the acceptable design can be implemented by using the average as K_{eff}.

Part IV: Conclusion

The concept of effective dielectric constant K_{eff} is discussed in this paper. In most cases, the average of K_{eff} can be used to implement acceptable designs.

Part V: References

[1] Microstrip. Retrieved Dec 10, 2019, from https://www.microwaves101.com/encyclopedias/microstrip