

A Comparative Study of Microstrip, Stripline and Coplanar Lines on Different Substrate Technologies for High-Performance Applications

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Abstract

This paper presents a comparative study of the losses of 4 commonly used planar transmission lines (microstrip, coplanar, grounded coplanar and stripline). The losses are separated into conductor dielectric and radiation losses and investigated on 3 different technologies. These technologies are thin-film polymer substrate, low cost printed circuit board and glass. The attenuation on these 4 lines is computed using quasi-static methods and full wave simulations. The goal is to get an insight on the different frequency-dependent behaviour of the lines to provide the optimal line configuration for a given substrate technology and frequency region.

Keywords: planar transmission lines, microstrip, coplanar, stripline, attenuation

1. Introduction

To obtain optimal results in RF/high-speed micro systems it is necessary to take good care of the transmission structures that interconnect sub-systems. These interconnections add reflection and losses thus degrading the signal quality. There are three main loss mechanisms that affect transmission lines. These are conductor, dielectric and radiation loss. They depend on the field distribution in the transmission line. Therefore different line configurations will have different attenuation.

So far much work has been done on conductor and dielectric losses using analytical expression e.g. [1-4,7,8] and using full wave simulations [5,6]. There are also papers that compare different transmission line configurations neglecting radiation loss [9] or compare these losses only at a single frequency [10]. In this paper we compare 4 common line configurations (microstrip, coplanar, grounded coplanar and stripline) regarding the 3 loss mechanisms in 3 different substrate technologies for frequencies up to 100 GHz. These 3 technologies are thin film polymer, low cost printed circuit board (pcb) and glass. To do so we apply quasi static

analysis to evaluate conductor and dielectric losses. Since the quasi static approach does not account for radiation, full wave simulations are performed to capture the radiation losses. The 4 configurations are compared with equal cross sections and with equal characteristic impedance. The aim of this paper is to provide an optimum transmission line for a given substrate technology and frequency region. The paper is organized as follows: first we present line configuration and simulation setup, next we describe briefly the 3 loss mechanisms and at the end we discuss the results

2. Configurations

In this paragraph the setups will be discussed. The necessary technology parameter could be seen in Table 1. The dimensions of the lines are presented in Table 2. These values are obtained using Linecalc from agilent. This tool uses analytical, quasi static approximation.

The column 'Equal Cross Section' displays the characteristic impedance the lines with the dimensions given in Table 1 have. The column named ' $Z_0=50 \Omega$ ' shows the dimensions a line must have if its characteristic impedance should be 50Ω .

Glass	• Permittivity $\epsilon_r=4.7$ • Loss Tangent $\tan\delta=0.001$ • Substrate Thickness $h=300\mu\text{m}$ • Conductor Thickness $t=5\mu\text{m}$ • Conductor Material Gold • Line Width $w=50\mu\text{m}$ • Slot Width $s=20\mu\text{m}$
FR 4	• Permittivity $\epsilon_r=4.2$ • Loss Tangent $\tan\delta=0.02$ • Substrate Thickness $h=1.55\text{mm}$ • Conductor Thickness $t=35\mu\text{m}$ • Conductor Material Copper • Line Width $w=150\mu\text{m}$ • Slot Width $s=100\mu\text{m}$
Thin Film (BCB)	• Permittivity $\epsilon_r=2.6$ • Loss Tangent $\tan\delta=0.0008$ • Substrate Thickness $h=10\mu\text{m}$ • Conductor Thickness $t=1\mu\text{m}$ • Conductor Material Gold • Line Width $w=10\mu\text{m}$ • Slot Width $s=5\mu\text{m}$

Table 1: Technology Parameter

		Equal Cross section	$Z_0=50\ \Omega$
Microstrip	BCB	84 Ω	$w=27\mu\text{m}$
	Glass	127 Ω	$w=540\mu\text{m}$
	FR 4	154 Ω	$w=3100\mu\text{m}$
Coplanar	BCB	83 Ω	$w=131\mu\text{m}$ $s=5\mu\text{m}$
	Glass	60 Ω	$w=104\mu\text{m}$ $s=20\mu\text{m}$
	FR 4	69 Ω	$w=574\mu\text{m}$ $s=100\mu\text{m}$
Grounded Coplanar	BCB	69 Ω	$w=20\mu\text{m}$ $s=5\mu\text{m}$
	Glass	69 Ω	$w=98\mu\text{m}$ $s=20\mu\text{m}$
	FR 4	59 Ω	$w=537\mu\text{m}$ $s=100\mu\text{m}$
Stripline	BCB	35 Ω	$w=5.5\mu\text{m}$
	Glass	71 Ω	$w=119\mu\text{m}$
	FR 4	87 Ω	$w=690\mu\text{m}$

Table 2: Line Dimensions for 3 Substrates

3. Loss Mechanisms

3.1 Conductor Loss

Conductor loss is the attenuation the transmission line undergoes due to the limited conductivity of the transmission line. There are two regions that have to be considered. The DC loss occurs when the current is flowing uniformly distributed in the conductor. The amount of this loss could be easily determined via the

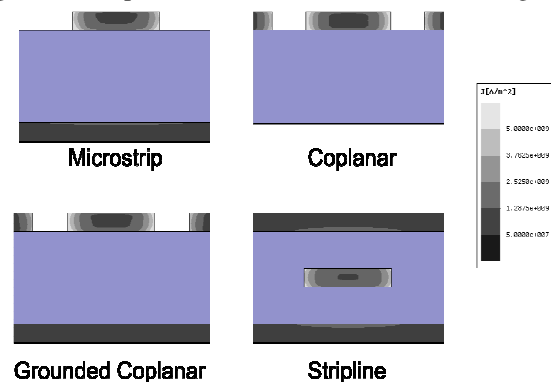
resistance per unit length given by $R' = \frac{1}{\kappa A}$ where κ

is the conductivity and A is the cross section of the transmission lines. The attenuation per unit length is

$$\alpha_c = \frac{R'}{2Z_0} \text{ where } Z_0 \text{ is the characteristic impedance}$$

of the transmission line.

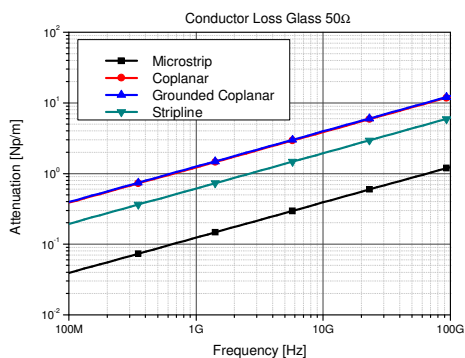
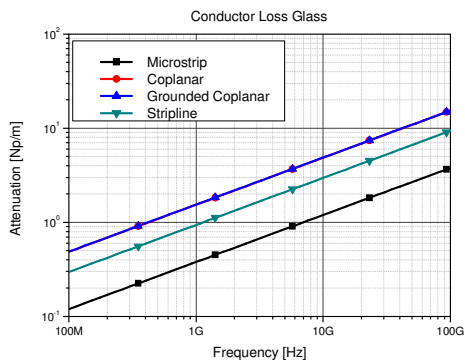
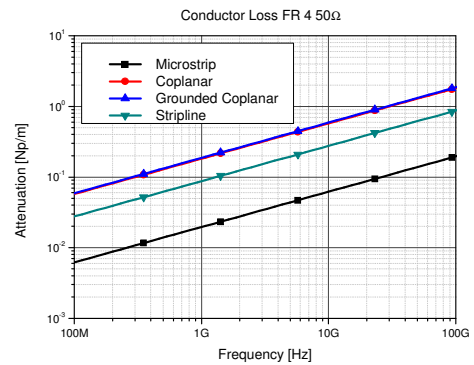
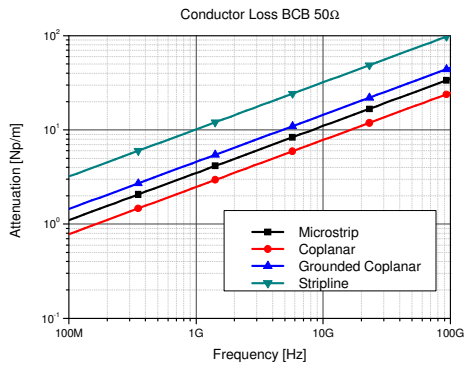
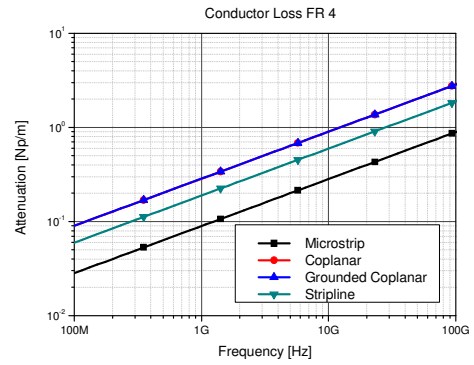
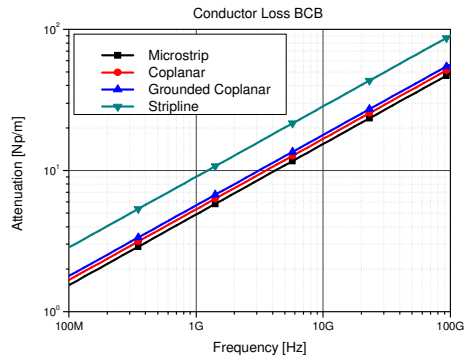
The second region is the high frequency region. At higher frequencies, the current migrates into the skin of the conductor due to the skin effect. Other conductors in the vicinity, like a return current path, can cause additional current crowding. Since the current distribution differs related to the configuration of the conductors the high frequency losses differ as well. In Figure 1 the distribution of the current density for the 4 different configurations (microstrip, coplanar, grounded coplanar and stripline) at 400 MHz is depicted. This relatively low frequency is chosen because the effect can't be visually resolved at higher frequencies. It can be seen, that the current flows on the vertical edges for coplanar and grounded coplanar while there is also a significant current on the horizontal sides for microstrip (bottom side) and stripline (top and bottom side). That means, that the current will flow in a smaller area for coplanar and grounded coplanar, thus the attenuation will be larger.

**Figure 1: Current Density Distribution**

3.1.1 Results

The results presented in this section are computed using quasi static approximations taken from [4] (microstrip), [7] (coplanar and grounded coplanar) and [3] (stripline).

It can be seen that if the cross section of the transmission lines are equal microstrip suffers the least conductor loss. The amount is about 1/5 of the conductor loss of coplanar in glass and FR 4. This agrees with the considerations made earlier. For 50 Ω lines it has to be considered that microstrip has the biggest strip width except for thin film substrates. That is the reason why the conductor loss of coplanar is 10 times the conductor loss of microstrip for 50 Ω glass and FR 4 technologies.



3.2 Dielectric Loss

Dielectric loss is the attenuation due to the displacement of the charges in the dielectric. If an electrical field is applied, charged particles in the substrate align with this external field. If the field is alternating the particles will be shifted with the same frequency. This causes heat and power loss due to friction. This attenuation is proportional with frequency and calculated with

$$\alpha_D = \frac{\pi \sqrt{\epsilon_{r,eff}} \tan \delta}{\lambda_0}$$

where $\epsilon_{r,eff}$ is the relative, effective permittivity of the substrate and is dependent on the line configuration, $\tan \delta$ is the loss tangent of the substrate material and λ_0 is the free space wave length. Figure 2 depicts the field distribution of the 4 transmission line configurations at 500 MHz. It can be seen that the field is entirely in the substrate for stripline and for coplanar roughly half of it is in the substrate. Therefore we expect coplanar to have the least dielectric loss and stripline to have the most.

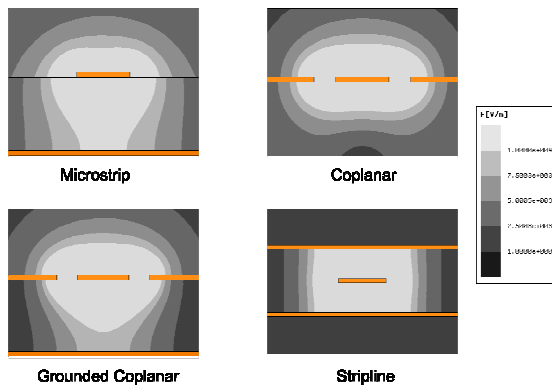


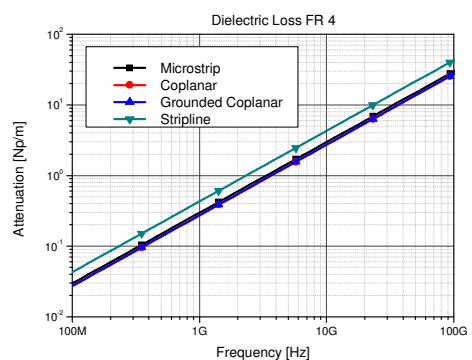
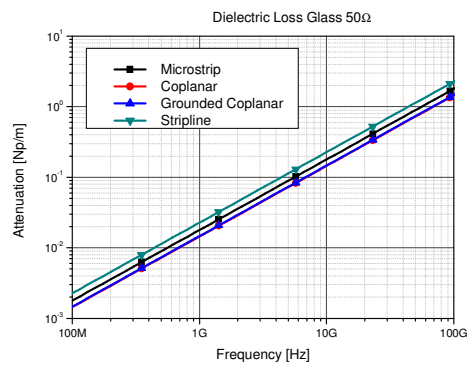
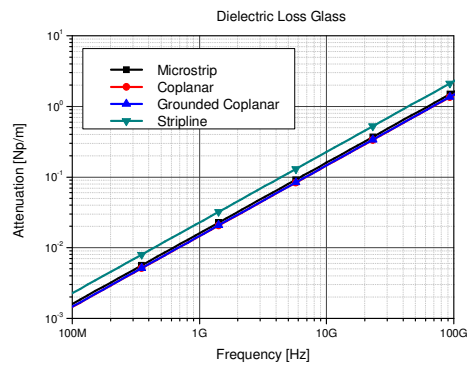
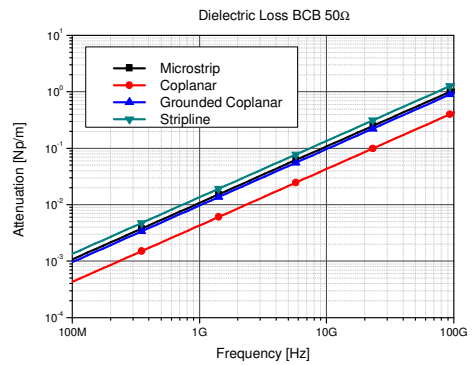
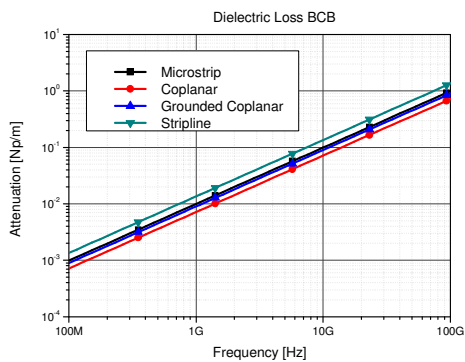
Figure 2: Electric Field Distribution

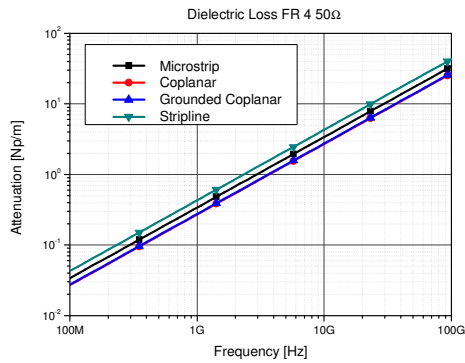
3.2.1 Results

The results presented in this section are computed using quasi static approximations taken from [4] (microstrip), [7] (coplanar and grounded coplanar) and [3] (stripline).

The dielectric losses are biggest for stripline. This is due to the fact the electric field is entirely in the substrate. The coplanar configurations have the lowest loss because the field is roughly half in air and half in the substrate. But the differences are smaller than for conductor losses.

For glass and BCB the conductor losses dominate over the whole frequency bandwidth. For FR 4 the dielectric losses overtake the conductor losses roughly around 1 GHz. Because of the large loss tangent this material is not suitable for frequencies beyond 1 GHz.





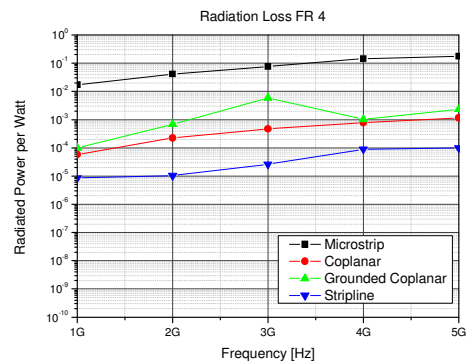
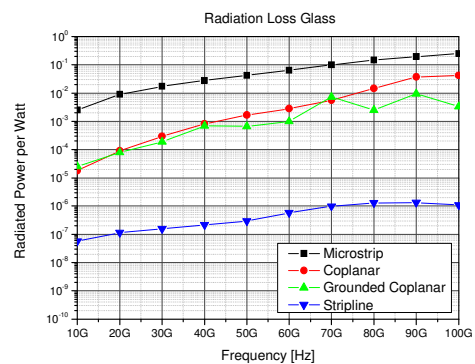
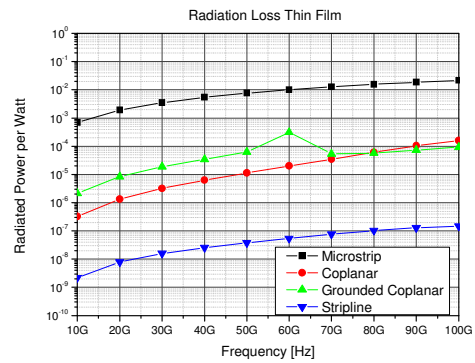
3.3 Radiation Loss

Radiation occurs if there is a time dependent field. Since a time varying electric field generates a magnetic field and vice versa power can be radiated into the substrate or into free space from the transmission line. If signal and return current are close together, their contributions in the far field cancel and radiation loss will be low.

3.3.1 Results

The radiation losses are computed using HFSS from ANSOFT. This is a software tool using finite element method to solve Maxwell's equations.

Since the large substrate thickness of FR 4 would lead to higher order modes and it is a rather low frequency material the radiation losses are compared for frequencies up to 5 GHz. Thin film polymer and glass configuration are compared for frequencies up to 100 GHz. To compute the radiation losses a length of the signal conductor of 1 mm for thin film and glass is assumed and 20 mm for FR 4. This is about a third free space wavelength at the highest frequency. The radiation losses are smallest for stripline since this configuration is shielded and there will be no significant field contribution above or below the ground planes. Microstrip on thick substrate suffers the biggest radiation losses since the signal line is not shielded and signal current and return current are farthest away for this configuration



4. Experimental Validation

In order to validate the simulation and modelling approach, test structures were designed, simulated and measured. The measurements were performed with VNA HP 8510C. Due to its higher degree of accuracy, the LRRM calibration technique was applied. For all four transmission lines configurations examined in this work, a very good correlation was obtained. However, in Figure 3, only a comparison between the simulation and measurement results for the case of the coplanar configuration on glass substrate is shown. As can be seen a very good correlation is obtained up to 40 GHz.

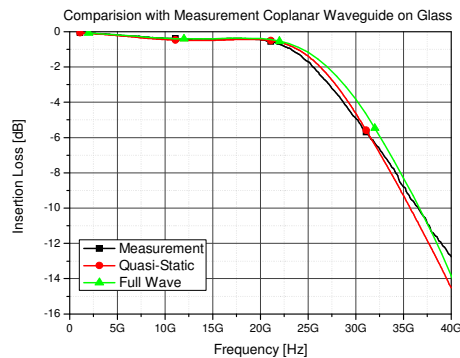


Figure 3: Comparison Measurement and Simulation

5. Conclusion

We compared 4 transmission line configurations with equal cross sections and equal characteristic impedance in 3 different substrate technologies regarding their losses. It was found that the conductor loss plays the most important role in finding an optimal line configuration for a given technology. It turns out that microstrip has the lowest conductor losses if compared to the other configurations with equal cross section. If characteristic impedance is given very thin substrates lead to narrow strips in microstrip therefore coplanar lines could have fewer losses at thin substrates.

In choosing an optimum transmission line the dielectric attenuation plays a minor role. Even though the field distribution differs from fully confined in the substrate (stripline) to half confined in the substrate (coplanar) the difference is less than 3 times the loss of coplanar.

Concerning radiation loss the best transmission line configuration is stripline because of the shielding cover above and below the stripline.

If the length of the signal line could be held short in terms of wavelength microstrip is the optimum transmission line configuration. If the line length is into the order of wavelength stripline is the configuration of choice.

6. Acknowledgement

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