

Modeling the effect of hatched grounds on the radio-frequency performance of microstrip lines on flexible substrate

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Abstract

Cross-hatching of PCB grounds refers to a process in which certain ground planes appear as copper lattices; regular openings are placed at regular intervals. Nowadays, the efficacy of ground hatching on rigid PCBs is minimal. However, it is becoming essential for flexible hybrid electronics. Utilizing hatched grounds for flexible applications could offer some benefits. Hatched grounds can perform dual roles, act as ground surfaces, and offer structural support. Hatched grounds are more durable for bending and stretching applications. Also, hatched grounds are desirable in terms of material conservation.

In this paper, we focus on studying how hatched grounds affect the RF performance of a straight microstrip line. Simulations show that cross-hatched grounds with more than 50% filling produces good radio-frequency performance. We will study the effect hatching pattern as well as the density of the hatching on the RF performance of the microstrips. The theoretical modeling is considered in this work and fabricating aerosol jet silver ink microstrip lines on PET substrates will be considered as an extension of this work.

Key words

flexible-hybrid electronics, hatched-grounds, meshed grounds, Microstrip lines, Modeling, RF

I. INTRODUCTION

Flexible and stretchable electronics are the ultimate key for sensing applications, primarily environmental and health monitoring [1]. Flexible hybrid electronics (FHE) technology offers the bridge combining the conventional subtractive silicon manufacturing techniques with the additive manufacturing printing methods. FHEs are getting more attention from academia and the industry today [2]. Researchers face some potholes in integrating the two worlds; they must understand how flexible circuits are made. Circuit designs are usually based on conventional printed circuit board (PCB) design rules [2]. Available materials and fabrication processes impose design issues. There is an increasing need to address and develop the design rules for flexible circuits to uncover the best practices for the maturity of FHEs.

Conventional rigid PCBs typically use solid grounds [3]. On the other hand, flexible circuits can utilize hatched ground planes for signal routing [3]. Hatching of a PCB ground plane refers to the approach in which specific areas of the ground plane look like a latticework of copper; regular gaps (openings) are spaced at regular intervals [4], [5]. The need

for these hatched grounds is uncommon for rigid PCBs nowadays [5]. However, hatched grounds have great potential for printed flexible circuits [5]. Hatched grounds are desirable for flexible printed electronics in terms of material conservation and the cost and speed of fabrication [6].

In this paper, we will computationally study the effect of hatched grounds on the radio-frequency (RF) performance of straight microstrip lines. Also, we will investigate the hatching pattern and percentage that result in optimum results compared with solid grounds.

II. LITERATURE REVIEW

In earlier days of PCB fabrication, roughening the copper grounds of inner layers were involved in improving the adherence to the resin during the lamination processes [4]. One way to address the smooth copper surfaces is to cross-hatch the copper ground layer. This process created tiny openings in the copper ground layer to allow the adhesion with the resin in the prepreg lamination processes [4]. By the late 1980s, two (black and brown) micro etch approaches were developed to create a very robust bond between the prepreg resins and the copper layers [4]. This marked the end

of hatching grounds in the rigid PCBs industry.

The benefits of using hatched grounds in flexible circuits include, but are not limited to, controlling the impedance under transmission lines, providing structural support, and being more susceptible to bending [7], [8]. Hatched grounds help provide reference plane and control impedance routing [5]. Also, hatched grounds maintain the circuit and assembly flexibility; it offers the support needed while reducing the rigidity of the copper layer [5]. Modeling hatched grounds is crucial to account for those missing copper [5]. The width of the trace should be greater than that in the case of the solid ground; this lowers the inductance and increases the capacitance to adjust the impedance [5]. Hatched grounds are desired for some applications and are inadequate for other applications [6]. One of the applications that hatched grounds was desirable when the circuit designs have many vias between different layers [6].

III. METHODOLOGY

We used ANSYS® HFSS to model and design these microstrip lines with different hatched ground patterns [9]. ANSYS® HFSS is a finite element method (FEM) based 3D electromagnetic software that uses adaptive meshing to divide the structure into tetrahedral elements. Then, Maxwell equations are solved to determine the electric and magnetic fields, respectively [10].

IV. SIMULATIONS AND RESULTS

In this section, we will study one-inch microstrip lines with different patterns for hatched grounds and compare the results with the solid ground results. The substrate we are using for simulations is 127 μm thick PET. For the conductor, we used silver-nano particle thin film with a thickness of 10 μm . The width of the main trace is 315 μm to achieve 50 Ω matching. We run our simulations from 10 MHz to 40 GHz.

A. Solid ground

First of all, we simulated our microstrip line on solid ground to be used as a reference for comparison with different hatched ground patterns. Fig. 1 shows the top and bottom views of the microstrip design. Also, it shows the reflections (S11) smith chart and the insertion loss (S21) in dB.

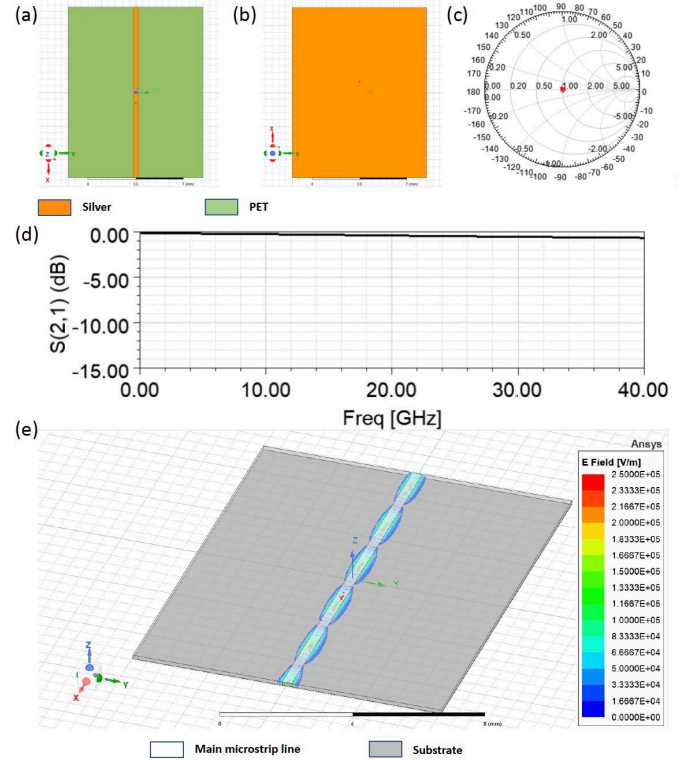


Fig. 1. Microstrip line design with solid ground (a) top view and (b) bottom view. (C) the reflection (S11) smith chart and (d) the insertion loss (S21) in dB for the microstrip line design with solid ground. (e) Electric-field distribution inside the substrate at 40GHz.

The results agree with what we expect from theory. Fig. 1 (d) shows that the losses slightly increase as the frequency increases. Fig. 1 (e) shows the Electric-field distribution inside the substrate at 40GHz; the electric field is confined in the substrate beneath the microstrip line trace.

B. Hatched ground along (in the same direction) the microstrip line

The first design we tried was a microstrip line with hatched ground along (in the same direction) the microstrip line. The hatch width is 315 μm , the same as the width of the main microstrip line trace. The hatch pitch is 730 μm resulting in a gap (opening) width of 315 μm . Fig. 2 (a) and (b) show this microstrip line design's top and bottom views. Fig. 2 (c) and (d) show the S11 smith chart and S21 in dB, respectively.

The results show resonance at specific frequencies. Fig. 2 (e) shows that the Electric-field is not confined only beneath the microstrip line trace; a significant portion of the field is distributed along the substrate. To investigate how to control these resonances, we moved the trace with respect to the hatched ground. In the initial configuration, the microstrip line was aligned to one of the openings, as shown in fig. 3 (a). Then, we moved the main microstrip line trace to cover half gap and half conductor hatch as well as to cover all

conductor hatch. These configurations are shown in fig. 3 (b) and (c), respectively. Fig. 3 (c) shows the S21 in dB for the three configurations.

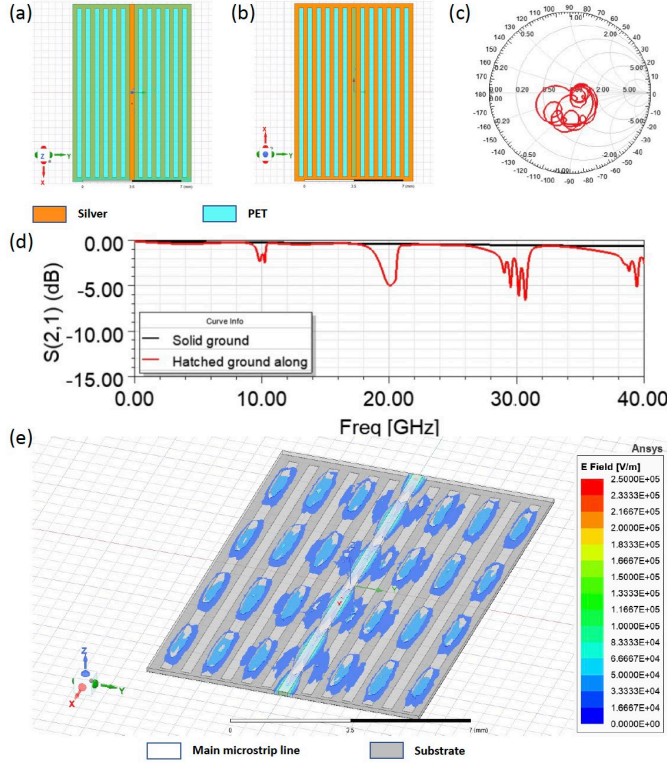


Fig. 2. Microstrip line design with hatched ground along (in the same direction) the microstrip line (a) top view and (b) bottom view. (C) the reflection (S11) smith chart and (d) the insertion loss (S21) in dB for this design. (e) Electric-field distribution inside the substrate at 40GHz.

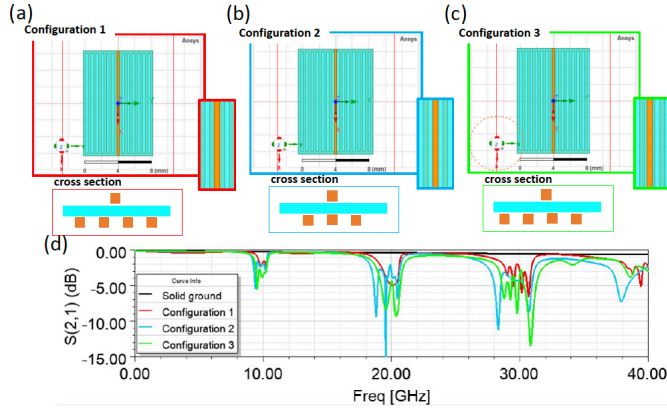


Fig. 3. (a), (b), and (c) show the three alignment configurations of the main microstrip line trace with respect to the hatched ground. The insets show the back side and the cross-section of these configurations. (d) the insertion loss (S21) in dB for the three configurations.

Moving the hatched ground plane with respect to the main microstrip line trace results in the same resonance behavior at almost the same frequencies; the width and magnitude of

the loss differ slightly.

Hatched ground across (perpendicular to) the microstrip line

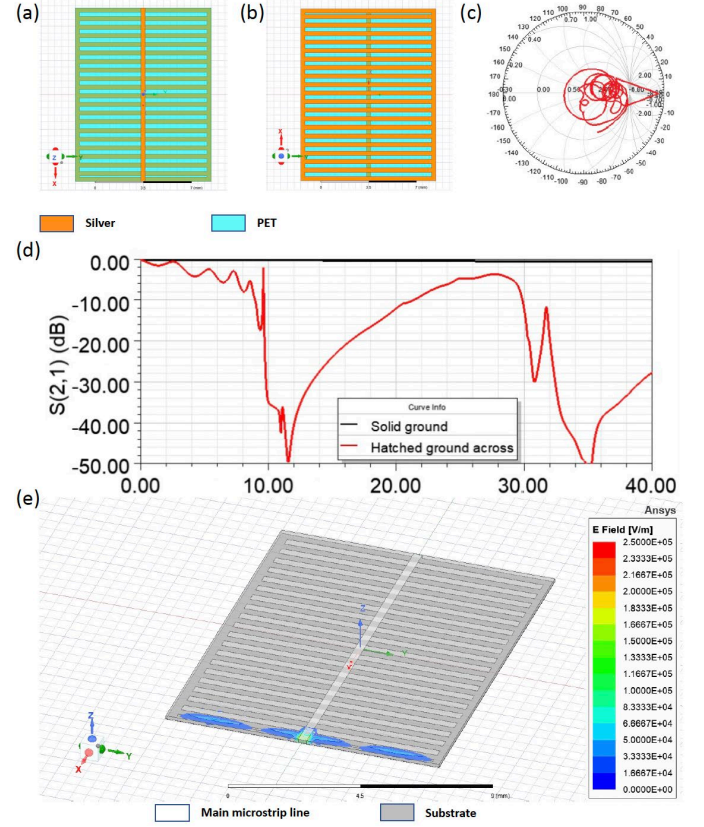


Fig. 4. Microstrip line design with hatched ground across (perpendicular to) the microstrip line (a) top view and (b) bottom view. (C) the reflection (S11) smith chart and (d) the insertion loss (S21) in dB for the microstrip line design with solid ground. (e) Electric-field distribution inside the substrate at 40GHz.

Then, we tried hatched ground across (perpendicular to) the main microstrip line. We used the same hatch width and pitch as the previous design; these hatch width and pitch will also be used for sections DEF. Fig. 4 (a) and (b) show this microstrip line design's top and bottom views. Fig. 4 (c) and (d) show the S11 smith chart and S21 in dB, respectively. This design did not behave as a microstrip line; the design resulted in very high losses. This behavior can be explained in terms of the electric field; as shown in Fig. 4 (e), the electric field is not guided by the microstrip line trace.

C. Hatched ground diagonal to the microstrip line

After that, we moved to the hatched diagonal to the main microstrip line. Fig. 5 (a) and (b) show this microstrip line design's top and bottom views. Fig. 5 (c) and (d) show the S11 smith chart and S21 in dB, respectively.

The design did not behave as a microstrip line as the design with hatched grounds across the main microstrip line. The design resulted in higher losses across a wide range of frequencies. Also, some resonance behavior is observed around specific frequencies. In Fig. 5 (e), the electric field,

again, is not confined beneath the microstrip line trace; a considerable portion of the energy is dissipated through the substrate.

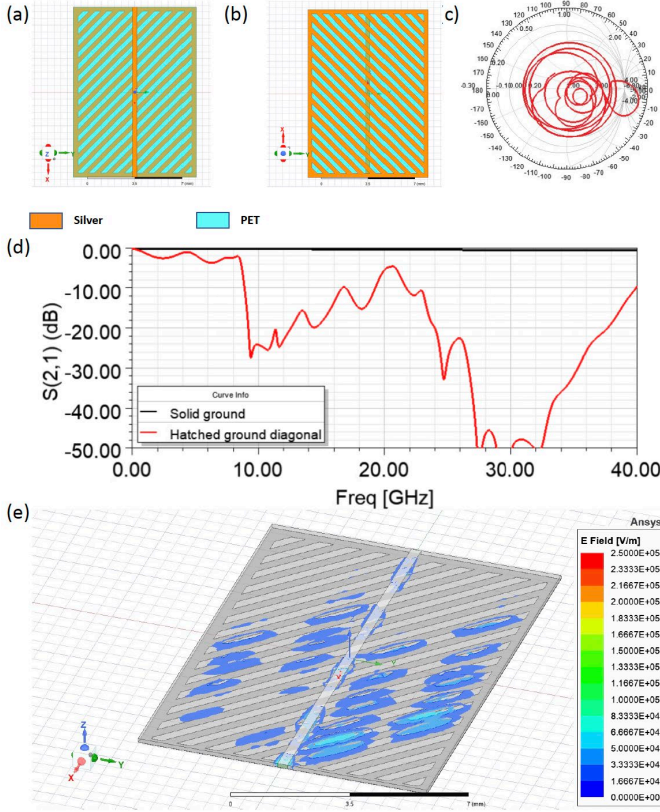


Fig. 5. Microstrip line design with hatched ground diagonal to the microstrip line (a) top view and (b) bottom view. (C) the reflection (S11) smith chart and (d) the insertion loss (S21) in dB for this design. (e) Electric-field distribution inside the substrate at 40GHz.

D. Cross-hatched ground

Afterward, we tried the most researched and cited hatched grounds pattern, cross-hatched ground [6]. Fig. 6 (a) and (b) show this microstrip line design's top and bottom views. Fig. 6 (c) and (d) show the S11 smith chart and S21 in dB, respectively.

The cross-hatched ground design behaves as the design with solid ground, as shown in Fig. 6 (d). The difference in the losses is minimal. We can also see from the smith chart in Fig. 6 (c) that the S11 is a perfect dot at the center. In Fig. 6 (e), the electric field is guided by the microstrip line trace, and the energy is transmitted to the end of the microstrip line. All the frequencies are being transmitted as the microstrip with solid ground.

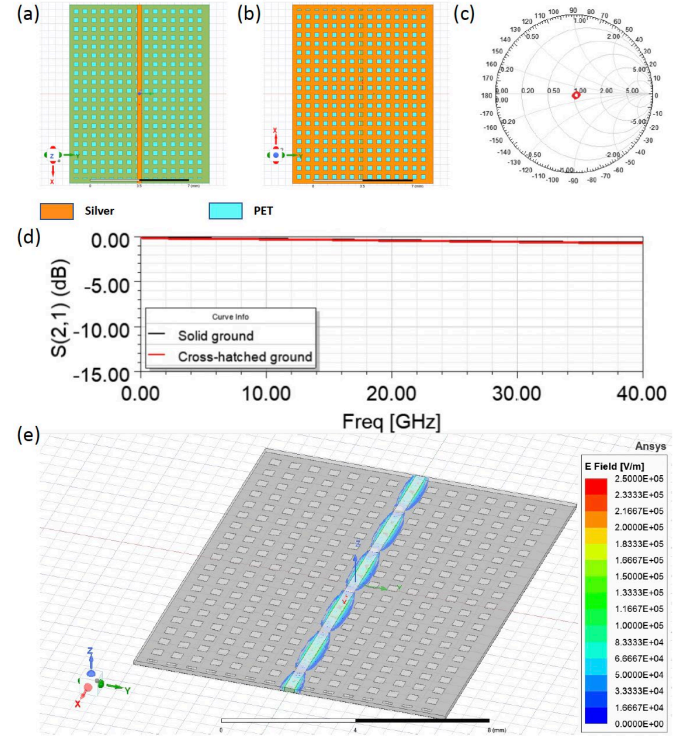


Fig. 6. Microstrip line design with cross-hatched ground diagonal to the microstrip line (a) top view and (b) bottom view. (c) the reflection (S11) smith chart and (d) the insertion loss (S21) in dB for this design. (e) Electric-field distribution inside the substrate at 40GHz.

E. Diagonal cross-hatched ground

We also tried diagonal cross-hatched ground. Fig. 7 (a) and (b) show this microstrip line design's top and bottom views. Fig. 7 (c) and (d) show the S11 smith chart and S21 in dB, respectively.

The S21 is almost comparable to the microstrip line with solid ground, as shown in Fig. 7 (d). The difference in the losses is minimal. In Fig. 7 (e), the electric field is guided by the microstrip line trace, and the energy is transmitted to the end of the microstrip line. The diagonal cross-hatched ground design behaves as cross-hatched ground design.

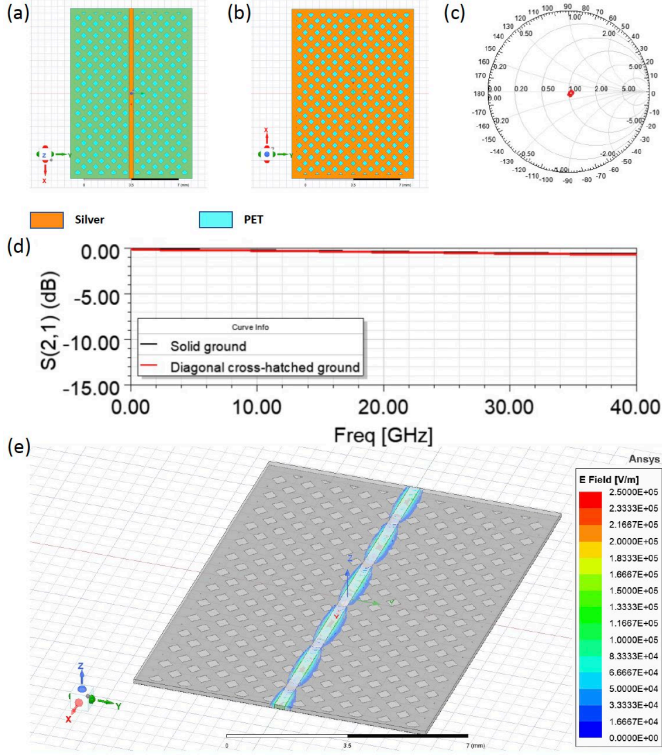


Fig. 7. Microstrip line design with diagonal cross-hatched ground diagonal to the microstrip line (a) top view and (b) bottom view. (C) the reflection (S11) smith chart and (d) the insertion loss (S21) in dB for this design. (e) Electric-field distribution inside the substrate at 40GHz.

F. Investigating the filling percentage of cross-hatched grounds for Microstrip lines

Since both the cross-hatched grounds and the diagonal cross-hatched grounds give the same results, we decided to use cross-hatched ground design to investigate the optimal filling percentage that gives good RF performance. We did a sweep by varying the hatch width while keeping the hatch pitch constant at 730 μm . Fig. 8 (a) shows the top view of the microstrip line design, and Fig. 8 (b), (c), and (d) show the bottom view of this microstrip line design for some of the filling percentages (75%, 50%, and 25%).

Fig. 8 (e) shows S21 in dB for the sweep. The sweep results show that having at least 50% filling results in good RF performance matching with the solid ground design.

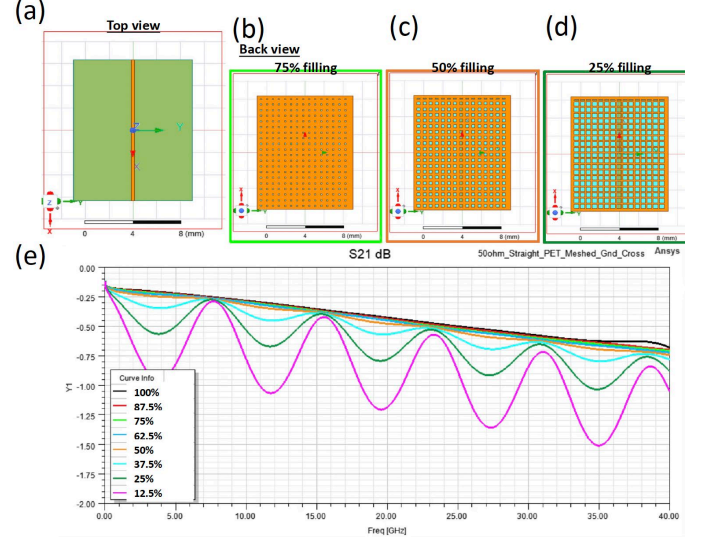


Fig. 8. (a) shows the top view of the design. (b), (c) and (d) show the bottom view of the designs with 75%, 50%, and 25% filling hatched grounds, respectively. (e) the insertion loss (S21) in dB for the three configurations.

V. CONCLUSIONS AND FUTURE WORK

In this work, we investigated how the hatched ground patterns and filling percentages can affect the RF performance of microstrip lines. For Hatched ground along (in the same direction) the microstrip line: moving the hatched ground plane with respect to the main microstrip line trace results in the same resonance behavior at almost the same frequencies. Hatched grounds perpendicular and diagonal to the microstrip line do not behave as the designs with solid grounds; they result in very high losses and resonance behaviors at specific frequencies. Crossed (in two dimensions) hatched grounds have better results compared with hatched grounds only in one dimension. At least 50% filling for cross-hatched grounds is needed for good RF performance. We are planning to use aerosol jet printing to fabricate these designs to confirm the theory (simulation results). Also, as an extension to this work, we will perform an extensive bending and stretching study to explore the durability of hatched grounds for FHEs.

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