Parametric Study of an Ultra-wideband 2-18 GHz Microstrip to Coplanar Stripline Transition

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Abstract. Microstrip line has become the most utilized transmission line for microwave circuits, but it has unbalanced characteristic, while coplanar stripline is a popular balanced transmission line for designing balanced circuits. Most of the ultrawideband antenna is a balanced antenna type such as dipole, bow tie, or two arms antenna. Therefore, we need a transition line to feed a balanced antenna because the port is usually an unbalanced structure like an sma connector. In this paper, a microstrip to coplanar stripline transition design is proposed. The goal is to design a compact and low-cost transition line that works at 2-18 GHz band to feed a balanced antenna. To achieve the goal, we propose a transition line with FR4 as the substrate. FR4 chosen as the substrate because it is available at the local market and has a low-price tag. The transition line has been constructed and simulated in CST Studio Suite to find the most appropriate design.

1. Introduction
A transition structure or balanced-to-unbalanced (balun) is a device that used to convert signals between an unbalanced circuit structure and a balanced circuit structure. Directly connecting an unbalanced structure like an sma connector to a balanced antenna can affect the radiation. Therefore, we need a transition line to avoid the unwanted radiation. A transition line can be made by connecting two transmission line with different characteristic into one structure. Microstrip (MS) line has become the most utilized transmission line for microwave circuits, but it has unbalanced characteristic, while coplanar stripline (CPS) is a popular balanced transmission line for designing balanced circuits.

Various method of designing MS-CPS transition have been reported. A transition with ground shaped taper using RT/Duroid 5880 as the substrate have been reported in [1]. In [2], a transition with radial stub on the top layer using RT/Duroid 5870 as the substrate have been reported. While transition with microstrip line equal to quarter wavelength using RO4003 as the substrate have been reported in [3] and a transition with three via holes on the CPS using Rogers 4003C as the substrate have been reported in [4]. There is no transition design using FR4 as the substrate even though it has cheaper fabrication cost compared to other substrate as mentioned before. In this paper, a microstrip to coplanar stripline transition using FR4 substrate is proposed. FR4 that used on our design has dielectric constant of 4.4 and thickness of 1.6 mm. The transition targeted to work at 2-18 GHz band to feed a balanced antenna. The impedance of microstrip (unbalanced) adjusted at 50 Ω and the impedance of coplanar stripline (balanced) adjusted at 150 Ω.
2. Transition design

Our transition line design refer to the design of microstrip to coplanar stripline transition with ground shaped taper proposed by Kim, et al [1] as shown in Figure 1.

![Diagram of transition structure](image)

**Figure 1.** Refered transition structure [1].

The structure has three parts, there are a microstrip section, a transition section and a coplanar stripline section. Microstrip transmission line has a formula to determine the width of the strip. Using the microstrip line formula [5] below we can calculate the width for microstrip with 50 Ω impedance.

\[
\text{for } \frac{W}{d} < 2 \\
\frac{W}{d} = \frac{8e^A}{e^{2A} - 2}
\]

\[
\text{for } \frac{W}{d} > 2 \\
\frac{W}{d} = \frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2 \varepsilon_r} \left( \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right) \right]
\]

where

\[
W = \text{width of microstrip} \\
d = \text{substrate thickness} \\
A = \frac{Z_0}{60} \left( \frac{\varepsilon_r + 1}{2} \right)^{1/2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left( 0.23 + \frac{0.11}{\varepsilon_r} \right)
\]

\[
B = \frac{377\pi}{2Z_0(\varepsilon_r)^{1/2}}
\]

Using the formula (2) we can determine the width to make a 50 Ω microstrip line on FR-4 substrate, the calculated result is 2.96 mm. After simulated with CST Studio Suite, the 2.96 mm width has higher impedance value. The closest width for 50 Ω impedance is 2.9 mm. Therefore, we use 2.9 mm for the microstrip line width.

Microstrip is a ground backed transmission line, while coplanar stripline composed by two symmetric stripline without ground. Because the width of microstrip has been fixed at 2.9 mm, to make a coplanar stripline we have to add another separated strip with a determined gap.

There is a synthetic formula [6] to calculate the width or the gap of coplanar stripline. Because we already have the width dimension so we have to calculate the gap part. The formula (5) and (6) shows how to calculate the gap between two strips on coplanar stripline.

\[
S = W \cdot G
\]

where

\[
G = 21.385 \left\{ \left( \frac{\eta_0}{Z_0(\varepsilon_r + 0.86)^{1/2}} \right) \left[ 1 + \exp \left( \frac{0.1W (\varepsilon_r - 1.52)}{H \varepsilon_r} \right)^{0.681} \right] \right\}^{-3.753}
\]
Using the formula (5) and (6), to get 150 $\Omega$ coplanar stripline impedance, we have to set 6.8 mm for the gap between two strips with 2.9 mm width. After simulated, the impedance value of the coplanar stripline is 166.6 $\Omega$. Multiple simulation has been done to make a coplanar stripline with 150 $\Omega$ impedance and the result is 3.5 mm gap has the closest impedance value that is 149.5 $\Omega$.

In order to optimally match the characteristic impedances between the microstrip line (50 $\Omega$) and the coplanar stripline (150 $\Omega$), a taper consist of ‘ground-shaped micro-coplanar stripline with vias’ [1] is used. The taper design shown in Figure 2.

![Figure 2. Taper design of the transition structure.](image)

### 3. Simulation results and discussion

Our proposed transition line design shown in Figure 3 have to meet the following specifications,

- Range frequency: 2-18 GHz
- Return loss: $\leq$ -10 dB
- Coplanar stripline (balanced) impedance: 150 $\Omega$
- Microstrip (unbalanced) impedance: 50 $\Omega$

![Figure 3. Layout of the initial proposed MS-CPS transition structure.](image)

The simulation results from the initial design are shown in Figure 4. S-Parameters shows return loss and insertion loss from both transmission line ports. S11 is the return loss of the microstrip line, S21 is the microstrip line insertion loss, S12 is the insertion loss of the coplanar stripline, S22 is the return loss of the coplanar stripline.

![Figure 4. S-Parameters of initial design.](image)

It can be observed from Figure 5 that the simulation results of return loss from the initial design still more than -10 dB at 2 GHz for both microstrip and coplanar stripline. This result means that the transition structure has not complied with the specification.
Figure 5. Return loss (S11 and S22) of initial design.

Figure 6 shows the insertion loss of the simulated initial design. The results from initial design have insertion loss almost reaching -10 dB at 18GHz.

The microstrip impedance from initial design is observed at 49.56 Ω, because it is close to the 50 Ω target impedance, there is no need to change the width of microstrip line. While the impedance of coplanar stripline is observed at 166.6 Ω, it is necessary to change the distance between two strips (gap) of the strip in coplanar stripline to achieve the 150 Ω of impedance.

To find the ideal distance or gap close to achieve coplanar stripline 150 Ω of impedance, other simulations have been done by changing the distance between two strips (gap). The simulation results of changing the gap from 1-4 mm are listed in Table 1.

**Table 1. Coplanar Stripline impedance with various gap.**

| Gap between Strips | Impedance  |
|--------------------|------------|
| 1 mm               | 107.6 Ω    |
| 2 mm               | 129 Ω      |
| 3 mm               | 142.4 Ω    |
| 4 mm               | 151.4 Ω    |

As listed on the Table 1, we can see the closest impedance value to 150 Ω is within 3 - 4 mm of gap. When the design simulated using the gap value of 3.1 - 4 mm between the two strips, the closest impedance value to 150 Ω achieved at 3.5 mm with 149.5 Ω impedance value.

After found the most ideal gap for the coplanar stripline, other simulations have been done to find the effect of the via hole diameter. Figure 7 shows the microstrip line return loss (S11) results obtained from a parameter sweep simulation using different via hole diameter from 1 – 2 mm.
Figure 7. Microstrip return loss (S11) with different via hole diameter.

Figure 8 shows the coplanar stripline return loss (S22) results obtained from a parameter sweep simulation using different via hole diameter from 1 – 2 mm.

Figure 8. Coplanar stripline return loss (S22) with different via hole diameter.

It can be observed that the smallest magnitude of the microstrip return loss (S11) and coplanar stripline return loss (S22) are achieved by using 2 mm via hole diameter compared to the 1 and 1.5 mm via hole diameter. Therefore, the design of transition structure use 2 mm via hole diameter. Simulation using via diameter larger than 2 mm were not performed because it is too close to the edge of the strip.

Since there are no formula to calculate the ideal transmission line length, multiple simulations have been done by changing the length of the two transmission lines. Simulations are performed comparing the two different lines with different length. Figure 9 shows the simulation result that have most significant differences of insertion loss (S21) when the microstrip line adjusted at 20 mm with different coplanar stripline length from 10, 20 and 30 mm.

Figure 9. S21 result using different coplanar stripline length.

Figure 10 shows the simulation result that have most significant differences (S11) when the coplanar stripline adjusted at 20 mm with different microstrip length from 10, 20 and 30 mm.
Simulation results show coplanar stripline length affects the insertion loss. At the longest CPS length simulated (30 mm), the insertion loss was observed has a value -10 dB at 18 GHz, at the shortest CPS length (10 mm) insertion loss observed has a value -7 dB at 18 GHz. The impact of the microstrip line length is observed affects the lowest frequency. When the design using the shortest microstrip length (10 mm) the simulation results shows a return loss value of -10 dB higher than 2 GHz frequency, at the longest microstrip length (30 mm) the return loss value of -10 dB is observed at 1.5 GHz frequency. Therefore, to create a design with the lowest insertion loss, the coplanar stripline has to be made as short as possible. To create a design with lowest frequency, the microstrip line has to be made as long as possible.

After observing the simulation results, both of the transmission lines length is adjusted. The length of the microstrip line is adjusted at 15 mm with the length of the coplanar stripline adjusted at 9.2 mm to obtain the total length of the structure is 60 mm. The details of the optimized structure length described in Table 2.

Table 2. Optimized structure length.

| Optimized Structure Length |
|-----------------------------|
| Microstrip line length      | 15 mm          |
| Transition length           | 35.8 mm        |
| Coplanar stripline length   | 9.2 mm         |
| Total length                | 60 mm          |

Another simulation has been done by adding via holes to see the effect of the number of via holes on S-Parameter. There is no change in the transition structure beside adding via holes. Adding more via holes is done because the previous simulation shows via diameter affecting the simulation results. Therefore, the effect of adding via hole needs to be observed. Using the structure dimension described in Table 2, the simulation begins with the gap between two strips set to 3.5mm. Figure 11 shows microstrip line return loss (S11) results obtained from a parameter sweep simulation using different number of via holes.

Figure 10. S11 result using different microstrip length.

Figure 11. S11 with different number of via holes.
Figure 12 shows coplanar stripline return loss (S22) results obtained from a parameter sweep simulation using different total via holes.

![Figure 12. S22 with different number of via holes.](image)

Figure 13 shows insertion loss (S21 and S12) results obtained from a parameter sweep simulation using different total via holes.

![Figure 13. Insertion loss with different number of via holes.](image)

From the simulation results, it can be observed that the most optimal transition line performance achieved when the design using 9 via holes. Return loss of both lines (S11 and S22) has less than -10 dB value at 2-18 GHz frequency with smallest insertion loss value (S21 and S12). The optimal design shown in Figure 14. The dimensions of the structure are described in Table 3. Simulated optimal design is described in the next section.

![Figure 14. (a) Top view of the optimal design. (b) Bottom view of the optimal design.](image)

**Table 3.** Detail dimension of the optimal design.

| Detail Dimension of The Optimal Design |  |
|----------------------------------------|--|
| Microstrip line length                 | 15 mm |
| Coplanar stripline length              | 9.2 mm |
| Transition structure length            | 35.8 mm |
| Gap between two strips                 | 3.5 mm |
| Strip width (MS, CPS, Transition)      | 2.9 mm |
| Via hole diameter                      | 2 mm  |
3.1. S-Parameters of the optimal design
The insertion loss (S21 and S12) observed in Figure 15 is -7 dB at 18 GHz with the return loss of both lines (S11 and S22) less than -10 dB at 2 – 18 GHz. This result shows that the transition line has achieved the range frequency specification at 2-18 GHz with the smallest insertion loss compared to the initial design.

![Figure 15. S-Parameters of the optimal design.](image)

3.2. Microstrip (Unbalanced) Impedance
The optimal design simulation result shown in Figure 16 has microstrip line impedance value of 49.56 Ω. Since it is close to the impedance target of 50 Ω, the microstrip impedance specification considered has been achieved.

![Figure 16. Microstrip line impedance of the optimal design.](image)

3.3. Coplanar Stripline (Balanced) Impedance
The optimal design simulation result shown in Figure 17 has coplanar stripline impedance value of 149.5 Ω. Since it is close to the impedance target of 150 Ω, the coplanar stripline impedance specification considered has been achieved.

![Figure 17. Coplanar stripline impedance of the optimal design.](image)
Overall, the optimal design achieved all the specifications of a balanced-unbalanced transition line. The optimal simulation results are described in Table 4.

**Table 4. Simulation Results**

| Specification                  | Target        | Achievement  |
|-------------------------------|---------------|--------------|
| Frequency range               | 2 – 18 GHz    | 2 – 18 GHz   |
| Return loss                   | < -10 dB      | < -10 dB     |
| Coplanar Stripline impedance | 150 Ω         | 149.5 Ω      |
| Microstrip impedance          | 50 Ω          | 49.56 Ω      |

Based on the simulation results, the insertion loss (S21 and S12) has a big value (-7 dB at 18 GHz). This is caused by FR4 characteristic that has a typical loss tangent in the region of 0.02, which is too high for many circuit applications [7].

4. Conclusions
A transition between microstrip and coplanar stripline using FR-4 has been designed. The transition structure has three parts, there are a microstrip section, a transition section and a coplanar stripline section. Simulation result shown the return loss (S11) has less than -10 dB value from 2-18 GHz. The impedance of the microstrip is obtained at 49.5 Ω and 149.5 Ω for the coplanar stripline. The best result is achieved by optimizing the transition line structure. Several parameters have been changed like strip gap of coplanar stripline, via holes diameter, transmission lines length and adding more via holes to achieve all the determined specifications.

References
[1] Kim Y, Woo D, Kim K W and Cho Y 2007 A New Ultra-wideband Microstrip-to-CPS Transition *IEEE MTT-S Int. Microw. Symp.* 1563–1566
[2] Suh Y and Chang K 2001 A Wideband Coplanar Stripline to Microstrip *IEEE Microw. Wirel. COMPONENTS Lett.* 11 1 28–29
[3] Mandal M K and Chen Z N 2013 Compact Ultra-Wideband Microstrip-to-Coplanar Stripline Transitions *IEEE MTT-S Int. Microw. RF Conf.* 1 8–11
[4] Jiang Q, Domier C and Luhmann N C 2012 A Wideband Low Loss Planar Microstrip-to-CPS Balun *Proc. APMC 2012, Kaohsiung, Taiwan.* 1205–1207
[5] Pozar D M 2011 * Microwave Engineering *(Hoboken, NJ: JohnWiley & Sons, Inc.)
[6] Chan S W 2005 New and Very Simple Synthesis Formulas for Coplanar Stripline,” *Microw. Opt. Technol. Lett.* 44 2 199–202
[7] Aguilar J R, Beadle M, Thompson P T and Shelley M W 1998 The Microwave And RF Characteristics Of FR4 Substrates *IEEE Colloquium Low Cost Antenna Technol. - IET Conf.* 0–5