**EERF 6311 – Final Design Project, Omkar Kulkarni**

# Design of Coupled Three-Line Impedance Transformers

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***Review paper summary***: In this paper, the author proposes a novel approach for improving impedance transformers at RF frequencies. Impedance transformers are a crucial component in almost every RF circuit and are used to liaison between components of different impedances and maximize power transfer. The date of publication in IEEE was December 03, 2013. The structure discussed in the paper uses 3 coupled lines and has 3 main advantages: better bandwidth, higher transformation ratio and small size (the equivalent of a quarter wavelength line) as compared to the existing approaches mentioned in the paper. Coupled lines inherently have better frequency response and this circuit exploits this property opportunely. The circuit is realized on Rogers RO4003 ($\epsilon_r$ = 3.55, b = 3 mm) material in stripline technology. The circuit is simulated in ADS at a center frequency of 1.5 GHz using coupled lines component. The analysis is briefly discussed using even/odd mode method and assuming arbitrary node voltages.

**Conventional Design Details:** The paper discusses the transformation of impedances which are only resistive in nature. The conventional design is a quarter wave transformer. The quarter wave transformer has an electrical length 90° or λ/4 physical length at the design frequency. The characteristic impedance of the quarter wave section is the geometric mean of the two impedances, $Z_T = \sqrt{Z_1 Z_2}$. The paper mentions multiple design options for the realization of the transformer, however, the 50 - 150 Ω option is explained in detail. Going forward with these parameters, $Z_T = \sqrt{50 \times 150} = 86.6\,\Omega$ , the electrical length is 90° at 1.5 GHz. A notch response is observed at the center frequency. The problem with this conventional design is poor frequency response. To widen the bandwidth cascaded quarter wave transformers can be used but it leads to increased physical dimensions.

**Paper Design Details:** The authors discuss a solution using a symmetric three-line coupler, leaving one end of the middle section open circuited. The length of the coupled line is kept a quarter wavelength long. An even - odd mode analysis and finite elements method similar to [3] [4] are used to calculate the characteristic impedance of the six-port structure. The design can be tuned by varying the widths of the coupled lines and spacings between them. Increase in width of the middle line and corresponding decrease in the spacing can help in achieving wider bandwidth but degrades the return loss slightly. It is recommended to keep the widths of the outer lines identical and minimum adjustment for optimum results.

**Simulation:** The authors have used ADS simulator to test the performance of the transformer. For transforming the 50-150 Ω the design parameters are: $W_1 = W_3 = 0.3$ mm, $W_2 = 0.35$ mm, $S_1 = S_2 = 0.15$ mm and l = 26.5 mm which is resonant at 1.5 GHz.

Figure 3 is the schematic of the impedance transformer realized in stripline technology for a design frequency of 1.5 GHz. The stripline substrate used has $H_1 = H_2 = 1.5$ mm and T = 0.001 mm, ρ = 1 (normalized to gold), $\epsilon_r$ = 3.55 and tanδ = 0.0002 which are referred from the datasheet of Rogers RO4003. The lengths and widths of feed lines for the 50 and 150 Ω ports are calculated from TxLine tool in AWR MWO. Figure 4 is the rectangular plot of this schematic. Figure 5 is the schematic of proposed impedance transformer with the center frequency scaled to 1.5 times of the center frequency (2.25 GHz) proposed in the paper realized on same stripline substrate. This scaling is achieved by altering the quarter wavelength sections of the coupled line. The $W_2$ is

| Design-frequency | Spacing (mm) | Electrical length (degrees) | Width (mm) | Physical length (mm) |
|---|---|---|---|---|
| 1.5 GHz – $f_0$ | $S_1$ = 0.15<br>$S_2$ = 0.15 | 90 | $W_1$ = 0.3<br>$W_2$ = 0.35<br>$W_3$ = 0.3 | 26.5 |
| 2.25 GHz – 1.5 $f_0$ | $S_1$ = 0.15<br>$S_2$ = 0.15 | 90 | $W_1$ = 0.3<br>$W_2$ = 0.36<br>$W_3$ = 0.3 | 17.29 |

further tuned to obtain a symmetric response. Figure 6 is the response of this new design.

**Table 1:** Specifications of Coupled 3 – line transformers

**Results and Discussion:** Based on the discussion above a coupled 3 – line impedance transformer of transformation ratio 3, wide bandwidth and quarter wavelength long is presented using AWR MWO. It is evident from the response in figure 4 that the return loss response has 3 reflection zeros. The corresponding design parameters are reflected in table 1.

Design 1 is a simple quarter wave impedance transformer and has perfect matching only at the center frequency. Design 2 provides a drastic improvement in the performance over the conventional approach and has a fractional bandwidth of 82.26% and provides return loss greater than 20 dB from 0.97 GHz to 1.97 GHz. This new design allows higher transformation ratios while keeping compact size and better bandwidth. The authors also compared 6 other state of the art impedance transformers, but this design has many practical advantages over them as well. This design doesn't require air bridges, vertical components and doesn't require tighter spacing which makes the other designs difficult to realize. The plots obtained are within acceptable variance as discussed by the authors. However, the graph presented in figure 4 yields a more symmetric response and 3 clear reflection zeros if $W_2$ is tuned to 0.4 mm (This simulation is not included). The design gives a similar response when scaled to 1.5 times the proposed design frequency, figure 6.

**Conclusion:** This design helped in overcoming the limitations of the conventional impedance transformer and is also easily realizable. This course has helped build a solid foundation of RF concepts which can be extended to analyze more complex concepts in my future classes and career.

**References:**

[1] Design of Coupled Three-Line Impedance Transformers, Huy Thong Nguyen, Kian Sen Ang, Geok Ing Ng, Nanyang Technological University, Singapore, IEEE, Vol. 24, No. 2, Feb-14

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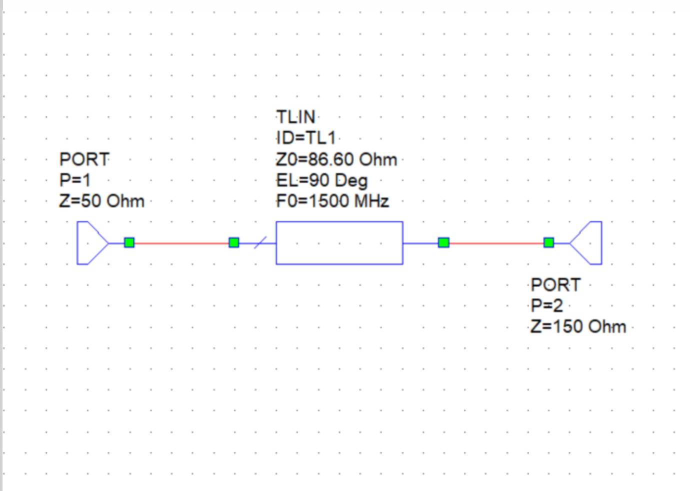


Figure 1: Schematic of convention Quarter wave impedance transformer ($f_0$ = 1.5 GHz)

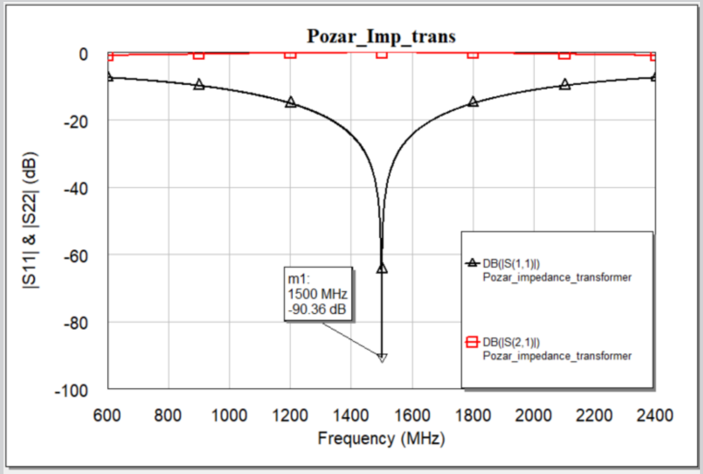


Figure 2: Rectangular plot of the convention Quarter wave impedance transformer ($f_0$ = 1.5 GHz)

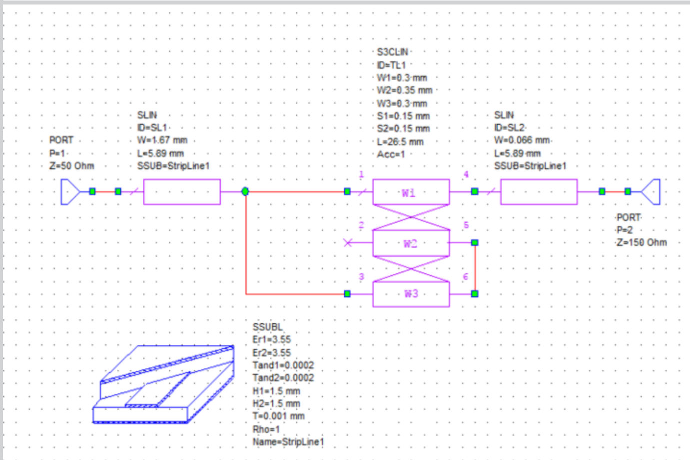


Figure 3: Schematic of Coupled Three-Line Impedance Transformer on stripline ($f_0$ = 1.5 GHz)

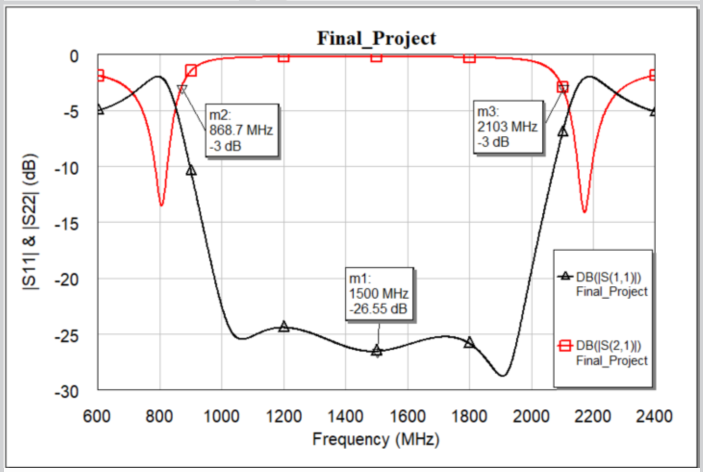


Figure 4: Rectangular plot of Coupled Three-Line Impedance Transformer on stripline ($f_0$ = 1.5 GHz)

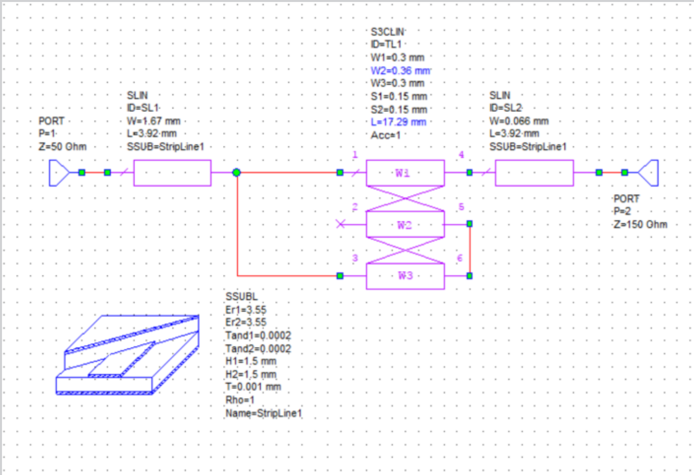


Figure 5: Schematic of Coupled Three-Line Impedance Transformer on stripline ($f_0$ = 2.25 GHz)

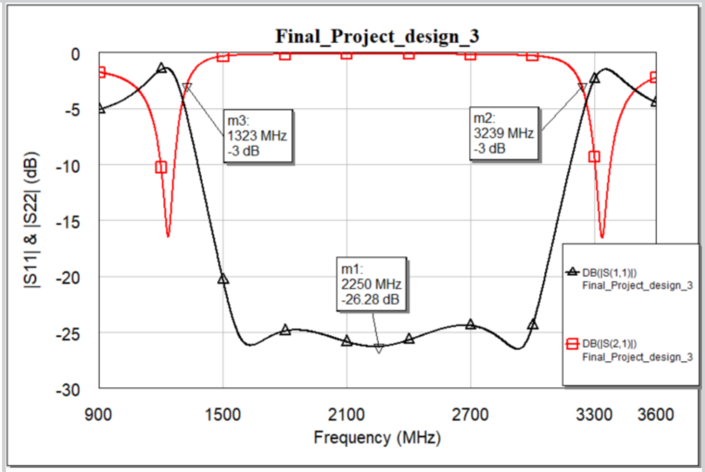


Figure 6: Rectangular plot of Coupled Three-Line Impedance Transformer on stripline ($f_0$ = 2.25 GHz)