A Novel MMIC Filter - Measured and Simulated Data

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Abstract

We introduced new MMIC band-pass filters with Triple Coupled CPW (TCC) lines We realized 7th order filters at 17GHz center frequency with 10GHz pass-bands. The pass-band insertion loss is about 5 dB. The size of the smallest filter layout is $0.3\lambda_g \times 0.4\lambda_g$, the smallest passive uniplanar filters reported as we know The measured characteristics agreed well with the design.

Introduction

In recent years, there has been an increasing interest in creating filters on Monolithic Microwave Integrated Circuits(MMICs). Traditional microwave filter structures using stubs as building elements require large areas so they are not suitable for MMICs [1, 2]. Using couplers for filters reduces the area, but it is still too large [3, 4]. To reduce the length of the filters, interdigital solutions may be considered. In the case of single-layer metallization (for easier fabrication and reproducibility), the traditional well-known microstrip structures cannot be used further. Coplanar wave guides (CPW) are widely used as common uniplanar solutions, but, in general, interdigital structures are not suitable with CPW lines because of the small ground capacitance of the inner lines. However, we found that three coupled CPW lines can be used to create basic filter elements.

Three coupled lines as filter elements

The general equivalent circuit for a triple coupled transmission line structure is shown in Figure 1, which is very useful for filter applications [5]. The equivalent circuit parameters (Z1, Z2, Z3, n1, n2) define the capacitance matrix of the multicoupled structure as,

$$C_{11} = \frac{\varepsilon\eta}{\sqrt{\varepsilon_r}}\frac{n_1(n_1-1)}{Z_1}, C_{22} = \frac{\varepsilon\eta}{\sqrt{\varepsilon_r}}\frac{n_2(n_2-1)}{Z_2} \quad (1)$$

$$C_{33} = \frac{\varepsilon\eta}{\sqrt{\varepsilon_r}}\left\{\frac{1}{Z_3} - \frac{(n_1-1)}{Z_1} - \frac{(n_2-1)}{Z_2}\right\} \quad (2)$$

$$C_{13} = \frac{\varepsilon\eta}{\sqrt{\varepsilon_r}}\frac{n_1}{Z_1}, C_{23} = \frac{\varepsilon\eta}{\sqrt{\varepsilon_r}}\frac{n_2}{Z_2} \quad (3)$$

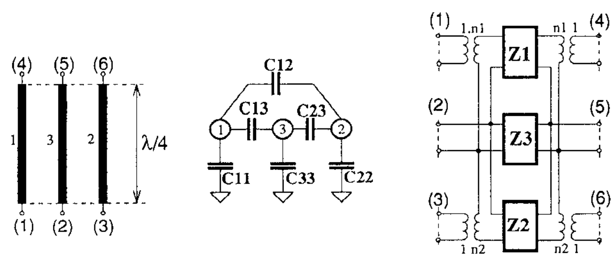
$$C_{12} = 0 \quad (4)$$

$$\varepsilon = \varepsilon_0\varepsilon_r, \eta = 120\pi[\Omega], \varepsilon_0 = \frac{10^{-9}}{36\pi}[F/m] \quad (5)$$

Employing open and short ends on the three coupled lines (see Figure 2) results in a two-port, which is equivalent to a third order filter element. The impedance of the transmission line sections at this equivalent circuit it the case of equal transformer ratios are follows,

$$n_1 = n_2 = n, Z_{o1} = Z_1/n^2, Z_{o2} = Z_2/n^2, Z_{o3} = Z_3/n^2 \quad (6)$$

By cascading such structures, the order of the equivalent filter can be increased by two with each additional module. The transformer ratios are free parameters of the filter design, which allows the line capacitance to be scaled to make the structure possible. For the cascading, it is not essential to employ equal transformer ratios at a section, but neighboring transformers should be equal.



TCC structure | Capacitance model | Equivalent circuit

Figure 1. Equivalent circuit for triple coupled transmission lines.

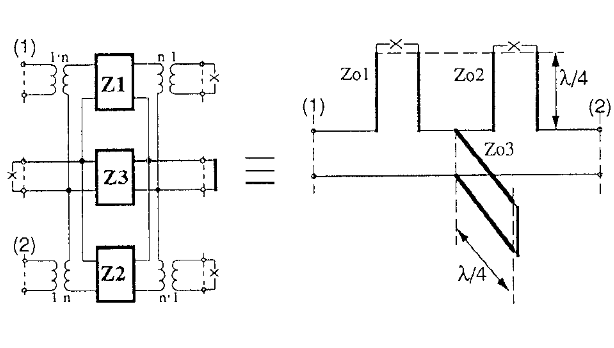


Figure 2. Transforming the triple coupled lines into a two port.

Filter design

The initial filter design is based on traditional methods [6]. First, the low pass prototype was transformed into a high-pass one because the structure needs open-ended serial stubs. Next, we transformed the high-pass equivalent by the Richard's transformation into a series of serial connected open-ended and parallel connected short-ended stubs, which can be directory converted to the capacitance matrix of the couplers with the equations given above.

We designed seventh order filters which can be realized by three coupler sections. Because the filters are symmetrical, they consist of two different couplers; a middle and two identical input/output ones. In order to use the coupler equivalence, we split the inner open-ended serial connected stubs of the filter two ones to provide the necessary stubs for the input and middle coupler sections. We split the stubs in such a way to make the input couplers symmetrical (see Figure 3). The filters were designed for 0.1dB pass-band ripple. The scaling factor of the Richard's transformation was 0.55. The parameters for the stub equivalent of the filters are shown in Table I.

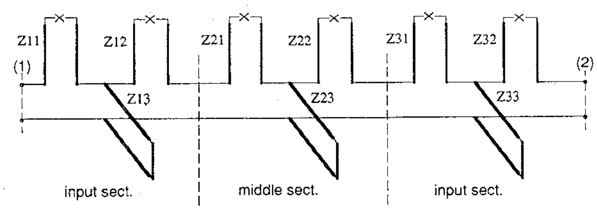


Figure 3. The stub equivalent of the filters.

Table I. Parameters of the stub equivalents (in Ohms)

System	Zo	50.0
Input/Output	Z11=Z12=Z31=Z32	107.4
	Z13=Z33	19.3
Middle	Z21=Z22	83.1
	Z23	17.6

Triple Coupled CPW lines

Figure 4 shows the triple coupled structure of the CPW lines as we used. [7] The filter fabrication employs a two metal layer process with a dielectric layer between them. However,the second metal layer and the dielectric layer are used for making supplemental connecting bridges. Therefore, TCC lines need a single layer metal process essentially.

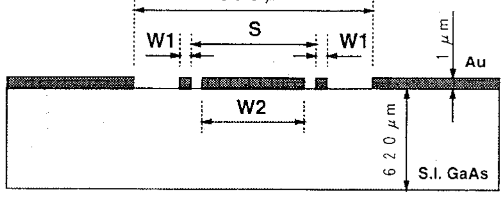


Figure 4. Triple coupled CPW lines.

The filter design gives the line capacitance based on the equations mentioned above. To find the geometry for the necessary capacitance matrix we used a structure simulator, which calculates the matrix parameters for multicoupled transmission lines [8]. After a few iterations (about 10-15 steps) we were able to find the proper geometry.

We realized the filters on a semi-insulated GaAs wafer with 0.62mm thickness, relative permittivity ε_r=13, dielectric loss of tan(δ) =0.0016, a couple of nominal 1μm gold metallization with about 1×10^7S/m conductivity and a spin-coated polyimide of ε_r=3.3. In general we need very narrow (about 1-2 μm) side-lines beside a wide center-line, which may be difficult to realize with high accuracy. We employed a minimal line width of 3μm. To fulfill this requirement we scaled the line capacitance by choosing a suitable transformer ratio at each coupler section.

In table II, the necessary capacitance values are given for the filters together with the calculated ones and the geometrical data for the filters (see notations on Figure 4).

Table II. Parameters of the filters
(capacitances in pF/m, width in μm)

	C11	C33	C13	W1	W2	S	C12
Input/Output	41.1	73.0	41.1	3.0	46.5	80.5	2.6
Middle	50.2	86.9	55.8	7.0	49.0	87.5	3.6

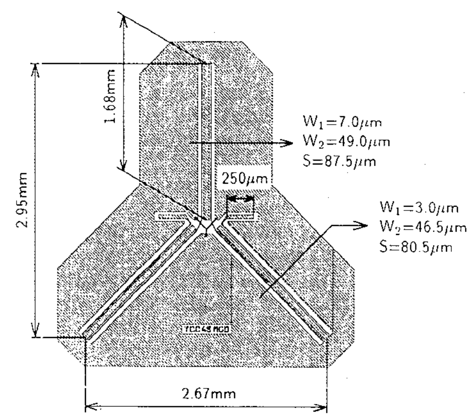


Figure 5. Filter layout.

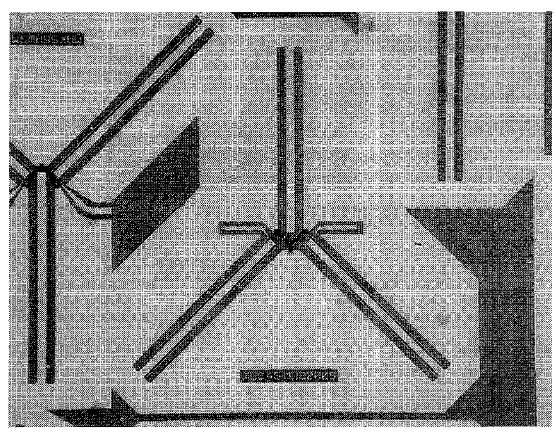


Figure 6. Photograph of a filter.

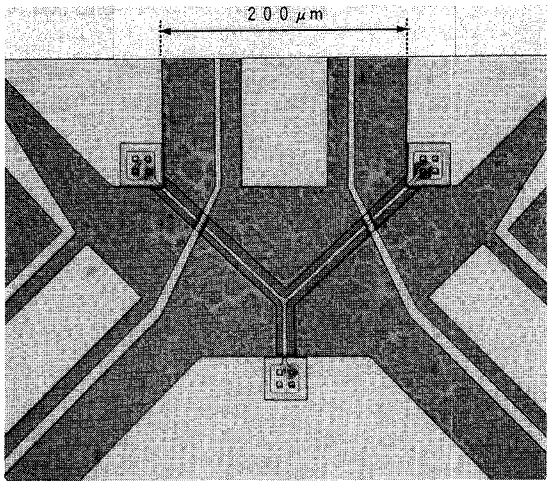


Figure 7. Close up of the connecting bridge.

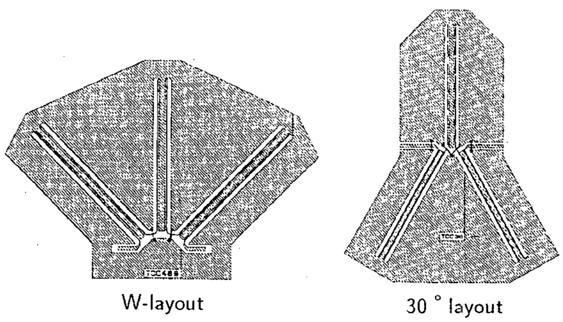


Figure 8. Alternative filter layouts.

Ideally the coupler sections should be connected directly. We calculated that a connecting line shorter than $200\mu m$ has negligible effect on the filter characteristics. Figure 5. shows a typical filter dimension. Figure 6 and 7 show an external view of a filter and a close-up of the connecting bridge. Figure 8 shows alternative filter layouts. The smallest layout arrangement (Figure 8, left) resulted in a filter size less than $0.3\lambda_g \times 0.4\lambda_g$, the smallest passive uniplanar MMIC filters reported as yet.

Measurements

Figure 9 compares measured and simulated filter characteristics for the filter structure in Figure 5, the agreement is very good. An unusual maximum can be observed at the return loss in the pass-band due to the non-zero capacitance between the side lines (refer C12 in Table II). The pass-band losses are higher than with conventional filters, but this is common with MMICs because of the low conductivity of the metallization. There is a small sift in the measured characteristics compared to the simulated one due to the discontinuities (open and short ended lines).

Figure 10 compares measured characteristics for the Y-shaped and W-shaped filter layouts in Figure 5 and Figure 8 left respectively. They show very close characteristics except the wider bandwidth at the low-end in the W-shaped filter because of the non-optimized bridge position and the imperfect bridge connection.

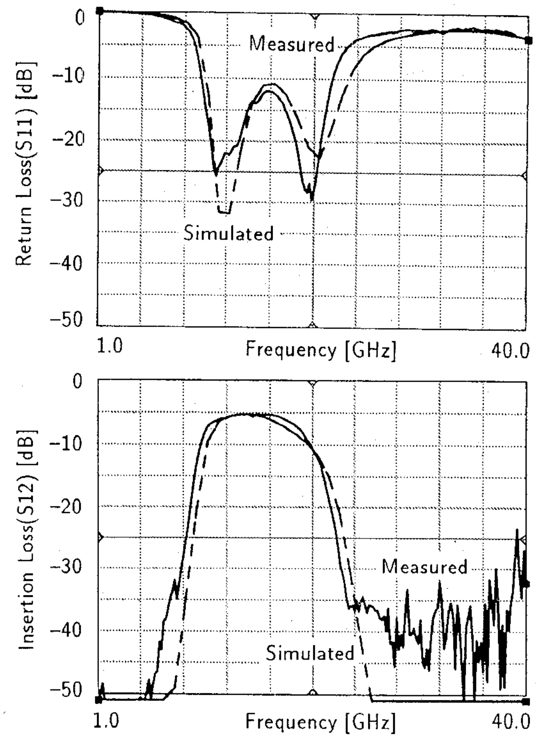


Figure 9. Comparison of simulated and measured data.

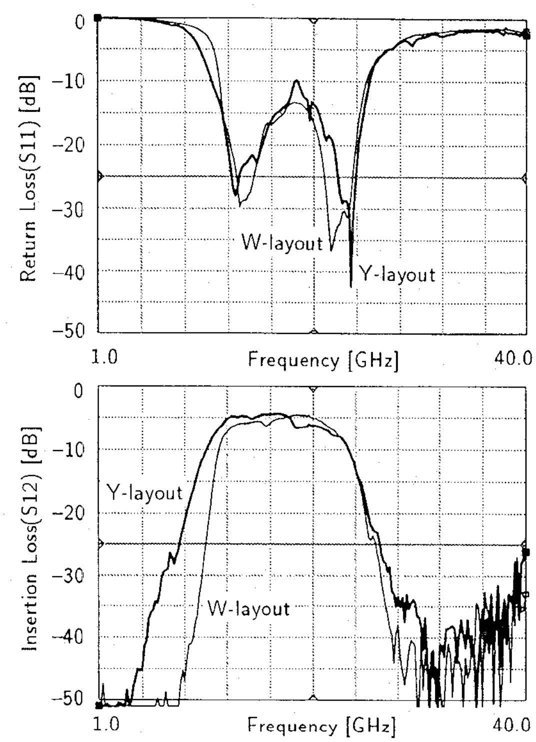


Figure 10. Comparison of Y-layout and W-layout.

Figure 11 shows a comparison of the layout variation in the angle between the input and the ouput TCCs. The angle doesn't change both return loss and insertion loss characteristics. This means that there may be more room to reduce a total dimension of filter structures.

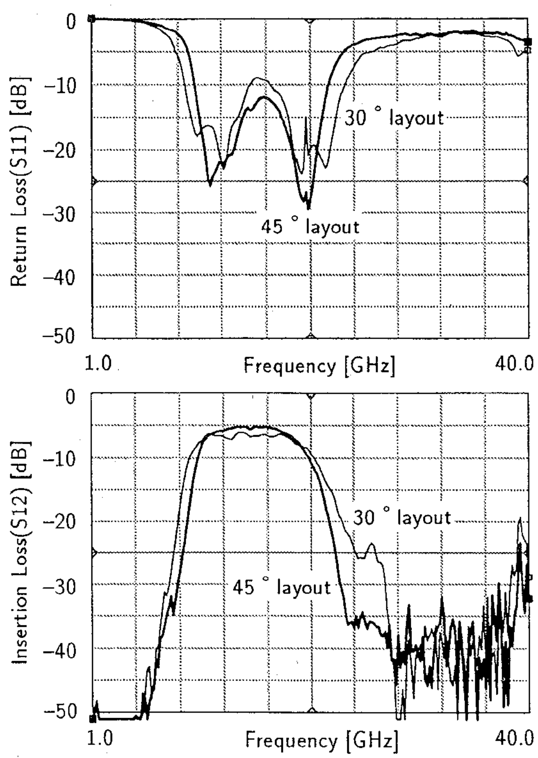


Figure 11. comparison of 45 ° layout and 30 ° layout.

Conclusions

With the new Triple Coupled CPW lines (TCC lines) we created the smallest passive filters on unilateral MMICs reported as yet. We used traditional filter design methods for the capacitance matrix of the multicoupled lines. The geometry was found by iterations carried out with a structure simulator. The measured characteristics agree very well with the simulations.

References

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