Broadband Lumped-element Quadrature Hybrid For Intermediate Frequency Applications

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***Abstract-* A broadband lumped-element quadrature hybrid is proposed and implemented for intermediate frequency (IF) applications. The proposed topology not only enables a wide fractional bandwidth (FBW) of 33% with only 7 elements, but also makes the required capacitance and inductance values lower, which is helpful for size reduction when establishing elements using interdigital capacitor and spiral inductor implementation instead of 0402 package element implementation. The size of the proposed quadrature hybrid is only 8 mm × 3 mm. Measured S_{11}, S_{21}, S_{31} and S_{41} are better than -14, -4.3, -3.6 and -13 dB from 50 to 70 MHz, respectively. And the measured inband phase difference between the coupled and direct ports is within 91°±1°. Yield analysis, discussions and size comparisons are also implemented.**

Keywords—broadband; lumped-element; quadrature

I. INTRODUCTION

The quadrature hybrid, or branch-line coupler, is an elemental component used in microwave circuits, such as balanced amplifiers, balanced mixers, phase shifters and beam-forming networks for array antennas [1]. It's also one of the largest components in super heterodyne receivers, especially after frequency down-converting to a lower intermediate frequency (IF) band (most $f_{IF} < 200$ MHz). For IF band applications, distributed-element structured hybrids are too large to integrate as the working frequencies are too low. Compact quadrature hybrids working at low intermediate frequencies only can be made using lumped elements [2-10] for size reductions. Four types of conventional lumped topologies of quadrature hybrids (Type LLC, Type CCL, Type LCC, Type CLL) with their performance are summarized in Figure 1(a), (b), (c) and (d), respectively. However, those four types of topologies with 8 elements (capacitors and inductors) suffered a narrow fractional bandwidth (FBW) of only 1~2%, which cannot meet the needs of modern wideband communications. Wideband lumped topology for quadrature hybrid with only 7 elements has been reported in [11], shown in Figure2 (a). But it requires comparative high capacitance and inductance, which lead to large size of equivalent interdigital capacitor and spiral inductor implementations.

In the paper, a novel topology of quadrature hybrid is proposed and implemented at the extremely low center-frequency of 60 MHz. The proposed topology not only enables a wide FBW of 33% with only 7 elements, but also makes the required capacitance and inductance lower, which is helpful for size reduction when establishing elements using interdigital capacitor and spiral inductor implementation instead of 0402 package element implementation. And the size of the proposed quadrature hybrid is only 8 mm × 3 mm.

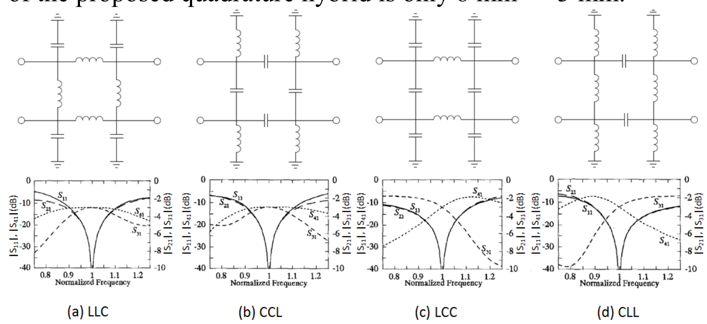

Figure 1 Narrowband topologies of quadrature hybrid (a) LLC type (b) CCL type (c) LCC type and (d) CLL type

II. CIRCUIT DESIGN

Our goal is to design a lumped quadrature hybrid for 50 to 70 MHz IF band applications. Since the wide FBW is the only challenge of this work, the first step is to find an appropriate wideband circuit topology with a small number of elements. Figure2 (b) shows the proposed circuit topology with its simulated S-parameters. The proposed topology is derived from that in [11] using elements reciprocal theory (capacitors and inductors position exchanging). In Figure 2(a), the 3 center-located inductors are replaced with 3 capacitors and 4 side-located capacitors are replaced with 4 inductors. In the proposed topology, the 3 capacitors have the same capacitance C and the 4 inductors have the same inductance L. So the topology can be easily optimized with only 2 parameters. To make both topologies in Figure 2(a) and (b) work from 50 to 70 MHz, elements' values (C=57 pf & L=143 nH) in Figure 2(a) and elements' values (C=51 pf & L=126 nH) in Figure 2(b) are obtained using AWR Microwave Office simulator [12]. The proposed topology makes the required capacitance and inductance 10% lower than those in [11]. The advantage of the proposed topology is for size reduction if using interdigital capacitor and spiral inductor implementation as the size of interdigital capacitors and spiral inductors can be smaller.

$$L = \frac{Z_0}{2\pi f} \quad (1)$$

$$C = \frac{1}{2\pi f Z_0} \quad (2)$$

where Z_0 is the port impedance. The cascaded connections of the circuits can be conveniently analyzed by means of the transmission (ABCD) matrix in [11] further.

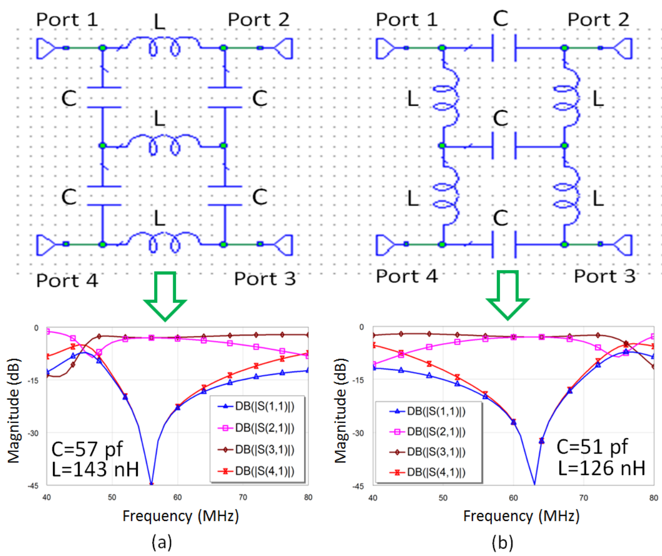

Figure 2 Circuit topology with simulated S-parameters for 50~70 MHz applications. (a) topology in Ref [11] and (b) the proposed topology.

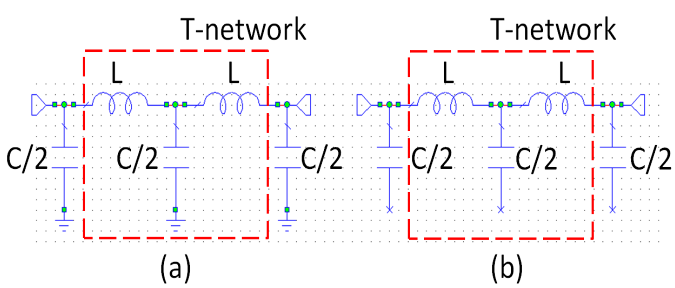

Figure 3 odd and even mode equivalent half circuits of the proposed topology. (a) odd mode and (b) even mode.

A low-cost 0.8 mm thick FR-4 printed circuit board (PCB) with a dielectric constant of 4.5 and a loss tangent of 0.015 was employed to validate analytical results. The 0402 package (1 x 0.5[mm]) 51 pF capacitors and 126 nH inductors are used to establish the circuit. The photograph of the proposed quadrature hybrid is shown in Figure 4. Its layout is the same with its topology in Figure 2(b). And the size of the proposed quadrature hybrid is only 8 × 3 mm.

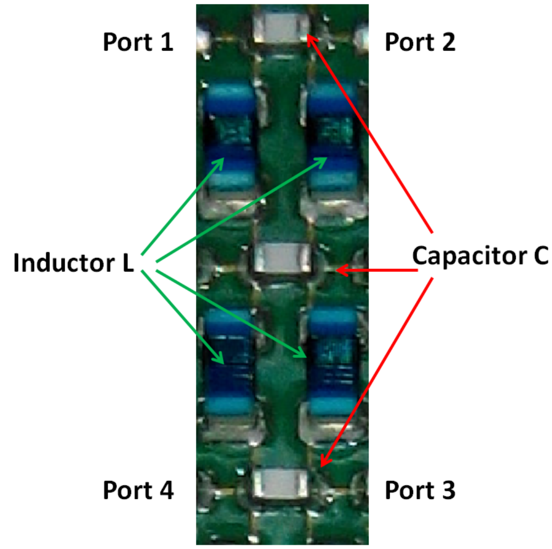

Figure 4 Photograph of the proposed quadrature hybrid

III. YIELD ANALYSIS AND MEASURED RESULTS

Simulation results of the proposed quadrature hybrid are shown in Figure 2(b). To guarantee a satisfied fabrication yield, yield analysis and optimization is also accomplished using AWR Microwave Office simulator. Considering the capacitor and inductor dispersions, a 5% tolerance of capacitance ***C*** and a 5% tolerance of inductance ***L*** are included. Finally shown in Figure 5, the yield is 95%, which can fulfill our design needs.

Measurements are carried out by Agilent N5230C network analyzer and Cascade Microtech Summit 9000 probe stations. Figure 6 shows the measured S-parameters and Figure 7 shows the phase difference between the through and coupled port. As can be seen in Figure 6, the measured S_{11}, S_{21}, S_{31} and S_{41} are better than -14, -4.3, -3.6 and -13 dB from 50 MHz to 70 MHz, respectively. And the inband phase balance between the coupled and direct ports is 91°±1°. The measurements agree well with the simulation results in Figure 2(b).

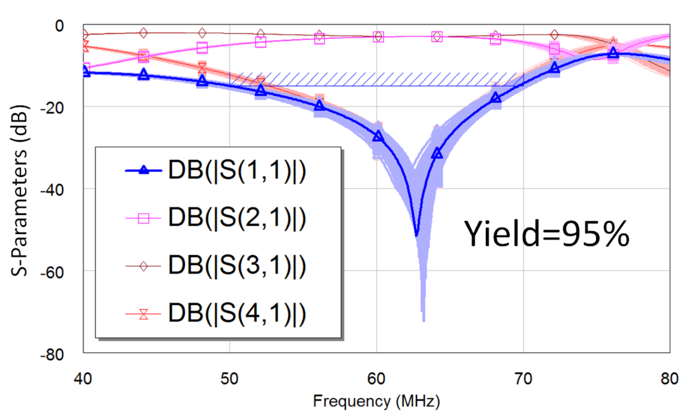

Figure 5 Yield analysis results

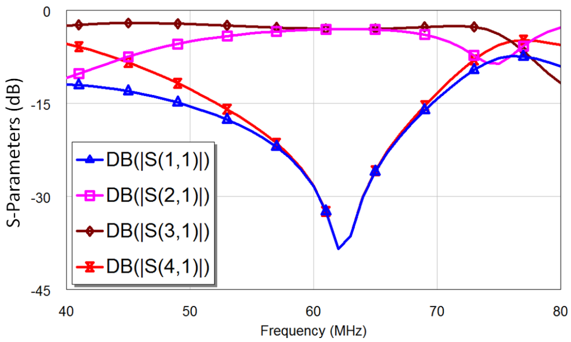

Figure 6 Measured S-parameters of the proposed hybrid

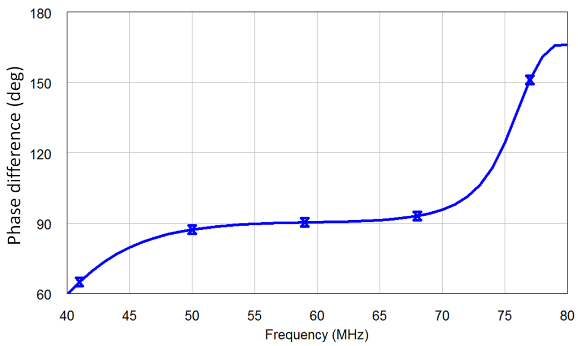

Figure 7 Measured S-parameters of the proposed hybrid

IV. DISCUSSIONS AND COMPARISONS

To well illustrate the advantages of the proposed topology, structures using the proposed topology and the topology in [11] are both made for size comparisons, shown in Figure 8 (a) and (b). The 0402 package capacitors and inductors are replaced by interdigital capacitor and spiral inductor implementations. The implementation using the topology in Ref [11] is shown in Figure 8(a), and the implementation using the proposed topology is shown in Figure 8(b). As we can see that the proposed implementation in Figure 8(b) achieved a size reduction of 40% compare to the one in Figure 8(a). The great size reduction are due to the proposed quadrature hybrid topology enables the required capacitance and inductance values lower, which makes the interdigital capacitors and spiral inductors much smaller.

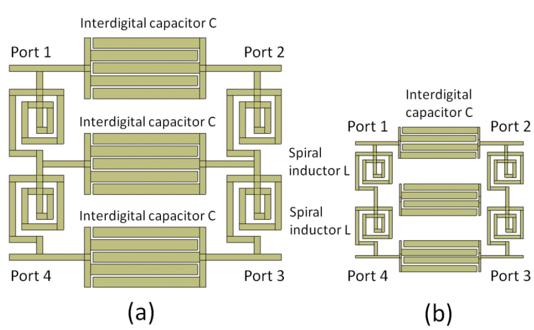

Figure 8 Size comparison using interdigital capacitor and spiral inductor implementions (a) implementation using the topology in Ref [11] and (b) implementation using the proposed topology.

V. CONCLUSION

A wideband lumped-element quadrature hybrid is proposed and implemented for 60 MHz applications. The proposed topology not only enables a wide fractional bandwidth (FBW) of 33% with only 7 elements, but also makes the required capacitance and inductance lower, which is helpful for size reduction when realizing using interdigital capacitor and spiral inductor implementations. The size of the proposed quadrature hybrid is only 8 mm × 3 mm. Measured S_{11}, S_{21}, S_{31} and S_{41} are better than -14, -4.3, -3.6 and -13 dB from 50 to 70 MHz, respectively. And inband phase difference between the coupled and direct ports is within 91°±1°. Yield analysis, discussions and size comparisons are also implemented.

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