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Miniaturized and Folded Multisection Quadrature Hybrid for UWB Applications

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Abstract—This letter presents the development of a miniaturized and folded multisection quadrature hybrid for ultra-wideband (UWB) applications. For a size reduction, Stages 1, 2 and 3 are placed on the top of PCB, and Stages 5, 7 and 7 are placed on the bottom of PCB. The transition between top and bottom layers uses via transitions. Stage 4 is proposed with vertical via transitions and microstrip lines on the top and bottom sides of PCB, which is helpful for bandwidth increment and size reduction. The overall size of the proposed UWB hybrid is only 21 mm by 14 mm, and a size reduction of 50% is achieved compared with a planar multisection one. Performance comparisons are also implemented and discussed compared with a planar one.

1. 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 beamforming networks for array antennas. Conventional single section quadrature hybrid with equal power division has a limited bandwidth about 15% over which the power balance is within 0.5 dB. Bandwidth can be increased using coupled lines [1–6] and multisection structures [7–13]. However, hybrids using coupled lines are hard to be implemented on microwave monolithic integrated circuit (MMIC), and multisection hybrids occupy large size due to its planar multisection structure, shown in Figure 1(a).

In this letter, a folded multisection quadrature hybrid is proposed for UWB applications, shown in Figure 1(b). A size reduction of 50% is achieved using the proposed folded structure. Performance comparisons are also discussed compared with a planar multisection quadrature hybrid.

2. ANALYSIS OF CASCADED MULTISECTION HYBRID

A multiple cascading stage technique [14] is used to enhance the bandwidth. Here, a two-section impedance transforming hybrid is employed to show the synthesis method for a cascaded multisection hybrid.

A two-section cascaded hybrid is shown in Figure 2. Using odd-even mode analysis, the even and odd mode cascade element matrices at a center frequency are given by

$$M_e[1] = \begin{bmatrix} A & B \\ C & D \end{bmatrix}; \quad M_O[1] = \begin{bmatrix} A & -B \\ -C & D \end{bmatrix} \tag{1}$$

where

$$A = \frac{b^2}{hj} - 1; \quad B = -j\frac{ab}{h};$$

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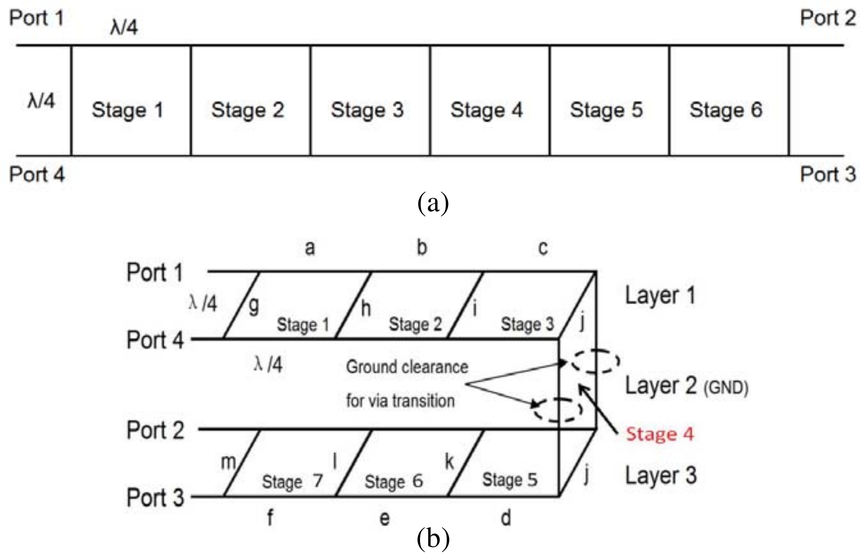

Figure 1. (a) Conventional multisection hybrid in planar and (b) the proposed hybrid.

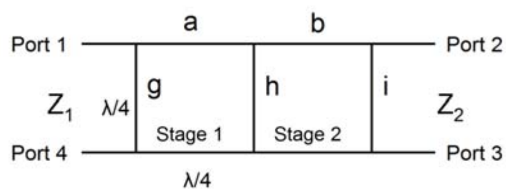

Figure 2. Two-section cascaded quadrature hybrid.

$$C = -j\left(\frac{1}{g} + \frac{1}{i} + \frac{1}{ghi}\right) \text{ and } D = \frac{a^2}{gh} - 1 \tag{2}$$

where a, b, g, h and i are the impedance of each branch line, shown in Figure 2. Using $S_{11} = S_{41} = 0$ and the lossless condition, the design equations for an impedance transforming two section hybrid are given by

$$g = \frac{Z_1\sqrt{r(t^2 - r)}}{t - r} \tag{3}$$

$$i = \frac{Z_1\sqrt{r(t^2 - r)}}{t - 1} \tag{4}$$

$$\frac{ab}{h} = Z_1\sqrt{r - \frac{r^2}{t^2}} \tag{5}$$

where $t^2 = (1 + k^2)r$, Z_1 and Z_2 are input and output impedances of the two sections, respectively. r is the impedance transformation ratio, and k^2 is the power division ration between port 2 and port 3, shown in Figure 2.

To develop a UWB hybrid that can work from 3.1 to 10.6 GHz, structure that cascades 7-stage quarter wavelength sections is adopted to meet the UWB requirements. According to Eqs. (1)–(5) and with the help of CAD calculation and optimization, impedances for each branch line are derived as: $a = f = 34.5\,\Omega$, $b = e = 30.2\,\Omega$, $c = d28.4\,\Omega$, $g = m = 41.6\,\Omega$, $h = l = 28.4\,\Omega$, $i = k = 32.2\,\Omega$ and $j = 25\,\Omega$, shown in Figure 1(b). Parameters are defined in Figure 1(a).

3. CIRCUIT DESIGN

A folded three-layer structure is proposed to minimize the size of a conventional planar multisection hybrid. As shown in Figure 1(b), three quarterwavelength sections (Stages 1, 2 and 3) are printed on the top of the LTCC substrate, and the other three sections (Stages 5, 6 and 7) are etched on the bottom side. Stage 4 is established with vertical via transitions and microstrip lines on the top and bottom sides of PCB. Stage 4 does not take up large area as it is a vertical stage inside the PCB substrate. A metal sheet is inserted in the center of the intermediate layer to provide a ground plane for isolation between top and bottom sections. So there is no coupling effect between top and bottom layers. Vertical via transitions in Stage 4 are used to connect Section 3 on top layer and Section 5 on bottom layer. Quarter wavelength branch length of each section at the center frequency of 6.85 GHz is 5.9 mm based on a thickness of 1 mm in RGogers 4350 material with a dielectric constant of 4.4 and loss tangent of 0.002.

We have also designed a planar version of the quadrature hybrid for comparisons. Figure 4 demonstrates prototypes of both the hybrids. Figures 4(a) and (b) show the proposed folded multilayered hybrid top side and bottom side, respectively. Figure 4(c) shows an equivalent planar implementation. The planar hybrid branch line coupler is 43 mm long, whereas the folded circuit is only 21 mm long, resulting in a size reduction of 50%.

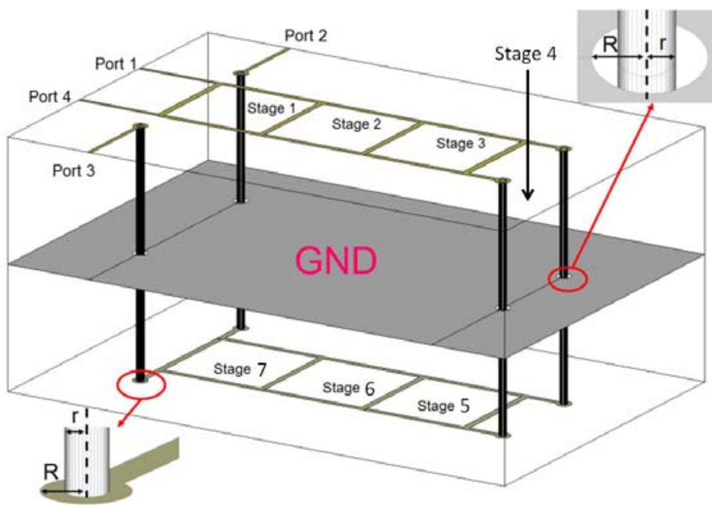

Figure 3. Structure of the proposed folded quadrature hybrid.

4. RESULTS AND DISCUSSION

Microwave Office AXIEM [15] solver which is a full-wave electromagnetic solver based on spectral-domain method of moments (MoM) is used to design and optimize the proposed UWB hybrid. Finally, optimized widths of each branch are: $W_a = W_f = 0.27$ mm, $W_b = W_e = 0.33$ mm, $W_c = W_d = 0.36$ mm, $W_g = W_m = 0.2$ mm, $W_h = W_l = 0.36$ mm, $W_i = W_k = 0.3$ mm and $W_j = 0.43$ mm. Radius of pad and ground (R) are both 0.42 mm, and radius of via transition (r) is 0.29 mm. Structure parameters are defined in Figure 1(a) and Figure 3.

Measurements were carried out using an Agilent N5230C network analyzer. Measured S_{11} and S_{41} of the proposed quadrature hybrid are better than -10 and -9 dB from 3.1 to 10.6 GHz, respectively shown in Figures 5(a) and (b). Measured S_{21} and S_{31} also agree with simulated results well and can meet the UWB requirements, shown in Figure 5(c). Measured phase difference from 90° of the proposed UWB hybrid is less than 0.8° from 3.1 to 10.6 GHz, shown in Figure 5(d). The insertion loss and isolation are 0.5 and 4 dB worse, respectively, than a planar multisection hybrid implementation. This is because of the discontinuity from top to bottom layers via transitions.

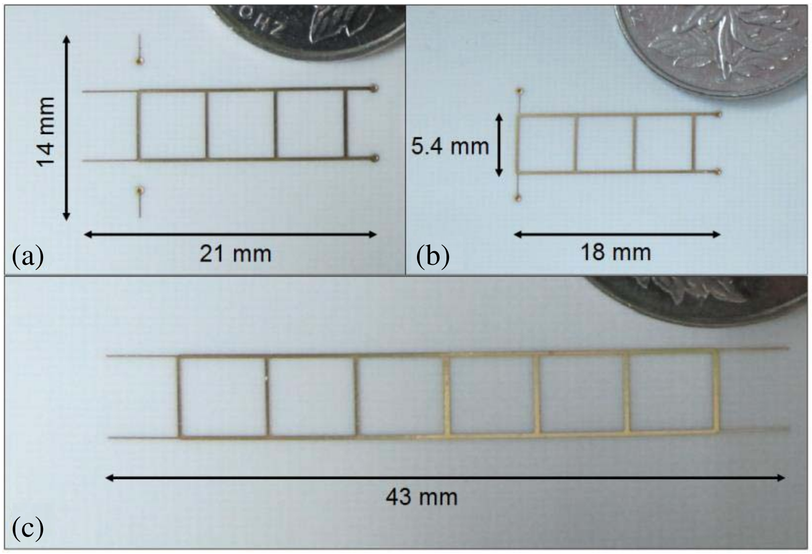

Figure 4. Photograph of folded multisection LTCC hybrid, (a) top side, (b) bottom side and (c) equivalent implementation.

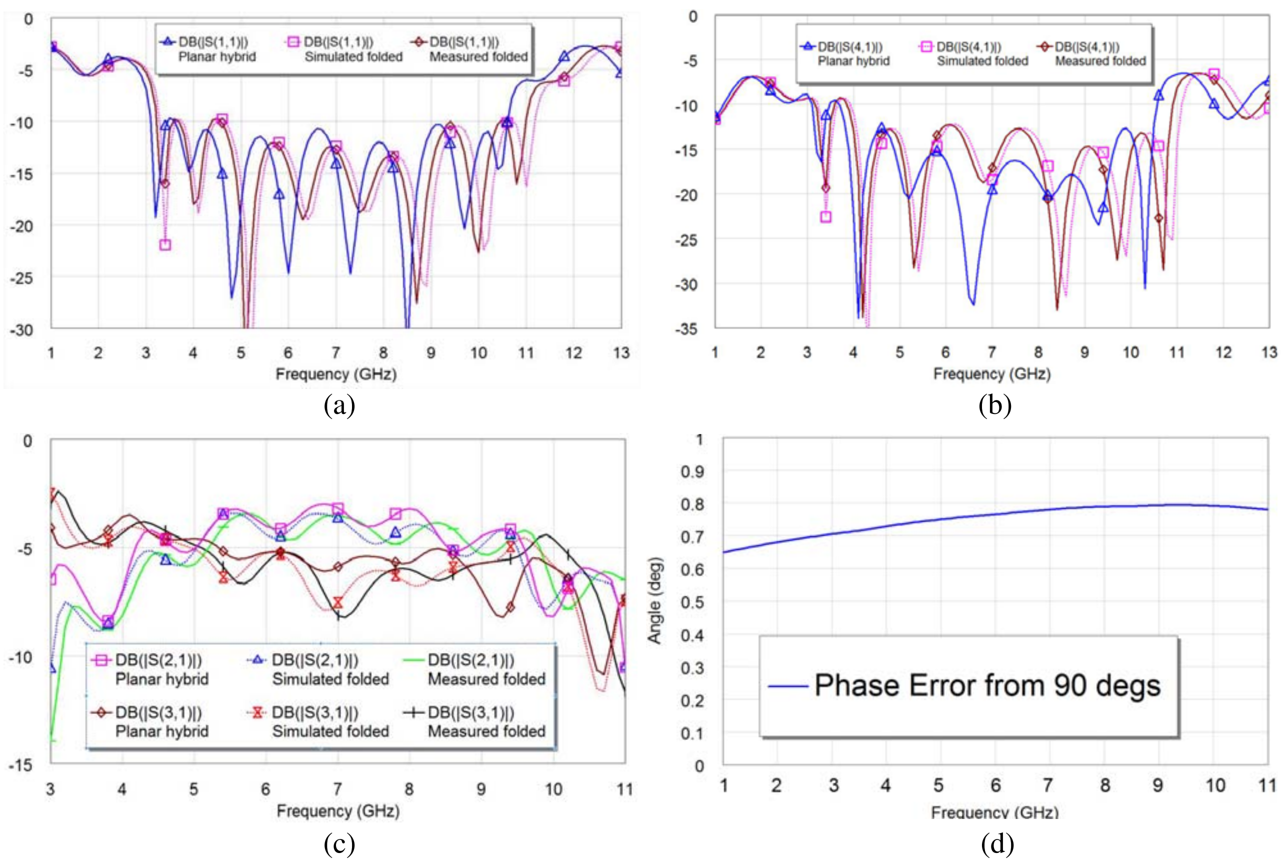

Figure 5. Simulated and measured results, (a) S_{11}, (b) S_{41}, (c) S_{21} and S_{31} and (d) measured phase difference from 90 degree.

5. CONCLUSION

A folded multisection quadrature hybrid for UWB applications is proposed and implemented. A vertical stage is built to interconnect stages on the top and bottom, which is good for increasing bandwidth and saving areas. A UWB characteristic and size reduction of 50% compared with equivalent planar multi-section hybrid is achieved using the proposed folded multilayered structure. Performances comparisons are also implemented and discussed compared with a planar multi-section hybrid.

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