# G-2

## IMPEDANCE TRANSFORMING 3-dB 90° HYBRIDS*

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### ABSTRACT

Design techniques and performance results for impedance transforming 3-dB 90° hybrids are presented. A broadband hybrid with 50- to 20-Ω impedance transformation has been realized by tandem connection of coupled-line sections. Measured results show an amplitude balance of 3.7 ± 0.68 dB and return loss and isolation of approximately 15 dB over the 3- to 5-GHz range. Test results for a 50-Ω tandem hybrid and a 50- to 25-Ω branch-line hybrid are also presented.

### INTRODUCTION

Branch-line and coupled-line (Lange) 3-dB hybrids have been used extensively in the design of balanced amplifiers. In the conventional approach, the hybrids are designed with 50-Ω input/output impedances. Hybrids that also transform 50-Ω input impedance to a lower value (20 to 25 Ω) significantly reduce the total number of elements required for FET amplifier matching. For a 4-GHz, 1-W balanced amplifier example (1), analysis has revealed that the size of matching networks could be reduced by more than 40 percent compared to the 50-Ω Lange hybrid design.

In-phase Wilkinson hybrids (2) and branch-line 90° hybrids (3),(4) with impedance transforming properties have been proposed in the literature. This paper discusses a new class of broadband impedance transforming 90° hybrids realized by tandem connection of coupled-line sections. For performance comparison and evaluation, test results for a 50-Ω tandem coupler and a 50- to 25-Ω single-section branch-line hybrid are also presented.

### 50- TO 25-Ω BRANCH-LINE HYBRID

Design values of the branch- and main-line impedances for multiple-section (3) and single-section (4) impedance transforming branch-line couplers have been derived previously. However, hardware realization of such couplers has not been extensively investigated. To evaluate hardware performance, a single-section, branch-line, 3-dB 90° hybrid with input and output impedances of 50 and 25 Ω was designed (Figure 1). Equations derived by Gupta and Getsinger (4) based on image parameter theory were used, and the circuit was realized on a 10-mil alumina substrate. Broadband, three-stage, quarter-wavelength impedance transformers were designed to transform 25 Ω at the output ports to 50 Ω for measurements in a 50-Ω system. Figure 2 shows the measured and modeled transmission parameters at the two output ports.

The circuit model was analyzed using SUPERCOMPACT, and the effect of discontinuities and T-junctions were included in the model. The bandwidth with 3.15 ± 0.25-dB signal balance at the output ports is approximately 20 percent at a 5.4-GHz center frequency. Measured return losses and isolation are better than 15 and 17.5 dB, respectively, and the phase balance is 88.5° ± 1.5° over the same frequency band. The useful bandwidth of impedance transforming branch-line couplers decreases as the impedance transformation ratio increases (3); however, the insertion loss is lower than that of coupled-line hybrids.

### COUPLED-LINE TANDEM HYBRIDS

Coupled-line hybrids have the potential of providing much larger bandwidth. Nonsymmetrical directional couplers that use coupled lines of unequal characteristic impedances have been described by Cristal (5) and Tripathi (6). These broadband couplers provide impedance transformation from incident and direct ports to coupled and isolation ports. The couplers discussed in this paper provide impedance transformation from incident and isolation ports to direct and coupled ports by using tandem connection of coupled lines.

Hybrid 3-dB couplers have been constructed in the past by tandem connection of two 8.34-dB couplers (7), which are much easier to realize because of relatively loose coupling. For an impedance transforming coupler design, three couplers may be connected in tandem to obtain a 3-dB coupler, as shown in Figure 3. For computation of the coupling ratios for each section, it may be assumed that the signal level at A is 1 and at A' is 0, and that the coupling coefficient of

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each section is k. The remaining signal levels are

$$B = k \quad , \quad B' = j(\sqrt{1 - k^2}) \qquad (1)$$

$$C = k^2 - (1 - k^2) \quad , \quad C' = j2k \sqrt{1 - k^2} \qquad (2)$$

$$D = k(4k^3 - 3) \quad , \quad D' = j(4k^2 - 1) \sqrt{1 - k^2} \qquad (3)$$

For 3-dB power division, signals at D and D' must be equal. Therefore,

$$k(4k^3 - 3) = (4k^2 - 1) \sqrt{1 - k^2} \qquad (4)$$

Computations show that a real value of $k = 0.2588$ (-11.74 dB) satisfies equation (4) and results in a 3-dB power split at the band center (with narrow bandwidth). For increased bandwidth, a coupling ratio of -11.44 dB ($k = 0.2679$) may be used, which corresponds to a balance of ±0.25 dB. For the 50-Ω hybrid, all three sections have 50-Ω characteristic impedances. For the 50- to 20-Ω hybrid design, each coupled section also acts as an impedance transformer. The impedances of the three sections were selected to be 41.55, 31.62, and 24.06 Ω, respectively (8). The length of these couplers is essentially quarter wavelength, plus additional interconnect lines. The width is determined by the spacings between different coupling sections and by the width of the coupled lines.

## REALIZATION OF 50- TO 20-Ω HYBRID AND 50-Ω TANDEM HYBRID

A 50- to 20-Ω impedance transforming hybrid was designed for a 4-GHz center frequency and implemented on 10-mil-thick alumina substrate. For performance comparison, a three-section 50-Ω tandem coupler (without impedance transformation) was also designed. Table 1 lists the even- and odd-mode impedances and corresponding line widths and spacings for the three sections. To minimize the mutual coupling effects, the spacing between the coupler sections was made larger (20 to 25 mil) relative to gaps in the coupled lines. The effect of mutual coupling between different sections was not included in the initial analysis. To maintain 90° phase difference at the output ports, the interconnect lines were maintained to be symmetrical and of the same physical length. The crossovers were achieved with minimum-length bond wires across a gap of 2 mil between the microstrip lines of each crossover. These bond wires introduce some asymmetry in the coupling structure. To minimize their effect, a large number of bond wires (minimum of four) are required. The effect of bond wires, 90° bends, and steps associated with interconnect lines were modeled on SUPERCOMPACT.

Figure 4 shows photographs of 50-Ω and 50- to 20-Ω tandem hybrids fabricated on 10-mil-thick alumina. The minimum spacing between coupled lines is 1.25 mil. A gold plating thickness of 2 μm was used. For testing, these hybrids were fabricated on 0.75 x 0.25-in. substrate with access lines. The overall dimensions of the 50-Ω and 50- to 20-Ω hybrids were 0.34 x 0.096 in. and 0.39 x 0.16 in., respectively. The impedance transforming coupler is larger than the 50-Ω hybrid because of wider interconnect lines and the width of the low-impedance lines. For testing the 50- to 20-Ω hybrid, a broadband, three-section, quarter-wavelength transformer (0.75 x 0.871 in.) was designed. This transformer was replaced with same-length 50-Ω lines for testing the 50-Ω hybrid.

Test results for the 50-Ω tandem hybrid and the 50- to 20-Ω impedance transforming hybrid are shown in Figures 5 and 6, respectively. For the impedance transforming hybrid, the amplitude balance is 3.7 ± 0.68 dB and the return loss and isolation are approximately 15 dB over the 3- to 5-GHz frequency band. In comparison, the amplitude balance for the 50-Ω tandem hybrid is 3.5 ± 0.5 dB and the return loss and isolation are better than 19 dB and 17.5 dB, respectively, over the same frequency band. These return loss measurements are made at fixture ports and include the effect of the 50-Ω access line, impedance transformers, and connectors.

Results for both cases reveal overcoupling. The effective section coupling for the impedance transforming hybrid for measured amplitude balance is 10.6 dB. Mutual coupling effects between different sections should be included in a more rigorous analysis of tandem couplers. The balance in these couplers can be improved by compensating for these effects. For example, a hybrid with a balance of ±0.2 dB over 3 to 5 GHz was realized (Figure 7) by redesigning the hybrid with section coupling to 12.1 dB. The phase balance was 93° ± 3° over the same frequency band. The losses for coupled-line hybrids were greater than for branch-line couplers.

Table 1. Design Parameters for 50-Ω and 50- to 20-Ω Three-Section Tandem Hybrids

| Coupler | Sections | Characteristic Impedance, $Z_o$ (Ω) | Even-Mode Impedance, $Z_{oe}$ (Ω) | Odd-Mode Impedance, $Z_{oo}$ (Ω) | Line Width, W (mil) | Line Spacings, S (mil) |
|---|---|---|---|---|---|---|
| 50-Ω | I, II, and III | 50 | 66.02 | 37.87 | 8.71 | 4.07 |
| 50- to 20-Ω | I | 41.55 | 54.68 | 31.68 | 12.44 | 3.38 |
| | II | 31.62 | 41.62 | 24.03 | 19.39 | 2.24 |
| | III | 24.06 | 31.67 | 18.28 | 28.48 | 1.25 |

## CONCLUSIONS

The feasibility of impedance transforming coupled-line hybrids by using tandem connection of coupled lines has been demonstrated. The bandwidth performance of these hybrids is comparable to that of conventional Lange couplers. Impedance transforming, single-section, branch-line couplers have been shown to have relatively low losses and narrower bandwidth. Impedance transforming hybrids can be used to design FET balanced amplifiers that have a smaller number of matching elements, thus reducing the overall size of the amplifiers.

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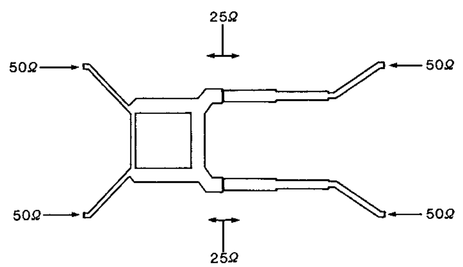



Figure 1. 50- to 25-Ω Impedance Transforming Branch-Line Hybrid

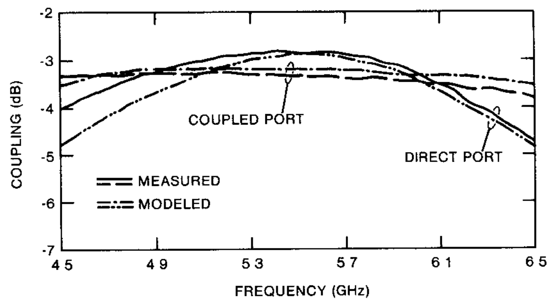



Figure 2. Measured and Modeled Amplitude Balance for 50- to 25-Ω Branch-Line Hybrid

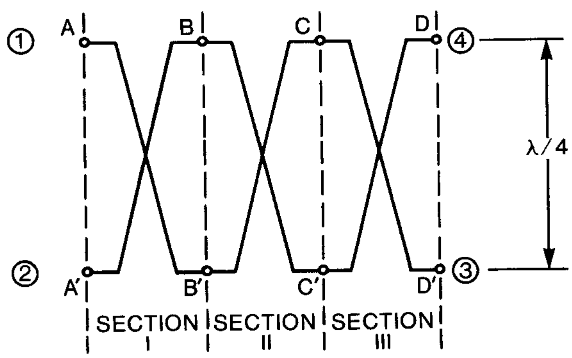
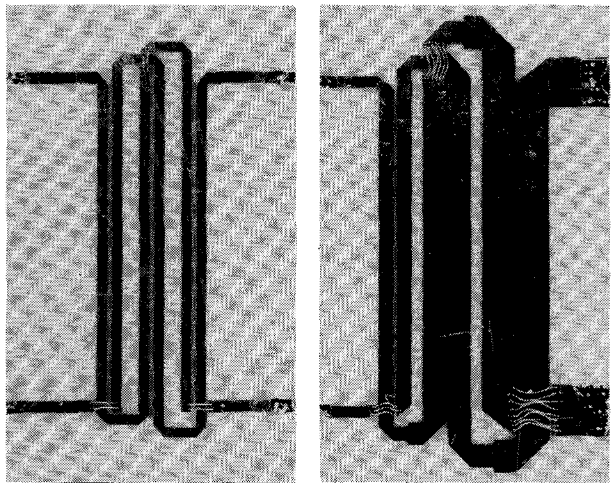



Figure 3. Tandem Interconnection of Three Couplers



(a) 50-Ω Tandem Hybrid (b) 50- to 20-Ω Tandem Hybrid

**Figure 4. Photographs of 50-Ω and 50- to 20-Ω 3-dB Hybrids (substrate: 10-mil-thick alumina)**

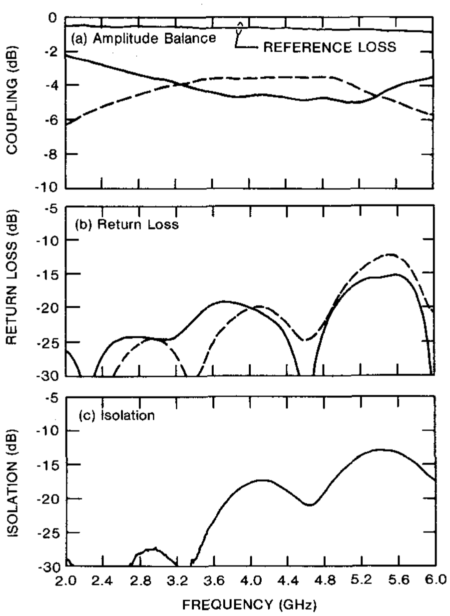



**Figure 5. Measured Performance of 50-Ω Tandem Hybrid (design section coupling: 11.44 dB)**

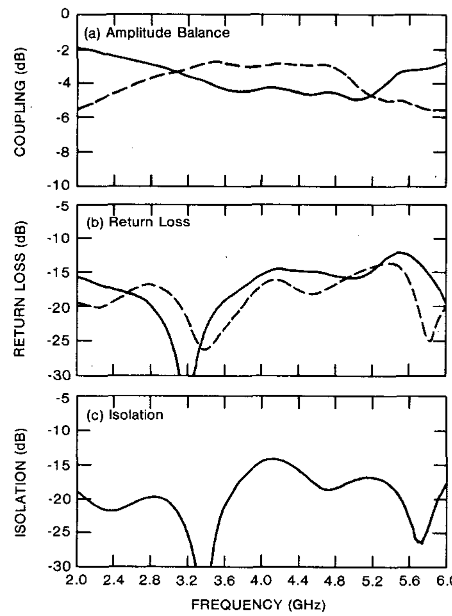



**Figure 6. Measured Performance of 50- to 20-Ω Impedance Transforming Hybrid (design section coupling: 11.44 dB)**

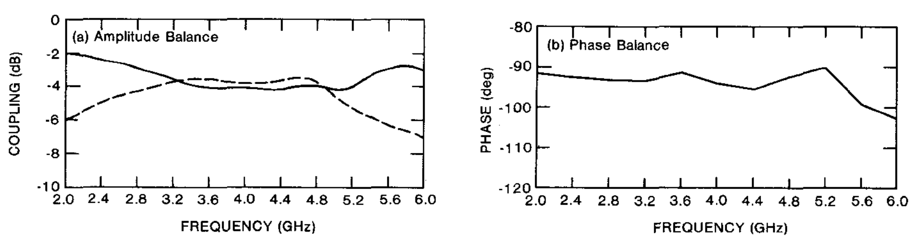



**Figure 7. Measured Performance of 50- to 20-Ω Impedance Transforming Hybrid (design section coupling: 12.1 dB)**