Letters

An All-Harmonic Coupling-Band Hybrid

J. S. WIGHT, W. J. CHUDOBIAK, AND V. MAKIOS

***Abstract*—A description is given of a microstrip branch-arm hybrid which exhibits 3-dB coupling at all harmonics of a fundamental frequency as compared to the odd-harmonic coupling exhibited by conventional branch-arm hybrid structures.**

INTRODUCTION

The development of mixer theory has resulted in circuits of increased complexity. Situations arise where local oscillator (LO) waveshaping is desirable in order to maximize the ratio of the conversion conductance to the input conductance. To apply waveshaping techniques to a balanced structure, 3-dB phase quadrature coupling is required at all harmonics of the fundamental. An all-harmonic coupling-band hybrid can be realized with a suitably designed parallel-line coupler. Due to geometrical limitations, however, a tandem pair of 8.34-dB couplers is required to obtain the necessary tight coupling, resulting in a large multisection structure [1]. A branch-arm hybrid on the other hand is readily realized in compact microstrip form. However, its swept frequency coupling characteristics repeat at each odd harmonic of the fundamental center frequency with no coupling and high input-port reflections occurring at each even harmonic. Consequently, it must be modified in order to achieve coupling at all harmonics of a fundamental frequency. A compact hybrid structure which performs this function in microstrip is described in this letter.

THEORETICAL DEVELOPMENT

An all-harmonic coupling-band hybrid may be constructed using the branch-arm and main-arm structures shown in Fig. 1(a) and (b). The even- and odd-mode transmission matrix for the branch arm is given by

$$T_{\substack{e\\o}} = \begin{bmatrix} 1 & 0 \\ j\left\{\begin{matrix} +Y_{01}\tan\beta l_1 + Y_{02}\tan\beta l_2 \\ -Y_{01}\cot\beta l_1 + Y_{02}\tan\beta l_2 \end{matrix}\right\} & 1 \end{bmatrix}_{\substack{e\\o}}. \tag{1}$$

The matrix elements in (1) must equal the corresponding matrix elements of a conventional hybrid branch arm at all harmonics. Consequently, the even-mode C element of the matrix must equal the negative of the odd-mode C element at each harmonic. In addition, the C element of the matrix (either mode) must equal $+j$ or $-j$ at each harmonic. The values for the four transmission-line parameters of the branch arm are readily obtained from the preceding four conditions as

$$Y_{01} = 0.866, \qquad \beta l_1 = \pi/6$$
$$Y_{02} = 0.289, \qquad \beta l_2 = \pi/3.$$

The practical difficulty of obtaining microstrip transmission-line admittances below 7 mmho restricts the use of the preceding branch-arm circuit to system transmission-line impedances below 40 Ω.

The net transmission matrix for the main arm is given by

$$T = \begin{Bmatrix} \cos^2\beta l_3 - \dfrac{Y_{04}}{Y_{03}}\tan\beta l_4 \sin\beta l_3\cos\beta l_3 - \sin^2\beta l_3 & j\left\{\dfrac{2}{Y_{03}}\sin\beta l_3\cos\beta l_3 - \dfrac{Y_{04}}{Y_{03}^2}\tan\beta l_4\sin^2\beta l_3\right\} \\ j(2Y_{03}\sin\beta l_3\cos\beta l_3 + Y_{04}\tan\beta l_4\cos^2\beta l_3) & \cos^2\beta l_3 - \dfrac{Y_{04}}{Y_{03}}\tan\beta l_4\sin\beta l_3\cos\beta l_3 - \sin^2\beta l_3 \end{Bmatrix}. \tag{2}$$

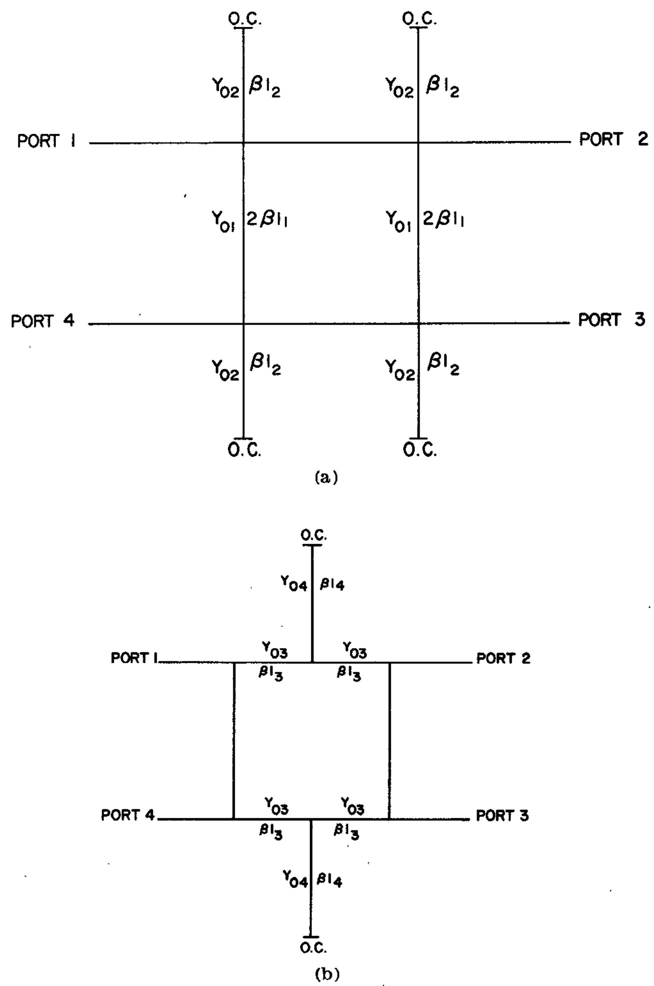

Fig. 1. (a) Main-arm structure. (b) Branch-arm structure.

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J. S. Wight and V. Makios are with the Applied Instrumentation Laboratory, Department of Electronics, Carleton University, Ottawa, Ont., Canada.
W. J. Chudobiak was with the Communications Research Center, Department of Communications, Ottawa, Ont., Canada. He is now with the Applied Instrumentation Laboratory, Department of Electronics, Carleton University, Ottawa, Ont., Canada.

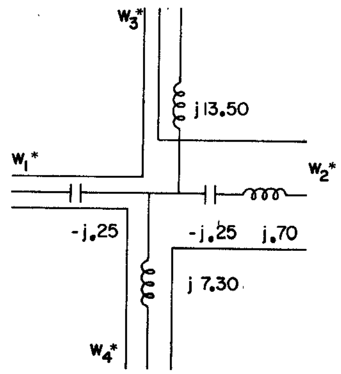

Fig. 2. Branch-arm junction with parasitic equivalent circuit (ϵ_r = 2.3, h = 10 mils, f = 8.2 GHz).

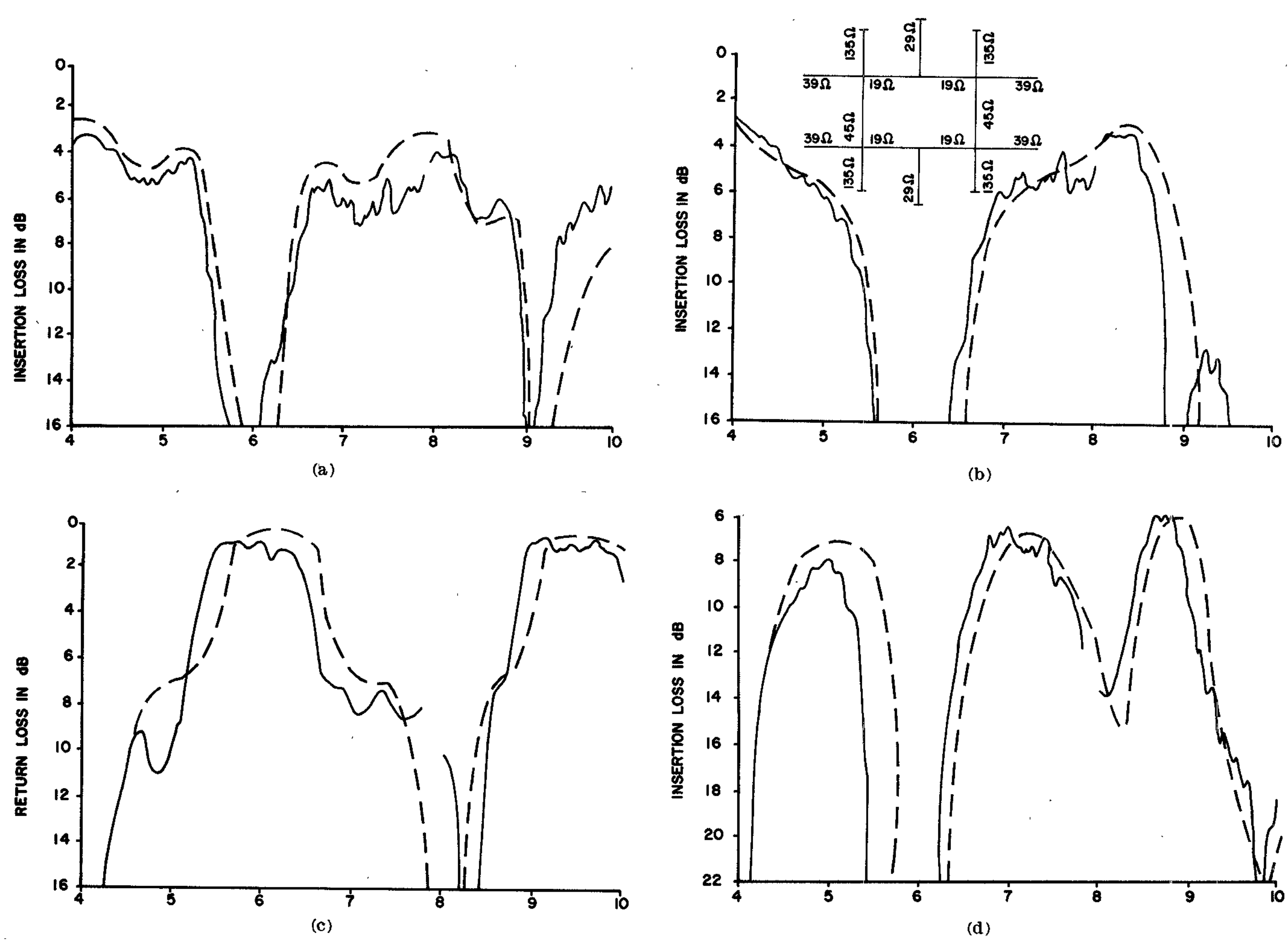

Fig. 3. Swept frequency characteristics. —: experimental; – –: theoretical. In all cases, frequency is in gigahertz. (a) Ports 1–2 insertion loss. (b) Ports 1–3 insertion loss. (c) Port 1 (input-port) return loss. (d) Ports 1–4 insertion loss.

The matrix elements in (2) must equal the corresponding matrix elements of a conventional hybrid main arm at all harmonics. Consequently, the A (or D) element of the matrix must equal zero at each harmonic. In addition, the C element of the matrix must equal $+j\sqrt{2}$ or $-j\sqrt{2}$ at each harmonic. From the principle of reciprocity, the B and C elements of the matrix are inversely related and as a result, additional conditions on the B element are not required. The values for the four transmission-line parameters of the main arm are readily obtained from the preceding four conditions as

$$Y_{03} = 2.45, \qquad \beta l_3 = \pi/3$$

$$Y_{04} = 1.63, \qquad \beta l_4 = 2\pi/3.$$

EXPERIMENTAL DESIGN AND RESULTS

A microstrip all-harmonic coupling-band hybrid with a fundamental frequency of 4.1 GHz was constructed on a thin plastic substrate (h = 10 mil, ϵ_r = 2.3, 1.0-mil copper metallization).

The hybrid was designed with a 39-Ω system and employed near-optimum transmission-line tapers [2] to 50-Ω lines.

Parasitic junction reactances have a significant effect on the characteristics of the hybrid. Since an analytical description of the complex junctions found would be very difficult to obtain, a superposition of equivalent circuits which have been analytically described elsewhere was employed. Leighton and Milnes [3] have shown that an asymmetrical T junction may be approximated by a symmetrical T junction for microstrip parasitic calculations provided W_1^* is approximately equal to W_2^*. The current authors have assumed that junctions of the form shown in Fig. 2 may be considered as a superposition of two T junctions, again provided W_1^* is approximately equal to W_2^*. In the hybrid structure constructed in microstrip, W_2^* is found to be much greater than W_1^* and a magnetic-field discontinuity similar to that formed in a step junction [4] must also be considered. A superposition of these three equivalent circuits (see Fig. 2) has been assumed to approximate the total parasitics of the junction.

The swept frequency characteristics of the hybrid are shown in Fig. 3. Equal power levels were obtained at the two output ports [Fig. 3(a) and (b)] at both 4.1 and 8.2 GHz. The input-port return loss was greater than 22 dB [off the trace shown in Fig. 3(c)], while the isolated-port insertion loss was greater than 14 dB [Fig. 3(d)] at both frequencies. The dielectric and resistive losses were approximately 1 dB. These characteristics are adequate for balanced mixer applications, however, it may be possible to still further improve the performance by employing alternative geometries.

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The Characteristic Impedance of Rectangular Coaxial Line with Ratio 2:1 of Outer-to-Inner Conductor Side Length

RYUITI TERAKADO

Recently, Riblet [1], [2] has given the exact dimensions of a family of rectangular coaxial lines with given impedance by conformal mapping. Before then the same problem was treated in [3], [4]. However, the previous literature does not include the case when the side of the outer and inner rectangle are in the ratio 2:1 both in width and in height: if in [1, eq. (11)] we put $\overline{OA} = \overline{DE}$ or $\overline{EO} = \overline{AB}$, modulus k coincides with modulus λ and the rectangular line becomes a square coaxial section, which is a special case of Bowman [5].

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The author is with the Department of Electrical Engineering, Ibaraki University, Hitachi, Ibaraki, Japan.

It is the purpose of this letter to show a method for obtaining the characteristic impedance of rectangular coaxial lines with the ratio 2:1, both in width and in height, by the principle of conformal mapping.

We consider rectangular and circular regions [Fig. 1(a) and (b)]. We regard the center of each region as a source of lines of electric force, and regard the whole of the circumference of each region as a sink. In the circular region any radius coincides then with a line of electric force. In the rectangular region, however, it is not simple to draw exactly all of the lines of electric force. The four segments OE, OF, OG, and OH of Fig. 1(a) coincide with lines of electric force, and it is clear that these lines of electric force correspond to the same lines of the circular region. Strictly, the transformation

$$z = \frac{1 \pm \mathrm{cn}(Z,k)}{\mathrm{sn}(Z,k)}$$

maps the rectangle in the Z plane into the circle in the z plane, where

$$\frac{OH}{OG} = \frac{K'(k)}{K(k)} \tag{1}$$

$$\cos\alpha = k. \tag{2}$$

If we cut off a partial region $OFCG$ from both of the rectangular and circular regions along the lines of electric force OF and OG, then L-shaped region $ABFOGD$ corresponds to three quarters of the circle shown by the same letters. We transform the three-quarters circle in the z plane into a half-circle in the W plane [Fig. 1(c)] by the transformation

$$W = z^{2/3}$$

and we transform the W plane into a lower half w plane [Fig. 1(d)] by the transformation

$$w = \frac{1}{2}\left(W + \frac{1}{W}\right).$$

Then the half-plane capacity C is

$$C = \frac{K'(k_0)}{K(k_0)}$$

where

$$k_0 = \frac{\{1 - \cos(\pi/3 - 2\alpha/3)\}\{1 - \cos(2\alpha/3)\}}{\{1 + \cos(\pi/3 - 2\alpha/3)\}\{1 + \cos(2\alpha/3)\}}. \tag{3}$$

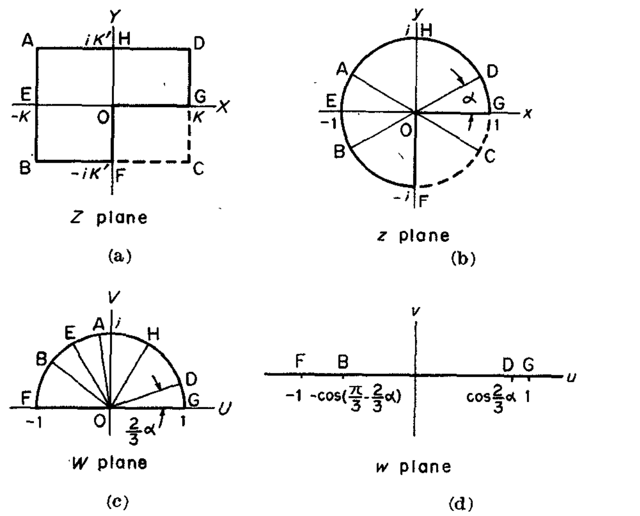

Fig. 1. Mapping of L-shaped region on lower half-plane.