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Broadband high power stripline compact multisection coupled-line coupler for VHF and UHF applications

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Abstract: In this study, a broadband stripline multisection coupled-line coupler is designed and fabricated. The coupler has 50 dB coupling in the frequency range of 30 to 1000 MHz. The coupler is designed by cascading several unit section couplers consisting of two unequal length coupled line sections connected by different length uncoupled transmission lines. The unequal length coupled line sections with different coupling coefficients introduce a degree of freedom for bandwidth improvement and can help to reduce the overall dimensions of the multisection coupler. A lumped-element compensating circuit is used in series with the coupling port of the coupler to flatten the overall coupling response of the coupler over multioctave frequency bands. The fabricated coupler is compact in size and handles up to 200 W of RF power. The flatness of the coupler depends on the frequency response of the multisection coupler and the compensating circuit. The designed coupler has maximum 1 dB ripple in the coupling response over multioctave bandwidth.

Key words: Coupler, stripline, multisection

1. Introduction

Coupled-line directional couplers are well-known microwave passive components that are extensively used in radio receivers and transmitters, frequency synthesizers, network analyzers, and many other microwave applications [1–3]. Over the recent years, extensive studies have been focused on the development of novel solutions, allowing mainly for performance improvement, broadband operation, and miniaturization of coupled-lines couplers [4,5]. Typical coupled-line directional couplers consist of single or multiple quarter-wavelength coupled-line sections. In broadband applications, multisection coupled line couplers are used [5,6]. Some new design methods use a combination of several coupled line sections that are connected with uncoupled transmission lines. These couplers were designed and analyzed by small reflection theory [7]. The use of some transmission line sections between the coupled line sections as delay lines for equalizing the even and odd phase velocities was introduced in [7], which results in considerable directivity improvement. The idea of combining two coupled line sections and connecting the uncoupled line was used by other authors for reducing the size of the directional coupler [8,9]. It was shown that inserting a transmission line between two coupled line sections introduces flexibility in the layout and dimension of the coupler while the coupling remains unaffected. Further study of the combination of two coupled line sections and the connecting transmission line showed considerable bandwidth improvement compared to a coupler with two cascaded coupled line sections [10]. For a large coupling coefficient coupler as in 3 dB couplers, the combination of coupled line sections and the connecting transmission

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line has an equal ripple coupling response and has wider bandwidth compared to conventional multisection classical directional couplers.

In this paper, the two structures introduced in [8] and [9] are combined to form a new flexible two section coupler with uncoupled transmission lines between them. If the magnitude of the coupling coefficient is of concern and the phase response is superfluous, the circuit parameters of some of these structures are related. Our proposed structure uses this property and introduces more flexibility in the circuit design for a given coupling response. By cascading some unit sections couplers consisting of a two coupled line section and the connecting transmission line, a broadband coupler can be designed. The design and analysis is based on the theory of ABCD matrices. For multioctave applications a compensating lumped-element circuit is series connected to the coupled port. The inclusion of a lumped-element circuit for shaping the coupling response reduces the size of the coupler considerably. The design uses a low coupling factor to allow the insertion of conventional low power lumped elements in the coupling port for high power applications. As stated earlier, the design method is so flexible that each unit section coupler can be shaped arbitrarily. The designer can make use of this property to shape the coupler based on dimensional limitations and the power requirements of the coupler.

2. Theory and design

2.1. Unit section coupler

Figure 1 shows the generic schematic of a unit section coupler with two coupled line sections of equal length and electrical properties. The transmission lines that connect the coupled line sections are uncoupled to the rest of the circuit and in one of the structures their lengths are different. These structures are symmetric regarding the coupled line sections and were introduced in [8] and [9]. The analytical solution for the coupling factor (C) of the first structures is as follows [8]:

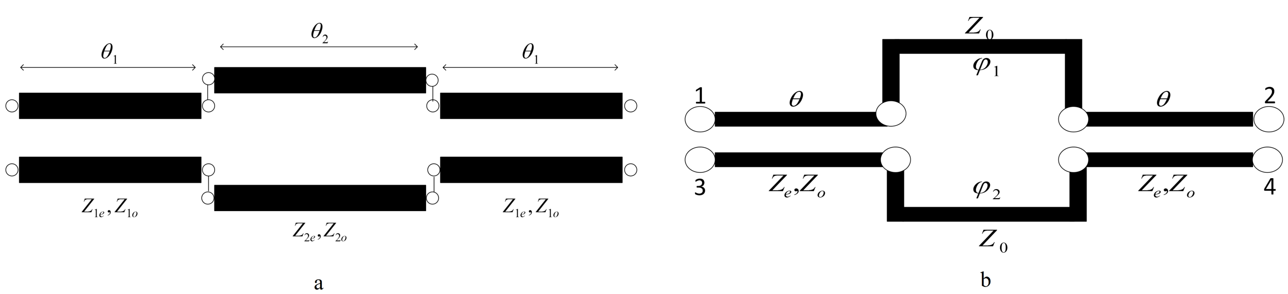


Figure 1. Schematic of the unit section coupler: a) proposed in [8], b) proposed in [9].

$$
\begin{aligned}
C &= \frac{N(\theta_1,\theta_2)}{D(\theta_1,\theta_2)} \\
N(\theta_1,\theta_2) &= j[2\left(z_{1e}-\frac{1}{z_{1e}}\right)\tan\theta_1+\left(z_{2e}-\frac{1}{z_{2e}}\right)\tan\theta_2+\left(\frac{z_{2e}}{z_{1e}^2}-\frac{z_{1e}^2}{z_{2e}}\right)\tan^2\theta_1\tan\theta_2 \\
D(\theta_1,\theta_2) &= 2-2\left(\frac{z_{1e}}{z_{2e}}+\frac{z_{2e}}{z_{1e}}\right)\tan\theta_1\tan\theta_2-2\tan^2\theta_1+j[2\left(z_{1e}+\frac{1}{z_{1e}}\right)\tan\theta_1 \\
&\quad+\left(z_{2e}+\frac{1}{z_{2e}}\right)\tan\theta_2-\left(\frac{z_{2e}}{z_{1e}^2}+\frac{z_{1e}^2}{z_{2e}}\right)\tan^2\theta_1\tan\theta_2]
\end{aligned}
\tag{1}
$$

θ_1 and θ_2 are the electrical length of the coupled line sections and the transmission line between them, respectively. N and D are functions in terms of θ_1 and θ_2 and are the numerator and denominator of the coupling factor, respectively. Although the transmission lines between the coupled line sections are uncoupled, they are represented by even and odd mode characteristic impedances in [8]. z_e and z_o are normalized even and odd mode impedances with respect to the characteristic impedance of the coupled line section or the connecting transmission line. Similarly for the second structure, shown in Figure 1, an analytical solution exists for the coupling coefficient and is as follows [9]:

$$\begin{aligned} C &= \frac{N(z_e,\theta,\varphi_1+\varphi_2)}{D(z_e,\theta,\varphi_1+\varphi_2)} \\ N\left(z_e,\theta,\varphi_1+\varphi_2\right) &= 2\left(z_e - z_e^{-1}\right)\tan\theta - \left(z_e^2 - z_e^{-2}\right)\tan^2\theta\tan\left(\frac{\varphi_1+\varphi_2}{2}\right) \\ D\left(z_e,\theta,\varphi_1+\varphi_2\right) &= 2\left(z_e + z_e^{-1}\right)\tan\theta + 2\tan\left(\frac{\varphi_1+\varphi_2}{2}\right) - \left(z_e^2 + z_e^{-2}\right)\tan^2\theta\tan\left(\frac{\varphi_1+\varphi_2}{2}\right) \\ &\quad + j2\left[\left(z_e + z_e^{-1}\right)\tan\theta\tan\left(\frac{\varphi_1+\varphi_2}{2}\right) + \tan^2\theta - 1\right] \end{aligned} \tag{2}$$

where θ is the electrical length of coupled line sections, φ_1 and φ_2 are the electrical lengths of transmission lines between coupled line sections, and z_e is the normalized characteristic impedance of coupled line sections.

Some of the unknown parameters in Eqs. (1) and (2) can be obtained if the magnitude of coupling C is given at a prescribed frequency.

$$|C||_{\omega=\omega_0} = C \tag{3}$$

An additional design equation is obtained by the requirement that the coupling should be maximized at the desired operating frequency:

$$\left.\frac{d\,|C|}{d\omega}\right|_{\omega=\omega_0} = 0 \tag{4}$$

Figure 2 shows for three coupling levels of 10 dB, 15 dB, and 20 dB the calculated electrical length of the coupled line sections and the connecting transmission line versus the even mode impedance. If the magnitude of the coupling coefficient is similar in the two structures, the sum of the lengths of the uncoupled transmission lines in the second structure is twice the length of the uncoupled transmission lines of the first structure. This property is valid if only equal coupling magnitude is considered and the phase response of the coupling is neglected. This property can be used to relate the electrical properties of the two structures and convert them if necessary. In the design of a broadband multisection coupler, this property will be used to simplify the overall structure. The electrical length of the uncoupled transmission line in the two structures using the notations used in [8] and [9] has the following relation:

$$\theta_2 = \frac{\varphi_1+\varphi_2}{2} \tag{5}$$

2.2. Single section couplers

Figure 3 shows the generic schematic of our proposed unit section coupler, consisting of two coupled-line sections with the same coupling coefficient. These coupled line sections are connected with two transmission lines, which are uncoupled to the rest of the circuit, and their lengths are arbitrary. This unit section coupler is described

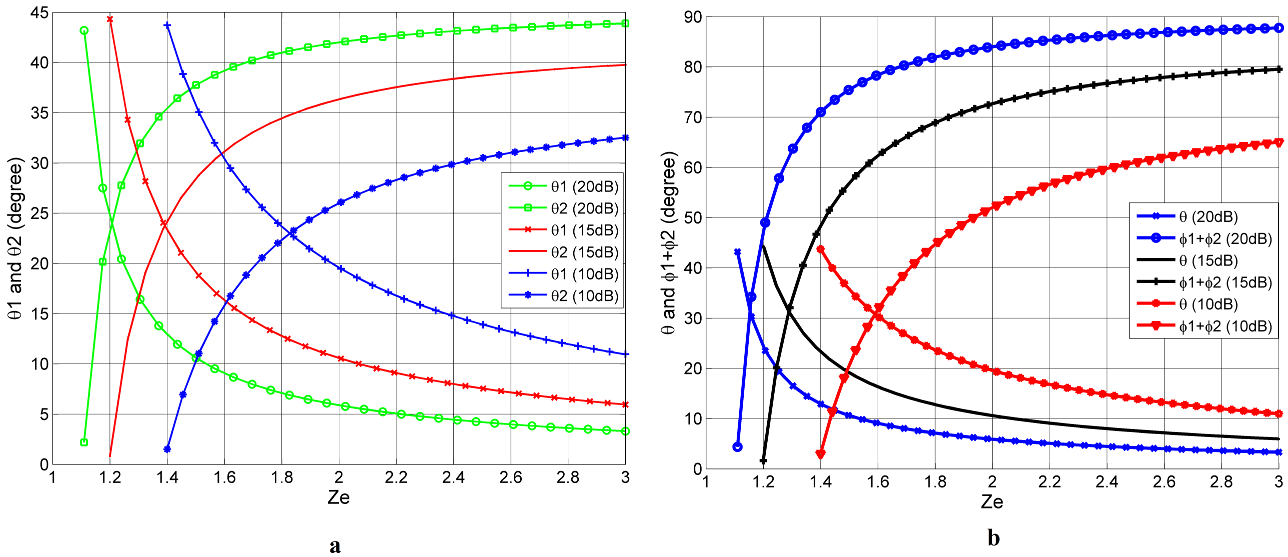


Figure 2. Comparison of lengths of uncoupled transmission-line sections of papers [8] and [9]: a) results of [8], b) results of [9].

by the characteristic impedance of coupled lines and the interconnecting transmission line (Z_0), the coupling coefficient of each coupled line section (k), the electrical lengths of each coupled line section ($\theta_1\theta_2$), and the electrical length of the transmission lines connecting the two coupled line sections (θ_{TL}). In this structure, the length of coupled sections can be different, which increases the degrees of freedom in the design equations. Using coupled line sections with different length in the unit section can help to compact the overall size of the coupler, especially if the coupler is of multisection type.

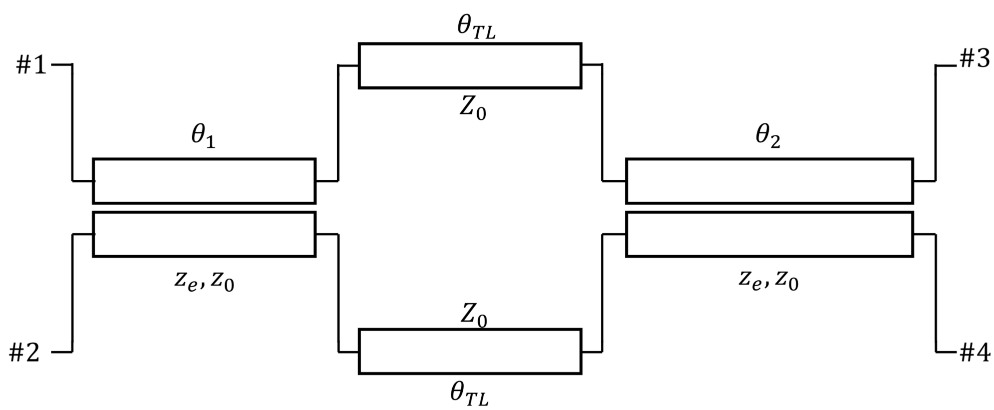


Figure 3. Generic schematic of symmetrical form of proposed single section coupler.

In this paper we assume a given frequency response for the coupling coefficient of the multisection coupler and that the multisection coupler consists of several unit section couplers, as introduced earlier. Furthermore, we try to find by numerical methods the optimum length of the coupled line sections and the transmission lines connecting them. There exists an analytical solution for the coupling coefficient (C) and electrical parameters of the unit section coupler for equal length coupled line sections in [8] and [9]. In this work the coupled line sections and the interconnecting transmission lines are of different length, so a numeric synthesis method has to be performed to find the electrical lengths and coupling coefficient of the different coupled line sections and the transmission lines connecting them. A unit section coupler with equal length uncoupled transmission lines can be easily analyzed by the ABCD matrix method. In a design where only the magnitude of the coupling coefficient is of concern, the unsymmetrical unit section coupler can be converted by Eq. (5) to a symmetrical unit section coupler and vice versa.

The coupling of each coupled line section in a symmetrical unit section coupler is derived by the ABCD matrix method and is as follows:

$$k = \frac{z_e^2 - 1}{z_e^2 + 1} \tag{6}$$

where $z_e = Z_e/Z_0$ and $z_o = Z_o/Z_0$ are normalized even and odd mode characteristic impedances of the coupled line sections. They are related by $z_e z_o = 1$.

The proposed unit section coupler is shown in Figure 3. The even mode ABCD matrix can be calculated analytically by the following equation [2]:

$$\begin{bmatrix} A_e & B_e \\ C_e & D_e \end{bmatrix} = \begin{bmatrix} \cos\theta_1 & jz_e \sin\theta_1 \\ \frac{j}{z_e}\sin\theta_1 & \cos\theta_1 \end{bmatrix} \begin{bmatrix} \cos\theta_{TL} & j\sin\theta_{TL} \\ j\sin\theta_{TL} & \cos\theta_{TL} \end{bmatrix} \begin{bmatrix} \cos\theta_2 & jz_e \sin\theta_2 \\ \frac{j}{z_e}\sin\theta_2 & \cos\theta_2 \end{bmatrix} \tag{7}$$

According to even/odd mode analysis of a coupler, the coupling coefficient is numerically equal to the even mode reflection coefficient [1]. The reflection coefficient (Γ_e) is obtained by the components in the transmission matrix given in Eq. (7) as follows:

$$\Gamma_e(z_e\theta_1\theta_2\theta_{TL}) = \frac{A_e + B_e - C_e - D_e}{A_e + B_e + C_e + D_e} \tag{8}$$

In the design of a coupler with a desired coupling coefficient, there are four unknowns: $\theta_1\theta_2\theta_{TL}$, and z_e. As previously stated there are only two equations for these four unknowns. This results in four degrees of freedom in the design equations. One can set the section impedance to a desired value within the range of practical and realizable values and calculate the electrical lengths θ_1 and θ_2 of the coupled line sections in terms of θ_{TL}, the electrical length of the uncoupled transmission line. The electrical length of a single section coupled line and a transmission line is a linear function of frequency:

$$\theta = \frac{2\pi l}{\lambda} = \frac{2\pi l\sqrt{\varepsilon}_{eff}}{c} f \tag{9}$$

where l, λ, ε_{eff}, c and f respectively represent the line length, wavelength, effective permittivity, velocity of light, and center frequency. Therefore, the bandwidth BW in a broad band coupler, described by the ratio of maximum to minimum frequency, equals the ratio of the electrical lengths associated with these frequencies:

$$BW = \frac{f_{max}}{f_{min}} = \frac{\theta_{max}}{\theta_{min}} \tag{10}$$

It is obvious from Eq. (10) that the bandwidth can be controlled with the electrical lengths of the coupled and uncoupled line sections. It is also evident from Eq. (10) that using unequal length sections in the unit section coupler can increase the bandwidth of the coupler. Figure 4 shows the relation between the length of each coupled line section and the length of the transmission line between them for two values of even mode impedances, $z_e = 1.1$ and $z_e = 1.2$, and 20 dB coupling. The design assumed a center frequency of 0.5 GHz. As depicted in Figures 4a–4c, the coupler is relatively wideband and its bandwidth can be increased by adding more unit coupler sections. The unit sections added can have equal characteristic impedance, and the bandwidth can be controlled by the unsymmetrical nature of the coupled line sections and the connecting transmission line. This results in equal width lines in the coupler layout, which is of paramount importance for high power applications. Allowing a higher ratio for the maximum to minimum line length in the unit section coupler, the bandwidth can be improved. This is depicted in Figure 4c for two values of $\frac{\theta_{\max}}{\theta_{\min}} = 3.3$ and $\frac{\theta_{\max}}{\theta_{\min}} = 3.65$.

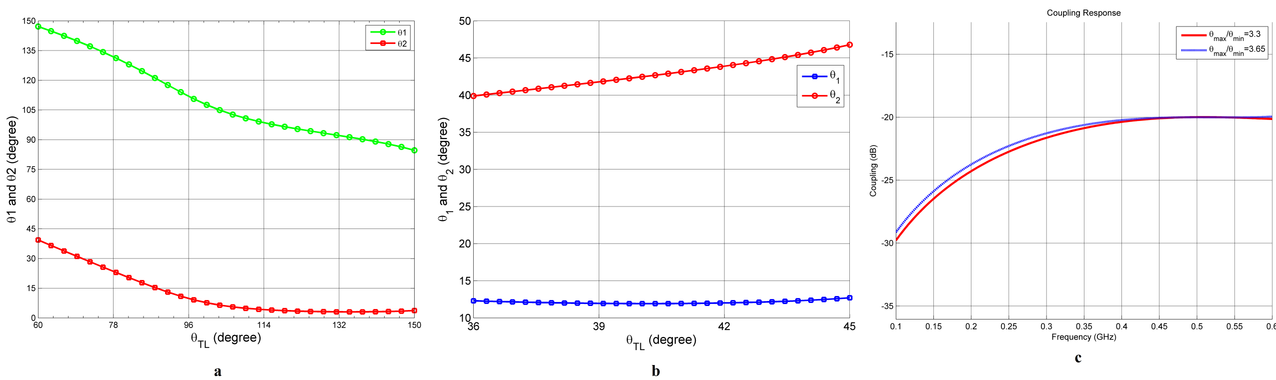


Figure 4. Design case: a) electrical lengths of coupled line sections in terms of electrical length of uncoupled transmission line section for $z_e = 1.1$; b) electrical lengths of coupled line sections in terms of electrical length of uncoupled transmission line section for $z_e = 1.2$; c) coupling response for 20 dB single section coupler with $z_e = 1.2$ designed at 0.5 GHz for two different ratios of maximum to minimum electrical lengths.

2.3. Multisection couplers

Cascading several unit section couplers, as shown in Figure 3, results in a multisection coupler. The number of sections depends on the required bandwidth. For the weak coupling couplers as in 20 dB couplers, Eqs. (3) and (4) must be satisfied at the center frequency for the entire coupler. It was shown in [6] that for a 20 dB coupling with the requirement of 0.5 dB ripple in the coupling frequency response a three section asymmetric quarter-wavelength coupler can reach a 6:1 bandwidth. The unit section couplers proposed in this study are similar to conventional quarter wavelength couplers regarding the frequency response. Cascaded three unit section couplers can feature the properties of three section conventional quarter wave couplers, with reduced overall size. Figure 5 shows a schematic of a general three section coupler that is based on the proposed unit section coupler in Figure 3. In this design the even mode impedances of all coupled line sections are equal. The odd mode impedance can be calculated by the well-known formula of $Z_e Z_o = Z_0^2$. Making the even mode impedance in each section be equal results in equal width lines. The power handling of the coupler depends on the width of the main transmission line, which does not change across the coupler. As shown in Figure 5, the electrical lengths of each coupled and uncoupled section can be different, so the designer has a high degree of freedom. For a specified coupling response in the design process, a numerical method combined with an optimization algorithm is required to find the unknown parameters of the coupler

The coupler of Figure 5 can be analyzed using the ABCD matrix method, described in the previous section for a unit section coupler. Referring to Figure 5, the ABCD matrices of each unit section are multiplied to obtain the reflection coefficient of the cascaded coupler. There are nine ABCD matrices, which must be

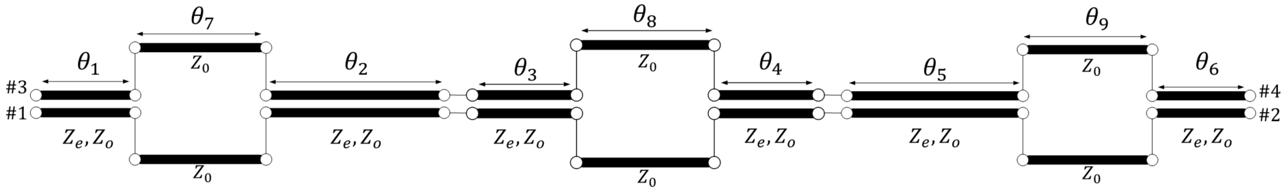


Figure 5. Schematic of general proposed three section couplers.

multiplied. It is difficult and time-consuming to obtain the reflection coefficient analytically, so an numerical optimization program based on a genetic algorithm is used to find the electrical parameters of each unit section coupler.

The bandwidths in the proposed multisection couplers can be increased at the cost of size increase. The coupler in Figure 5 is designed without constraints for the electrical lengths of each unit section coupler and for 20 dB coupling. The electrical lengths of each section are shown in Table 1. To validate our design method, the coupler is realized by an offset broadside coupled stripline structure and simulated by the method of moments in an electromagnetic simulator. The cross-section and dielectric properties of the substrate are shown in Figure 6.

Table 1. Electrical lengths and impedances of the proposed couplers obtained by means of the optimization program based on Figure 5 parameters.

Coupler of Figure 7a		Coupler of Figure 8a			Coupler of Figure 9a		
$\boldsymbol{\theta_1}$	3.86°	θ_1		3.86°	θ_1		2.25°
$\boldsymbol{\theta_2}$	6.88°	θ_2		6.88°	θ_2		1.28°
$\boldsymbol{\theta_3}$	6.88°	θ_3		6.88°	θ_3		1.28°
$\boldsymbol{\theta_4}$	6.88°	θ_4		6.88°	θ_4		4.83°
$\boldsymbol{\theta_5}$	6.88°	θ_5		6.88°	θ_5		4.83°
$\boldsymbol{\theta_6}$	3.86°	θ_6		3.86°	θ_6		4.14°
$\boldsymbol{\theta_7}$	32.68°	θ_7	φ_1	58.45°	θ_7	φ_1	21.83°
			φ_2	6.91°		φ_2	3.47°
$\boldsymbol{\theta_8}$	24.24°	θ_8	φ_3	41.57°	θ_8	φ_3	7.8°
			φ_4	6.91°		φ_4	3.86°
$\boldsymbol{\theta_9}$	58.44°	θ_9	φ_5	109.9°	θ_9	φ_5	7.3°
			φ_6	6.91°		φ_6	3°
$\boldsymbol{z_e}$	1.27	z_e		1.27	z_e		1.27

The layout of the coupler is shown in Figure 7a. It is worth noting the black and gray lines are in different layers. Figure 7b shows the coupling response obtained by numerical optimization and verified by electromagnetic simulation. The design was performed for 20 dB coupling with three unit section couplers at the center frequency of 0.5 GHz.

The coupler of Figure 7a is symmetric in nature. As depicted in Figure 7a, the signal flows in a long line with multiple bends (the line between ports #1 and #2). The length of the line and multiple bending results in signal loss in the trough path, which is undesired in high power applications. For this reason, reconfiguration

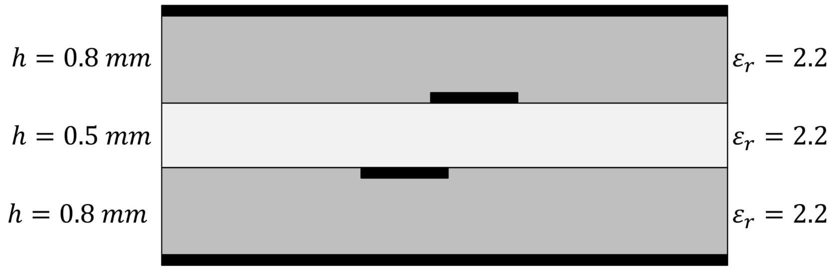
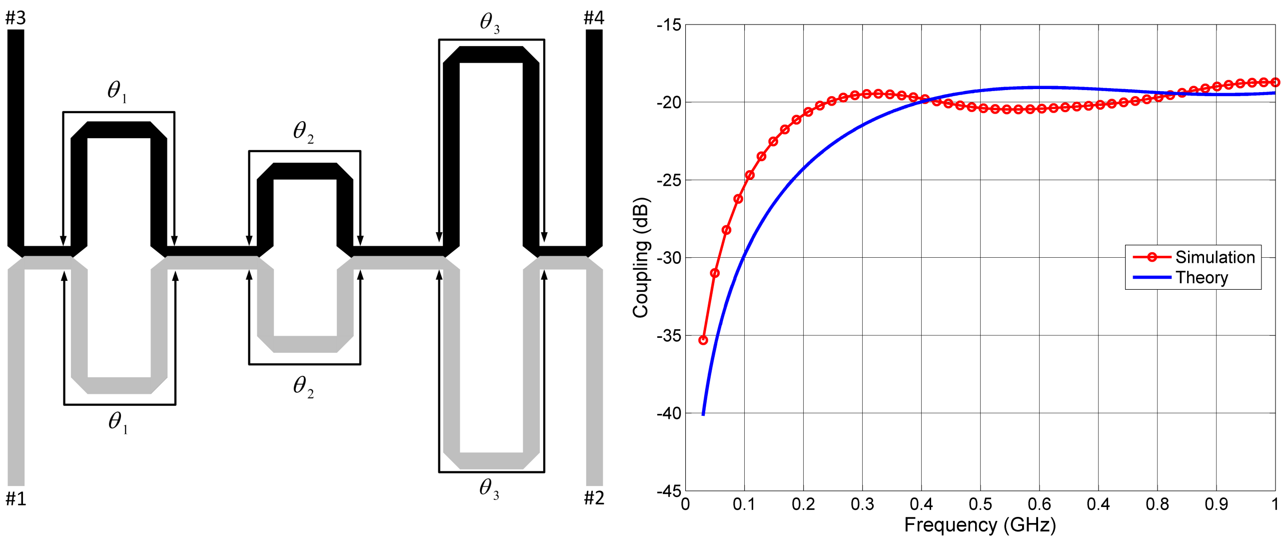


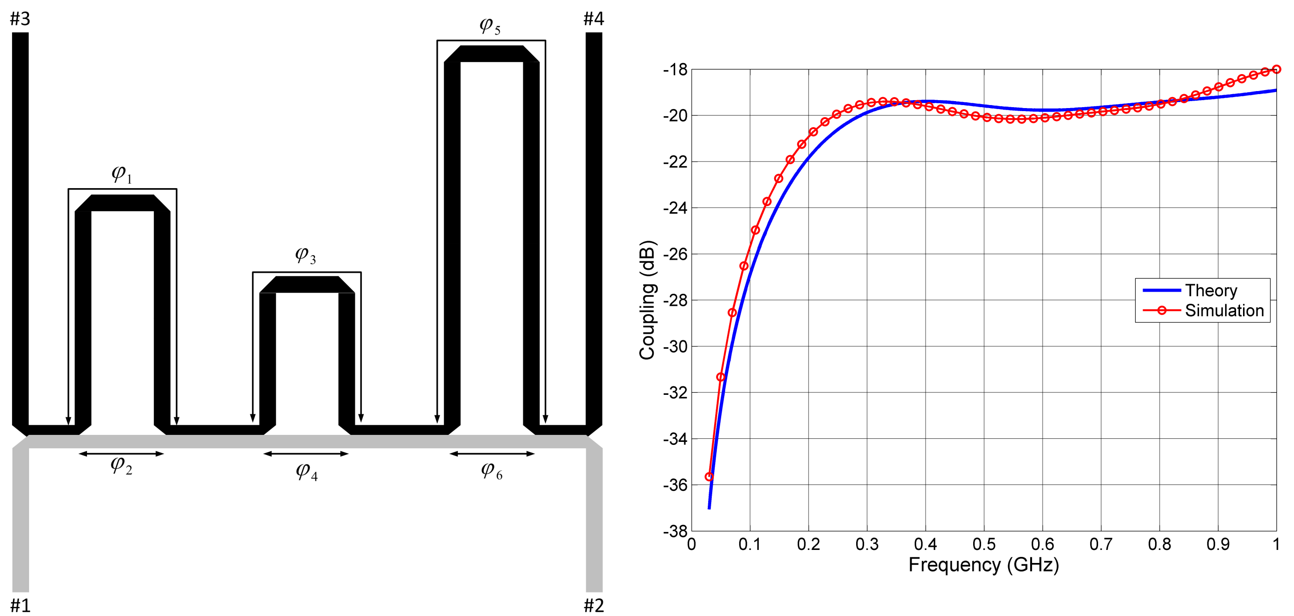
Figure 6. Cross-sectional view of geometric structure used for the design of the 20 dB multisection couplers.



a b

Figure 7. Three section coupler designed with unconstrained electrical lengths: a) layout of 20 dB three section coupler (gray: top layer, black: bottom layer); b) coupling response of 20 dB three section coupler over the frequency band of 30 MHz to 1000 MHz.

of the structure seems to be necessary. Regarding Subsection 2.1, we can use Eq. (5) to reconfigure the layout of the coupler without changing the magnitude of the coupling response. In a new design, the primary line is realized by a straight line. To compensate for the reduction of the transmission lines between the coupled sections on one side, the length of the uncoupled transmission lines on the other side is doubled (the line between the ports #3 and #4). The required uncoupled transmission line lengths in each section are obtained by Eq. (5) ($\theta_1 = \frac{\varphi_1+\varphi_2}{2}, \theta_2 = \frac{\varphi_3+\varphi_4}{2}, \theta_3 = \frac{\varphi_5+\varphi_6}{2}$). The resultant electrical lengths are shown in Table 1. Figure 8a illustrates the layout of the coupler with a straight line for the signal path and bended uncoupled lines in the coupled path. It is expected that the coupling response does not significantly change compared to the previous design. As depicted in Figure 8b, the coupling response of the ideal transmission line coupler and the stripline coupler simulated by methods of moment are in good agreement with the coupling responses shown in Figure 7b. A drawback of the couplers shown in Figures 7a and 8a is the growth of the dimension of the coupler for the required bandwidth. The dimension of the multisection coupler with uncoupled lines is comparable to the size of the conventional quarter-wavelength couplers. It seems that these structures have no benefits over conventional quarter-wavelength couplers.



a b

Figure 8. Three section coupler designed with unlimited electrical lengths with simplified primary line: a) layout of 20 dB three section coupler (gray: top layer, black: bottom layer); b) coupling response of 20 dB three section coupler over the frequency band of 30 MHz to 1000 MHz.

Another problem with these types of couplers that is evident in Figures 7b and 8b is the rapid falloff of the coupling response at lower frequencies (e.g., lower than 200 MHz). It is obvious that in order to shape the response at these frequencies to be flat, the size of the coupler will grow even larger than the sizes shown in Figures 7a and 8a. The coupling response has to be compensated at these frequencies by another method. The new method that is described in the following section makes it possible to design compact couplers with flat coupling response in the required bandwidth.

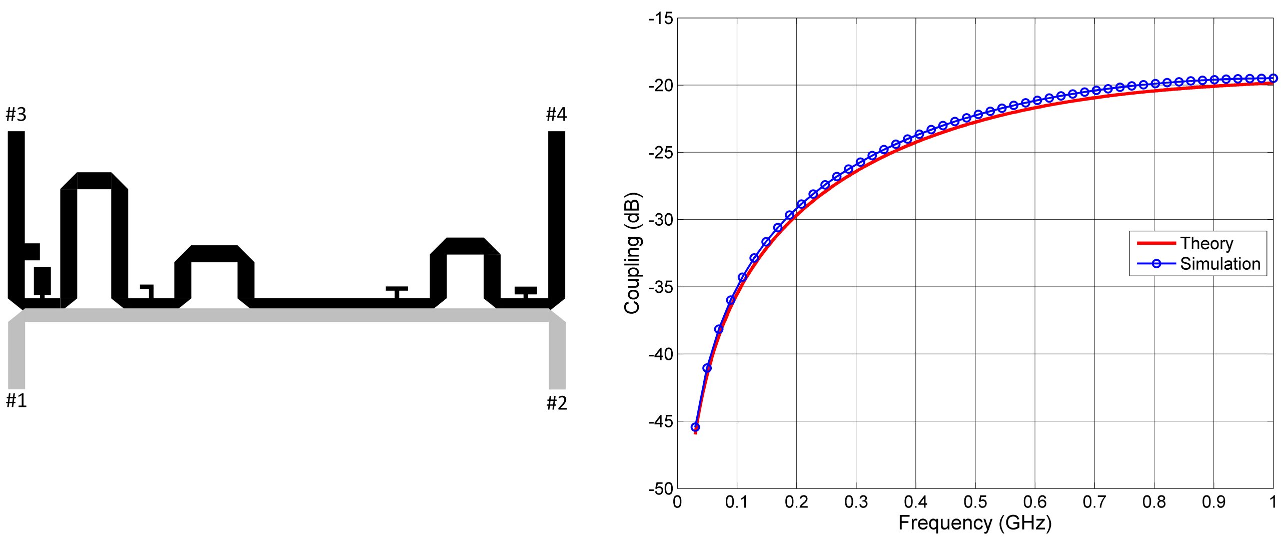
3. Compensation and compacting

3.1. Compensation method

The compensation method for the coupling response is applicable for couplers with weak coupling (20 dB) and reduces the overall coupling more than 30 dB. In such couplers, due to weak coupling, the coupled port power is below several watts even in high power applications. The compensation method uses a lumped-element low-pass circuit. With lumped-element circuits it is possible to design low-pass filters with a shaped out of band response. Therefore, adding a low-pass filter with a combination of appropriate roll off and flat out of band response at high frequencies can modify the coupling response of the coupler. The low-pass filter is connected in series to the coupled port of the coupler. It does not affect the insertion loss of the coupler but results in approximately 30 dB reduction in the overall coupling coefficient.

The coupling responses of the couplers designed in the previous section are high-pass in nature. The addition of the compensating lumped-element circuit makes it possible to compact the size of the coupler as long as the coupling response of the overall coupler does not fall at higher frequencies. The low-pass filter is tuned for lower frequencies and the out of band response of it does not affect the flatness of the coupler at higher frequencies. By this method we can decrease the electrical lengths of the coupler. The fall down of the coupling response at the end of the band constrains the size reduction. Applying some constraints to the electrical lengths in the optimization program, the optimized electrical lengths are obtained and listed in the third column of Table 1.

Figure 9a shows the layout of the coupler with compensating distributed capacitances to compensate the reactance of transitions between the uncoupled and coupled transmission lines (see [11]). The coupling response of the coupler is depicted in Figure 9b. Comparing the electrical lengths of the newly designed coupler with the previous two couplers, it can be seen that the overall length of the coupler is significantly decreased. When realized as a stripline with the aforementioned substrate, the overall length of the coupler is about 60 mm, about one-fifth of a conventional three section quarter-wavelength coupler. It will be shown that using the compensating lumped-element circuit results in a bandwidth improvement of 33:1 for 50 dB coupling. Compared to the 6:1 bandwidth of the conventional three section coupler, this improvement is considerable.



a

b

Figure 9. Compact three section coupler designed with limited electrical lengths with simplified primary line: a) layout of 20 dB compact three section coupler (gray: top layer, black: bottom layer); b) coupling response of 20 dB compact three section coupler over the frequency band of 30 MHz to 1000 MHz.

3.2. Compensated 50 dB high power coupler

To design a 50 dB coupler using the 20 dB multisection coupler of the previous section, a compensating lumped-element circuit is attached to the coupled port (port #3 in Figure 9a). The compensation circuit decreases the overall coupling at the final coupler to 50 dB but its low-pass response shapes the flatness of the coupler and results in a flat response of 50 dB over the frequency band of 30 to 1000 MHz. The proposed compensation lumped-element circuit is shown in Figure 10. Port #1 of this circuit is connected to the coupling port of the coupler of Figure 9a (port #3) and then the output coupling port will be port #2 of the lumped-element circuit. The inductor L_5 with resistor R_2 shapes the main low-pass response and the RLC filter consisting of L_4, C_4, R_3 will help to flatten the out of band response. The remaining elements affect the flatness of the overall coupling response. The element values are shown in Table 2.

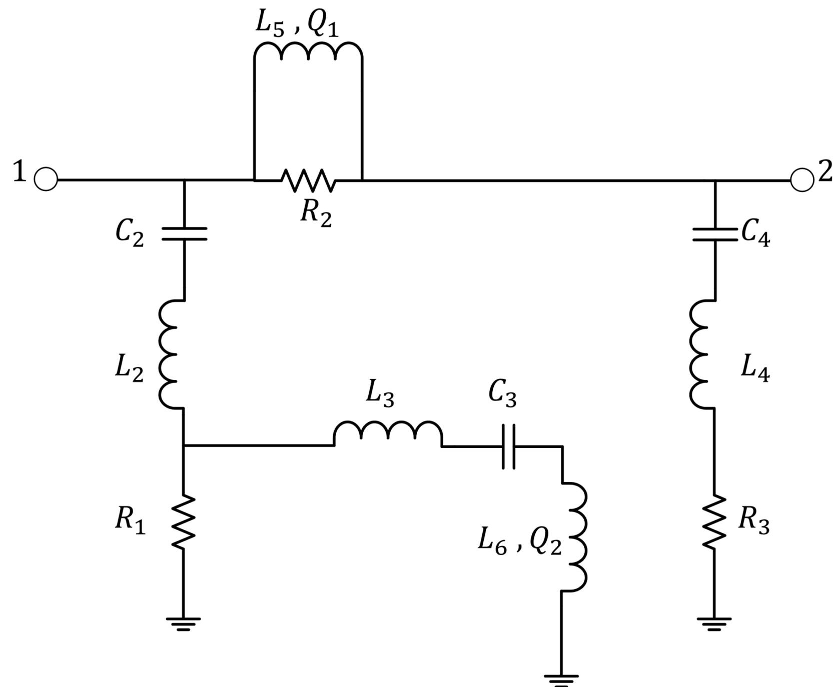


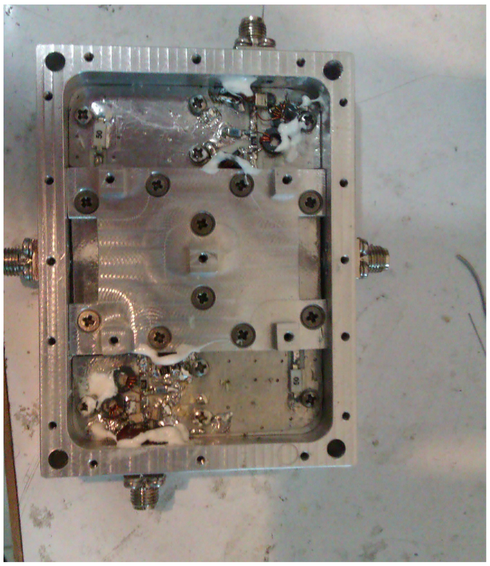
Figure 10. The proposed compensation lumped-element circuit.

Table 2. Values of proposed lumped-element circuit.

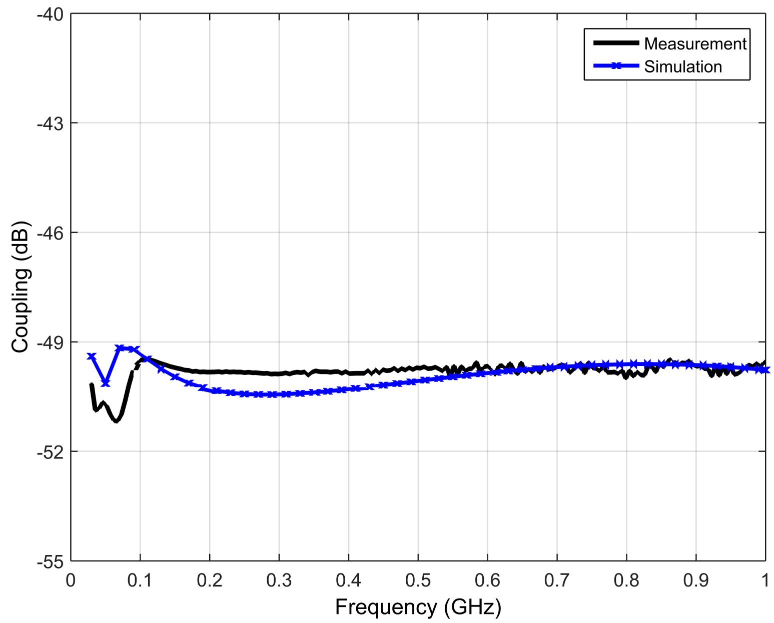
R_1		**100 Ω**	
C_2		33 pF	
L_2		0.6 nH	
L_3		0.6 nH	
C_3		100 pF	
R_2		750 Ω	
L_4		0.6 nH	
C_4		33 pF	
R_3		33 Ω	
L_5	Q_1	193 nH	15
L_6	Q_2	397 nH	13

4. Experimental results

The proposed coupler compensated by lumped-element circuit was realized in a stripline and simulated in the Agilent Advanced Design System (ADS). The substrate properties are shown in Figure 6. For construction of the coupler an RT 5880 microwave laminate from Rogers Corporation was used. The signal path is straight and the power handling of the stripline with a given width and medium can be calculated by a calculator provided by Rogers Corp. The 50 Ω signal line can handle 200 W up to 1000 MHz for a conductor thickness of 1 oz. The power handling of the coupler is tested by a 200 W broadband power amplifier. Under this condition, because of 20 dB coupling in the main stripline coupler, the power that enters the lumped-element circuit is approximately 1 W. Some lumped-element surface mound devices (SMDs) can handle this power without burning or degradation in performance. The compensating circuit is realized by SMD components. The fabricated coupler is shown in Figure 11a. The simulated and measured coupling responses of the coupler with compensating circuit are shown in Figure 11b. As Figure 11b shows, the results of simulation and measurement are in good agreement and the flatness of the coupling response is better than 1 dB over the frequency range of 30 MHz to 1000 MHz (33:1).



a



b

Figure 11. Final coupler: a) manufactured 50 dB coupler with its compensating lumped-element circuit operating at the frequency band of 30 MHz to 1000 MHz; b) results of simulations and measurements for the 50 dB coupler.

5. Conclusion

A new method for the design of 20 dB and weaker coupled-line couplers was introduced. It has been shown that multisection broadband coupled-line couplers can be realized with simplified structures. The even-odd mode impedances of coupled-line sections and the bandwidth of such couplers can be controlled by the electrical lengths of the coupled and uncoupled line sections. Moreover, a wideband 20 dB coupler was compacted such that the coupling response remains unaffected at the end of the desired operating band. Compacting increases the lower corner frequency of coupling response in the coupled line coupler, which is high-pass in nature. A new compensating low-pass filter shapes the overall coupling response of the coupler flat. The compensating circuit consists of lumped-element low power components. By this method a coupler with 50 dB coupling was designed and tested. The design theory with ideal transmission lines was confirmed by electromagnetic simulation and measurements. The coupler was realized in stripline technology with offset broadside coupled line sections and its response was measured in the frequency range of 30 to 1000 MHz. The measured flatness of the coupling response was better than 1 dB in the intended frequency range.

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