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Miniaturization of 3-dB/90° and 180° power splitters using microstrip technology

Mathieu Caillet, Michel Clénet and Yahia M. M. Antar

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Abstract

This document reports on the analysis and design of miniaturized 3-dB / 90° and 180° power splitters. Several miniaturization techniques are presented, and were applied to the design of microstrip splitters.

Concerning the 3-dB / 180° splitters, two miniaturized microstrip circuits have been designed using two different methods. The first one is a Moore 2nd iteration fractal ring hybrid, of size 23 *x* 28 mm^2 (23 % of the conventional ring hybrid area) with similar performance over the 1.15-1.6 GHz frequency band. Over this band, characterization has shown a maximum 3-dB coupling imbalance of 1 *dB* and an output phase difference varying by 22° (± 11°). The second proposed circuit is an H-shaped aperture-coupled transition, of compact size and wide frequency bandwidth. Its size is 23 *x* 30 mm^2, including the slot and matching network. Measurements revealed a maximum 3-dB imbalance of 0.3 *dB* and an output phase difference fluctuation of 1° (± 0.5°) over the 1.15-1.6 GHz band.

Regarding the 90° splitters, two miniaturization methods have been investigated to reduce the size of a branch-line hybrid. The first technique is based on fractal geometries as for the 180° splitter. A Sierpinski 2-nd iteration fractal branch-line hybrid has been simulated and showed a coupling imbalance of 0.4 *dB* and a phase difference variation of 1° (± 0.5°) over a 10 % bandwidth. Its size is about 50 % of the area of the branch-line hybrid. The second miniaturization technique that has been investigated is founded on lumped distributed elements to reduce the size of a microstrip line. The possible size reduction is 50 % as well.

Résumé

Le présent document porte sur l'analyse et la conception de diviseurs de puissance 3-dB / 90° et 180° miniatures. Plusieurs techniques de miniaturisation sont décrites, et elles ont été appliquées à la conception de diviseurs de puissance microruban.

Concernant les diviseurs de puissance 3 dB / 180°, deux circuits microrubans miniatures ont été conçus en utilisant deux méthodes différentes. Le premier circuit est un diviseur hybride en anneau à géométrie fractale de la 2ème itération de Moore, mesurant 23 *x* 28 mm^2 (23 % de la superficie d'un coupleur hybride en anneau classique), et offre des performances similaires sur la bande de fréquences 1,15-1,6 GHz. Sur cette bande, les mesures ont montré un déséquilibre du couplage à 3 dB de 1 *dB* maximum et une variation de la différence des phases de sortie de 22° (± 11°). Le deuxième circuit proposé est une transition ligne-fente-ligne à ouverture en H, compacte et ayant une bande de fréquence large. Il mesure 23 *x* 30 mm^2, fente et réseau d'adaptation compris. Les mesures ont révélé un déséquilibre du couplage à 3 dB de $0,3$ *dB* maximum et une variation de la différence des phases de sortie de 1° (± $0,5$°) sur la bande 1,15-1,6 GHz.

Quand aux diviseurs de puissance 3 dB / 90°, deux méthodes de miniaturisation ont été étudiées en vue de réduire la taille d'un coupleur hybride à quadrature. La première technique est basée sur une géométrie fractale comme dans le cas du diviseur 180°. Un coupleur hybride à quadrature a été conçu avec une géométrie fractale de la 2ème itération de Sierpinski, et un déséquilibre du couplage à 3 dB de $0,4\ dB$ maximum avec une variation de la différence des phases de sortie de 1° ($\pm\ 0,5^\circ$) a été obtenu en prenant en compte une largeur de bande de 10 %. Sa superficie est environ 50 % celle du diviseur hybride à quadrature classique. La deuxième technique de miniaturisation qui a été étudiée est basée sur l'utilisation d'éléments distribués semi-localisés pour réduire la taille d'une ligne microruban. La réduction de taille réalisable est également de 50 %.

Executive summary

Miniaturization of 3-dB / 90° and 180° power splitters using microstrip technology

Mathieu Caillet, Michel Clénet, Yahia M. M. Antar; DRDC Ottawa TM 2007-257; Defence R&D Canada – Ottawa; November 2007.

Background: 90° and 180° power splitters are commonly used in the design of circularly polarized antenna feeding circuits. Baluns and hybrids are easily realized using planar circuit technology as they employ only transmission lines without additional components. However, as the electrical lengths of the transmission line elements are either 90° or 270°, such circuits consume a significant amount of circuit area, especially at lower frequencies. This report shows the development of miniaturized 3-dB / 90° and 180° power splitters. Electromagnetic simulation and experimental results were used to confirm the design approach for hybrids operating at 1.37 GHz. The frequency response of the proposed hybrids is similar to conventional hybrids.

Principal results: Concerning the 3-dB / 180° splitters, two miniaturized microstrip circuits have been designed using two different methods. The first one is a Moore 2nd iteration fractal ring hybrid, of size 23 *x* 28 mm^2 (23 % of the conventional ring hybrid area) with similar performance over the 1.15-1.6 GHz frequency band. Over this band, characterization has shown a maximum 3-dB coupling imbalance of 1 *dB* and an output phase difference varying by 22° (± 11°). The second proposed circuit is an H-shaped aperture-coupled transition, of compact size and wide frequency bandwidth. Its size is 23 *x* 30 mm^2, including the slot and matching network. Measurements revealed a maximum 3-dB imbalance of 0.3 *dB* and an output phase difference fluctuation of 1° (± 0.5°) over the 1.15-1.6 GHz band.
Regarding the 90° splitters, two miniaturization methods have been investigated to reduce the size of a branch-line hybrid. The first technique is based on fractal geometries as for the 180° splitter. A Sierpinski 2-nd iteration fractal branch-line hybrid has been simulated and showed a coupling imbalance of 0.4 *dB* and a phase difference variation of 1° (± 0.5°) over a 10 % bandwidth. Its size is about 50 % of the area of the branch-line hybrid. The second miniaturization technique that has been investigated is founded on lumped distributed elements to reduce the size of a microstrip line. The possible size reduction is 50 % as well.

Significance of results: The methods used here consist of reducing the surface area occupied by conventional structures through the use of space-filling curves and distributed lumped elements having the same electrical characteristics. Additionally, a microstrip aperture-coupled transition has been designed, providing a compact solution for a 3-dB / 180°

power splitter. The achieved size is 23 to 50 % the area of conventional geometries, with a frequency response similar to conventional circuits. Numerous other methods have been developed to reduce the size of the balun and hybrid topologies: use of metamaterials, planar artificial transmission lines, Coplanar Printed Waveguide (CPW), etc. Usually, the size reduction is around 50 %.

Future work: It is planned to do some tests with a substrate with dielectric losses lower than the FR4 substrate to see if the insertion loss could be improved. Moreover, other techniques can further reduce more the size of the circuits. For instance, coupled lines are integrable using Low Temperature Co-fired Ceramic (LTCC). Finally, the presented results concern narrowband circuits; for broad frequency band applications, the obtained performances are not sufficient, and the studied methods could be investigated as well to design wide-band circuits.

Sommaire

Miniaturization of 3-dB / 90° and 180° power splitters using microstrip technology

Mathieu Caillet, Michel Clénet, Yahia M. M. Antar ; DRDC Ottawa TM 2007-257 ; R & D pour la défense Canada – Ottawa ; novembre 2007.

Contexte : Les diviseurs de puissance 90° et 180° sont couramment utilisés dans la conception de circuits d'alimentation d'antenne à polarisation circulaire. Des diviseurs symétriques Balun et des coupleurs hybrides peuvent être facilement produits à l'aide de la technologie des circuits planaires car ils n'utilisent que des lignes de transmission sans éléments additionnels. Cependant, comme les longueurs électriques des éléments de ligne de transmission sont de 90° ou 270°, ces circuits occupent une superficie importante, particulièrement aux fréquences basses. Le présent rapport traite du développement de diviseurs de puissance 3 dB / 90° et 180° miniatures. La simulation électromagnétique et les résultats d'experiences ont été utilisés pour valider la méthode de conception des coupleurs hybrides fonctionnant à 1,37 GHz. La réponse en fréquence des coupleurs hybrides proposés est similaire à celle des coupleurs hybrides classiques.

Résultats principaux : Concernant les diviseurs de puissance 3 dB / 180°, deux circuits microrubans miniatures ont été conçus en utilisant deux méthodes différentes. Le premier circuit est un diviseur hybride en anneau à géométrie fractale de la 2ème itération de Moore, mesurant 23 *x* 28 mm^2 (23 % de la superficie d'un coupleur hybride en anneau classique), et offre des performances similaires sur la bande de fréquences 1,15-1,6 GHz. Sur cette bande, les mesures ont montré un déséquilibre du couplage à 3 dB de 1 dB maximum et une variation de la différence des phases de sortie de 22° ($\pm$ 11°). Le deuxième circuit proposé est une transition ligne-fente-ligne à ouverture en H, compacte et ayant une bande de fréquence large. Il mesure 23 *x* 30 mm^2, fente et réseau d'adaptation compris. Les mesures ont révélé un déséquilibre du couplage à 3 dB de $0,3$ dB maximum et une variation de la différence des phases de sortie de 1° ($\pm$ $0,5$°) sur la bande 1,15-1,6 GHz. Quand aux diviseurs de puissance 3 dB / 90°, deux méthodes de miniaturisation ont été étudiées en vue de réduire la taille d'un coupleur hybride à quadrature. La première technique est basée sur une géométrie fractale comme dans le cas du diviseur 180°. Un coupleur hybride à quadrature a été conçu avec une géométrie fractale de la 2ème itération de Sierpinski, et un déséquilibre du couplage à 3 dB de $0,4$ dB maximum avec une variation de la différence des phases de sortie de 1° ($\pm$ $0,5$°) a été obtenu en prenant en compte une largeur de bande de 10 %. Sa superficie est environ 50 % celle du diviseur hybride à quadrature classique. La deuxième technique de miniaturisation qui a été étudiée est basée sur l'utilisation d'éléments distribués semi-localisés pour réduire la taille d'une ligne microruban. La réduction de taille réalisable est également de 50 %.

Portée des résultats : Les méthodes présentées ici consistent à réduire la surface occupée par les structures classiques en ayant recours à des géométries fractales et à des éléments distribués semi-localisés ayant les mêmes caractéristiques électriques. De plus, une transition ligne-fente-ligne à couplage à travers une ouverture offre une solution compacte pour un diviseur de puissance 3 dB / 180°. Les tailles obtenues sont de 23 à 50 % celle des structures classiques, avec une réponse en fréquence similaire. De nombreuses autres méthodes ont été présentées dans la littérature en vue de réduire la taille des topologies des diviseurs symétriques Balun et des coupleurs hybrides : utilisation de métamatériaux, lignes de transmission artificielles planaires, circuits imprimés coplanaires (CPW), etc. Habituellement, la réduction de la taille est d'environ 50 %.

Perspectives : Il pourrait être intéressant de faire des essais avec un substrat dont les pertes diélectriques sont plus faibles que celles du substrat FR4 utilisé, afin de déterminer si les pertes d'insertion pourraient être réduites. En outre, il est possible d'utiliser d'autres technologies pour réduire davantage la taille des circuits. Par exemple, les lignes couplées peuvent être intégrées à l'aide de céramique pressée à basse température (LTCC). Enfin, les résultats présentés ont trait à des circuits à bande étroite. Pour les applications à large bande de fréquences, les performances obtenues ne sont pas suffisantes, et l'utilisation des méthodes étudiées pourrait être envisagée également pour la conception de circuits large-bande.

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1 Introduction

90° and 180° power splitters are commonly used in the design of circularly polarized antenna feeding circuits. For instance, a quadrifilar helix antenna [1] needs to be fed by a network having one input port and four output ports with equal magnitude and 90° phase difference between each port. Baluns and hybrids are frequently used due to simple designs and ease of realization using a standard printed circuit board fabrication process. However, the main limitation for their use lies in the large surface area required, especially at lower frequencies.

Numerous methods have been developed to reduce the size of these topologies [2, 3, 4]. Recently, a novel method based on the use of space-filling curves has been proposed by Ghali and Moselhy [5]. This method consists of choosing a fractal geometry and the associated iteration number to determine the corresponding area reduction. It allows one to reduce greatly the occupied area of baluns and hybrids [6]. Additionally, the use of distributed lumped elements is an interesting technique to reduce the length of a transmission line [7]. Particularly, it can be applied to the miniaturization of branch-line hybrids.

This report describes the analysis and design of miniaturized 3-dB power splitters. The 3-dB / 180° power splitters are presented in Section 2 and the 3-dB / 90° power splitters in Section 3. Simulations and characterization results are provided for several designs. Conclusions and future plan are given in Section 4.

2 Simulation and characterization of 3-dB / 180° power splitters

Two different types of compact circuits are reviewed here that evenly split the power and provide a 180° phase difference between the two outputs. The first circuit is the conventional ring hybrid, which has been miniaturized using fractal geometry. The second splitter is an aperture-coupled transition built on a double layer substrate technology, which is of compact size. The performances are evaluated between 1.15 and 1.6 GHz, and the center frequency is 1.37 GHz. All simulations have been performed by taking material losses into account.

2.1 The microstrip ring hybrid

The 180° hybrid junction includes a ring, with an impedance of 70.7 Ω and a perimeter of 1.5 λ_g (λ_g is the guided wavelength at 1.37 GHz), and 4 input lines of 50 Ω. This forms a four-port network with a 180° phase shift between two specified output ports. The distance between the ports in the top ring is $\lambda_g/4$.

Figure 1 shows the geometry and the convention for the ports. If the input is applied to port 1, the power will be evenly split into two components with a 180° phase difference at ports 3 and 4, and port 2 will be isolated. Details on the functioning of the 180° hybrid can be found in [8].

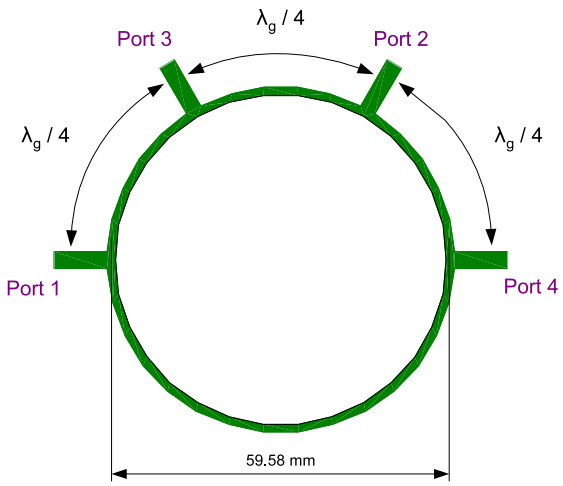


Figure 1: *Microstrip ring hybrid on 60-mil FR4 substrate*

2.1.1 Simulations

Simulation results of S-parameters obtained on a 60-mil FR4 substrate ($\varepsilon_r = 4.4$ and $tg\ \delta = 0.009$) with the dimensions of Fig. 1 are presented in Fig. 2. Two commercial simulation tools have been used to compare results; Ansoft Designer, based on the method of moments, and Ansoft HFSS, based on the finite element method. The model developed with Designer has infinite substrate and ground plane, while with HFSS the size of the substrate and ground plane is 101.6 *x* 101.6 mm^2. The 50 Ω and 70.7 Ω lines are 2.9 *mm* and 1.4 *mm* wide respectively. Simulation results agree quite well for both simulation methods. One can notice a difference on return loss.

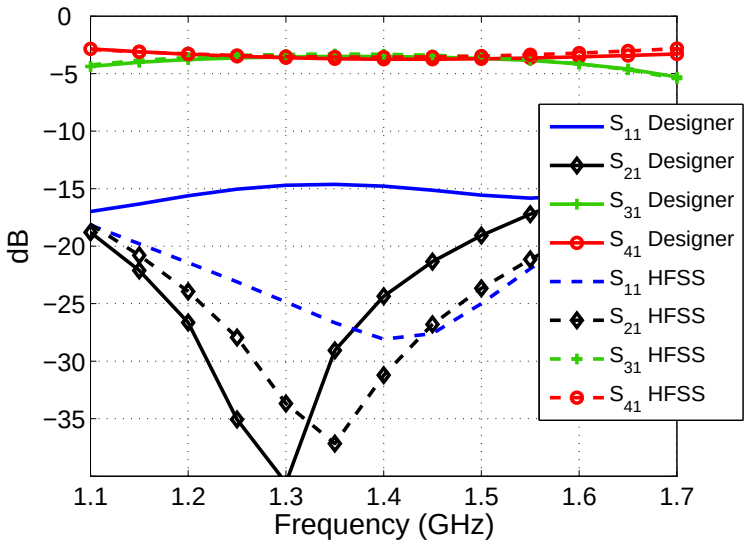
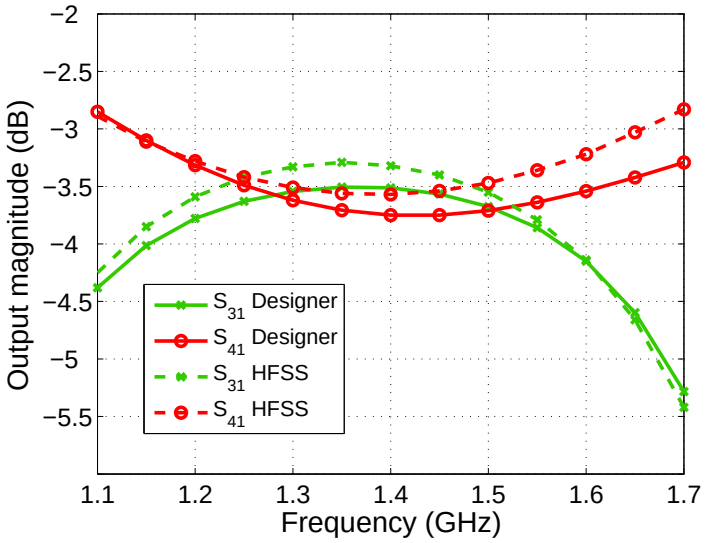


Figure 2: *Simulated ring hybrid S-parameter magnitudes*

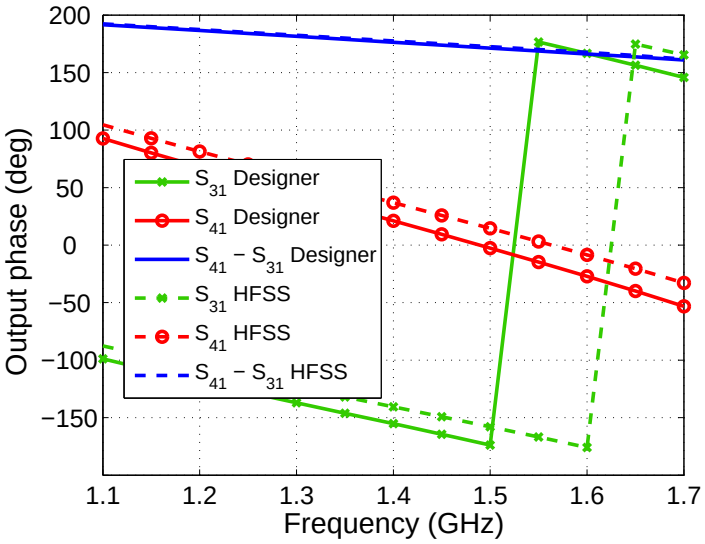
Magnitude and phase data are given in Fig. 3. Between 1.15 and 1.6 GHz, a 3-dB coupling with maximum amplitude unbalance of less than 0.9 dB is obtained and the phase variation is 23° (± 11.5°) over the frequency band.

2.1.2 Characterization and results

A prototype of the ring hybrid has been fabricated using a 60-mil FR4 substrate (Fig. 4). The characterization results for magnitude and phase are shown in Fig. 5. The return loss is -25.9 dB at 1.4 GHz, which is in agreement with simulation (-28.1 dB). Comparison of simulation (Ansoft Designer) and measured results for output S-parameters are given in Table 1. The data are close to perfect agreement.



(a)



(b)

Figure 3: *Simulated ring hybrid outputs: (a) magnitude and (b) phase*

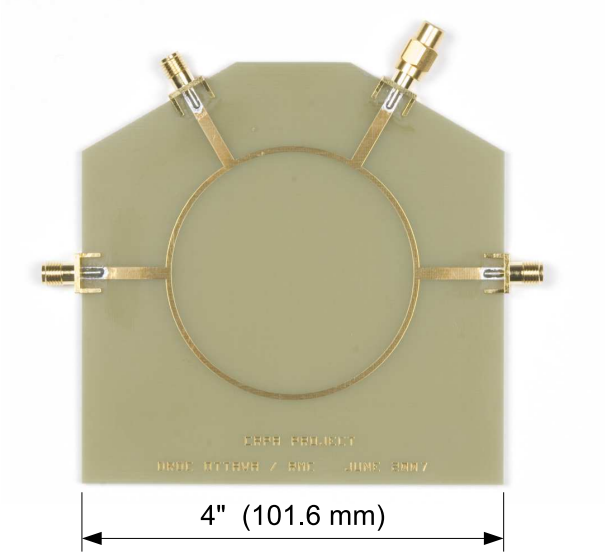
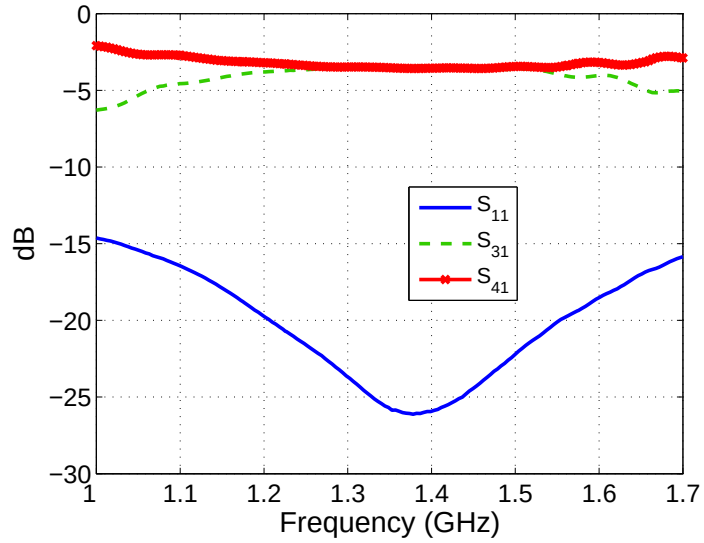


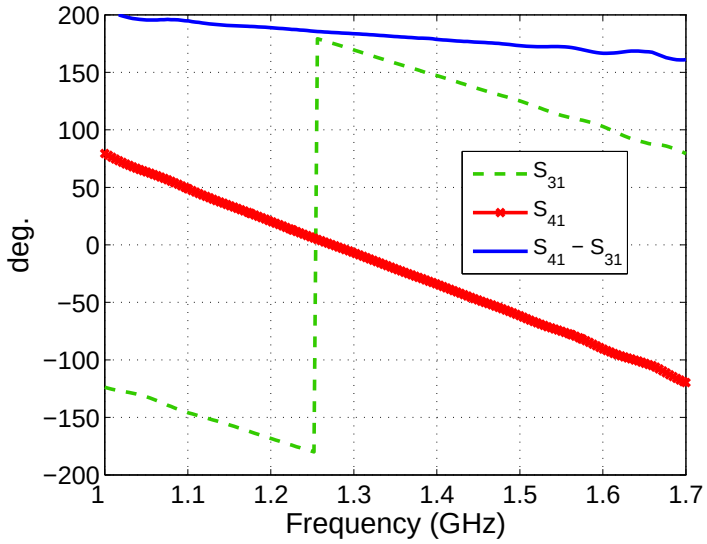
Figure 4: *Fabricated microstrip ring hybrid on 60-mil FR4 substrate*

	Amplitude S_{31}/S_{41} (dB)		Phase diff. (°)	
	Simu.	Charact.	Simu.	Charact.
1.15 GHz	-4.02/-3.10	-4.14/-3.07	189.1	190.7
1.35 GHz	-3.51/-3.71	-3.44/-3.53	179.0	181.2
1.6 GHz	-4.15/-3.54	-4.03/-3.18	166.2	166.6

Table 1: *Comparison of simulated and characterized results for the ring hybrid*



(a)



(b)

Figure 5: *Characterization results of the ring hybrid S-parameters: (a) magnitude and (b) phase outputs*

2.2 Fractal microstrip 180° hybrid

In [6], some fractal geometries are presented to design compact hybrids. These are called Moore, Sierpinski, and Minkowski constructions. Among these shapes, Moore's allows the best reduction in area and thus has been selected to reduce the size of the 180° ring hybrid. The implementation and design are described in this section.

2.2.1 Moore 1-st iteration fractal hybrid

The first iteration of Moore's geometry has the shape of the letter 'I' (Fig. 6). One can note that this structure includes 16 segments. To find the length of a segment, the equation $8\ segments = 3\ \lambda_g/4$ has to be solved. To take into account the width of the line, the length of the segment has to be shortened depending on the width of the line.
A ring hybrid has been implemented on a 60-mil FR4 substrate (Fig. 6). The impedance of the central line is 70.7 Ω, which corresponds to 1.54 *mm* for the selected substrate. The length of each segment has been adjusted to 11.54 *mm*. The four outputs have a 50 Ω impedance.

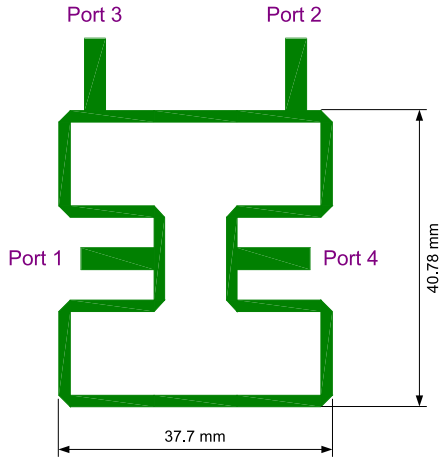
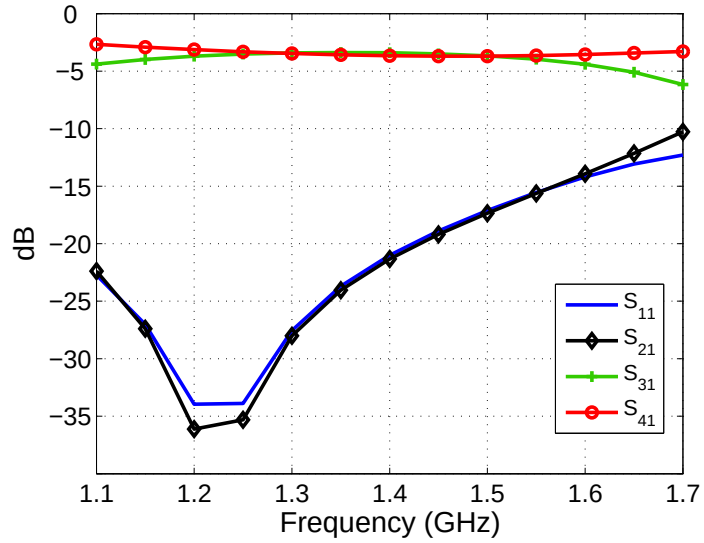


Figure 6: *Moore 1-st iteration fractal 180° hybrid on 60-mil FR4 substrate*

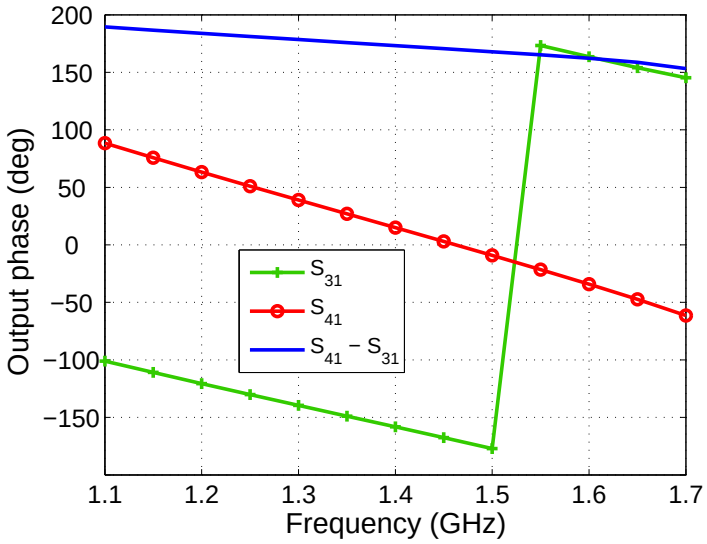
The simulated S-parameters for the designed circuit on a 60-mil FR4 substrate with the dimensions of Fig. 6 are presented in Fig. 7(a). Phase data are given in Fig. 7(b). Between 1.15 and 1.6 GHz, a 3-dB coupling with maximum amplitude unbalance of less than 1 dB is obtained and the phase variation is 24° (± 12°) over the frequency band.

If the area of the ring hybrid is $\pi.r^2$, with r the radius of the ring, and the area of the Moore 1st iteration fractal hybrid is defined as $a.b$, with a and b the lengths of sides, the fractal geometry area is 55 % of the ring area.

A prototype has been built on a FR4 60-mil substrate (Fig. 8). The characterization results for magnitude and phase are shown in Fig. 9. The return loss is in agreement with



(a)



(b)

Figure 7: *Moore 1-st iteration fractal 180° hybrid S-parameters: (a) magnitude and (b) phase outputs*

simulation. Comparison of simulation and measured results are given in Table 2 for output magnitude and phase difference. A shift of $-0.5\ dB$ can be noted for S_{31} compared to simulation, but not for S_{41}. As a consequence, the magnitude difference of 1 dB between S_{31} and S_{41} in simulation at 1.15 and 1.6 GHz increase to 1.5 dB in measurement. A shift of 5° is observed in the phase difference.

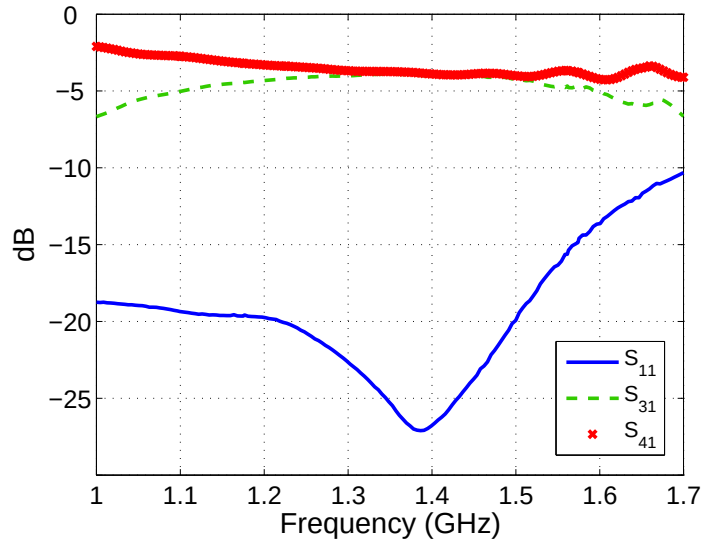
Figure 8: *Fabricated Moore 1-st iteration fractal hybrid on 60-mil FR4 substrate*

	Amplitude S_{31}/S_{41} (dB)		Phase diff. ($^\circ$)	
	Simu.	Charact.	Simu.	Charact.
1.15 GHz	-3.98/-2.91	-4.56/-3.07	186.7	190.2
1.35 GHz	-3.38/-3.58	-3.90/-3.74	175.8	180.6
1.6 GHz	-4.41/-3.56	-5.00/-4.24	162.3	168.2

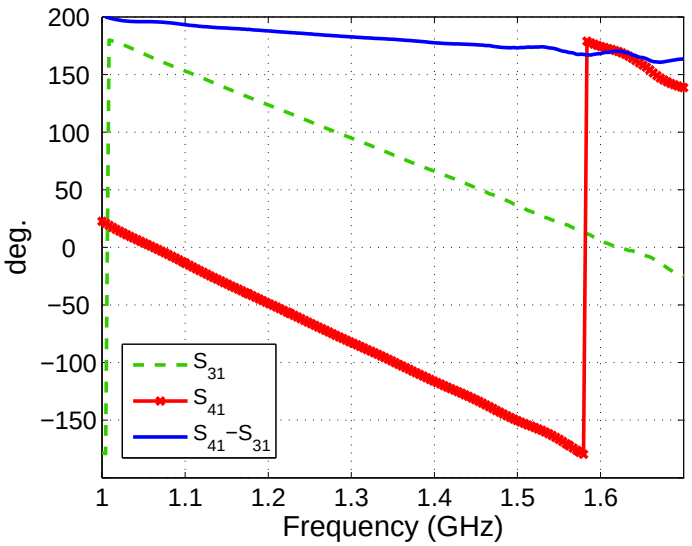
Table 2: *Comparison of simulated and characterized results for the Moore 1-st iteration fractal hybrid*

2.2.2 Moore 2-nd iteration fractal hybrid

The second iteration of the Moore's construction allows a higher reduction in the ring hybrid's area. Indeed, the perimeter of the central line is confined in a smaller surface because the construction includes more meanders (Fig. 10). This structure includes 64 segments, and 4 segments could be added in the center area to provide more room to the input and output lines and limit coupling between lines. In this case, the line length is around 2.4 *mm* at 1.37 GHz.



(a)



(b)

Figure 9: *Characterization results of the Moore 1-st iteration fractal hybrid S-parameters: (a) magnitude and (b) phase outputs*

So far in this report, ring hybrids have been implemented on 60-mil FR4 substrate. On this material, the trace width corresponding to the 70.7 Ω impedance equals 1.54 *mm*. However, due to small segment length, the use of such a width is not practicable. To avoid such problems, the coupler could be designed with a higher characteristic impedance (100 Ω for instance) and with quarter-wave lines for matching. But at 1.37 GHz, the length of a quarter wave line is important (around 30 mm). Another solution is to implement the coupler on a 30-mil FR4 substrate. In this case, the width of lines can be maintained for 70.7 Ω and no additional matching is needed. A segment of the fractal geometry on a 30-mil dielectric material is 2.6 *mm* long and 0.77 *mm* wide.

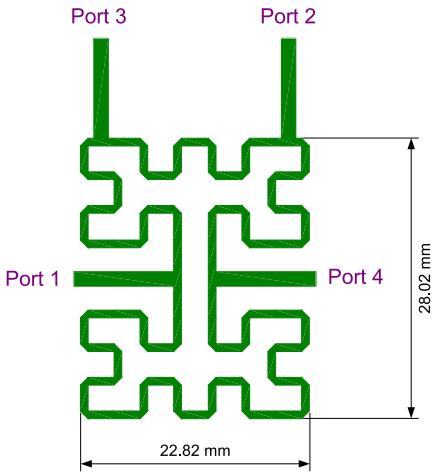


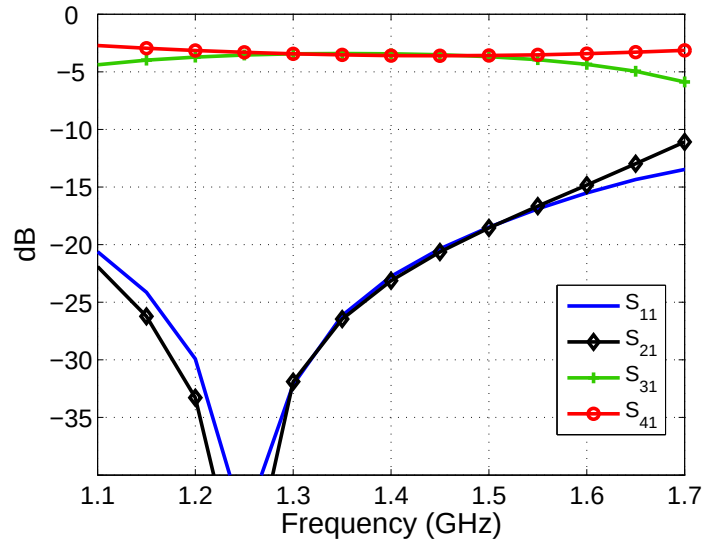
Figure 10: *Moore 2-nd iteration fractal 180° hybrid on 30-mil FR4 substrate*

Simulation results of S-parameters obtained for a 30-mil FR4 substrate with the dimensions of Fig. 10 are presented in Fig. 11(a). Phase data are given in Fig. 11(b). Between 1.15 and 1.6 GHz, a 3-dB coupling with maximum amplitude unbalance of less than 1 *dB* is obtained and the phase variation is 24° (± 12°) over the frequency band. The performance is similar to that of the Moore 1-st iteration fractal hybrid realized on a 60-mil FR4 substrate. However, in the case of the Moore 2-nd iteration, the fractal geometry area is 23 % of the ring area.

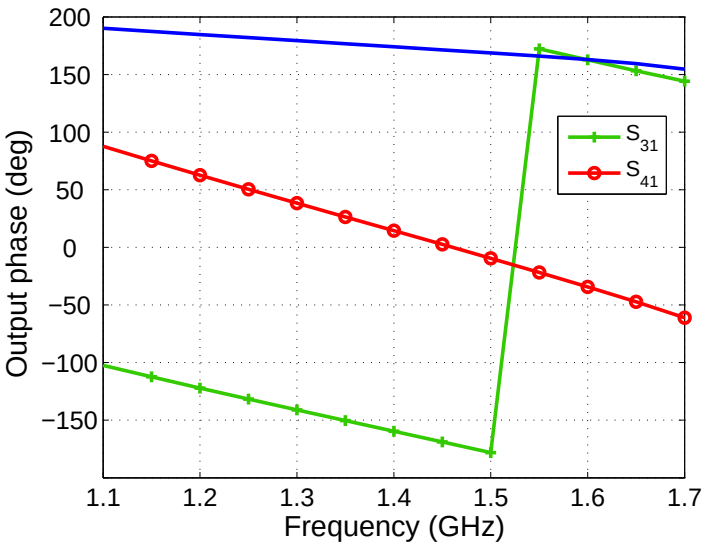
A prototype has been fabricated on an FR4 30-mil substrate (Fig. 12). The characterization results for magnitude and phase are shown in Fig. 13. The return loss is in agreement with simulation. Comparison of simulation and measured results are given in Table 3. The amplitude difference of 1 *dB* between S_{31} and S_{41} in simulation at 1.15 GHz is also observed in measurement. Here again, a shift of 6° is noted in the phase difference.

2.3 Double layer aperture-coupled transition structure

The aperture-coupled transition is another structure that can be used to build a 180° power splitter [9]. This structure includes two layers of substrate and a slot etched in the ground



(a)



(b)

Figure 11: *Moore 2-nd iteration fractal 180° hybrid S-parameters: (a) magnitude and (b) phase outputs*

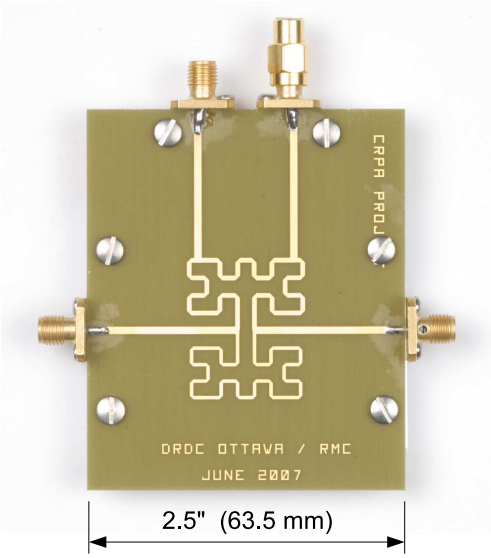
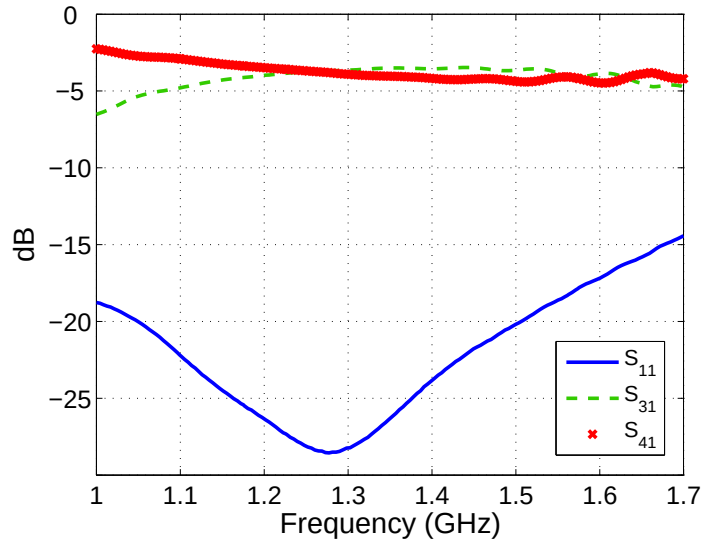


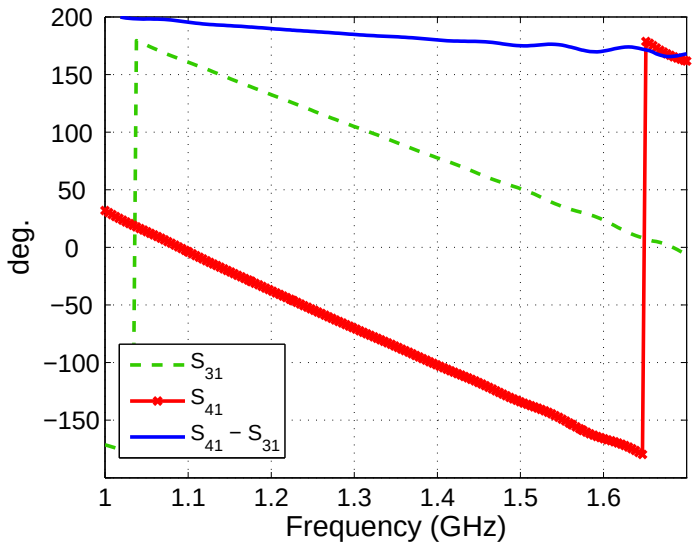
Figure 12: *Fabricated Moore 2-nd iteration fractal hybrid on 30-mil FR4 substrate*

	Amplitude S_{31}/S_{41} (dB)		Phase diff. (°)	
	Simu.	Charact.	Simu.	Charact.
1.15 GHz	-3.99/-2.95	-4.27/-3.25	187.4	192.3
1.35 GHz	-3.41/-3.53	-3.51/-4.03	176.7	182.8
1.6 GHz	-4.35/-3.43	-3.88/-4.48	163.0	170.4

Table 3: *Comparison of simulated and characterized results for the Moore 2-nd iteration fractal hybrid*



(a)



(b)

Figure 13: *Characterization results of the Moore 2-nd iteration fractal hybrid S-parameters: (a) magnitude and (b) phase outputs*

plane (Fig. 14). The feeding line (port 1) is located on the lower layer and the outputs (ports 2 and 3) are on the upper layer. A serial stub is needed on the lower layer to transform port 1 to 50 Ω. A quarter-wavelength line is placed on top of the slot between the two outputs to match the T-junction.

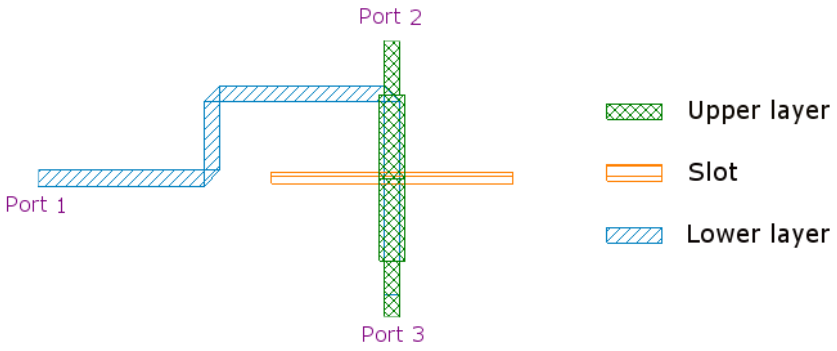


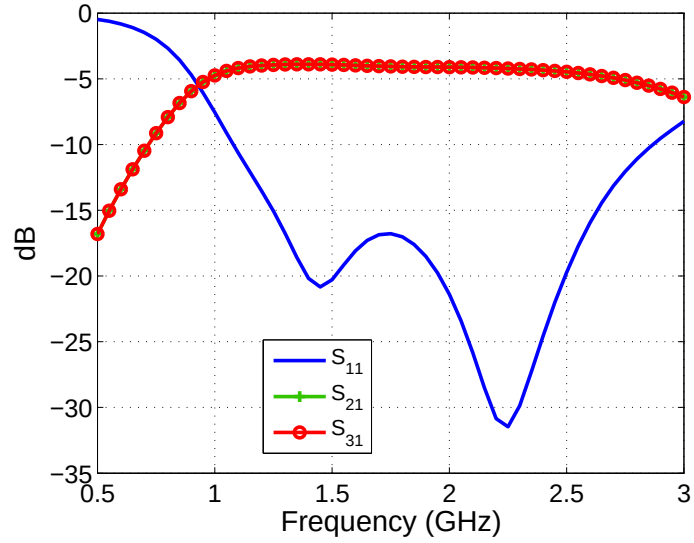
Figure 14: *Aperture-coupled transition on 60-mil FR4 double layer substrate*

2.3.1 Simulations

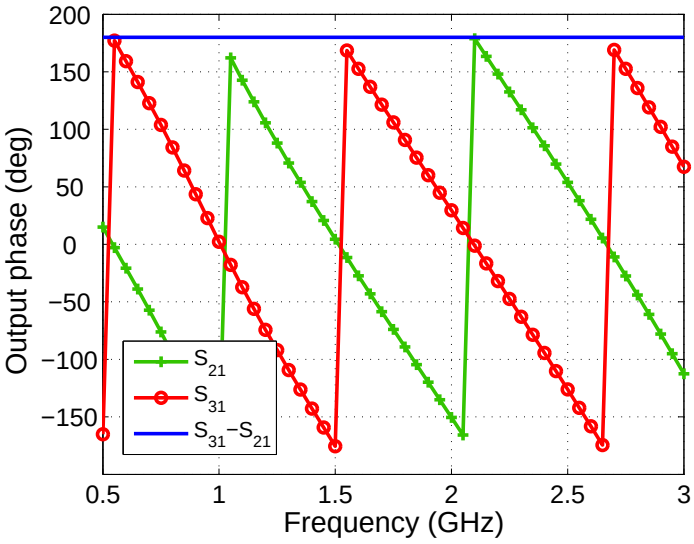
For an implementation with a 60-mil FR4 substrate, a $2-mm$ wide linear slot has been chosen. The length of the slot is 44 *mm*, and the stub realized with a 50 Ω line is 21 *mm* long. The quarter-wavelength line is 4.8 *mm* wide and 30 *mm* long.

Simulation results of S-parameters obtained with this geometry (Fig. 14) are presented in Fig. 15(a). Phase data are given in Fig. 15(b). Between 1.15 and 1.6 GHz, a 3-dB coupling with an amplitude unbalance of nearly 0 dB is obtained and the phase variation is close to zero over the frequency band. This compact structure has good performance over a wide frequency band. Because the frequency band of the aperture-coupled transition is wider than the desired band (1.15-1.6 GHz), the slot, the quarter-wavelength line and the stub have been designed to shift the desired band to the lower band of the overall transition frequency band. This way the size of the slot is smaller than if this latter was designed to work at a center frequency of 1.37 GHz.

The size of the aperture-coupled transition can be further reduced by modifying the shape of the slot. Indeed, an H-shaped slot provides an improvement of the coupling [10], as well as reducing its length. The linear slot is 44 *mm* long, the middle part of the H-shaped slot and the two arms are 19 *mm* long (Fig. 16). The dimensions of the stub and the upper quarter-wavelength line remain identical. The H-shaped aperture-coupled transition simulation results (Fig. 17) are very similar to the linear aperture ones, except that the magnitude of outputs is around $-3.7\ dB$ instead of $-4.0\ dB$ in the case of the linear slot.



(a)



(b)

Figure 15: *Linear aperture-coupled transition S-parameters: (a) magnitude and (b) phase outputs.* $|S_{21}|$ *and* $|S_{31}|$ *curves are overlaid.*

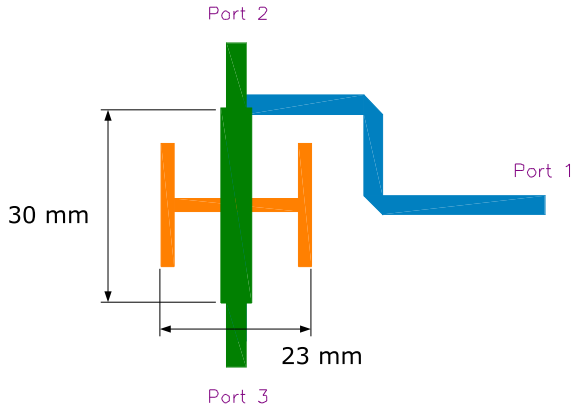


Figure 16: *H-shaped aperture-coupled transition on 60-mil FR4 double layer substrate – Top view*

2.3.2 Characterization and results

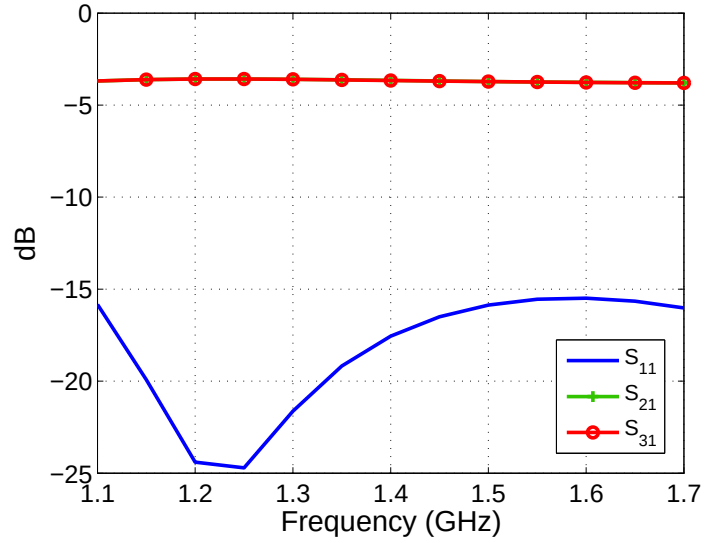
An H-shaped aperture-coupled transition has been fabricated to demonstrate the performance of the design. Two layers of 60-mil FR4 substrate have been used, and a 10 μm bonding film of FR4 equivalent material added to assemble the two layers (Fig. 18). The prototype is shown in Fig. 19. Characterized S-parameters and phase outputs are given in Fig. 20. The return loss is in agreement with simulation. Comparisons of simulated and measured output magnitudes and phase difference are given in Table 4. Output magnitude shows a maximum unbalance of 0.3 dB between 1.15 GHz and 1.6 GHz. A flat phase difference is observed in this frequency band.

	Amplitude S_{21}/S_{31} (dB)		Phase diff. (°)	
	Simu.	Charact.	Simu.	Charact.
1.15 GHz	-3.61/-3.61	-3.60/-3.93	180.0	180.4
1.35 GHz	-3.63/-3.63	-3.66/-3.93	180.0	180.5
1.6 GHz	-3.77/-3.77	-3.79/-3.93	180.0	180.3

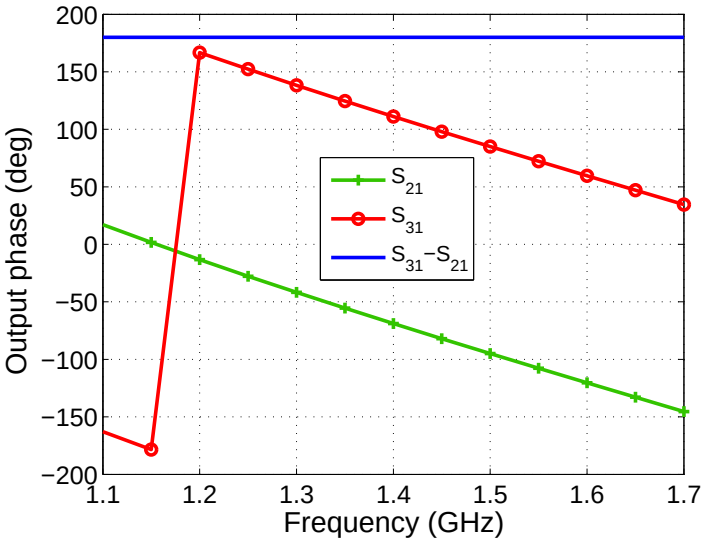
Table 4: *Comparison of simulated and characterized results for the H-shaped aperture-coupled transition*

2.4 Concluding remarks

Three microstrip 180° hybrids have been simulated around 1.37 GHz on FR4 substrate using different structures. The first one is the conventional ring hybrid. Its diameter is 59.58 mm and a 3-dB coupling with a maximum amplitude unbalance of less than 0.9 dB



(a)



(b)

Figure 17: *H-shaped aperture-coupled transition S-parameters: (a) magnitude and (b) outputs phase.* $|S_{21}|$ *and* $|S_{31}|$ *curves are overlaid.*

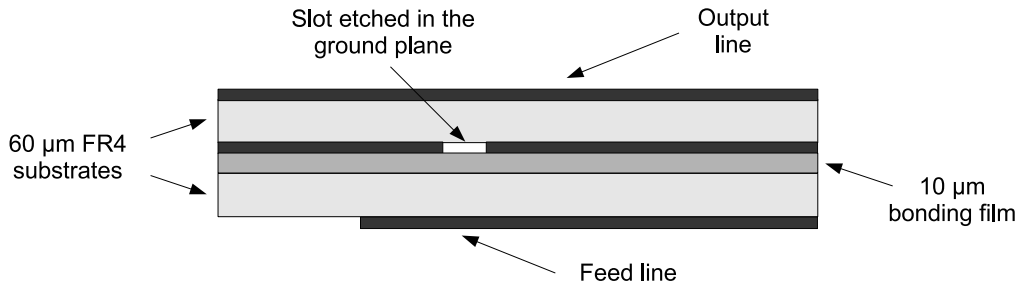
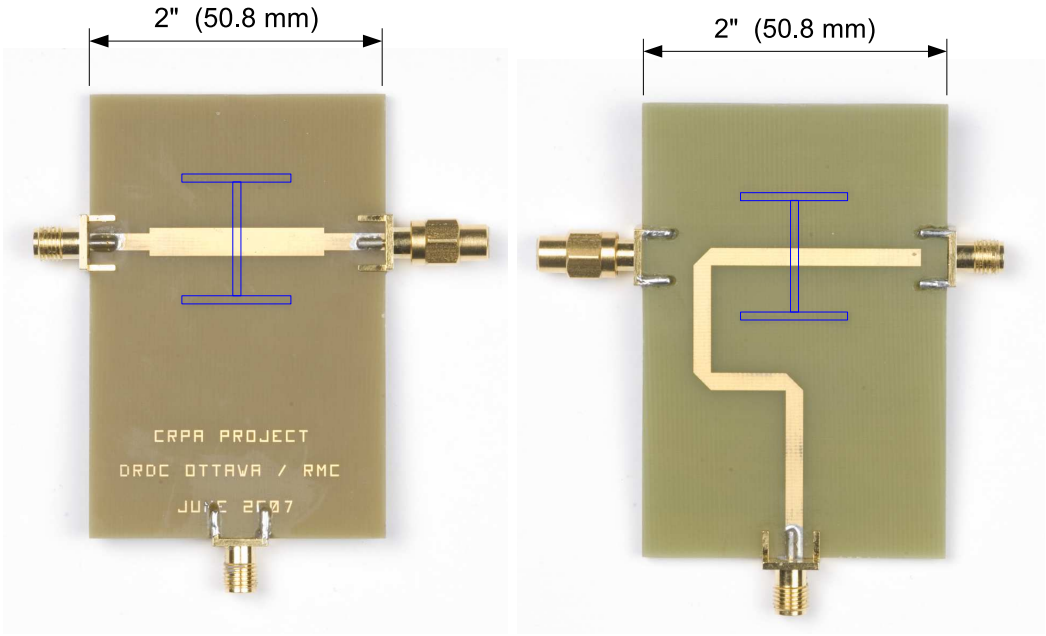


Figure 18: *H-shaped aperture-coupled transition structure*

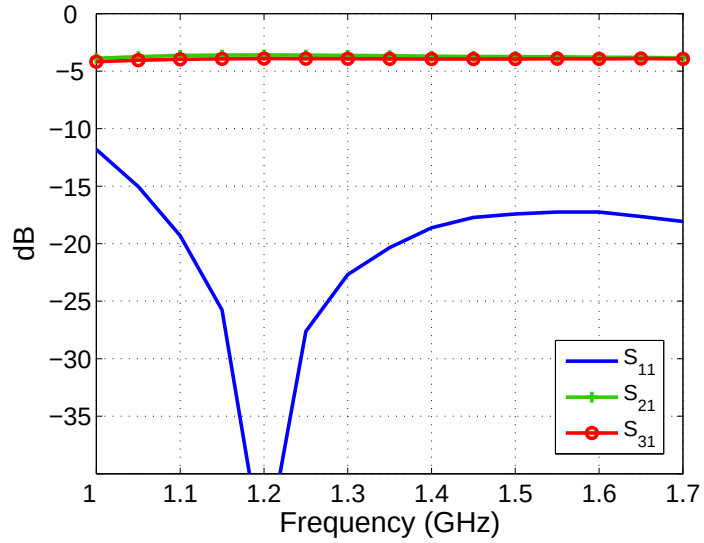


(a) (b)

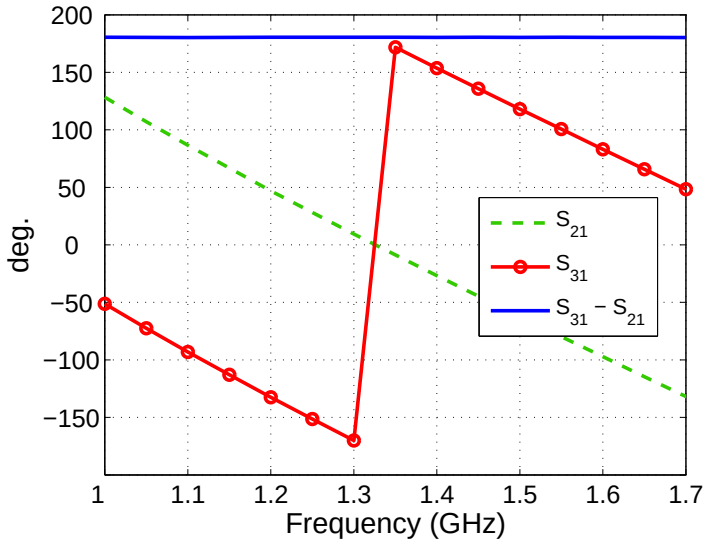
Figure 19: *H-shaped aperture-coupled transition prototype (a) top and (b) bottom view – Thin lines show the position of the slot in the ground plane*

between 1.15 and 1.6 GHz has been observed. Over this frequency band, the phase variation is 23°. To reduce the size, two fractal geometries of the ring hybrid have been investigated. The surfaces of these two couplers are 55 and 23 % respectively of the conventional ring hybrid's area and the performances on the 1.15-1.6 GHz frequency band are similar.

Additionally, an aperture-coupled transition has been used in a double layer structure. The shape of the slot is an 'H' to reduce the size and to improve the coupling. This geometry provides good performance on a broad frequency band. Between 1.15 and 1.6 GHz, the 3-dB maximum coupling amplitude unbalance is less than 0.3 dB and the phase variation is close to zero.



(a)



(b)

Figure 20: *Characterization results of the H-shaped aperture-coupled transition S-parameters: (a) magnitude and (b) phase outputs*

Figure 21 presents the different prototypes on the same scale allowing for direct size comparison. Good results have been obtained during characterization. Unbalanced amplitude 0.5 *dB* higher than simulation has been noted for the Moore 1-st iteration fractal hybrid. Small phase difference shifts have been observed for the hybrids.

Figure 21: *Hybrid designs on same scale using FR4 substrate*

3 Simulation and characterization of 3-dB / 90° power splitters

Two types of miniaturization techniques have been investigated for the design of 3 dB / 90° microstrip splitters. Results presented here concern an investigation with a branch-line hybrid. The first method to reduce the size of the hybrid consists of using fractal geometries, as previously reported for the 3 dB / 180° hybrid. The second technique employs lumped distributed elements to decrease the size of a transmission line.

All simulations have been performed by taking material losses into account. No prototypes have been realized because this study is similar to the previous one with 180° power splitters, which has shown good agreement between simulation and characterization.

3.1 Conventional 3-dB / 90° branch-line hybrid

The 90° printed branch-line hybrid includes four $\lambda_g/4$ lines (with opposite sides parallel), with impedances of 50 Ω and 35.36 Ω, and 4 lines of 50 Ω. This forms a four-port network with a 90° phase shift between the two output ports.
Figure 22 shows the geometry and the convention for the ports. If the input is applied to port 1, the power will be evenly split into two components with a 90° phase difference at ports 3 and 4, and port 2 will be isolated. For more details on the functioning of this device, refer to [8].

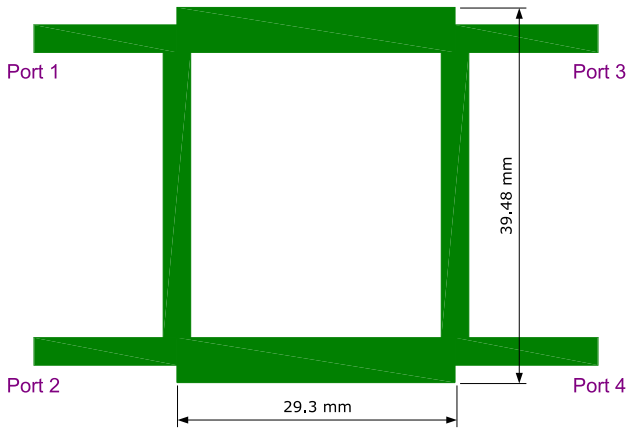
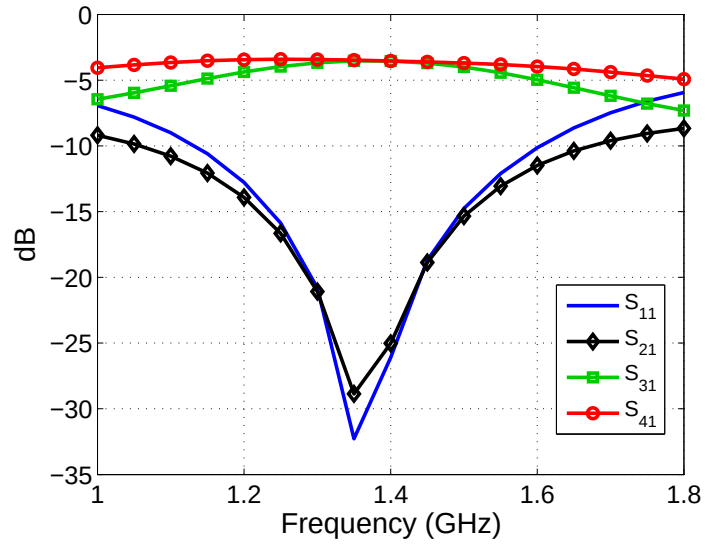


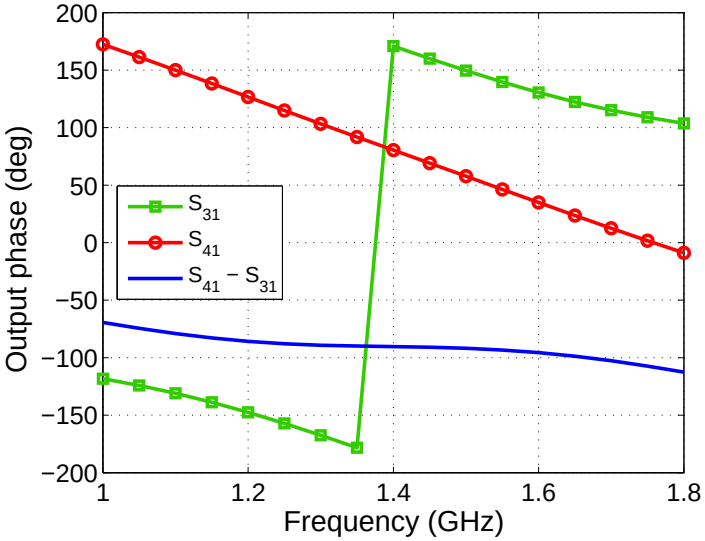
Figure 22: *Microstrip branch-line hybrid on 60-mil FR4 substrate*

Simulation results of S-parameters obtained for a 60-mil FR4 substrate ($\varepsilon_r = 4.4$, and $tg\ \delta = 0.009$) with the dimensions mentioned in Fig. 22 are presented in Fig. 23(a). Phase data are given in Fig. 23(b). One can notice that the frequency bandwidth is rela-

tively narrow, around 10 %. Considering this bandwidth, the coupling imbalance is 0.2 *dB* and the phase variation is 2° ($\pm\ 1^\circ$).



(a)



(b)

Figure 23: *Branch-line hybrid simulated S-parameters: (a) magnitude and (b) phase outputs*

3.2 Fractal printed hybrid

Based on the results presented in section 2.2, fractal geometries have been considered here to miniaturize the branch-line hybrid. Sierpinski's shape has been chosen in this case.

3.2.1 Sierpinski 1-st iteration fractal hybrid

The first iteration of the Sierpinski's geometry has the shape of a 4-petal flower (Fig. 24). One can notice that this structure includes 16 segments. To find the length of a segment, the equation 4 $segments = \lambda_g/4$ has to be solved. To take into account the width of the line, the length of the segment has to be shortened depending on the width of the line.

A branch-line hybrid has been implemented on a 60-mil FR4 substrate (Fig. 24). The impedances of the hybrid lines are 50 and 35.36 Ω, which correspond to 2.9 *mm* and 5.04 *mm* respectively, for the selected substrate. The length of each segment has been adjusted to 6.4 *mm*. The four outputs have a 50 Ω line impedance.

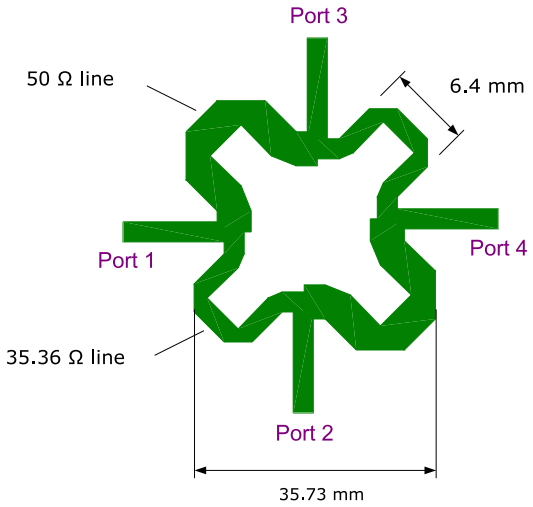
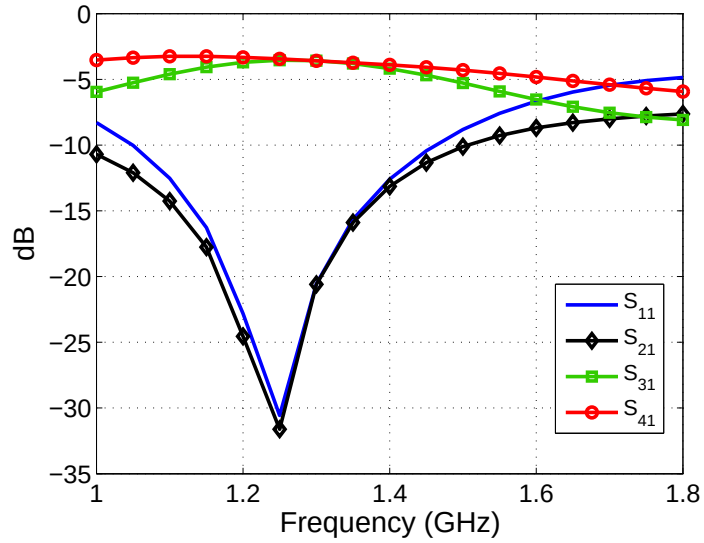


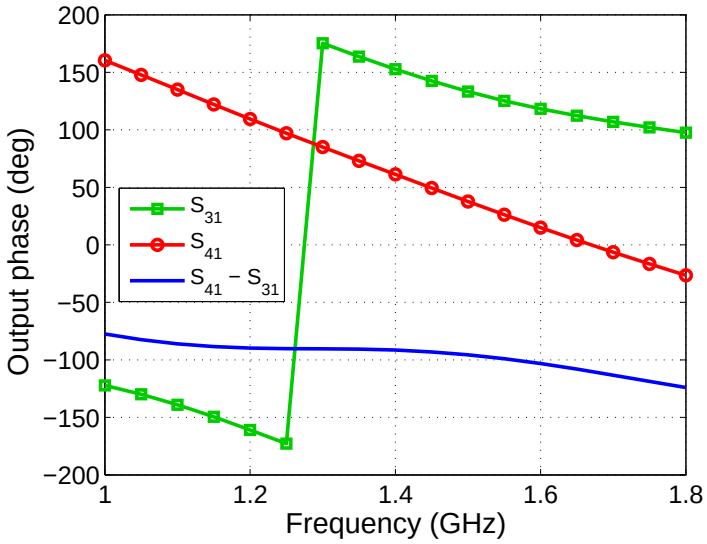
Figure 24: *Sierpinski 1-st iteration 90° fractal hybrid on 60-mils FR4 substrate*

Simulation results of S-parameters obtained for a 60-mil FR4 substrate with the dimensions mentioned in Fig. 24 are presented in Fig. 25(a). Phase data are given in Fig. 25(b). Here again, the frequency bandwidth is 10 % about, with a coupling imbalance of 0.25 *dB* and a phase variation of 2° (± 1°).

The sizes of the conventional branch-line hybrid and the 1st iteration Sierpinski fractal hybrid are similar.



(a)



(b)

Figure 25: *Sierpinski 1-st iteration 90° fractal hybrid simulated S-parameters: (a) magnitude and (b) phase outputs*

3.2.2 Sierpinski 2-nd iteration fractal hybrid

The second iteration of the Sierpinski's construction allows a reduction of the branch-line hybrid's area. Indeed, the perimeter of the central line is confined in a smaller frame because the construction includes more meanders (Fig. 26). This structure includes 64 segments corresponding to λ_g. In this case, the segment length is around 1.6 *mm* at 1.37 GHz. So far in this chapter, branch-line hybrids have been implemented on 60-mil FR4 substrate. The trace width corresponding to a 35.36 Ω impedance equals 5.04 *mm*. However, due to small segment lengths, the use of such a width is not practicable. To avoid such problems, the coupler could be designed with higher characteristic impedances (100 and 70.7 Ω for instance) and using quarter-wavelength lines for matching. But at 1.37 GHz, the length of a quarter-wavelength line is significant (around 30 *mm*). Another solution is to implement the coupler on a 30-mil FR4 substrate. In this case, the width of the lines can be maintained and no additional matching is needed. The 35.36 Ω segment of the fractal geometry segment on a 30-mil dielectric material is 1.6 *mm* long and 2.47 *mm* wide, the 50 Ω segment is 1.6 *mm* long and 1.45 *mm* wide.

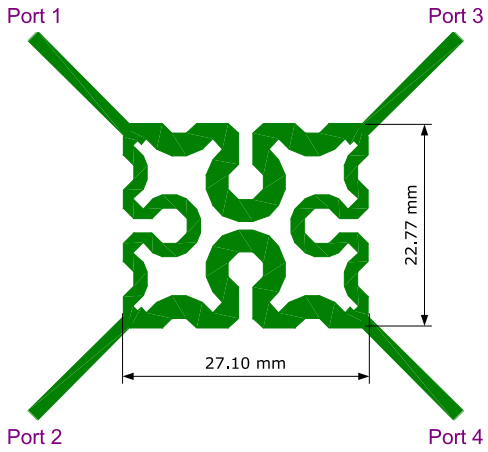


Figure 26: *Sierpinski 2-nd iteration 90° fractal hybrid on 30-mil FR4 substrate*

Compared to the conventional branch-line hybrid, similar simulation results have been obtained on a 30-mil FR4 substrate with the dimensions of Fig. 26. In the case of the Sierpinski 2-nd iteration, the obtained fractal geometry area is 53 % of the branch-line hybrid area. Figure 27 presents the different designs on the same scale allowing for direct size comparison.

One can note that the size reduction is achieved by decreasing the height. Another miniaturization technique will be presented in section 3.3 to reduce the width of the branch-line hybrid.

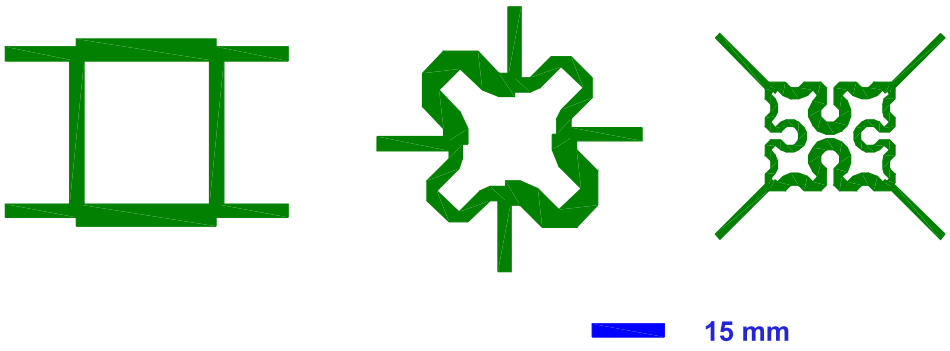


Figure 27: *Hybrid designs on same scale using FR4 substrate*

3.3 Lumped distributed elements

The use of lumped distributed elements is another miniaturization technique for reducing the size of a 90° branch-line hybrid [7]. This miniaturization method is presented in this section.

The lumped distributed elements method consists of shrinking a conventional transmission line having a Z_c impedance and a θ electrical length (Fig. 28(a)) by replacing it by a shorter transmission line, of impedance Z_s and an electrical length of θ_s, and two open stubs having a Z_{o1} impedance and a θ_{o1} electrical length (Fig. 28(b)).

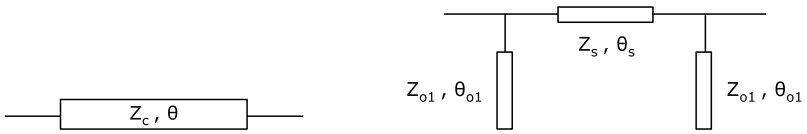


Figure 28: *Size reduction scheme using lumped distributed elements. (a) Conventional transmission line. (b) Equivalent transmission line with a series transmission line and two open stubs.*

Two design equations are needed to find the parameters of the equivalent transmission line:

$$B_{o1} = \frac{\cos\ \theta_s - \cos\ \theta}{Z_c \sin\ \theta} \tag{3.1}$$

$$Z_s = \frac{Z_c \sin\ \theta}{\sin\ \theta_s} \tag{3.2}$$

where B_{o1} is the input admittance of the open stubs defined by

$$j\, B_{o1} = j\ \tan\ \theta_{o1}/Z_{o1}. \tag{3.3}$$

The ratio θ_s/θ represents the size reduction factor. Knowing θ, θ_s is fixed to have the desired reduction. The equivalent transmission line of Fig. 28(b) is a filter, so the cutoff frequency has to be considered. The authors of [7] show that $\theta = 30^\circ$, $\theta_s = 12.5^\circ$ associated with 50 Ω stubs allows wide-band applications as well as high cutoff frequency. Thus, the quarter-wavelength lines would be split into 3 segments.

3.4 Concluding remarks

Three microstrip 90° hybrids have been simulated around 1.37 GHz on FR4 substrate using different geometries. The first one is the conventional branch-line hybrid. Its size is 29.3 x 39.5 mm^2 and a 3-dB coupling with maximum amplitude unbalance of less than 0.2 dB between 1.32 and 1.47 GHz. Over this frequency band, the phase variation is 2° ($\pm 1^\circ$).

To reduce the size, the lumped distributed elements method has been investigated. The size has been approximately divided by two with the second iteration of the Sierpinski fractal geometry. Compared to the conventional branch-line hybrid, similar simulation results have been obtained on a 30-mil FR4 substrate.

Finally, the lumped distributed elements miniaturization technique has been described. As for the fractal geometry technique, the size is divided by two, approximately, but here the length is reduced.

4 Conclusions and future work

Investigations into the miniaturization of 3-dB / 90 and 180° power splitters have been reviewed in this report. Several circuits and miniaturization techniques have been presented and used in the design of microstrip splitters.

Concerning the 3-dB / 180° splitters, two miniaturized microstrip circuits have been designed using two different methods. The first one is a Moore 2nd iteration fractal ring hybrid, of size $23\ x\ 28\ mm^2$ (23 % of the conventional ring hybrid area) with similar performance over the 1.15-1.6 GHz frequency band. Over this band, characterization has shown a maximum 3-dB coupling imbalance of 1 dB and an output phase difference varying by 22° (± 11°). The second proposed circuit is an H-shaped aperture-coupled transition, of compact size and wide frequency bandwidth. Its size is $23\ x\ 30\ mm^2$, including the slot and matching network. Measurements revealed a maximum 3-dB imbalance of 0.3 dB and an output phase difference fluctuation of 1° (± 0.5°) over the 1.15-1.6 GHz band.

Characterization of the aperture-coupled transition involves some fabrication difficulties. For instance, the bonding film masks holes made for the probes, and pad associated with via holes are needed to access the ground for probe implantation. Technological solutions have been found but a longer design time is required during the circuit fabrication process.

Regarding the 90° splitters, two miniaturization methods have been investigated to reduce the size of a branch-line hybrid. The first technique is based on fractal geometries as for the 180° splitter. A Sierpinski 2nd iteration fractal branch-line hybrid has been simulated and showed a coupling imbalance of 0.4 dB and a phase difference variation of 1° (± 0.5°) over a 10 % bandwidth. Its size is about 50 % of the area of the branch-line hybrid. The second miniaturization technique that has been investigated is founded on lumped distributed elements to reduce the size of a microstrip line. The possible size reduction is 50 % as well.

Regarding future work, it is planned to do some tests with a substrate with dielectric losses lower than the FR4 substrate to see if the insertion loss could be improved. Moreover, other techniques can further reduce more the size of the circuits. For instance, coupled lines are integrable using Low Temperature Co-fired Ceramic (LTCC). Finally, the presented results concern narrowband circuits; for broad frequency band applications, the obtained performances are not sufficient, and the studied methods could be investigated as well to design wide-band circuits.

References

[1] K. Chang, editor (2005), Encyclopedia of RF and microwave engineering (pp. 1925-1935), John Wiley & Sons, Inc.

[2] Hirota, T., Minakawa, A., and Muraguchi, M. (1990), Reduced-size branch-line and rat-race hybrids for uniplanar MMICs, *IEEE Trans. Microwave Theory Tech.*, 38(3), 270–275.

[3] Ahn, H. R., Chang, I. S., and Yun, S. W. (1994), Miniaturized 3-dB ring hybrid terminated by arbitrary impedances, *IEEE Trans. Microwave Theory Tech.*, 42(12), 2216–2221.

[4] Eccleston, K. W. and Ong, S. H. M. (2003), Compact planar microstripline branch-line and rat-race coupler, *IEEE Trans. Microwave Theory Tech.*, 51(10), 2119–2125.

[5] Ghali, H. and Moselhy, T. A. (2004), Miniaturized Fractal Rat-Race, Branch-Line, and Coupled-Line Hybrids, *IEEE Trans. Microwave Theory Tech.*, 52(11), 2513–2520.

[6] Ghali, H. and Moselhy, T. A. (2004), Design of Fractal Rat-Race Coupler, *in Proc. of International Microwave Symposium Digest MTT-S*, 1, 323–326.

[7] Chun, Y.-H. and Hong, J.-S. (2006), Compact Wide-Band Branch-Line Hybrids, *IEEE Trans. Microwave Theory Tech.*, 54(2), 704–709.

[8] Pozar, D. M. (2005), Microwave Engineering (3rd edition), John Wiley & Sons, Inc.

[9] O. Lafond, O. Vendier Y. Cailloce, M. Himdi (2005), Thick-slot transition and antenna arrays in the Q band, *Microwave and Optical Technology Letters*, 44(1), 24–29.

[10] Pozar, D. M. and Targonski, S. D. (1991), Improved coupling for aperture coupled microstrip antennas, *Electronics Letters*, 27(13), 1129–1131.

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This document reports on the analysis and design of miniaturized 3-dB / 90° and 180° power splitters. Several miniaturization techniques are presented, and were applied to the design of microstrip splitters.

Concerning the 3-dB / 180° splitters, two miniaturized microstrip circuits have been designed using two different methods. The first one is a Moore 2nd iteration fractal ring hybrid, of size $23\ x\ 28\ mm^2$ (23 % of the conventional ring hybrid area) with similar performance over the 1.15-1.6 GHz frequency band. Over this band, characterization has shown a maximum 3-dB coupling imbalance of $1\ dB$ and an output phase difference varying by 22° ($\pm\ 11^\circ$). The second proposed circuit is an H-shaped aperture-coupled transition, of compact size and wide frequency bandwidth. Its size is $23\ x\ 30\ mm^2$, including the slot and matching network. Measurements revealed a maximum 3-dB imbalance of $0.3\ dB$ and an output phase difference fluctuation of 1° ($\pm\ 0.5^\circ$) over the 1.15-1.6 GHz band.

Regarding the 90° splitters, two miniaturization methods have been investigated to reduce the size of a branch-line hybrid. The first technique is based on fractal geometries as for the 180° splitter. A Sierpinski 2-nd iteration fractal branch-line hybrid has been simulated and showed a coupling imbalance of $0.4\ dB$ and a phase difference variation of 1° ($\pm\ 0.5^\circ$) over a 10 % bandwidth. Its size is about 50 % of the area of the branch-line hybrid. The second miniaturization technique that has been investigated is founded on lumped distributed elements to reduce the size of a microstrip line. The possible size reduction is 50 % as well.

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