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A Novel Compact Feeding Network for Array Antenna

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Abstract—A novel feeding network is investigated both theoretically and experimentally. The proposed system with combination of a Wilkinson power divider and two branch-Line couplers is established. The output signals of the system have the same amplitude and 90° phase difference with each other. The size reduction technique is applied to minimize the physical size of the proposed network. In this technique, the ground of the structure is defected, and distributed capacitors and inductors are added to empty space of the branch-line couplers. Moreover, meandered lines are used in order to match the output impedance of the Wilkinson power divider arms and reduce its size. The initial design realized in 2.5 GHz shows the fractional bandwidth of 24%. Then a miniaturized structure is fabricated with 42% smaller size than the main structure while it shows similar electrical performance. For both cases, measurement and simulation results are in good agreement with each other.

1. INTRODUCTION

The demand on the development of microwave compact components, such as couplers and power dividers in communication systems, has been increased, recently. These kinds of devices play an important role in today's communications systems. In order to reach the requirements of telecommunication systems, various techniques and methods have been used to create different types of feeding networks such as sequential rotation and series-parallel feeding network and feeding networks based in CORPS, Butler matrix, etc. [1, 2–17]. In [2], a feeding network consists of seven quarter-wavelength transformers linked together in a sequential rotation manner with alternative parallel and series connection to form a front-port network. In [3], a microstrip-feed network is presented which has a 180° ring hybrid coupler, two 90° hybrid (branch-line) couplers and a delayed line on the topside of the antenna. A meta-lines based feeding network is also investigated in [4] that consists of two anti-parallel quadrature power splitters connected by a 180° out-of-phase power splitter. The Butler matrix, another type of feeding network, is a corporate multiple beam feed. Butler matrix is usually designed with an equal number of input (beam) and output (antenna) ports ($N \times N$) [16].

In this project, a system which has four outputs with the same magnitude and 90° phase-difference is presented. The proposed structure consists of two branch-line quadrature hybrid couplers which are connected to each other by a Wilkinson power divider. A hybrid branch-line coupler shows 90° phase differences between output signals with equal amplitudes. These features make it a very useful component. On the other hand, power divider is a well-known three-port device which gives two equal outputs and provides high isolation between outputs [5]. In addition, all of its ports can be matched. As depicted in Fig. 1, a power divider produces two outputs with same amplitude and 180° phase difference. Output powers of a power divider are applied to couplers. Each coupler has two outputs with 90° phase-difference. The first coupler receives a power with 0° phase and divides it into two equal powers with 0° and 90° phases, and the second one converts 180° input power to two outputs with 180° and 270° phases. So a network with one input and four outputs is designed.

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Table 1. Dimension of the structure in Fig. 2(a) (mm).

symbol	value	symbol	value	symbol	value
$L1$	7.1	$L12$	3.9	d	15.4
$L2$	17.5	$L13$	2.8	e	7.7
$L3$	17.5	$L14$	3	$W1$	1.1
$L4$	16.6	$L15$	2	$W2$	1.1
$L5$	17.5	$L16$	6.7	$W3$	2
$L6$	13.7	$L17$	0.27	$W4$	1.1
$L7$	3	$L19$	4.6	$W5$	1.1
$L8$	4.1	a	72.2	$W6$	0.6
$L9$	4.1	b	31.7	$W7$	0.6
$L10$	4.1	c	28.8	$W8$	1.6
$L11$	4.1	$L20$	6		

Table 2. Dimension of the structure in Fig. 3 and Fig. 4 (mm).

symbol	value	symbol	value	symbol	value
d_1	7.1	t_2	1.1	x_{19}	0.4
d_2	11	t_3	2	x_{20}	2.2
d_3	6	t_4	0.9	x_{21}	0.75
d_4	11	t_5	1.66	x_{22}	1.1
d_5	3.2	t_6	0.58	x_{23}	1.3
d_6	5	t_7	1.08	x_{24}	3.95
d_7	4.48	t_8	0.58	x_{25}	0.55
d_8	1.7	x_1	3.75	x_{26}	2.8
d_9	2.7	x_2	1.1	x_{27}	2.7
d_{10}	1.7	x_3	1.35	G_1	3.55
d_{11}	5.5	x_4	0.221	G_2	6.19
d_{12}	1.5	x_5	0.8	G_3	3.44
d_{13}	4	x_6	0.75	G_4	6.04
d_{14}	4.4	x_7	2.6	G_5	7.64
d_{15}	5.84	x_8	2.2	G_6	7.84
d_{16}	2.08	x_9	0.6	G_7	6.34
d_{17}	3.2	x_{10}	0.2	g_1	2.2
d_{18}	5	x_{11}	0.2	g_2	0.75
d_{19}	0.55	x_{12}	0.2	g_3	0.15
k	54.8	x_{13}	0.4	g_4	0.4
n	21.2	x_{14}	0.6	g_5	0.2
m	25.2	x_{15}	0.429	g_6	2
p	12.4	x_{16}	0.4	g_7	0.2
s	8.2	x_{17}	1.3	g_8	0.6
t_1	1.1	x_{18}	1.8	g_9	0.4
g_{10}	0.2				

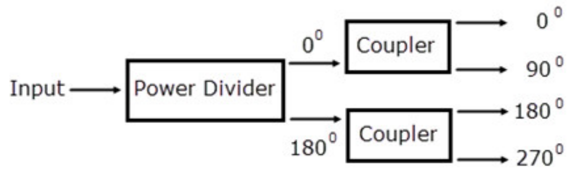

Figure 1. Block diagram of proposed structure.

2. DESIGN PROCEDURE

The layout of the feeding network is shown in Fig. 2(a). These couplers and power divider are made of microstrip lines with different impedances. A branch-line hybrid coupler has four $\frac{\lambda}{4}$ transmission lines wherein one pair has characteristic impedances of 35.4 Ω and the other pair has 50 Ω characteristic impedances. In this structure, two couplers are connected to output arms of the power divider. In fact, the power divider gives the signals with equal amplitudes and 180° phase differences to couplers. Two branch-line couplers have been used for dividing the outputs of the power into four equal outputs with the relative phases of 0°, 90°, 180°, 270°.

The substrate used is Ro4003 with a thickness of 0.508 mm, relative dielectric constant of $\epsilon_r = 3.55$

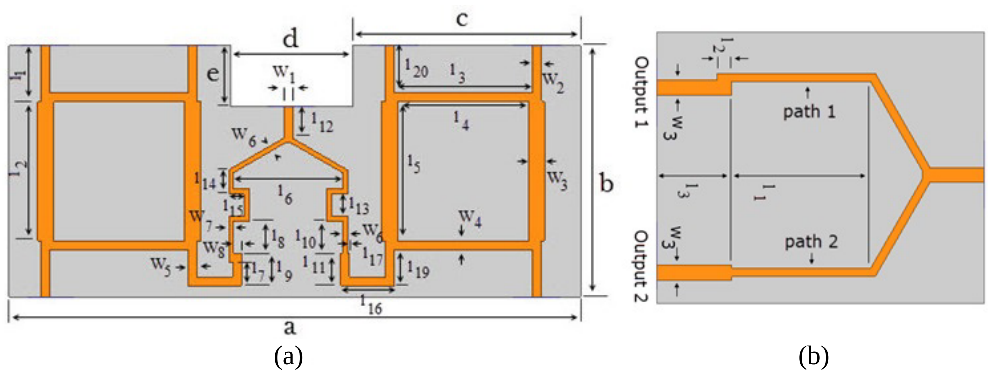

Figure 2. (a) Configuration of proposed system. (b) Wilkinson power divider with 180 phase difference.

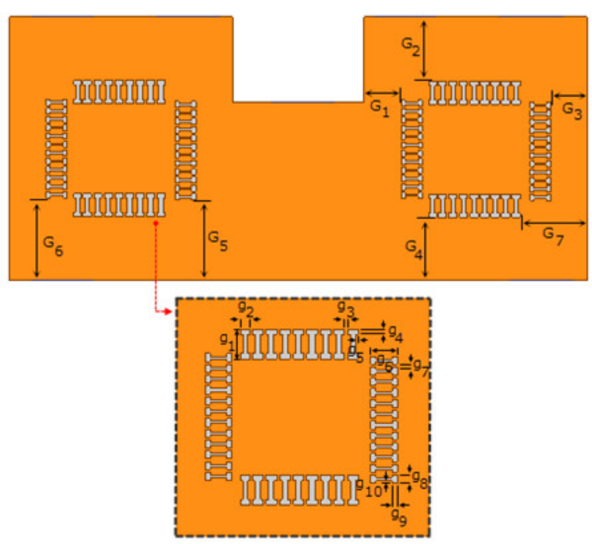

Figure 3. Bottom of the miniaturized structure.

and $\tan\delta = 0.0027$. In most cases, power dividers provide equal amplitude and 0° phase difference. In Wilkinson power divider, outputs are also in phase. In this article, a Wilkinson power divider with 180° phase difference in outputs is presented (Fig. 2(b)). Path 1 is about 1.1 mm longer and 0.6 mm wider than path 2 (in $l2$ section). The arms of the proposed power divider in the shown part ($l2$) have different lengths and widths, which result in 180° phase difference. Based on $\theta = \beta L$, altering L changes θ, also changing W which affect Z_0 and result in 180° phase difference. Finally, both outputs have about $50\Omega \pm 1$ impedance. The length and width of $l2$ do not affect the impedance matching because $l2$ is very small in size, and it just alters the phase. So by changing both length and width, 180° phase difference is achieved. The amount of width and length are achieved by optimization.

The dimensions of couplers and power divider are presented in Table 1 according to Fig. 2(a). The system in Fig. 2(a) is composed of two branch-line couplers which occupy a large area especially at low frequencies as 2.5 GHz. In the next step, the size of the structure is decreased. There are several methods to minimize the coupler's size such as π-equivalent model [5, 6], T-shaped structure [7], dual TLs [8], quasi-lumped elements [9, 10], and fractal structure [11]. Defected Ground Structure (DGS) [12] and loading the transmission lines of couplers with inductance (L) and capacitance are used to reduce the size of the system. The dimensions are listed in Table 2. This technique is used on the ground face of the couplers of the feeding network which is shown in Fig. 3. Two different sizes of dumbbell shape DGS have been used in order to get a better result.

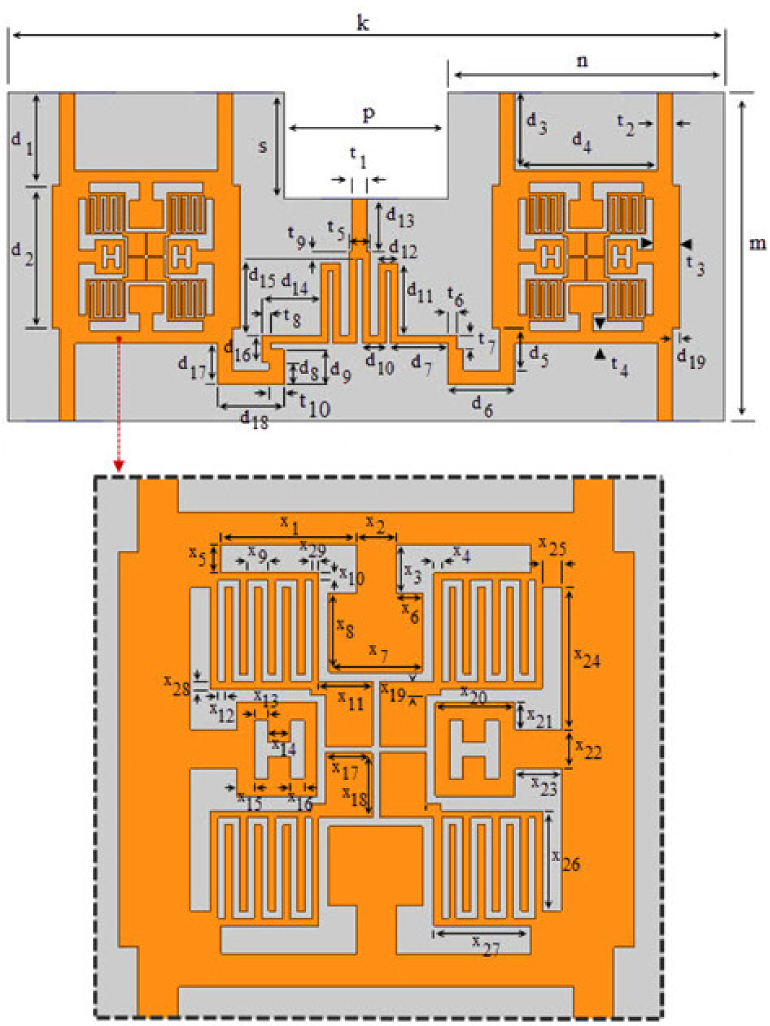

Figure 4. The structure of miniaturized feeding network.

According to the formulas below, v_p (Phase velocity) decreases by increasing L (inductance per unit length) and C (capacitance per unit length). The values of L and C must be increased with the same ratio in order to keep the value of Z_0 constant. The wavelength λ is also decreased with the mentioned condition, and the size reduction will be achieved.

$$\lambda = \frac{v_p}{f} \quad (1)$$

$$v_p = \frac{1}{\sqrt{LC}} \quad (2)$$

$$Z_0 = \sqrt{\frac{L}{C}} \quad (3)$$

By using these two methods, the size of the feeding network is decreased about 42%. The miniaturized structure is indicated in Fig. 4. Using a meander microstrip-line is a way to make the whole size of a system compact [13]. The size reduction of the Wilkinson power divider was achieved by folding the quarter-wave transmission lines into tightly coupled meander line. The first one occupies 15.4 mm × 21.5 mm, and the second one occupies 15.4 mm × 13.1 mm which shows nearly 40% size reduction. Because of the space needed for attaching the connectors, further size reduction is impossible.

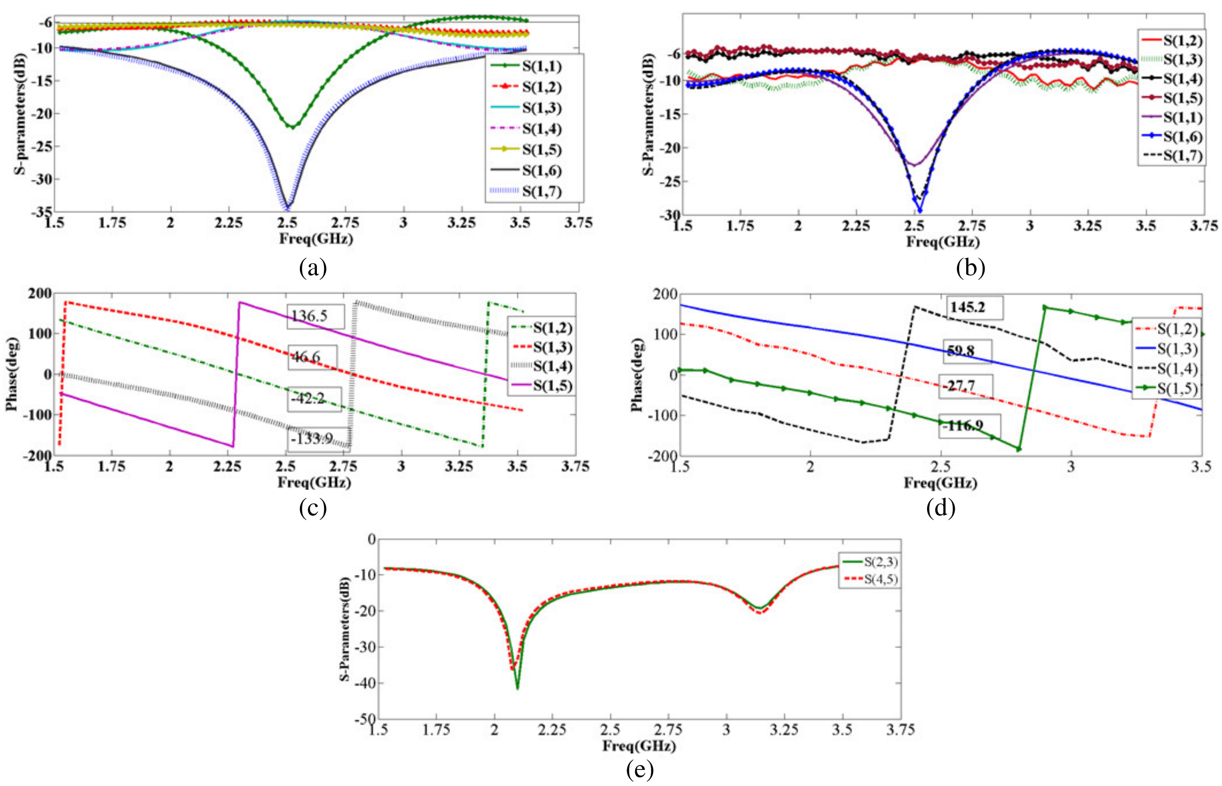

Figure 5. The first structure S-parameters, (a) magnitude simulation results, (b) magnitude measurement results, (c) phase simulation results, (d) phase measurement results, (e) isolation between ports.

3. MEASUREMENT AND SIMULATION RESULTS

Scattering parameters are measured over the frequency range from 1.5 GHz to 3.5 GHz. Each arm of the mentioned power divider has an impedance of 50 ohms and equal length that connected to the inputs of the couplers, with 50 ohms impedance which is needed for impedance matching. Both feeding networks have fractional bandwidth of 24%. Fig. 5 shows the simulation and measurement results of the first structure. Input return loss of the main network is less than −20 dB in both measured and simulated results. There are acceptable isolations between output ports as shown in Fig. 5(e). The main output level is about −6 dB, and phases of outputs are 136.5°, 46.6°, −42.2° and −133.9°, respectively, which show about 90° phase differences. Each coupler of the main network occupies 19.7 mm × 20.6 mm. In the second network, a size reduction about 42% is achieved. When the reduction techniques are used, the size of each coupler reaches 13.2 mm × 14.3 mm. According to Fig. 6, the small-sized structure has the outputs of nearly −6 dB, and the phases of outputs are 164.7°, 74.6°, −16.1°, −105.5°. The measured phases are 126.5°, 43°, −43.3°, −129.6° at 2.5 GHz that show about ±6° phase error. The return loss of input is better than −20 dB. Isolation ports of the system have reasonable responses in measurement about −16 dB. Finally, the top of the fabricated structures and bottom of them are illustrated in Fig. 7 and Fig. 8, respectively.

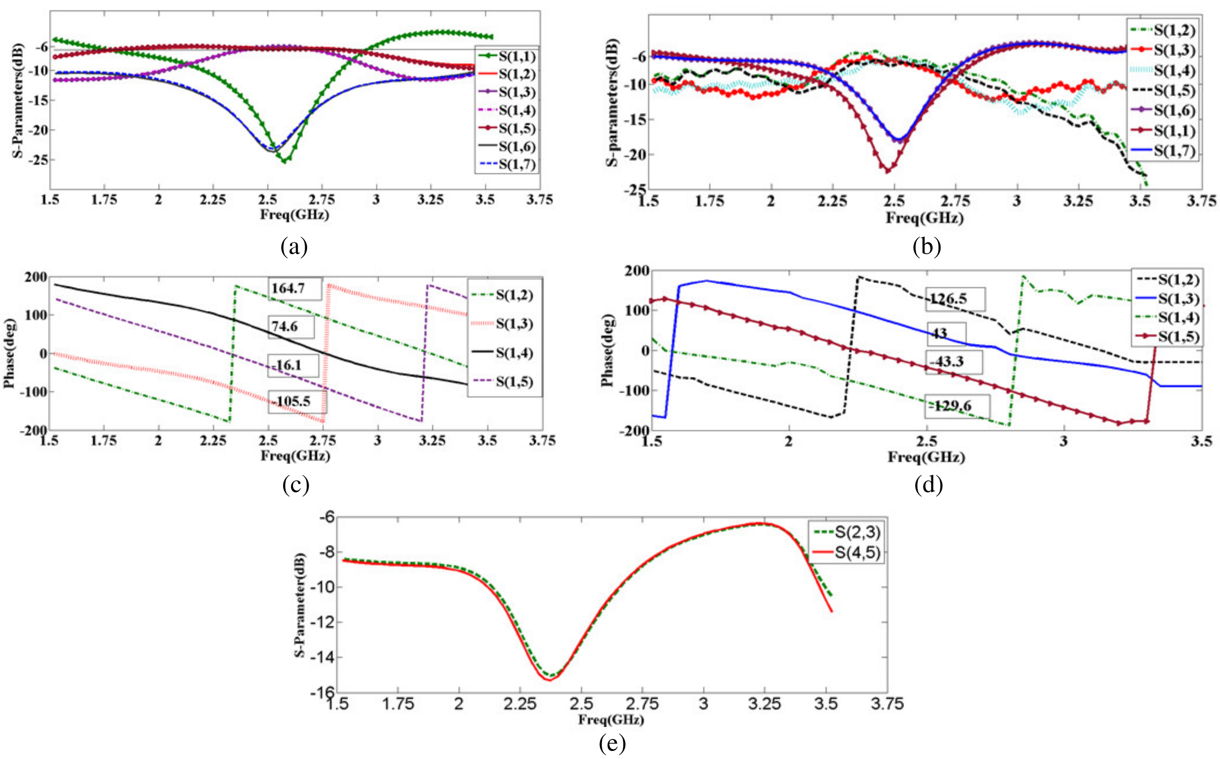

Figure 6. The results of the miniaturized structure S-parameters, (a) magnitude simulation results, (b) magnitude measurement results, (c) phase simulation results, (d) phase measurement results, (e) isolation between ports.

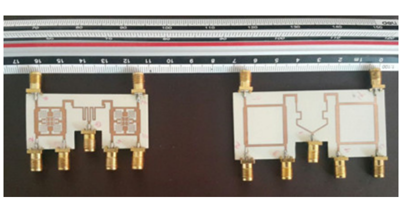

Figure 7. Top of the proposed structures.

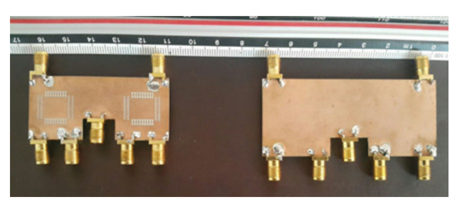

Figure 8. Bottom of the proposed feeding networks.

4. CONCLUSION

In this paper, a novel reduced-size feeding network is presented. The size reduction is achieved in the light of the DGS, and inductance and capacitance per unit length increment is 42%. This new form is established with a Wilkinson power divider and two branch-line couplers. The measurement results show four outputs with the same magnitudes and 90° phase differences. The fractional bandwidth is about 24% (2.2 GHz–2.8 GHz). Therefore, the proposed structure is a suitable solution for an array antenna feeding network.

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