BRIEF PAPER

Isolation Enhanced Multiway Power Divider for Wideband (4:1) Beamforming Arrays

Dooheon YANG[†a)], ***Student Member***, **Minyoung YOON**[†], ***and*** **Sangwook NAM**[†], ***Nonmembers***

SUMMARY This paper proposes a multiway power divider for wideband (4:1) beamforming arrays. The divider's input reflection characteristic (S11) is achieved using a multisection stepped-impedance transformer. Moreover, the divider's isolation (S32) bandwidth is increased by incorporating inductors and capacitors in addition to the conventional resistor only isolation networks of the divider. The analysis of the proposed divider and comparison with the previous research model was conducted with four-way configuration. A prototype of a wideband eight-way power divider is fabricated and measured. The measured fractional bandwidth is about 137% from 1.3 to 6.8 GHz with the −10 dB criteria of input reflection (S11), output reflection (S22) and isolation (S32) simultaneously.
key words: *bandwidth optimization, beamforming array, isolation bandwidth, wideband multiway power divider*

1. Introduction

Power dividers are important and basic microwave components and the Wilkinson power divider is the most well-known for two-way power division [1].

For array antenna systems more than two outputs, design schemes for multiway power dividers have been proposed [2], [3]. As a basic scheme, cascading Wilkinson power dividers was widely used with optimum interconnection lines [2]. After few years, a different scheme was suggested which can utilize the interconnection line as matching sections [3]. Above two schemes are mainly focused on the input return loss characteristic of the divider, but the isolation characteristic of the divider is also important for wideband beamforming arrays so that the signal from one port cannot be interfered from another to manipulate the beam direction without distortion [4].

In point of the Wilkinson power divider, there have been researches to incorporate elements such as inductors (L), capacitors (C) and transmission lines in isolation network of the divider in order to improve the characteristics of the divider [5], [6]. These kinds of concepts are well verified for the Wilkinson power divider, but to the author's knowledge, there have been no attempts to apply these techniques to multiway power dividers.

In this work, we propose an isolation bandwidth enhanced multiway power divider for wideband beamforming arrays which requires more than 4:1 bandwidth. The divider's input reflection (S11) is achieved by transforming the divider into stepped impedance transformers and isolation (S32) bandwidth is improved incorporating L and C in addition to the conventional R only isolation network of the divider.

The divider is analyzed with a four-way configuration to easily verify the proposed design scheme. However, this method can also be extended to eight and sixteen-way dividers also. The details of the proposed divider and experimental results are presented and discussed.

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[†]The authors are with the Institute of New Media Communication (INMC), School of Electrical and Computer Engineering, Seoul National University, Seoul, 151–742 Korea.
a) E-mail: doohuyn@ael.snu.ac.kr
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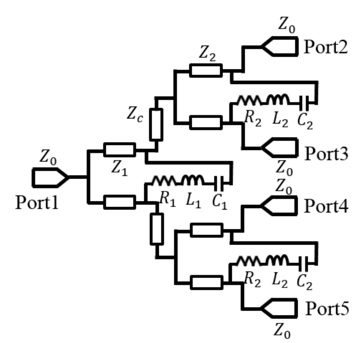
2. Proposed Multiway Power Divider

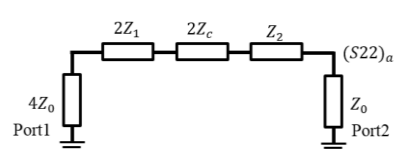
2.1 Input Impedance Characteristic Design

Figure 1(a) shows the schematic of the proposed divider, composed of two-way one-section dividers and their interconnection lines. The unit divider's isolation network is composed of series RLC components. The rectangular components in this schematic represent quarter-wavelength sections with different impedances.

The input characteristic of the proposed divider is designed with even-even mode equivalent circuit which is based on the work [3] as shown in Fig. 1(b). The $(S22)_a$



(a)



(b)

Fig. 1 (a) Schematic of the proposed four-way power divider. (b) Even-Even mode equivalent circuit of the divider of Fig. 1(a).

in this figure means the S-parameter of the even-even mode equivalent circuit seen from port 2. This equivalent mode circuit is same with the three-section stepped-impedance transformer, which transforms the impedance of port 2 (Z_0) into the impedance of port 1 ($4Z_0$) through three quarter-wavelength sections with impedances of $2Z_1$, $2Z_c$ and Z_2.

The determination of the section impedances of the stepped-impedance transformer is well described in the previous paper [7]. From the data of the three-section stepped-impedance transformer, the section impedances of the divider are determined as follows. $Z_1 = 1.51252Z_0$, $Z_c = Z_0$ and $Z_2 = 1.3222Z_0$ when the ripple of the return loss is set to 20 dB (VSWR < 1.22). With the above procedure, the proposed divider's input reflection (S11) characteristic can be designed at the desired frequency bandwidth.

2.2 Isolation Bandwidth Enhancement

The proposed divider in Fig. 1(a) has lumped L and C in the isolation network in addition to R which was the only component placed in the isolation network of the divider in [3]. With these L and C, we obtained enhanced isolation bandwidth characteristic. The effect of these additional elements can be analyzed with even-odd mode analysis.

The proposed divider's even-odd mode and x-odd mode equivalent circuits are shown in Fig. 2. Since the L and C in the isolation network of the divider have no effect on the even-even mode circuit in Fig. 1(b), they do not affect the S11 of the divider. However, as they are shown in the odd-even mode and x-odd mode equivalent circuit, they affect the characteristics of the divider which are seen from the output ports (S22, S32). The S-parameters of the equivalent circuit according to the excitation modes are given as $(S_{22})_b$ and $(S22)_c$.

Using the superposition of the even-even mode, odd-even mode and x-odd mode equivalent circuit characteristics, the S-parameter seen at the output ports (S22, S32) of the proposed divider can be expressed with following equations.

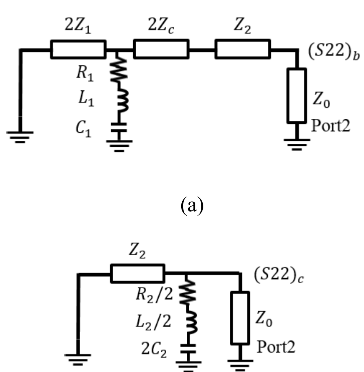


Fig. 2 Equivalent circuits of power divider in Fig. 1(a) due to each excitation mode. (a) Odd-Even mode. (b) X-Odd mode.

$$S22 = \frac{(S22)_a}{4} + \frac{(S22)_b}{4} + \frac{(S22)_c}{2} \quad (1)$$

$$S32 = \frac{(S22)_a}{4} + \frac{(S22)_b}{4} - \frac{(S22)_c}{2} \quad (2)$$

Due to the additional L and C in the isolation network of the proposed divider, the second and third terms on right hand side of (1) and (2) have an extra degree of freedom. The input impedances seen from port 2 of Fig. 2(a) and Fig. 2(b) can be controlled with additional frequency dependent elements (L, C), so that can obtain wideband matching characteristic. However, the divider suggested in previous research [3], the second and third terms on right hand side of (1) and (2) were only matched at the center frequency by R_1 and R_2. To verify this, the S-parameters of Fig. 2(a) and Fig. 2(b) with series RLC isolation network and R only isolation network are plotted in Fig. 3 when these two dividers are designed at the center frequency of 4 GHz.

As mentioned above, the narrow matching characteristic near center frequency of the conventional divider has changed into wider matching characteristic with the RLC isolation network, since $(S22)_c$ which is the dominant term in (1) and (2) has two poles on the border of the bandwidth and keeps good matching with lower than −10 dB from 1.4 to 6.8 GHz.

The value of the resistor for R only isolation network is adopted from the data of [3] in the case of one quarter-wavelength interconnection line.

The values of RLC elements of the proposed divider are obtained with ADS (Advanced Design System) optimization so that each equivalent mode circuits have the widest matching bandwidth. We have derived the input impedance equation seen from port 2 of Fig. 2(a) and Fig. 2(b) but it was too complex to obtain optimum RLC values analytically. So optimization using commercial tool is used to get the optimum values of RLC for the enhancement of isolation bandwidth and the optimized RLC values of proposed divider are listed in Table 1.

With this data, we compared the overall performance of our proposed four-way power divider of Fig. 1(a) and the divider of previous work [3] in Fig. 4. The simulation of the divider performance was conducted with ADS circuit simulation and both dividers are designed to operate having center frequency of 4 GHz. The impedances of the transmission

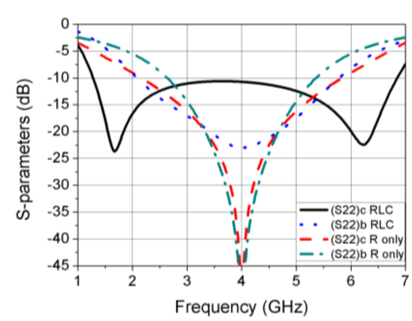


Fig. 3 Simulated $(S22)_b$ and $(S22)_c$ of the proposed divider and the divider which has R only in isolation network.

Table 1 Optimized divider component values in Fig. 1(a).

Component	Value	Component	Value
R_1	100 Ω	L_2	1.47 nH
R_2	56 Ω	C_1	1 pF
L_1	1.67 nH	C_2	1.6 pF

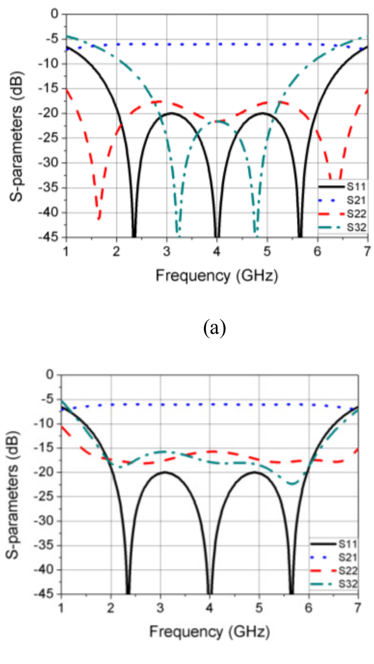


Fig. 4 Simulated four-way divider characteristic. (a) Previous work in [3]. (b) Proposed divider in Fig. 1(a).

line sections of the divider are same as notified in Sect. 2.1.

As shown in Fig. 4(a), the overall performance bandwidth of the previous divider in [3] is restricted by its isolation (S32) bandwidth. However, our proposed divider has enhanced isolation (S32) bandwidth due to additional L and C in isolation network and it is as wide as input reflection (S11) bandwidth. The expansion of the isolation (S32) bandwidth is achieved at the expens e of the degradation of output reflection (S22) level but this degradation does not affect the overall bandwidth of the divider. Additional L and C in the isolation network provide the degree of freedom to compromise these two characteristics of the divider.

3. Eight-Way Power Divider Design

With this proposed idea, we designed an eight-way power divider having a center frequency of 4 GHz and its schematic is shown in Fig. 5. The divider's even-even mode is equivalent to the eight section stepped impedance transformer and the impedances of the sections are to be introduced in following section. Optimized isolation network elements of the divider are listed in Table 2. The simulated performances of this divider are plotted in Fig. 6 and approximately 135% of operation bandwidth was obtained with input reflection (S11), output reflection (S22) and isolation (S32) simultaneously with the criteria of −10 dB. We

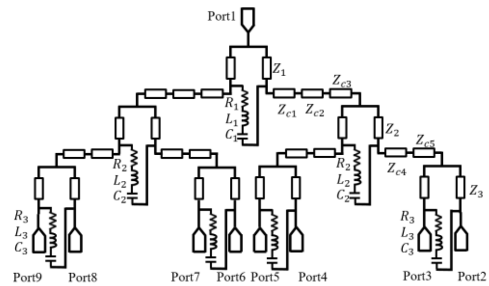


Fig. 5 Simulated eight-way power divider schematic.

Table 2 Optimized divider component values in Fig. 5.

Component	Value	Component	Value
R_1	187.27 Ω	L_3	1.31 nH
R_2	58.65 Ω	C_1	1.48 pF
R_3	66.83 Ω	C_2	1.09 pF
L_1	1.84 nH	C_3	1.82 pF
L_2	2.11 nH		

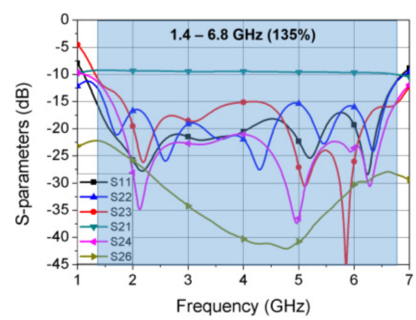


Fig. 6 Simulated eight-way divider characteristic shown in Fig. 5 when the element values are adjusted as Table 2.

define the operation bandwidth of the divider as the intersection of −10 dB of S11, S22 and S32 simultaneously. The level of S24 and S26 of the divider are under −10 dB so excluded from the operation bandwidth parameters of the divider. For the implementation of the divider, the 3D model of the divider was constructed and overall performance was simulated using commercial EM tool CST (Computer Simulation Technology).

4. Experimental Results and Discussion

To validate the design concept, the designed divider in Sect. 3 was implemented using 0.787 mm (31 mil) thickness of RT Duroid 5880 substrate. Figure 7 shows the photograph of the divider. The numbers marked on the figure indicate the counting of quarter-wavelength sections and its impedances. Dashed white rectangles represent isolation networks composed of series RLC commercial lumped elements.

Measured characteristics of the divider are plotted in Fig. 8. About 137% of the operation bandwidth from 1.3 GHz to 6.8 GHz was obtained with the −10 dB criteria of operation bandwidth. The measured S11 is degraded from the simulation result due to the non-ideal section impedances of fabricated model but other characteris-

Table 3 Comparsion with referenced multiway power dividers.

Reference	Topology	Process	S11 Bandwidth (-10 dB)	S32 Bandwidth (-10 dB)	Operation Bandwidth*
[2] (Measured)	Eight-way Cascaded Wilkinson	RO/Duroid 4003 ϵ_r = 3.38, h=0.305 mm	3 - 9 GHz (100 %)	1.5 - 8.5 GHz (116 %)	3 - 8.5 GHz (91 %)
[3] (Measured)	Four-way Stepped impedance transformer	RT/Duroid 5880 ϵ_r = 2.2, h=0.787 mm	0.4 – 1.6 GHz (120 %)	0.4 - 1.6 GHz (120%)	0.4 - 1.6 GHz (120 %)
This work (Measured)	Eight-way Isolation enhanced stepped impedance transformer	RT/Duroid 5880 ϵ_r = 2.2, h=0.787 mm	1.3 - 6.8 GHz (137 %)	1.5 - 7.2 GHz (142%)	1.3 - 6.8 GHz (137 %)

* The operation bandwidth is defined as the intersection of -10 dB input reflection (S11) output reflection (S22) isolation (S32).

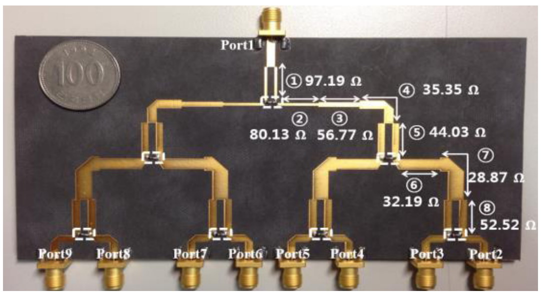


Fig. 7 Photograph of implemented eight-way power divider.

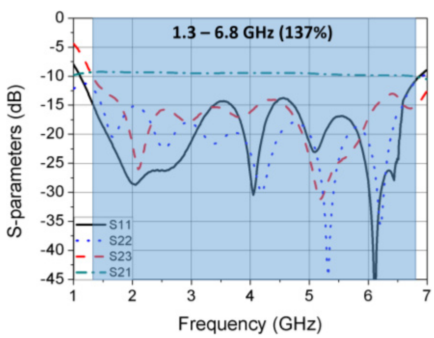


Fig. 8 Measured eight-way divider characteristic shown in Fig. 7 when the element values are adjusted as Table 2

tics are in a good agreement between the simulation and measurement. There is only one output port measurement performances of the divider shown in Fig. 8 for simplicity. However, the characteristics of the overall divider is quite uniform when seen from other output ports. Also, as could see in simulated result of the divider (Fig. 6), the measured value of S24 and S26 were so low that they do not affect the operation bandwidth of the divider thus they are omitted in measured characteristic graph (Fig. 8).

A performance comparison with referenced multiway power dividers is provided on Table 3. Since these dividers are designed in different configurations, it is hard to compare the listed divders objectively. However, the proposed divider has the widest performance bandwidth when compared with referenced works. Also, divider proposed in this work has a compact size when compared with the divider in [2], because it utlizes the interconnection line as a matching section. Additionally, it has wider isolation bandwidth when compared to the divider in [3], due to the additional L and C in isolation networks.

5. Conclusion

A design scheme for a multiway power divider was proposed which has operation bandwidth more than (4:1). Additional L and C are incorporated in the isolation network of stepped-impedance transformation divider and this leads to the isolation (S32) bandwidth enhancement. To verify the design scheme, a prototype of the eight-way power divider was implemented and wide performance bandwidth (137%) was obtained with −10 dB criteria and this validates the proposed idea.

Acknowledgments

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