Isolation Enhanced Multiway Power Divider for Wideband (3:1) Beamforming Array

Dooheon Yang[1], Byungjoon Kim[1], Kihyun Kim[1], Minyoung Yoon[1] and Sangwook Nam[1]
[1] INMC, Dep. of Electrical and Computer Engineering, Seoul National University, Seoul, Korea
doohuyn@ael.snu.ac.kr

***Abstract*—In this paper, an isolation enhanced multiway power divider for wideband beamforming array is proposed. This method is based on the concept which converts the divider into multi-section stepped impedance transformer. In addition to this scheme, lumped inductors and capacitors are incorporated in isolation networks to enhance the isolation bandwidth of the divider. In/Output reflection and isolation characteristic of the divider can be analyzed with the superposition of divider's excitation modes and its equivalent circuit characteristics. Due to additional inductors and capacitors, divider's isolation bandwidth has increased about 30% compared to resistor only divider.**

***Index Terms*—wideband multiway power divider, isolation, wideband beamforming array.**

I. INTRODUCTION

Power dividers play an important role as a RF feeding network. Wilkinson power dividers [1] are generally adopted for two-way power division. For array antenna systems more than 2 outputs, general design rules for multiway power dividers have been studied [2]-[3].

Multiway power dividers have been designed with some different schemes. As a basic scheme, cascading Wilkinson power dividers was widely used and its bandwidth can be broaden by composing unit divider with multiple quarter-wavelength sections [2]. After few years, different scheme for design of multiway power divider was suggested which can utilize the interconnection line between unit dividers as a matching section [3]. These schemes are focused on the input return loss characteristic, but the isolation characteristic is also important for wideband beamforming array so that the signal from one port cannot be interfered from another.

In point of the basic Wilkinson divider, there have been some researches to incorporate elements such as inductors, capacitors and transmission lines in the isolation network which was composed of resistor only. One of them achieved improved isolation bandwidth by putting series RLC isolation network instead of R [4]. Another approach was to improve input return loss, output return loss and isolation characteristic simultaneously by composing optimized isolation network with RLC and transmission line [5]. These studies are well verified for the Wilkinson divider but there were no attempts to apply these techniques to multiway power dividers.

In this paper, we propose an isolation enhanced multiway power divider for wideband beamforming array. Its input return loss characteristic has achieved by transforming the divider into stepped impedance transformers. The isolation characteristic of the divider has improved by putting L and C additionally in the isolation network instead of previous R only isolation network.

The analysis and the simulation of the multiway power divider are done with the four way divider for simplicity. However, it can be easily shown that the proposed method can be extended to 8 and 16-way divider also.

II. DESIGN OF A FOUR-WAY POWER DIVIDER USING STEPPED IMPEDANCE TRANSFORMATION

A four-way power divider can be constructed by cascading two-way power dividers with the interconnecting lines as shown in Fig. 1(a). The rectangular shaped components in this

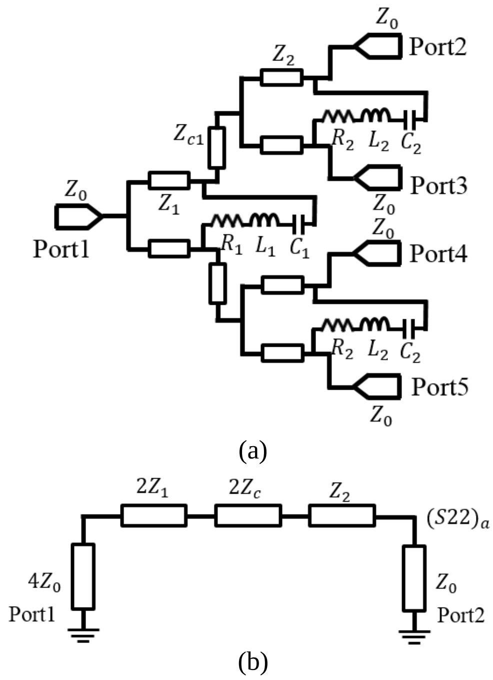


Fig. 1. (a) Schematic of the proposed four-way power divider.
(b) Even-Even mode equivalent circuit of the power divider of Fig. 1(a).

schematic stand for quarter-wavelength section. Lumped L and C are incorporated in the isolation network of each unit divider in addition to R to enhance the isolation characteristic of the divider.

As well described in the referred paper [3], the input reflection characteristic can be designed with the even-even mode equivalent circuit. When the even-even mode input and output signals are excited for the divider in Fig. 1(a), the divider can be bisected into half circuit for two times so that its equivalent circuit can be expressed as in Fig. 1(b). This equivalent circuit can be thought of a three section stepped impedance transformer which transforms the impedance of port 2 (Z_0) into impedance of port 1 $(4Z_0)$ via three quarter-wavelength sections whose impedances are $2Z_1, 2Z_c$ and Z_2

The optimum matching section impedance of stepped impedance transformer was well studied by previous papers [6]-[7], so we can determine the impedance of matching sections with the data of previous works. From the data of the three section stepped impedance transformer, the section impedances of the divider are as follows, $Z_1 = 1.5125Z_0, Z_c = Z_0, Z_2 = 1.322Z_0$ when the ripple of input reflection is set to be under -20 dB.

III. Isolation Enhancement

As mentioned in the introduction, the proposed divider has lumped L and C in the isolation network in addition to R which was the only component placed in the isolation network of usual multi-way dividers. With this L and C, we obtained enhanced isolation characteristic compared to previous work [3]. The contribution of these L and C on isolation characteristic can be analyzed by even-odd mode analysis.

When we categorize the equivalent circuits of the divider which corresponds to the eight excitation modes of the four-way power divider, we can sort into three representative equivalent circuits and S-parameters as shown in Fig 1(b) and Fig 2.

Since the lumped elements in the isolation network of the divider have no effect in the even-even mode circuit in Fig. 1(b), they do not affect S11 of the divider. As they can be seen in odd-even mode and x-odd mode circuits in Fig. 2(a) and Fig. 2(b), they affect the characteristic of the divider which is seen from the output port (S22, S32). So the S-parameters seen at the output port can be expressed by the following equations.

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

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

Above equations are superposition of the S-parameters from each equivalent circuits according to the excitation mode categories multiplied by the proportion of the categorized mode from the whole excitation modes.

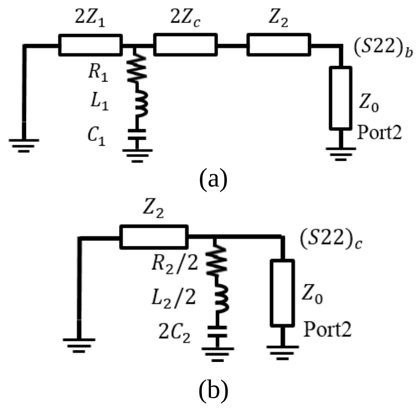


Fig. 2. Equivalent circuits of power divider in Fig. 1(a) due to each excitation modes. (a) Odd-Even mode. (b) X-Odd mode.

Due to the L and C in the first stage and second stage of the proposed divider, the second and third terms in right hand side of (1) and (2) have extra degree of freedom to obtain wideband characteristic. On the other hand, the divider suggested in previous work [3], the second and third terms in right hand side of (1) and (2) were only matched at center frequency by R_1 and R_2 which were the only component in isolation network The $(S22)_b$ and $(S22)_c$ of the proposed divider in Fig. 1(a) are compared with the divider of previous work [3] in Fig. 3.

Overall performance of previous divider and the proposed divider are shown in Fig. 4. The simulation has done with the circuit simulator ADS with ideal components. Due to the enhancement of isolation bandwidth, the divider's overall bandwidth has increased about 30 % with -15 dB criteria.

The divider's section impedances are same as described in previous section and the value of L and C of proposed divider are $L_1 = 1\,nH, L_2 = 1.487\,nH, C_1 = 1.5\,pF, C_2 = 1.4\,pF$.

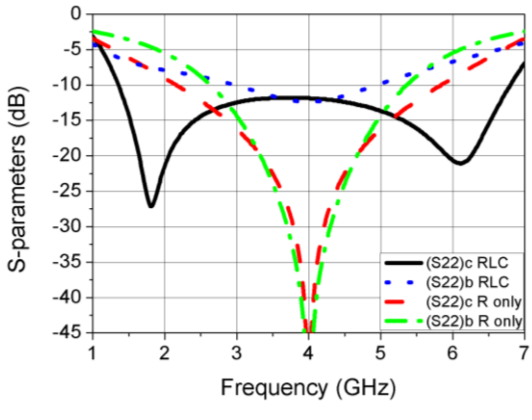
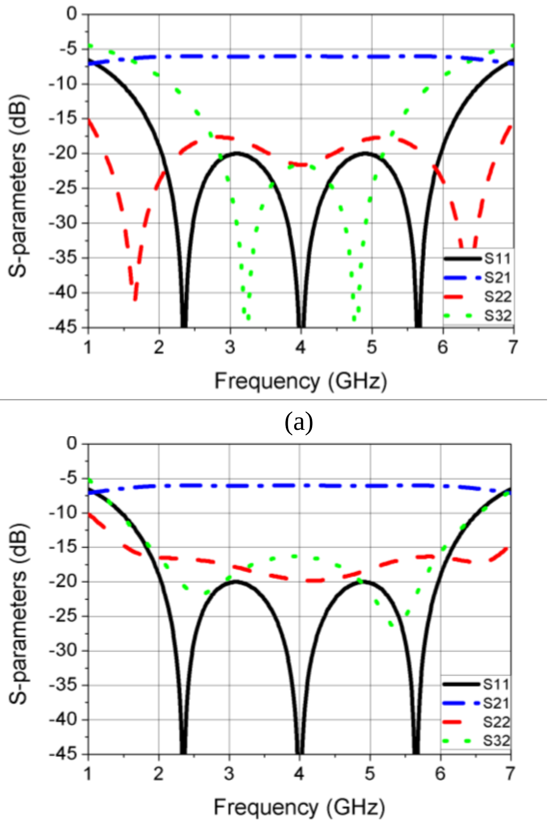


Fig. 3. Simulated (S22)b and (S22)c of the proposed divider and the divider which has R only in isolation network.



(a)

(b)

Fig. 4. Comparison of the divider characteristic. (a) Previous work in [3]. (b) Proposed Divider.

IV. Simulation of a Four-way Power Divider for Beamforming Array

To validate the design concept, a four-way wideband power divider for beamforming array model was constructed in the EM simulator as shown in Fig. 5. The divider's substrate is the 0.787 mm (31mil) thickness of Duroid 5880.

Section impedances and element values are designed with the values which are referred in previous section so that the divider operate from 2 to 6 GHz. The program CST (Computer Simulation Technology) was used for EM simulation.

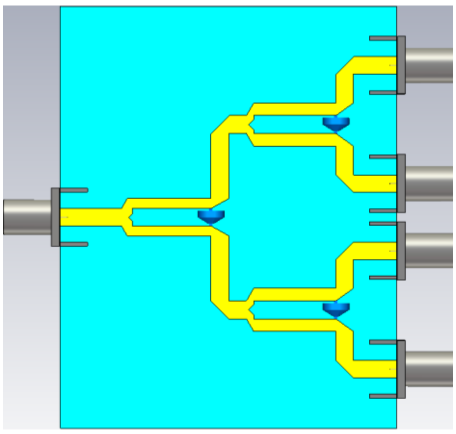


Fig. 5. Simulated EM model of the four-way power divider

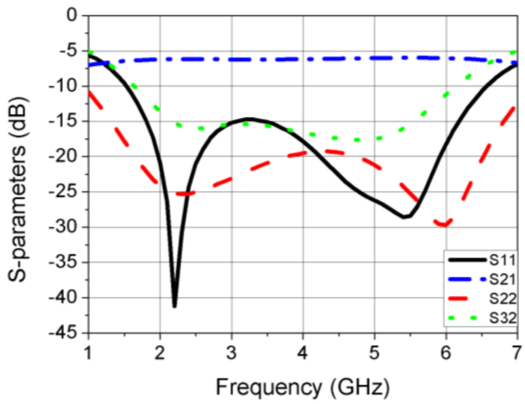


Fig. 6. Simulated divider characteristic in EM model.

Series RLC network was incorporated in the junction of the each stage of the divider to have wider isolation characteristic.

EM Simulated characteristics of the divider is shown in Fig. 6. The overall characteristic of the divider is slightly degraded from circuit simulation result because of realistic EM model environment. There is only one output port characteristic of the divider shown in Fig 6 for simplicity. However, the characteristic of the overall divider is quite uniform when seen from other output ports.

V. Conclusion

In this paper, an isolation enhanced multiway power divider for wideband beamforming array was proposed. The divider's input reflection characteristic is based on stepped impedance transformation scheme and its isolation characteristic has enhanced by putting additional L and C in isolation network.

The effect of additional L and C on isolation bandwidth enhancement was simulated with ADS and compared with the previous scheme.

For the verification of the idea, a PCB prototype of four-way power divider was simulated with EM simulator and wide performance covering more than 3:1 frequency range was measured. Performance of this work has compared with referenced multiway power dividers in Table I.

Table I. Comparison of Referenced Multiway Power Dividers and This Work

Reference	Topology	S11 Bandwidth (-10 dB)	S32 Bandwidth (-10 dB)
[2]	Multi-way Cascaded Wilkinson	3 – 9 GHz (100%)	1.5 – 8.5 GHz (116%)
[3]	Multi-way Stepped impedance transformer	0.5 – 1.5 GHz (100%)	0.5 – 1.5 GHz (100%)
This work	Multi-way Isolation enhanced Stepped impedance transformer	1.5 – 6.5 GHz (125%)	1.6 – 6.2 GHz (115%)

VI. ACKNOWLEDGEMENT

The authors gratefully acknowledge the support from Electronic Warfare Research Center at Gwangju Institute of Science and Technology (GIST), originally funded by Defense Acquisition Program Administration (DAPA) and Agency for Defense Development (ADD).

REFERENCES

[1] E.J. Wilkinson, "An N-way hybrid power divider," *IEEE Trans. Microw. Theory Tech.,* vol. MTT-8, no. 1, pp. 116-118, Jan. 1960.

[2] J. Zhou and K. A. Morris, and M,J. Lancaster, "General design of multi-way multi-section power dividers by interconnecting two-way dividers," *IEEE Trans. Microw. Theory Tech.,* vol.55, no. 10, pp.2208-2215, Oct. 2007.

[3] Y. Xu and R. G. Bosisio, "Design of Multiway Power Divider by Using Stepped-Impedance Transformers," *IEEE Trans. Microw. Theory Tech.,* vol.60, no. 9, pp.2781-2790, Sep. 2012.

[4] J. K. Kao, Z. M. Tsai, K. Y. Lin and H, Wang, "A modified wilkinson power divider with isolation bandwidth improvement," *IEEE Trans. Microw. Theory Tech.,* vol.60, no. 9, pp.2768-2780, Sep. 2012.

[5] V. Tas and A. Atalar, "An optimized isolation network for the wilkinson power divider," *IEEE Trans. Microw. Theory Tech.,* vol.62, no. 12, pp.3393-3402, Dec. 2014.

[6] L. Young, "Tables for cascaded homogeneous quarter-wave transformers," *IRE Trans. Microw. Theory Tech.,* vol. MTT-7, no.3, pp. 233-237, Apr. 1959.

[7] L. Young, "Tables for cascaded homogeneous quarter-wave transformers (correction)," *IRE Trans. Microw. Theory Tech.,* vol. MTT-8, no.3, pp. 243-244, Mar. 1960.