Broad-Banding Technique for In-Phase Hybrid Ring Equal Power Divider

Ban-Leong Ooi, W. Palei, and M. S. Leong

***Abstract*—A broad-banding technique for in-phase equal power divider is described. Detailed comparisons between the proposed variants of power dividers and the conventional in-phase power divider are also performed. Based on the 15-dB input and output return losses criteria, it is noted that a maximum impedance bandwidth of 44.3% for an amplitude error of ±0.9 dB and a phase error of ±1.8° can be achieved, for the first time, for divider with length more than $3\lambda/2$ ring impedance transformer. A systematic design technique that relaxes some of the conventional constraint in in-phase hybrid ring equal power divider design, is also described.**

***Index Terms*—Hybrid rings, in-phase equal power divider.**

I. Introduction

THE conventional broad-band in-phase equal power divider [1]–[3], also named as Gysel power divider, usually assumes the shape of a $3\lambda/2$ ring impedance transformer. The design of these conventional power dividers often requires the concurrent optimization criteria of good return loss, good isolation loss at all ports and equal power ratio between ports 2 and 3. With this concurrent set of criteria to satisfy, the resultant bandwidth based on the 15-dB input and output return loss criteria will be seriously limited to about 30% at most.

In this paper, the in-phase hybrid ring equal power divider is revised with the intention to increase the resultant bandwidth and preserving the good isolation and return loss provided by the divider. Through a relaxation of some of these criteria at certain design stages, it is noted that a much broader S_{21} bandwidth, good isolation and return losses can be achieved simultaneously. Using the 15-dB input and output return losses criteria, a new, 1.6λ hybrid ring equal power divider of a maximum bandwidth of 44.3% for an amplitude error of ±0.9 dB and a phase error of ±1.8° are obtained for the first time. To the author's knowledge, this is the largest bandwidth ever achieved to date. Numerical simulations on the proposed design are found to agree reasonably well with the measured results. Several other variants of in-phase hybrid ring equal power dividers are also investigated and compared in this paper.

II. Analyses

A Gysel power divider is made up of four $\lambda_o/4$ lines and one $\lambda_o/2$ line. The general configuration of the Gysel power divider is shown in Fig. 1. Typical methods of analysis for the Gysel power divider would include the odd and even mode analysis

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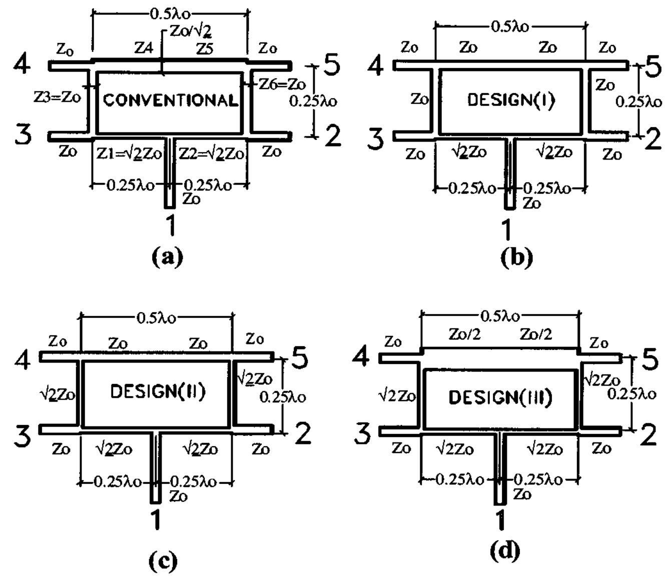

Fig. 1. Variants of Gysel power dividers with variations in arm impedances.

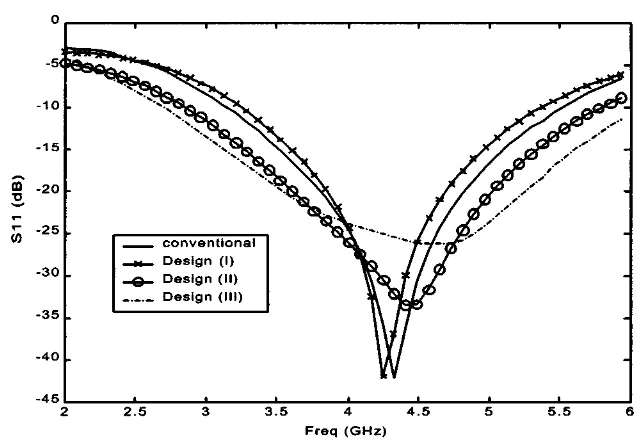

Fig. 2. S_{11} simulated results of Fig. 1.

[1], [2] or the unit elemental analysis [4]. In general, the impedances of the arms are evaluated to be

$$Z_1 = Z_2 = \sqrt{2}Z_o \tag{1}$$

$$Z_3 = Z_6 = Z_o \tag{2}$$

where Z_o is the characteristic impedance of the transmission line at port 1. Z_4 and Z_5 are usually taken as $Z_o/\sqrt{2}$ for convenience as in [2]. Through hardware verification, one typically observes that the bandwidth for this form of divider is about two times the bandwidth of the conventional hybrid ring coupler [1]. This limited bandwidth is a resultant of the fact that all ports 1–3

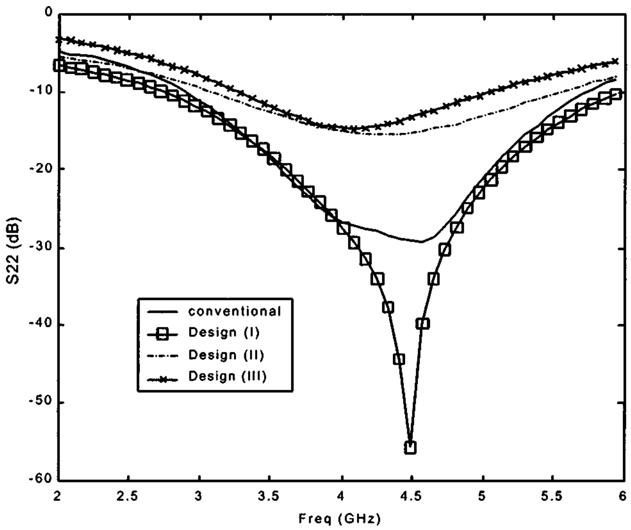

Fig. 3. S_{22} simulated results of Fig. 1.

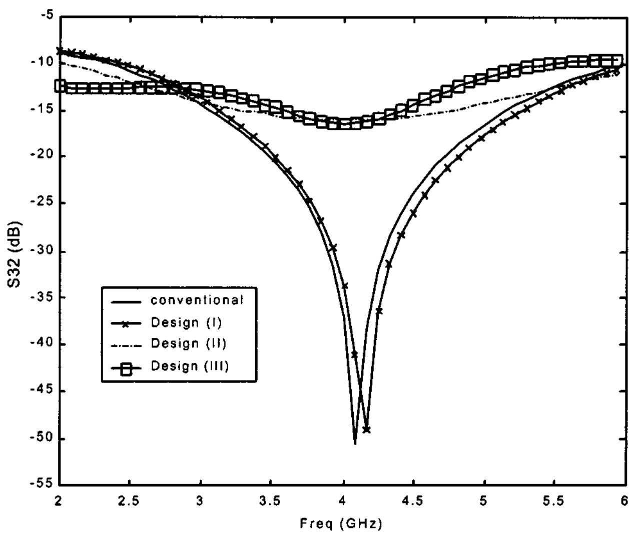

Fig. 4. S_{31} simulated results of Fig. 1.

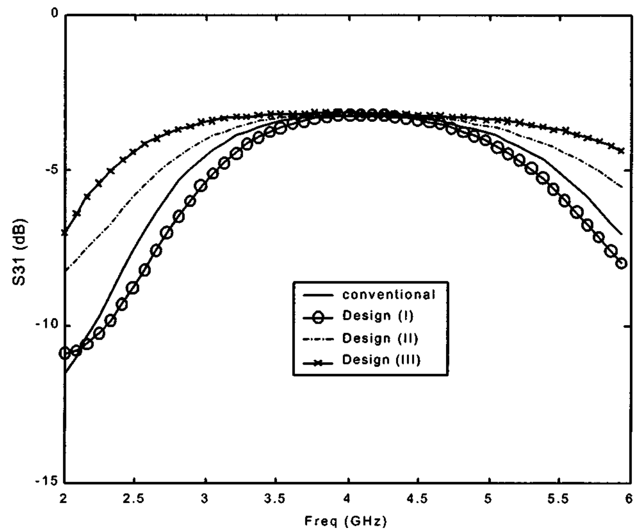

Fig. 5. S_{32} simulated results of Fig. 1.

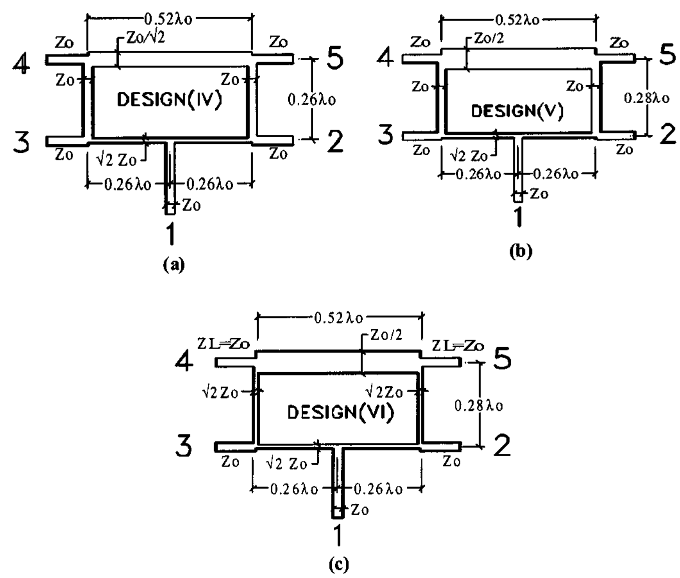

Fig. 6. Variants of Gysel power dividers with variations in the length of the ring transformer.

are to be fully matched using the stated Z_1, Z_2, Z_3 and Z_6 impedances. In addition, the odd and even mode analysis [1], [2] or the unit elemental analysis [4] does not account for the junction effects and the type of junctions adopted will seriously limit the resultant bandwidth. This fact can be visualized from the simulated HP ADS results in Figs. 2–5 for all the structures shown in Fig. 1. All results in Figs. 2–5 are simulated with the Hammerstad tee-junction model [5]. Since the structures in Fig. 1 are symmetrical, we have symmetry between S_{21} and S_{31} and thus, the result for S_{21} is not given in this paper.

In here, we have intentionally kept the overall length the same for all the structures and varied the respective arm impedances so as to investigate the effect of the impedances on the overall power divider's performance. As noted from these figures, the variation of the impedances Z_4 and Z_5 causes the overall power divider to have a smaller S_{31} bandwidth but preserves similar isolation and return losses. This salient feature is not highlighted in Mizera's paper [2] and their paper seems to imply that Z_4 and Z_5 have no effect on the overall power divider's performance. A mismatched at ports 2 and 3 such as Designs II and III, causes the divider to have a broader bandwidth for S_{31} but with a poorer isolation and return losses at ports 2 and 3.

A slight change of the overall length of the ring impedance transformer such as Designs IV–VI as in Fig. 6, is also investigated, and the measured and simulated results are presented in Figs. 7–10. From these figures, we see that Designs IV–VI have S_{31} bandwidth of 53.2%, 40.3%, and 29.4%, respectively. As compared to the conventional divider S_{31} bandwidth of about 25%, one can conclude that the increase of the overall length of the ring impedance transformer can help to improve the overall S_{31} bandwidth and isolation at all ports. The measured results and the HP ADS simulated results, as shown in the figure, agree reasonably well. Thus, with a combination of the changes in the overall length of the ring impedance transformer and the arms impedances, one can achieve an ultrawideband divider.

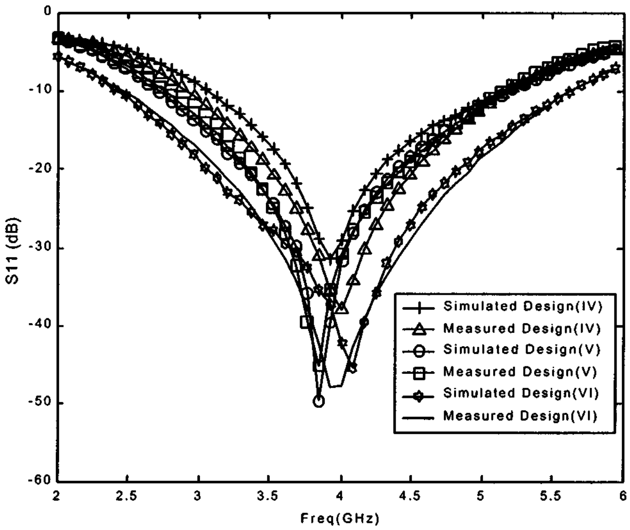

Fig. 7. S_{11} simulated results for Fig. 6.

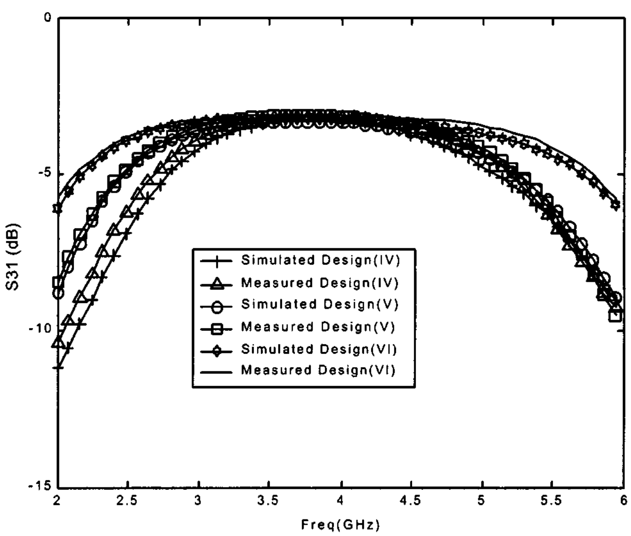

Fig. 8. S_{22} simulated results for Fig. 6.

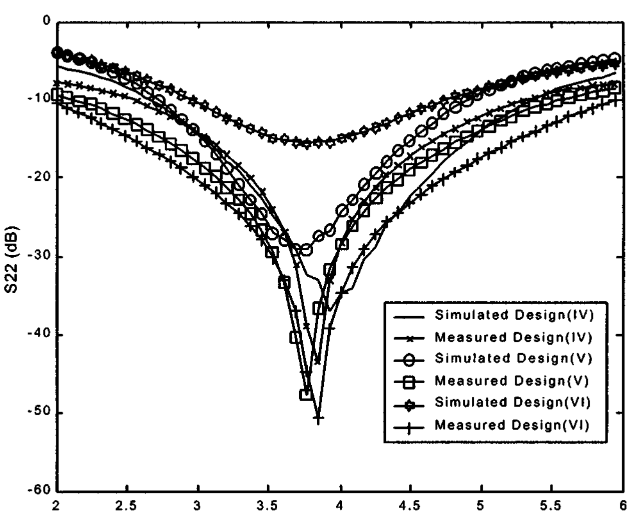

Fig. 9. S_{31} simulated results for Fig. 6.

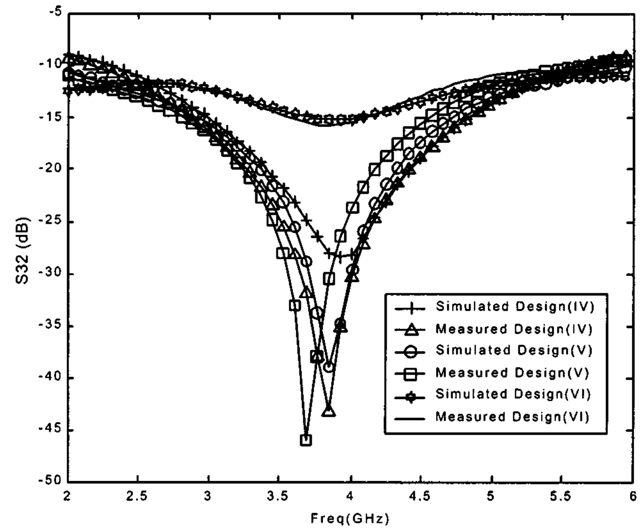

Fig. 10. S_{32} simulated results for Fig. 6.

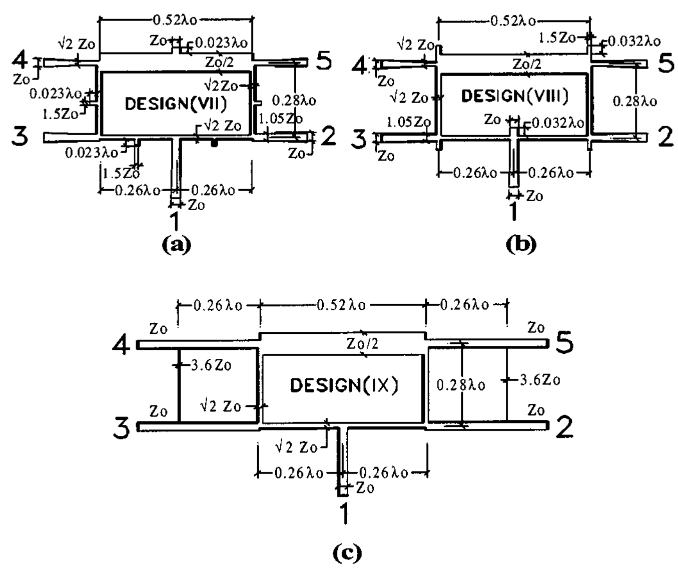

Fig. 11. Variants of Gysel power dividers with stubs and lines matching.

III. Broad-Band Design Approach

The approach of broad-band design would then be to first design the power divider with the largest S_{31} bandwidth, good isolation loss, and with reasonable return loss at port 1 at the initial stage. Subsequent matching networks are then added at ports 2 and 3 to improve the respective return losses.

Three new structures with different matching networks as in Fig. 11 are proposed in this paper. In Design VII, additional center stubs and simple tapered lines at each end of the ports are added to improve the return losses. A variation of the stub matching is given in Design VIII. Lastly, a tandem divider as in Design IX is also proposed. The structures as proposed in Fig. 11 are kept at relatively the same dimension as we would like to use the same fixture for measurement. All the physical dimensions are as shown in Fig. 11. All stubs locations are selected to make the structure symmetrical along the center line along port 1. The impedances of these stubs are prefixed to Z_o

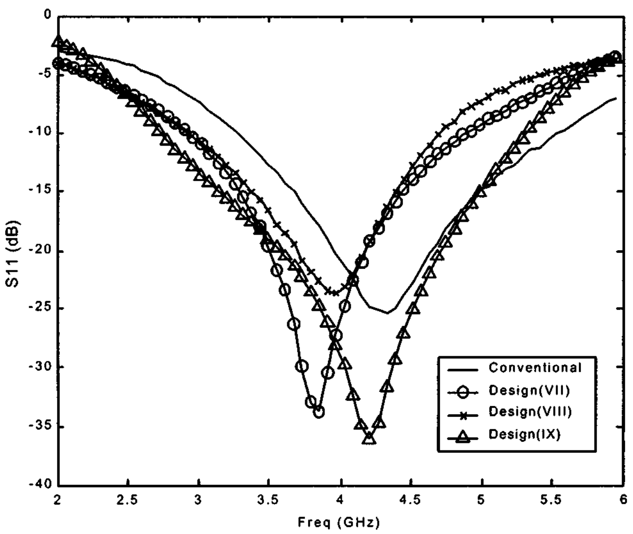

Fig. 12. Input return loss for the structures in Fig. 11.

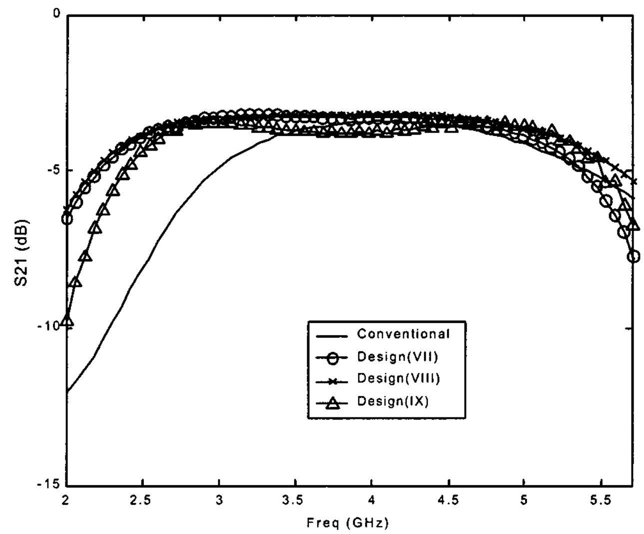

Fig. 14. S_{21} results for the structures in Fig. 11.

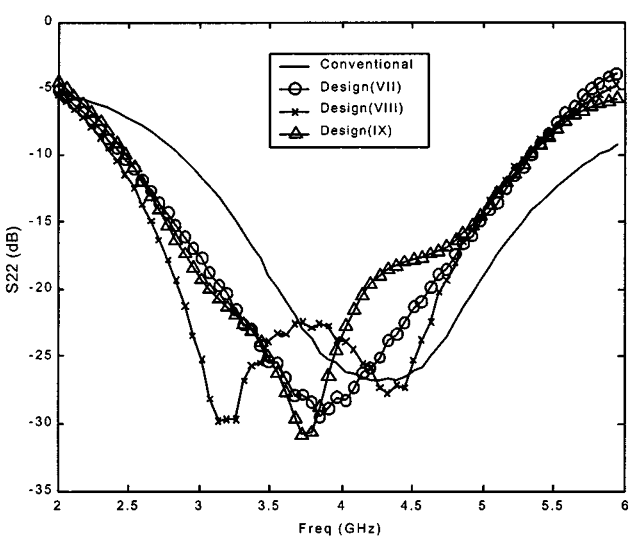

Fig. 13. Output return loss for the structures in Fig. 11.

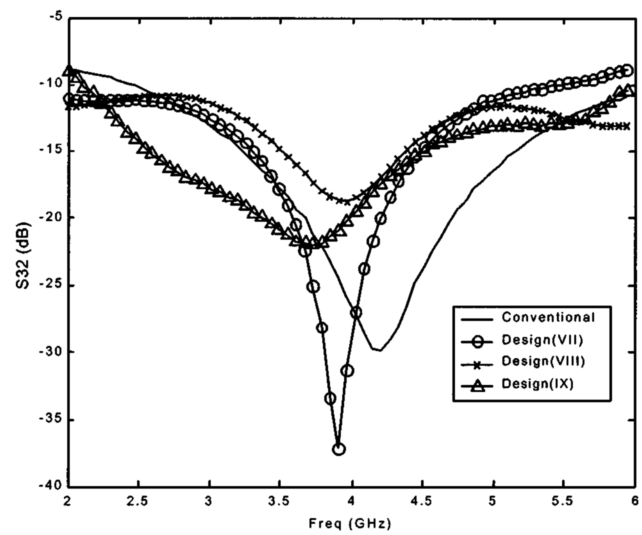

Fig. 15. Isolation results for the structures in Fig. 11.

or $1.5Z_o$ for ease of fabrication. Optimization is subsequently applied to get the appropriate length.

IV. Experimental Results and Discussions

All the structures, as shown in Fig. 11, are fabricated on Duroid substrate with permittivity $\epsilon_r = 2.2$ and a thickness of 0.508 mm. The design frequency is from 2 to 6 GHz. All the lengths of the structures are as shown in Fig. 11 and they are mainly composed of two $0.52\lambda_o$ lines and two $0.28\lambda_o$ lines. The S-parameters of all the proposed structures are obtained by using the HP8510C Network Analyzer. Appropriate de-embedding has been performed to remove the connectors' effects.

The measured coupling, output port isolation and return losses at ports 1 and 2 are respectively shown in Figs. 12–15. As shown in these figures, comparing with the conventional power divider as in Fig. 1(a), all the proposed structures have S_{21} bandwidth much larger than the conventional power divider. Good input and output return losses, and isolation have also been achieved by the proposed structures. Compared to the conventional power divider, the concept of separate matching of our proposed structures result in better input return loss and comparable output return loss. The output return losses at ports 2 and 3 can be much better if we have not constrained ourselves in using the same fixture for measurement. From the figures, based on the 15-dB input and output return losses criteria, a maximum bandwidth of 44.3% with an amplitude error of $\pm$0.9 dB and a phase error of $\pm 1.8^\circ$ has been achieved.

V. Conclusion

In conclusion, several novel in-phase hybrid power dividers, which have 1.6λ length of ring transformer, are proposed for the first time. Through a sequential matching technique, based on the 15-dB input and output return losses criteria, a maximum bandwidth of 44.3% with an amplitude error of $\pm$0.9 dB and a phase error of $\pm 1.8^\circ$ can be achieved. To the author's knowledge, this is the largest bandwidth ever reported in the literature. In here, we have not considered the miniaturization of the in-phase hybrid power divider for monolithic microwave integrated circuit (MMIC) implementation. This work will be referred in our future paper.

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W. Palei, photograph and biography not avavilable at time of publication.

M. S. Leong, photograph and biography not avavilable at time of publication.