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A Quasi Butler Matrix with 6×6 Beam-Forming Capacity Using 3×3 Hybrid Couplers

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Abstract

A novel 6×6 beam-forming network with the topology structure and the properties similar to Butler Matrices is represented in this paper. Two 3×3 hybrid couplers are adopted as the substitution of traditional 3dB-90° hybrids to introduce the factor of 3 into in this network for changing the numbers of ports and beams from conventional 2^n to 6. Moreover, one kind of 2×2 hybrid couplers with quasi-arbitrary phase-difference is utilized as well to eliminate using fixed phase shifters in this design for a smaller size and a lower loss. As an example, one proposed 6×6 network working at 5.8GHz has been designed, simulated, fabricated and measured. Good performances in matching, isolations, equal power divisions, coherent phase differences at all ports have been achieved. The possibility of improving structural flexibility of Butler Matrices by employing 3×3 hybrids is demonstrated in this paper.

1. Introduction

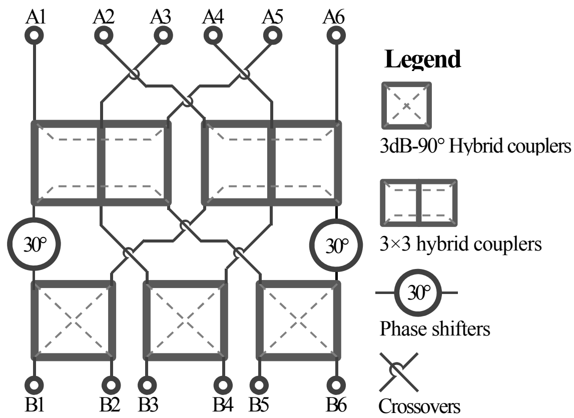
Multibeam antenna arrays with passive beamforming network (BFN) have been commonly considered as an efficient and cost-effective solution for beam-steering needs in civil and military sectors. As one of the widely known beam forming networks, Butler matrix [1] [2] has widely been discussed and applied for respective frequency bands in diverse forms [3] - [5]. A typical $N \times N$ Butler matrix connecting with an N-element linear array can generate N- independent beams with spatially orthogonal directions; perfect matching, isolation, and equal power division can be achieved at the same time. In general, N should be 2^n (here, n=1,2,3,...).

However, the restriction of number N will apparently limit the flexibility for many applications that may need the numbers of beams different than 2^n. There have already been many efforts for making certain changes about the numbers of antenna elements or beams [6] - [8].

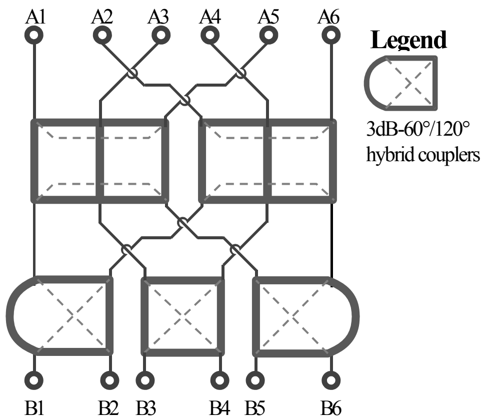
In this paper, one novel method is proposed based on the utility of 3×3 hybrid couplers [9]. By implicating the three-way components to replace the traditional two-way couplers partly, the factor of 3 can be introduced into this network, and provides more structural flexibilities for more applications. Besides, a kind of two-way couplers with quasi-arbitrary phase-difference [10] is utilized are applied as well to deduct the use of discrete fixed phase shifters for miniaturization and low-loss. Regarding to this concept, a 6×6 beam-forming network for 5.8GHz usage has been designed, manufactured, and measured as the experimental verification. Reasonable properties in matching, isolations, equal power divisions, and consecutive phase differences at all ports were obtained, and it agreed well with the simulation results.

2. Principle and Structure

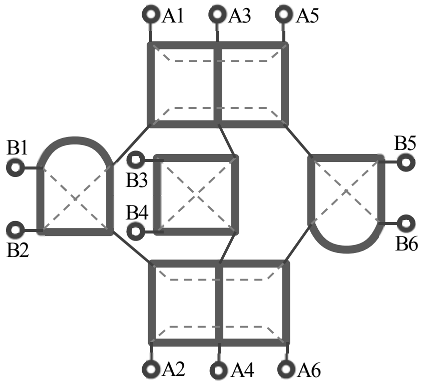
The fundamental principle and essentially structural layout for mentioned 6×6 BFN is demonstrated in Figure1 (a). The most conspicuous distinction than the classical Butler Matrix is the introduction of the 3×3 hybrid couplers.



(a) Fundamental construction of the 6×6 BFN



(b) Reducing the use of phase shifters by adopting the couplers with 60°/120° phase difference



(c) Reducing the use of crossovers by arranging all hybrid coupler to appropriate positions.

Figure1 The conformation and composition of proposed 6×6 network with quasi Butler Matrix structure(a) and its improvements of reducing phase shifters(b) or reducing crossovers either(c). Ports of A1-A6 are supposed to be connected with a linear array; ports of B1-B6 will respond to six independent beams respectively.

The 3×3 couplers can provide +120°, 0°, -120° phase differences between adjacent ports respectively respecting to which port has been activated. In addition, ideal matching, isolation and -4.8 power division can be acquired at each excitation port simultaneously. Based on the properties of 3×3 couplers, and using the concept of Butler Matrix, one 6×6 BFN can be constructed with six independent beams and theoretically perfect isolation, matching, and -7.8dB power division. The properties of quasi coherent output phase differences between adjacent ports are listed in Table1.

Table1 Output phase status with different ports activated

Excited Port	Output phase status on each port						Phase Differences
	A1	A2	A3	A4	A5	A6	
B1	0°	-60°	-120°	-180°	-240°	0°	-60°
B2	0°	+120°	+240°	0°	+120°	+240°	120°
B3	0°	-90°	0°	-90°	0°	-90°	-90° *
B4	0°	+90°	0°	+90°	0°	+90°	+90° *
B5	0°	-120°	-240°	0°	-120°	-240°	-120°
B6	0°	+60°	+120°	+180°	+240°	0°	60°

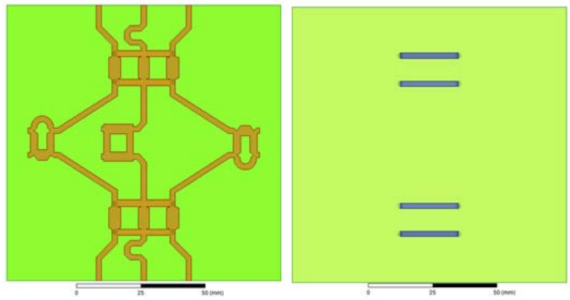
* Due to the restriction from the symmetry of the 3×3 couplers, when port B3 or B4 is excited, the perfect consecutive phase differences cannot be realized. Instead of that, an alternate phase difference of -90° or +90° can be achieved. In that both cases, the adjoining two elements, such as A1 and A2, A3 and A4, A5 and A6, can be seen as a subarray with declining beam. In this way, beam steering can be obtained by changing subarray's direction.

To decrease the complexity of the BFN and reduce the loss, a kind of hybrid couplers with quasi-arbitrary phase-difference is adopted (as shown in Figure1 (b)), and then the structure is simplified (as shown in Figure1 (c)).

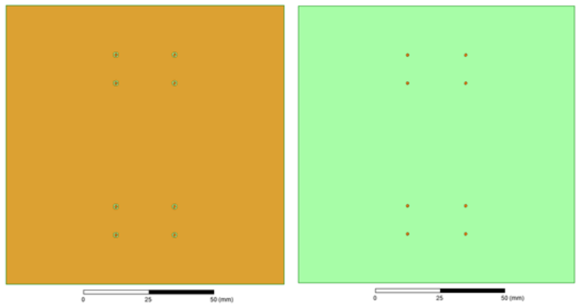
3. Simulation and experimental measurement

Based on the principle mentioned in Chapter 2, an example serving 5.8GHz applications was designed, simulated, and manufactured. The AD260A laminate (ε_r=2.60) with thickness h=30mil was selected as the substrate.

Since the 3×3 couplers have a double-layer structure, this 6×6 BFN is designed in a double-layer structure consequently. Each layout on various layers has been illustrated in Figure2.



(a)Top layer (b)Bottom layer

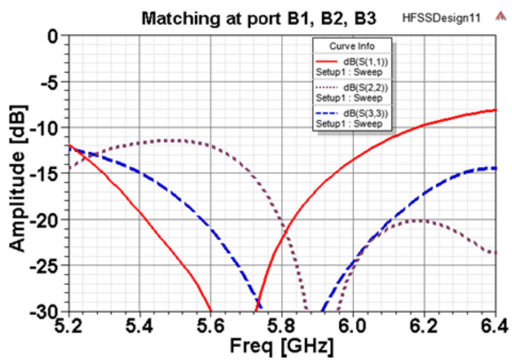


(c)Middle layer(common GND) (d)Drills

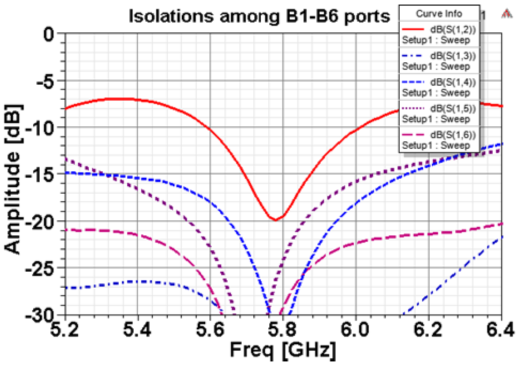
Figure2 The layouts in different layers.

ANSYS HFSS (v17) was exploited to design, simulate and optimize. The structure of BFN built in this software is shown in Figure2.

The principal simulation results, including matching, isolation, power division, and output phase difference, have been demonstrated in Figure3 and Figure4.

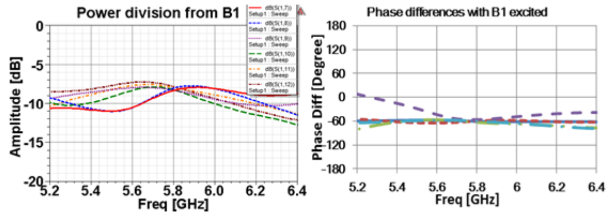


(a) Matching at B1 - B3ports

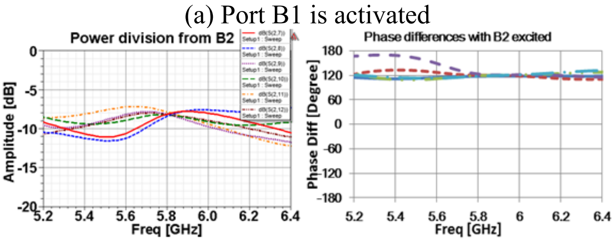


(b) Isolations between B1 and rest B-ports

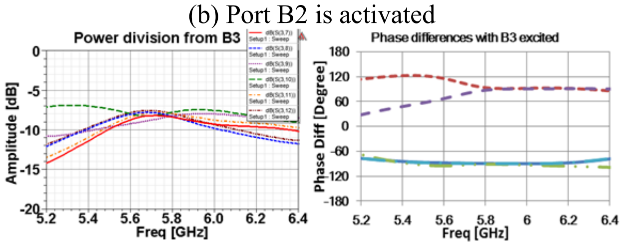
Figure3 The properties of matching and Isolations.



(a) Port B1 is activated



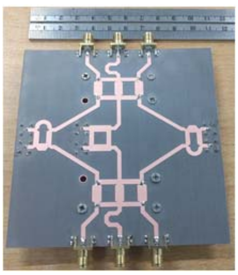
(b) Port B2 is activated



(c) Port B3 is activated

Figure4 The simulation results of power divisions at each A- ports(left ones) and the output phase differenes between adjacent A- ports(right ones) when different B-port is activated.

We can see that the performance of matching is less than -10dB reflection, and the isolation is higher than 10dB in the range of 5.6GHz – 6.0GHz. At 5.8GHz, the centre frequency point, the unbalance of power division is less than ±0.3dB, and error of output phase difference is less than ±4 degrees.


(a) Top view

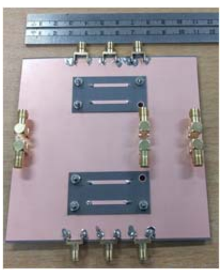
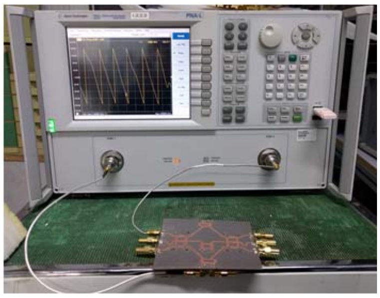
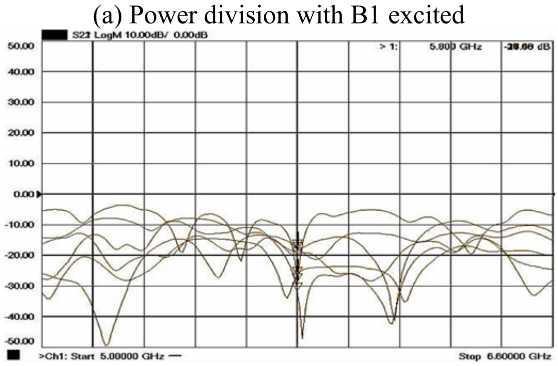

(b)Bottom view

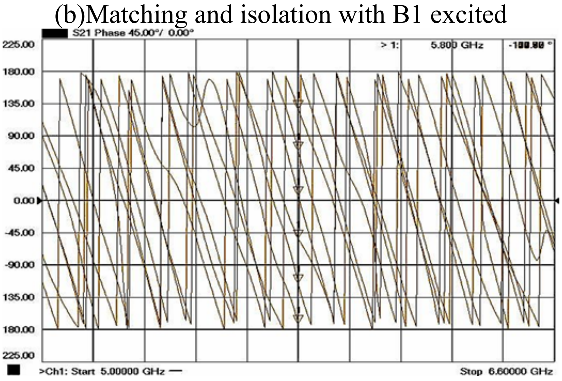
Figure5 Pictures of the example of 6×6 BFN.

One example has been fabricated for experimental test, shown in Figure5. The PNA-L 5230C was used to measure the example. The results are shown in Figure6.


(a) Power division with B1 excited



(b)Matching and isolation with B1 excited



(c)Output phase differences with B1 excited

Figure6 Pictures of measurement and its results.

We can see that some significant performances, such as matching, isolation, and phase differences, are reasonable at 5.8GHz and agreed well with simulation results.

6. Conclusion

A 6×6 beam-forming network with quasi Butler Matrix structure and capacity is presented. By introducing 3×3 hybrid couplers into this network, the possible of expanding the numbers of ports and beams from 2^n to 2^n3^m is partially demonstrated and preliminarily verified.

7. Acknowledgements

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8. References

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