Microstrip Line Digital Balanced Phase Shifter

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Abstract— Phase shifters finds application in areas like phase modulators, frequency up converters, phased array antenna systems, mobile communication system, WLAN and in PLL systems. For better detection of target in defence systems or surveillance systems phase shifters are needed to be installed on antenna systems to provide beam steering electronically without use of mechanical scanning for positioning. This proposed phase shifters are designed for 2.3 - 2.7 GHz (ISM band). 90° and 45° balanced structure provides better immunity against electromagnetic interference. Proposed design provides phase error around -2° to 5.67° for 45° phase shifter and 0.48° to 1.6° for 90° phase shifter. It also provides desired insertion loss.

Keywords— Microstrip lines, beam-steering, phased array antennas, MMIC, HEMT technology, ABCD matrix, phase error.

INTRODUCTION

Phase shifters are used in electronic warfare and active phased array radar systems. To achieve proper detection of ships in rough sea and heavy rain condition beam - steering antennas are required. Their significant applications like traffic control, regulation and collision avoidance radars in S band make them suitable to be installed on ships, aircrafts, and missiles in detection system. Beam-steering antennas are also used in smart base station antennas for WLAN and cellular communication. This is achieved through use of phased arrays. Here phase shifters are used to control main beam of antenna array. To achieve direction of beam's main lobe to be changed with time (scanning), rotation of antenna is required. However, mechanical rotation of single antenna is costly and time consuming. Hence electronic scanning should be done, which is possible using phased array antennas. This is done by varying electronically phase of radiating element. Electronically steerable phased array antenna is achieved by placing phase shifter on each radiating element [2].

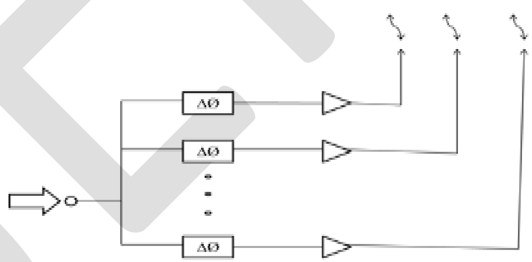


Fig. 1 A standard phased array antenna system

A phase shifter is a two port device whose fundamental function is to provide a change in phase of RF signal with negligible attenuation. Depending on the nature of the insertion phase (i.e., whether switchable continuously or in discrete steps), phase shifters are further classified into analog and digital. Analog phase shifter generates continuous phase difference corresponding to continuous variation of control signal, whereas digital phase shifter separates phase into predetermined states that are changed by digitally controlling each bit. Also they are categorized as balanced and unbalanced type or single ended. Balanced structures have symmetrical configuration and they provide better immunity to electromagnetic interference. Fig. 2(a) shows one element of balanced phased array system. For balanced antenna and balanced RFIC, single ended phase shifter needs two baluns to transform signal from balanced to single ended and vice versa. However in fig. 2(b) balanced phase shifter connects balanced antenna and balanced RFIC directly and reduce circuit size and complexity [1].

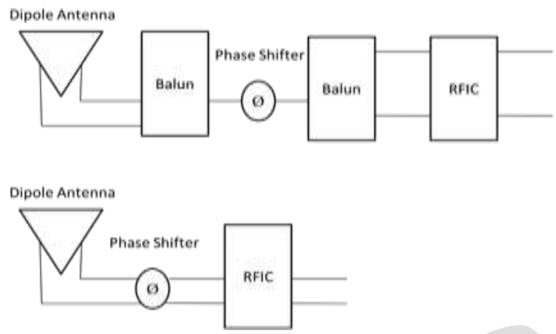


Fig. 2 (a) Single ended phase shifter, (b) Balanced phase shifter

LITERATURE SURVEY

In electronic warfare and active phased array radar systems they are used in transmit/receive module to adjust phase and hence they should be fabricated in MMIC (Monolithic Microwave Integrated Circuit) technology that achieves small size, light weight, low cost and low power consumption. To use phase shifters in electronic warfare they must operate in ultra wide bandwidth. Insertion loss, operating bandwidth and constant phase shift within the bandwidth are major concern in design of phase shifters [4].

Phase shifters are key elements in beam steering systems such as phase array antennas. Here multiple antennas are used and delay is added to signal of each antenna. It also utilizes beam forming technique which transmits the signal in specific direction that reduce power dissipated from transmitter [5].

Traditionally phase shifters are fabricated using III-V technologies like GaAs. Design of phase shifters with low cost light weight and low power consumption is of prime importance hence, HEMT technology is used. The high mobility of electrons and high quality factor of passives in these technologies achieves low insertion loss. Silicon substrates reduce their implementation costs significantly. In the 4-bit balanced active phase shifter is implemented by the vector sum method. However, the active components are unilateral, which makes it difficult to use as a reciprocal circuit in transmit /receive (T/R) module [3].

DESIGN

45° Balanced Digital Phase shifter:

45° loaded line phase shifter is as shown in fig 3. By controlling the input signal to be differential or common mode, *λ/8* transmission lines can be either short circuited stub as shown in fig. 3(a) or open circuited stubs in fig. 3(b). A loaded transmission line and its equivalent circuit are shown in fig. 7. Transmission line of electrical length $\theta\iota$ and impedance $Z\iota$ with two switchable susceptances $B1$ and $B2$ in fig. 4 represents ABCD matrix as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ jBi & 1 \end{bmatrix} \begin{bmatrix} cos\theta\iota & jZ\iota\, sin\theta\iota \\ jY\iota\, sin\theta\iota & cos\theta\iota \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jBi & 1 \end{bmatrix} \tag{1}$$

$$= \begin{bmatrix} (cos\theta\iota - Bi\, Z\iota)cos\theta\iota & j(Z\iota\, sin\theta\iota) \\ j(2Bi\, cos\theta\iota + Y\iota\, sin\theta\iota - Bi^2 Z\iota sin\theta\iota) & (cos\theta\iota - Bi\, Z\iota) \end{bmatrix} \tag{2}$$

where i =1 or 2 (switching states 0 or 1).

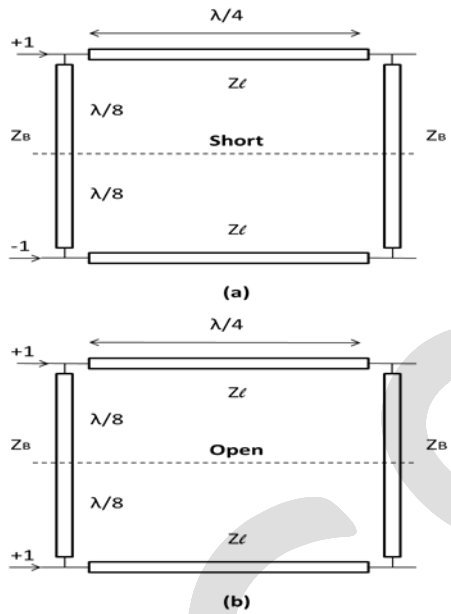


Fig. 3 45° balanced digital loaded-line phase shifter
(a) Odd mode (b) Even mode

ABCD matrix of transmission line of electrical length θei and impedance Zei,

$$\sqrt{Yei = Y\iota\,[1-(Bi\,Z\iota)^2 + 2Bi\,Z\iota\cot\theta\iota\,]} \quad (3)$$

$$\cos\theta ei = \cos\theta\iota - Bi\,Z\iota\sin\theta\iota \quad (4)$$

In our case B1=ZB (S.C.), B2= -ZB (O.C.), θι=90°,

Phase difference Δ∅ of two states is obtained as

$$\theta_{e1} = \cos^{-1}(-Z\text{B}.Z\iota) \quad (5)$$

$$\theta_{e2} = \cos^{-1}(Z\text{B}.Z\iota) \quad (6)$$

$$\Delta\emptyset = \theta_{e2} - \theta_{e1} \quad (7)$$

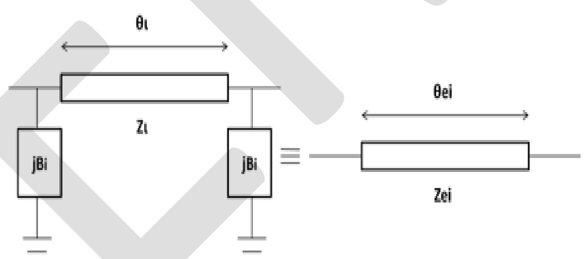


Fig. 4 Loaded transmission line connected with two
Susceptance and its equivalent transmission line

Calculated values of 45° balanced digital phase shifter is given in table I.

TABLE I
CALCULATED VALUES OF 45° BALANCED DIGITAL PHASE SHIFTER

θι	Zι	|Bi|	Θstub	Zstub
90°	45.9Ω	8.5×10^{-3}	45°	117.6Ω

90° Balanced Digital Phase Shifter :

To realize 90° phase shifter with broader bandwidth, loaded line phase shifter with three shunt susceptance can be used. 90 phase shifter is shown in fig. 6. Following same procedure of 45 phase shifter design equations will be

$$B^2 = \frac{2B^1}{(B^1 Z_\circ)^2 + 1} \quad (8)$$

$$\theta ei = 180° + \tan^{-1}\left(\frac{2B^1Z_\circ}{1-(B^1Z_\circ)^2}\right) \qquad (9)$$

where i=1 or 2, is insertion phase of one of two states. Since B1 in equation (9) only changes sign while changing state, phase difference of even and odd mode should be,

$$\Delta\emptyset = (\theta e2 - \theta e1) = 2\tan^{-1}\left(\frac{2\,|B_1Z_\circ|}{1-(B_1Z_\circ)^2}\right) \qquad (10)$$

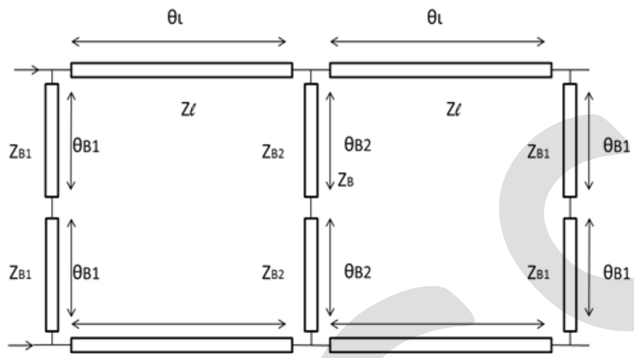


Fig. 5 90° balanced digital phase shifter

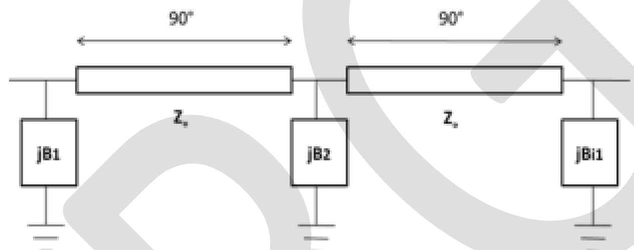


Fig.6 3 Element loaded- line phase shifter

Calculated values of 90° balanced digital phase shifter is shown in table II.

TABLE II
CALCULATED VALUES OF 90° BALANCED DIGITAL PHASE SHIFTER

θι	**$Z_\circ$**	**θstub1**	**Zstub1**	**θstub2**	**Zstub2**
90°	50Ω	45°	120.7Ω	45°	71Ω

IMPLEMENTATION

45° and 90°phase shifters are implemented using Agilent's ADS (Advanced Design System) EM simulation software. Circuit is first implemented in schematic and after fine tuning in circuit simulator it is simulated in EM simulator. These balanced digital phase shifters are implemented using microstrip lines with Rogers RO4003 substrate of thickness 0.508mm and dielectric constant of 3.58.

Design and results of 45° phase shifter*:*

Fig. 7 shows schematic of 45° phase shifter with physical dimension to be used in design using microstrip. Layout design from schematic is shown in fig. 8.

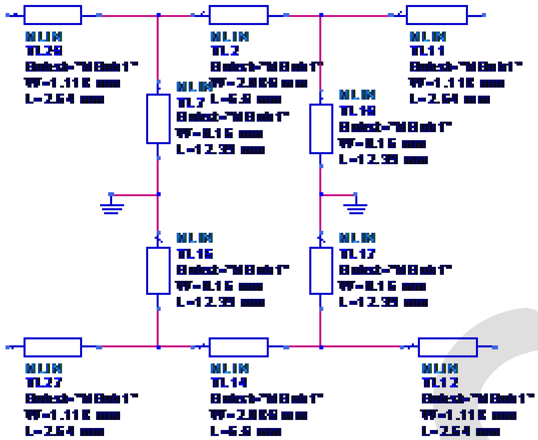


Fig. 7 Schematic of 45° phase shifter

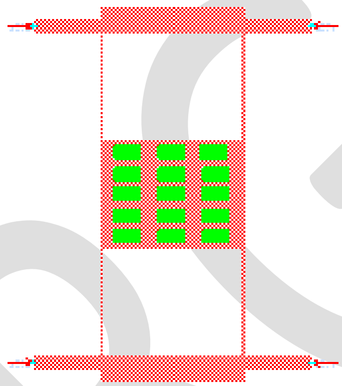
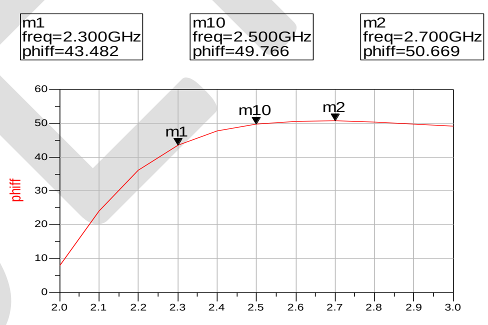
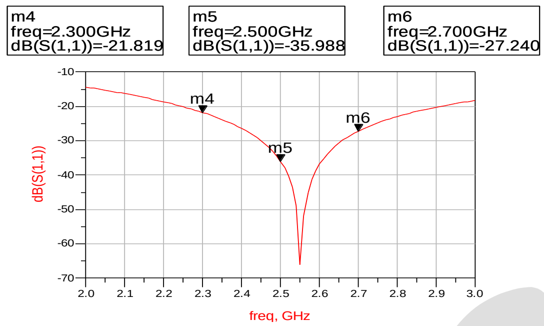


Fig. 8 Layout and results of45° phase shifter

Simulated results of designed circuit for the range from 2.3- 2.7GHz from fig. 9 shows desired phase shift, insertion loss and return loss. Insertion loss is approximately 0.01 to 0.03dB.



(a)



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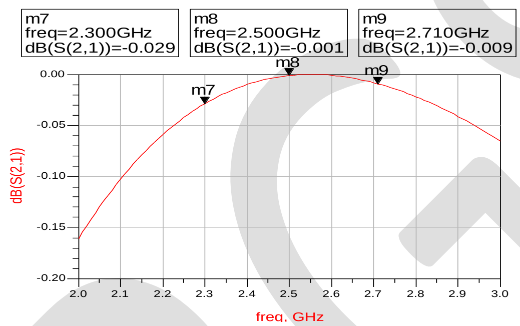


(c)

Fig. 9 Results of 45° Phase shifter (a) Phase-shift
(b) Return loss (c) Insertion loss

Design and results of 45° phase shifter:

Schematic and dimensions for 90 ° phase shifter are depicted in fig.10 while layout is shown in fig. 11. Simulated results including phase shift insertion loss and return loss are shown in fig.12. Insertion loss is around 1.8dB.

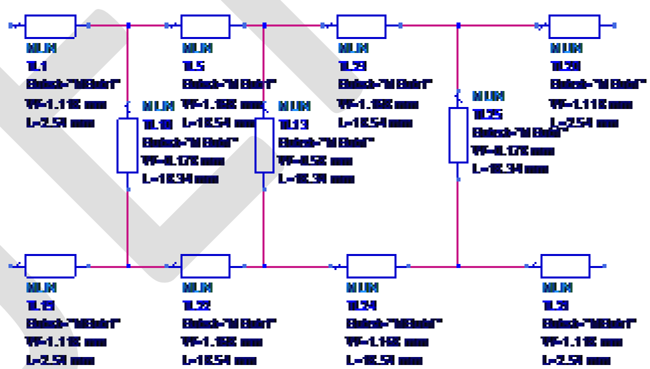


Fig. 10 Schematic of 90° phase shifter

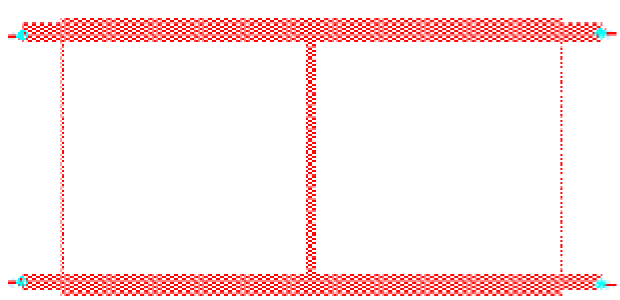
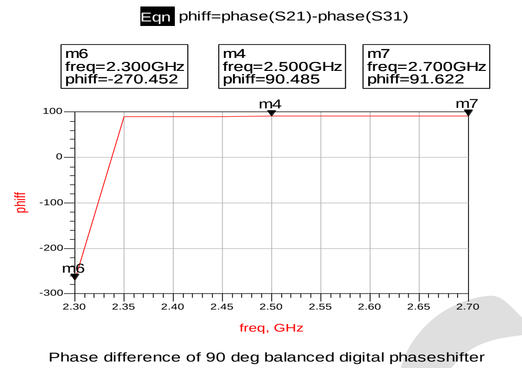
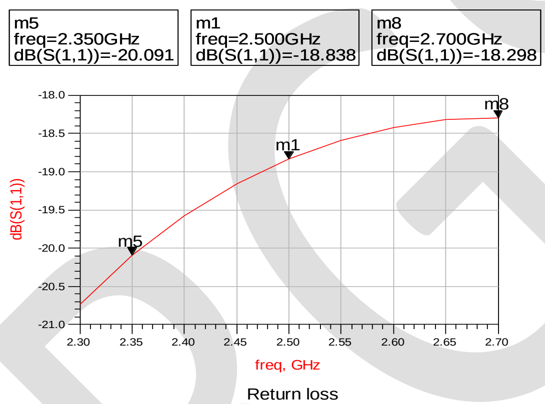


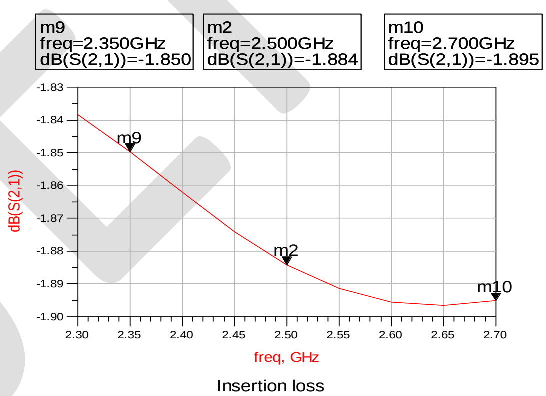
Fig. 11 Layout and results of45° phase shifter



(a)



(b)



(c)

Fig. 12 Results of 90° Phase shifter (a) Phase-shift
(b) Return loss (c) Insertion loss

From results we got -2 to 5.67 phase error for 45 phase shifter and 0.48 to 1.6 phase error for 90 phase shifter.

APPLICATIONS

- Phase Modulators
- Frequency Up-converters
- Phase Array Antenna Systems
- Mobile Communication systems

- Direct receiving in Digital Satellite Systems(DSS)
- Satellite modems and modems in WLAN network
- Digital Phased Locked Loop

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CONCLUSION

45° and 90° balanced digital phase shifters have been proposed in the paper. Both these balanced phase shifters are loaded by λ/8 open and short circuited stubs. Using both circuits and some control and switching circuitry different phase shifts can be achieved Circuit has less phase error around -2° to 5.67° for 45° phase shifter and 0.48° to 1.6° for 90° phase shifter.

REFERENCES

[1] Yun-Wei Lin, Yi- Chieh Chou, and Chi- Yang Chang, "A Balanced Digital Phase Shifter by Novel Switching-mode Topology," IEEE Transactions on Microwave Theory and Techniques, vol.61, no. 6, June 2013.

[2] Puneet Anand, Sonia Sharma, Deepak Sood, C. C. Tripathi, "Design of Compact Reconfigurable Switched Line Microstrip Phase Shifters for Phased Array Antenna," 1st International Conference on Emerging Technology Trends in Electronics, Communication and Networking, 2012.

[3] Seyedreza Hadian Ameri, Amir Pourhossien, "A 6-bit Digital Phase Shifter by using HEMT Technology," IEEE 8th International Colloquium on Signal Processing and its Applications, 2012.

[4] Yong-Sheng Dai, "A novel miniature 122 GHz 90° MMIC Phase Shifter with Microstrip Radial Stubs," IEEE Microwave and Wireless Components, vol. 18, no.2, February 2011.

[5] Y.Wang, M. E. Bialkowski, and A. M. Abbosh, "Double Microstrip-Slot Transitions for Broadband ±90° Microstrip Phase Shifters," IEEE Microwave and Wireless Components Letters, vol. 22, no. 2, February 2012.

[6] Jun Zhang, S.W. Cheung and Qi Zhu, "Design of 180° Switched-line Phase Shifter with Constant Phase Shift Using CRLH TL," IEEE Antennas and Propagation Society International Symposium (APSURSI), 2014.

[7] Jun Zhang, "Design of High Power Capacity Phase Shifter with Composite Right/Left–Handed Transmission Line," IEEE Transactions on microwave theory and techniques microwave and optical technology letter, Vol.54, No. 1, Jan 2012.

[8] S. H.Yeung, Q.Xue, and K. F.Man, "Broadband 90° Differential Phase Shifter constructed using a pair of Multisection Radial line Stubs," IEEE Trans. Microwave Theory Techniques, vol. 60, no. 9, pp. 2760–2767, Sep. 2012.

[9] X. Tang and K. Mouthaan, "Phase-shifter Design using Phase-slope Alignment with Grounded Shunt Stubs," IEEE Trans. Microwave Theory Techniques., vol. 58, no. 6, pp. 1573–1583, Jun. 2010.

[10] J. C. Lu, C. C. Lin, and C. Y. Chang, "Exact Synthesis and Implementation of New High-order Wideband Marchand baluns," IEEE Transactions Microwave Theory Techniques, vol. 59, no. 1, pp. 80–86, Jan. 2011.

[11] Shib Shankar Singh, "Design and Realization of S-band GaAs MMIC Two Bit Phase Shifter for Phase Array Radar Antenna Applications," IEEE Proceedings of International Conference on Microwave, 2008.

[12] S. H. Yeung, Q.Xue, and K. F. Man, "Broadband 90° Differential Phase Shifter constructed using a pair of Multi-section Radial Line Stubs," IEEE Transactions Microwave Techniques, vol. 60, no. 9, pp. 2760-2767, Sept. 2012.