IJCSN International Journal of Computer Science and Network, May 2014
ISSN (Online) : 2277-5420
www.IJCSN.org

Dual-band Six Port Receiver Module on Silicon

[1] Ayan Karmakar, [2] Navpreet Kaur

[1] MEMS Development Division, Semi-Conductor Laboratory (SCL), Mohali, Punjab.

[2] Dept. of Electronics and Communication, SUSWEC, Tangori, Punjab.

Abstract- This article details the design of six-port direct conversion front-end module for dual-band (1.575GHz and 2.680GHz) applications. Proposed planar architecture consists of single-stage (1:2) Wilkinson Power Divider and three numbers of quarter-wave 3-dB branch-line couplers working simultaneously at dual band of frequencies. Present article describes the designing of each building block and finally integrated those. Main challenge of this design is to optimize various RF parameters simultaneously at two arbitrarily chosen frequencies for higher permittivity substrate like Silicon. This six-port network offers an insertion loss 6.5 dB(max.), return loss of better than 12 dB, output port isolation of 9.1 dB(min.) and phase-error of around 1.89°(max) at both the frequency bands. Overall area occupied by the structure is 90×81 mm^2.

Keywords- *Dual-band WPD, Dual-band Branchline coupler, power divider, stepped-impedance stub, high resistive silicon, 6-port receiver.*

1. Introduction

Multiband circuits are getting utmost importance in present communication circuits. Simple configuration, compact size and easier fabrication processes are driving the new methodology to be adopted. In recent years, MIC based techniques have been initiated to develop various planar RF circuits on high resistive silicon ($\rho > 8$ KΩ-cm, $\tan\delta = 0.01$). RF performances on this are comparable to conventional microwave substrates, like- Alumina, GaAs, RT Duroid, FR4, etc.

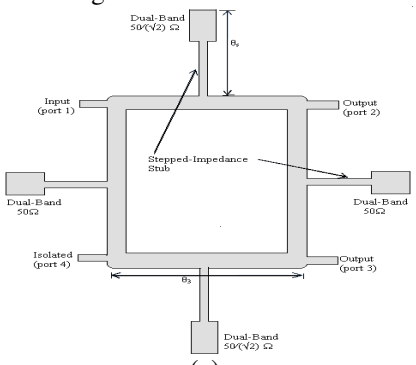
Six port architecture as proposed [1] deals with single frequency operation. Due to present scenario of multiband communication with compact size, it is necessary to develop system on higher permittivity substrates and adopting techniques for dual-frequency operation. Basic building block of the 6-port front-end receiver is power splitter to provide desired power ratio with required amount of phase shift. Standard topologies achieve dual-band operation by cascading two individual topologies which limits bandwidth & increase the overall size of the assembly. Out of six-ports of the receiver block, two ports are used for input and from the rest of the ports output signals are taken out, which bears the information regarding the phase comparison of input signals. The six-port topology is one of the accurate options for microwave power measurement. It is being used extensively in radar system for distance or velocity analysis or for Direction of Arrival (DOA) detection [1].

2. Design Details

Design of the whole assembly consists of individual block design of quadrature branch line coupler and Wilkinson's power splitter working in dual frequencies. Following three sub-sections describe the design in detail.

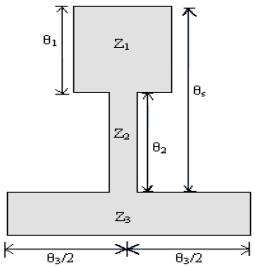
[A] Branch-line Coupler

Branch-line coupler is the back-bone of the phase-shifting network of the receiver architecture. Traditional 3-dB branch-line couplers consist of (λ/4) branches with 50 Ω and ($50/\sqrt{2}$ Ω) impedances. These branches have an electrical length of 90° at a single frequency [2, 3]. For dual-band operation, simple quarter wave lines have been replaced by modified t-line structures in various ways [4, 5]. Recently, Kuo-Sheng Chin et.al [5] reported the replacement of conventional λ/4 line with stub-loaded T-shaped stepped-impedance (SI) branches. The Stepped-impedance stub comprises of a signal path (Z_3,θ_3) tapped with a stepped-impedance stub of (Z_1,θ_1) and (Z_2,θ_2) at its centre. Overall, it acts as an equivalent circuit providing 90° electrical length and desired branch impedances at two distinct operating frequencies. The schematic diagram of the dual-band branch-line coupler with stepped-impedance stub is shown in Fig 1.



(a)

IJCSN



(b)

Fig 1(a): Schematic diagram of the dual-band branch-line coupler with stepped-impedance stub (b): Dual-band Stepped impedance stub.

Using the ABCD parameters of the whole structure, the values of several design parameters are evaluated by solving the transcendental equations [5].

$$Z_3 \tan(r_f\,\theta_3) = \frac{2Z_3\,\cot(r_f\theta_3) - Z_2\,\tan(r_f\theta_2)}{Z_2 + Z_1\,\cot(r_f\theta_1)\tan(r_f\theta_2)}$$

Now, $r_f = w_s/w_f$ where ω_s and ω_f are centre frequency of first and second bands, θ_1, θ_2 and θ_3 are all specified at . Here, $r_f = \frac{2.680\ \text{GHz}}{1.575\ \text{GHz}} = 1.701$. Again from $r_f = 1.701$ we can have

$\theta_3 = \frac{2n\pi}{1+r_f}$, n = 1, 2, 3, 4……so on.

TABLE -I
Design parameters of proposed dual-band branch-line coupler

Parameters	Electrical Value	Physical Dimension (mm)
Z_1 (of 50Ω line)	22 Ω	5.30
θ_1 (of 50Ω line)	8˚	1.90
Z_2 (of 50 Ω line)	120 Ω	0.151
θ_2 (of 50 Ω line)	40˚	11.71
Z_3 (of 50 Ω line)	50.139 Ω	1.17
θ_3 (of 50Ω line)	133.254˚	11.67
Z_1 (of 50/√2 Ω line)	18 Ω	2.15
θ_1 (of 50/√2 Ω line)	8˚	3.23
Z_2 (of 50/√2 Ω line)	86 Ω	0.18
θ_2 (of 50/√2 Ω line)	40˚	3.23
Z_3 (of 50/√2 Ω line)	35.862 Ω	0.707
θ_3 (of 50/√2 Ω line)	133.254˚	8.49

For a compact dual-line topology n=1 is chosen for analysis.

To solve the above transcendental equation, the ratio of θ_1 to θ_2 is chosen as free variable. Here, we assume $(\theta_1/\theta_2) = 0.5$.
Table-I summarizes the values of the all design parameter, computed analytically. Design is carried out using MoM & FEM based simulation environments taken high resistive Si substrate with Aluminium metallization of 3 µm.

Instead of reported topology [4, 5], further size reduction is carried out by placing the step-impedance stub internally & placing appropriately. Directly bending of the stubs is not feasible, as it enhances the chance of cross-over among transmission lines. Further, meandering of the stub-line gives an extra degree of freedom for two targeted frequencies. Proposed layout is shown in Fig.2, which occupies an area of 24.25 × 18.5 mm^2, which is 80 % reduction in size as compared to conventional topologies & 64% reduction compared to earlier structure [5].

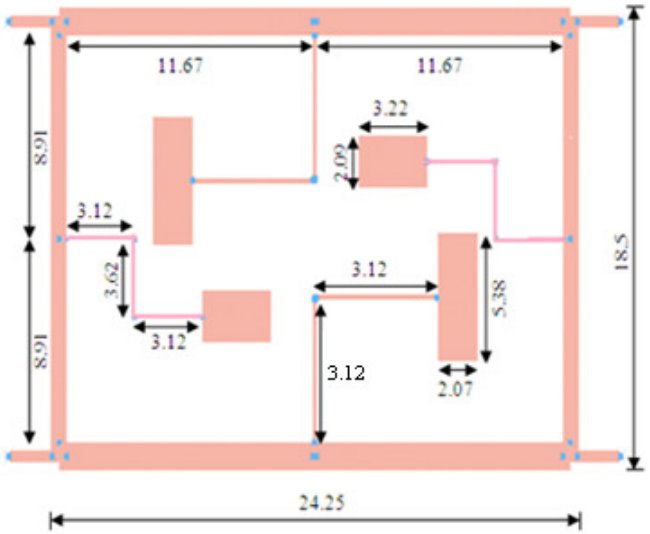


Fig 2: Layout of the proposed coupler

[B] Power Divider

Signals received by the front-end antenna of the receiver module is splitted equally in amplitude and phase with the aid of Wilkinson's power divider network, which provides excellent isolation between the two output ports as compared to other reported topologies. Current receiver module demand power splitter which operates at two desired frequencies (L and S-band). In context with this, a simplified compact MIC based circuit was reported [6] on 675µm High-Resistive Silicon substrate, whose layout structure is shown in Fig 3. The divider occupies an area of 28×14 mm^2.

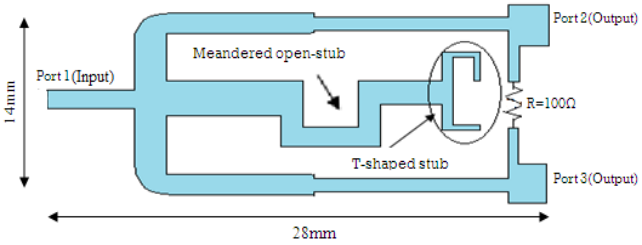
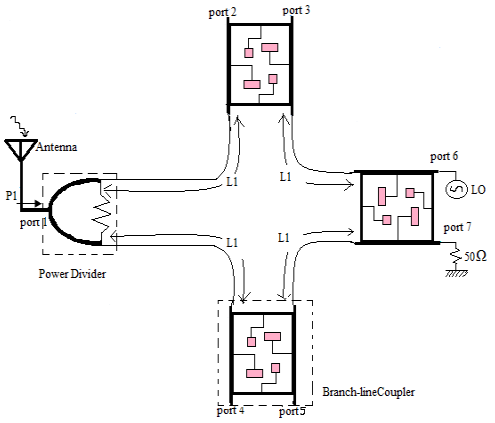


Fig. 3: Layout of the dual-band power divider

[C] Receiver Module

The complete receiver module is made by integrating power divider and quadrature hybrids for dual-band operation. The integrated structure is a non-reciprocal seven port lossy network, where port-1 is used for receiving antenna signal whereas local oscillator is connected to port-6. Four of the output ports (2, 3, 4 &5) provide the phase comparison of the input signals. Port number-7 is terminated with standard 50 Ω load. Fig-4 shows the schematic and 3D structure of the front-end module.



(a)

(b)

Fig 4: (a).Schematic diagram of the six-port architecture
(b) Isometric view of the structure

The main consideration of this integrated structure is length of the in-between lines (L1) so as not to interfere signal phases.

3. Result & Discussion

MoM and FEM based EM solvers [7, 8] have been used here for extracting the performance parameters. Designed RF performance of the coupler is shown in Table-II.

It depicts that higher losses and phase imbalance are observed at higher frequency band, whereas return loss and isolations are almost same at two frequencies. The S-parameters of the developed power splitter is summarized in Table-III. The complete RF performance of the integrated module is shown in Fig.5.

TABLE -II
RF performance of the designed dual-band coupler

Frequency (GHz)	I/O Return Loss (dB)	Max. I.L (dB)	Min. Isolation (dB)	O/P Phase Difference
1.575	-17.44	-3.34	-17.50	-270.16˚
2.680	-13.47	-3.97	-13.26	+95.915˚

TABLE -III
RF performance of the dual-band wilkinson's power divider

Frequency (GHz)	I/O Return Loss (dB)	Insertion Loss (dB)	O/P Port Isolation (dB)
1.575	-15.50	-3.33	-9.33
2.680	-14.25	-3.41	-21.83

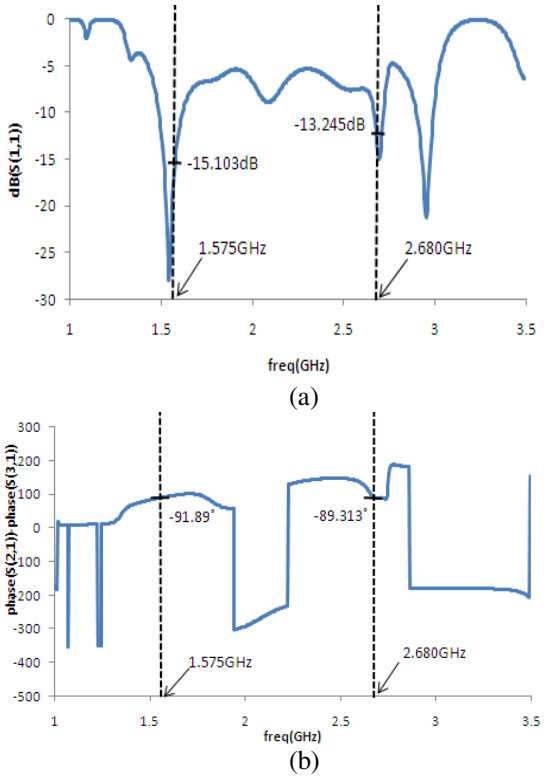


Fig.5: RF performance of the receiver module (a) Input Return loss (b)Output Phase Difference (c) Insertion loss (d) Isolation

Simulated results depicts that, this 6-port architecture offers an insertion loss 6.5dB(max.), return loss of better than 13dB, output port isolation of 9.1dB(min.) and maximum phase error of around 1.89° for both frequency bands.

4. Conclusion

This work presents the design of dual-band six-port direct conversion receiver and its basic building blocks. Incorporation of T-shaped stepped-impedance resonator (SIR) based stub is the novel feature of this topology. As per authors' knowledge, still now such a compact dual-band branch-line coupler and power divider for integrated receiver module is not reported for any higher permittivity substrate like silicon. The design can be scaled to other frequencies, media and process like-MMIC. The circuit is under fabrication using our in-house facility.

References

[1] A. Koelpin, G. Vinci, B. Laemmle, and R. Weigel, "The enhanced six-port receiver: A new concept for simultaneous data reception and direction of arrival detection", in Microwave Symposium, 2011. IEEE/MTT-S International, 2011.

[2] Pozar D.M. "Microwave Engineering", John Wiley and Sons Inc,New York,1998.

[3] Allan.W.Scott, "Understanding microwave", John Wiley and Sons Inc.,2005.

[4] Milad Mirzaee and Mehdi Nosrati, "A novel design approach to the miniaturization of dual-band branch-line coupler", IEICE Electronics Express, vol.8, pp. 2099-2034, Dec.2011.

[5] Kuo-Sheng Chin, Ken-Min Lin, Yen-Hsiu Wei, Tzu-Hao Tseng, Yu-Chien Yang, "Compact Dual-Band Branchline Coupler With Stepped impedance Stub line,"IEEE Transaction on Microwave Theory and Techniques, vol.58, No.5, pp.1213-1221,May 2010.

[6] Kamaljeet Singh, A.Karmakar and K.Nagachenchaiah, "Dual-band (1:4) Wilkinson Power Divider on Silicon", Journal Of Electronics, vol.1,No.1,May 2012.

[7] HFSS ver.11, www.ansys.com.

[8] ADS 2008U2 , www.agilent.com