RESEARCH ARTICLE OPEN ACCESS

Optimization of the radio channel Interface using a 3dB, 90 ° hybrid phase shifter with three branches.

Richard Essomba Mbondjo.[1]and David Monkam[2]
[1](*Doctoral School in Fundamental and Applied Sciences Faculty of Industrial Engineering ,PO Box 2701 University of Douala,Cameroon,*
[2](*Department of Physics, Faculty of Science, PO Box 24157University of Douala,*
Corresponding Author: Richard Essomba Mbondjo

ABSTRACT
This paper contributes to optimize the performance of the radio interface between the Mobile (Handset) and the relay antennas by using a 3db, 90° hybrid phase shifter with three branches whose objective is to maximize radiating incident waves on the main lobes, and minimize them on the secondary lobes by circular polarization. The circular polarization is obtained under the base of a phase shifter from a hybrid coupler capable of feeding three antennas arranged at very precise positions. As MIMO (Multiple input, Multiple output) technique is always used to optimize this radio channel without taking into account the impact of hybrid phase shifter as well, here this equipment is used to share power on 3db for each branch with 90° of phase by making sure that the coverage will be optimize through the three antennas. This hybrid phase shifter is designed for 2.34 GHz with an impedance (Z0) of 50Ω, the material used is the Rogers **Thermoset Microwave Materials (**TMM4) of dielectric constant equal to 4.55, thickness 0.8 mm and a tangent loss of 0.017. The simulation is performed with the **Advanced Design System (ADS)** software.
Key words: Radio channel, Optimization, circular polarization,3 dB hybrid coupler.

Date Of Submission: 30-06-2019 Date Of Acceptance: 19-07-2019

I. INTRODUCTION

Communication systems are extended in the millimeter wave (mmW) frequency range (30 to 300 GHz) because of high data rates demand. In this frequency range, small wavelengths lead to small circuit sizes and the feasibility of integrating an array of antennas, which enables steerable antenna arrays with high gain [1]-[2].Systems generally operate in so-called atmospheric windows, located at the local minima of atmospheric attenuation because of high atmospheric losses in this frequency range. 200-300 GHz frequency range is one of these windows[3] and has attracted several systems in recent years, with data rates of up to 100 Gbit / s [4] - [6]. However, all these systems are limited to fixed point-to-point links and are not able to modify electronically the direction of the radiation, i.e., they do not provide any kind of electronic beam steering.

To optimize performance of such systems with beam steering capabilities, integrated phase shifters are key elements [7]. Phase shifters are used to introduce a variable phase shift between two adjacent antennas of an antenna array, which results in a change of the main lobe direction.

Main function of microwave couplers devices is to divert a certain amount of information from one path to another [15]. The signal from the output side of the first path is called a "direct signal" because it is directly connected to the input port. The signal from the second path on the output side is called the "coupled" signal. Here, a -3 dB, 90-degree phase shift quadrature patch hybrid coupler is designed to mainly operate at the frequency 2.4GHz. A -3 dB, 90° hybrid coupler is a four-port device that can split an input signal equally or unequally with a resultant 90° phase shift between two output ports or to combine two signals by maintaining high isolation between the ports [5].

According to the fact that in telecommunication: Insertion loss is due to the insertion of a device. The quantity of insertion loss for any device is expressed in terms of decibels. Ideally the insertion loss for hybrid coupler is 3dB. If the power transmitted to the load before insertion is P1, therefore the power received by the load once insertion is P2, then the insertion loss in dB is known [9].Coupling factor is the parameter which occurs when the power is transferred from one circuit element to other circuit element [10].

If the power at port1 is P1 and power at coupling port is P3, then the coupling factor value can be expressed [11].Isolation is the parameter which will gives information about power transmitted between the unwanted ports [12]. In quadrature hybrid coupler the port 4 act as back port. Ideally there is no power is transmitted between port

1 and port 4 and isolation is considered as zero. But in practical case there will be some minimum power will be transmitted between port 1 and port 4. The isolation will give how much power is observed at port 4. If the power at port 1 is P1 and power at port 4 is P4 then isolation can be calculated [13]. Phase shift is the measure of phase difference between two signals and it is expressed in terms of degree. in hybrid coupler the phase shift is calculated between the signals coming at port2 and port3 normally a quadrature hybrid coupler provides a 90-degree phase shift between signals coming out at port1 and port3 [14]. Band width for quadrature patch hybrid coupler is defined as the range of frequencies for which hybrid coupler exhibits VSWR (voltage standing wave ratio) value less than 2. Sometimes bandwidth can be expressed in terms of percentage of band width with respect to center frequency [15]. The percentage of bandwidth for a hybrid coupler can be calculated using the formulae [16].

Insertion Loss, Coupling Factor, Isolation, Phase Shift, Band Width are key performance of any hybrid coupler [8]. A hybrid coupler is a special case of a directional coupler where the coupling factor is 3db (equal distribution) and the phase relationship between the output ports is 90 ° [18].

Couplers are widely used as power combiners or splitters and for telecommunications applications systems by choosing an appropriate capacity, the circuit can act as a phase-shifter and by cascading hybrids in a tree configuration one can change the polarization of an antenna in order to optimize the mean incident waves and accordingly the radio channel [19].

II. QUADRATURE HYBRID COUPLER PRINCIPLE

The quadrature hybrid coupler is a four-port network; the input is port1, and output ports2, 3 and port4 terminated by a match load. These types of circuits are composed of four wavelength transmission lines, two of which have a characteristic impedance Z0 (50Ω) and two others of characteristic impedance Z0 / √2 (~ 35Ω), as shown in figure1 a. Hybrid coupler operation is not affected when ports 1 and 4 are interchanged with ports 2 and 3 becauseof a high degree of symmetry [20]-[21]. Ports 2 and 3 are decoupled, a good isolation greater than 20 dB must exist between these ports.

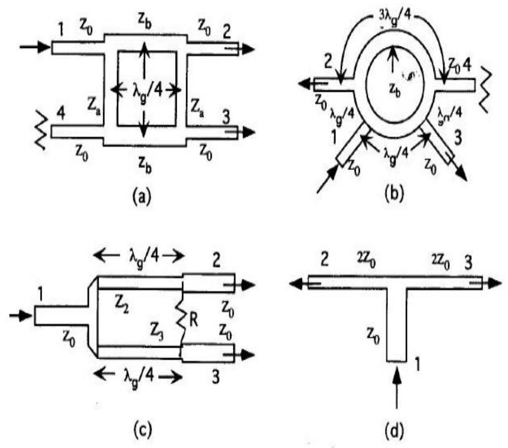


Figure1. (**a**) Quadrature hybrid, (**b**) hybrid ring coupler, (**c**) Wilkinson power divided, (**d**) **T-junctionpower divided**[2].

Hybrid couplers at 3dB and 90° are known as construction hybrids. Accordingly, the sign is applied at any input to divide it into two equal amplitude signals at 90°. This will not make any difference since outputs are also similar since these circuits are electrically and mechanically balanced. This relationship provides a high degree of isolation between the two output ports and therefore, the two input ports do not need interaction with each other [22].

III. 180° HYBRID RING COUPLER PRINCIPLE

Hybrid junction 180°is a four-port network with 180° phase shift between the two output ports. With reference to the hybrid symbol 180° shown in Fig. 1b, a signal applied to port 1 will be divided into two phases components at ports 2 and 3, and port 4 will be isolated. If the input is applied to port4, it will also be split into two components with 180 ° phase difference at ports 2 and 3, and port1 will be isolated. When used as a combined with the input signals applied to ports 2 and 3, the sum of the inputs will be formed at port 1, while the difference will be formed at port 4. Therefore, ports 1 and 4 are respectively designated under sum name and difference ports [23]-[24].

IV. ANALYSIS OF HYBRID COUPLER 3dB, 90 ° WITH TWO BRANCHES

This coupler has 4 ports which can be perfectly adapted to the working frequency if the impedances of the lines which constitute them are correctly chosen figure2. The input power P1 is divided into 2 output signals P2 (direct channel) and P3 (coupled channel). Port 2 is isolated from the entrance. The phase difference between the output ports is 90 °, this phase shift is independent of the coupling. To see a 3 dB coupling, the horizontal and vertical line segments must have wavelengths and a characteristic impedance of 35.4Ω and 50Ω [25] respectively (because the characteristic impedance of the access ports is50Ω).

Figure2. **Hybrid coupler (3dB, 90 °) standard**

Figure3.**Internal diagram of the 3dB hybrid coupler**[16].

Referring to Figure3, a signal applied to port1 splits equally between ports 2 and 3 with one of the outputs exhibiting a relative 90° phase shift. If ports 2 and 3 are properly terminated into matching impedances, nearly all the signal applied to port1 is transmitted to the loads connected to ports2 and 3. In this case, port 4 receives negligible power and is called isolated [26]. The settings important couplers are:

Coupling: The coupling factor indicates the percentage of the input power which is a couple at the exit port given by the relationship (C is coupling, P1 and P3 are power at port 1 and 3)

$$C = 10\log\frac{P_1}{P_3} \quad 1.1$$

Directivity is a measure of the coupler's ability to isolatetransmitted and reflected waves, it is given by the following relation: (D is directivity P4 is power at port 4)

$$D = 10\log\frac{P_3}{P_4} \quad 1.2$$

Isolation: also allows measuring the capacitance of the coupler to isolate. (I is isolation ,S14 is insertion loss).

$$I = 10\log\frac{P_1}{P_4} = -20\log\left|S_{14}\right| \quad 1.3$$

IV -1 Distribution Matrix

A linear microwave network may be characterized by a particular matrix, called a distribution matrix.This matrix is obtained by breaking down the voltage and the current at the access ports of the network in incident and reflected waves.The popularity of the distribution matrix for the characterization of linear arrays stems from the fact that the termsof this matrix are more easily measurable at the microwaves.This matrix also gives more direct information on useful parameters, such as the level of adaptation of the various access ports and the various transfer functions of the network, such as the gain and the level of isolation.We are interested in the latter type of coupler branched directional couplers stated above made using four sections of line Transmission Electron Microscopy (TEM) of the same length,but with different characteristic impedance and forming a ring structure. It is a 4-port network designed to operate on equal characteristic impedances on each port.

$$\overline{S} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad 1.4$$

The calculation of the distribution matrix of the branch coupler is done by taking advantage of the natural symmetry of the structure.

As the network is passive and reciprocal, $S_{ij} = S_{ji}$**, only the parameters located on the main diagonal and below must be determined. Moreover, since the structure is symmetrical, we have:**

$$\begin{aligned} S_{34} &= S_{21} \\ S_{24} &= S_{31} \\ S_{11} &= S_{22} \\ S_{22} &= S_{44} \end{aligned} \quad 1.5$$

Whichled to the followingequivalences:

$$\begin{aligned} S_{11} &= S_{22} = S_{33} = S_{44} \\ S_{21} &= S_{12} = S_{43} = S_{34} \\ S_{31} &= S_{13} = S_{42} = S_{24} \\ S_{41} &= S_{14} = S_{32} = S_{23} \end{aligned} \quad 1.6$$

The distribution matrix of the coupler is thus completely determined by the elements of the first column, and can be written:

In other words, the calculation of the distribution

$$\overline{S} = \begin{bmatrix} S_{11} & S_{21} & S_{31} & S_{41} \\ S_{21} & S_{11} & S_{41} & S_{31} \\ S_{31} & S_{41} & S_{11} & S_{21} \\ S_{41} & S_{31} & S_{21} & S_{11} \end{bmatrix} \qquad 1.7$$

matrix is reduced to the calculation of the four parameters:

S_{11}, S_{21}, S_{31} and S_{41}

Considering our ideal coupler and that the power to the ports 1 is transmitted and distributed in a way equal to the ports of outputs port 3 and 2 and without loss, the computation of the four parameters will lead us to the following matrix:

$$\overline{S} = \begin{bmatrix} 0 & -j/\sqrt{2} & -1/\sqrt{2} & 0 \\ -j/\sqrt{2} & 0 & 0 & -1/\sqrt{2} \\ -1/\sqrt{2} & 0 & 0 & -j/\sqrt{2} \\ 0 & -1/\sqrt{2} & -j/\sqrt{2} & 0 \end{bmatrix} \qquad 1.8$$

IV-2 Presentation of the ADS software

ADS is a modeling tool based essentially on the variation of the shape of the antenna and its conductive material, the nature and the thickness of the substrate whose goal is to obtain a structure that resonates in the frequencies desired for applications accurate. This software uses the method of moments. The technique consists in meshing and dividing the conductors into simple elements of triangular or rectangular shape. The mesh sizes can vary and thus allow the cells to be adapted to the geometry of the structure to be studied [17]

IV-3 Pre-dimensioning of the 90 degree hybrid coupler

Before starting the parametric study of the coupler it is advisable to calculate the theoretical parameters of the coupler according to the specifications This parametric study passes by the calculation of the following dimensions:

The length of a branch: the length of the branch must be equal to a quarter of the wavelength at the desired frequency.
The width**of a branch**: the coupling factor desired here is 3 dB the calculation of the width w is given by the following relation:

- The length of a branch: the length of the branch (L) must be equal to a quarter of the wavelength (λ) at the desired frequency (f), light velocity (c), propagation velocity (v_p) and relative permittivity (ε_r)

$$L = \frac{\lambda}{4}, \qquad 1.9$$

with $\lambda = \frac{v_p}{f} = \frac{c}{f\sqrt{\varepsilon_r}}$

- The width: the coupling factor desired here is 3 dB the calculation of the width w is given by the following relation with distance (d) and impedance (Z_0):

$$\frac{w}{d} = \begin{cases} \dfrac{8e^A}{8e^A - 2} \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B-1) + \dfrac{1}{2}\left\{\ln(B-1) + 0{,}39 - \dfrac{0{,}61}{\varepsilon_r}\right\}\right]; \dfrac{w}{d} \succ 2 \end{cases} \qquad 1.10$$

With $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}$ and

$$B = \frac{377\pi}{2Z_O\sqrt{\varepsilon_r}}$$

IV-4 Presentation of the 90 ° phase shifter results

This coupler is dimensioned and simulated by the MOMENTUM software [17] in order to work well at the central frequency of 2.34 GHz, the dimensions of the lines used are calculated by hpADS LINECALC software and this helped us to have below values after optimization.

IV-4-1 Case of the TMM4 substrate

Table 1. Coupler parameters.

Parameter	L1	W1	L2	W2	f_r	Z_0	$Z_0/2$
Value	1.48237mm	17.409mm	17.2538mm	2.46072mm	2.34	50Ω	35.35Ω

L:length of the branch W:stands for width

This coupler is characterized using the Rogers TMM4 substrate (εr = 4.55, h = 0.8 mm,tgδ= 0, 017).

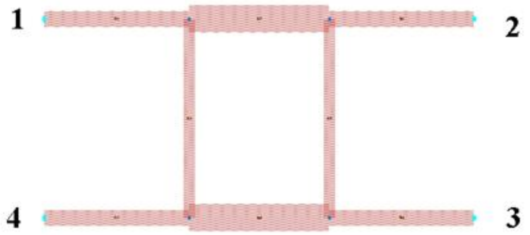


Figure 4. Layout of the new Momentum phase shifter of the 90 ° coupler.

The simulation results of the hybrid coupler (3dB, 90 °) are represented in the figures below.

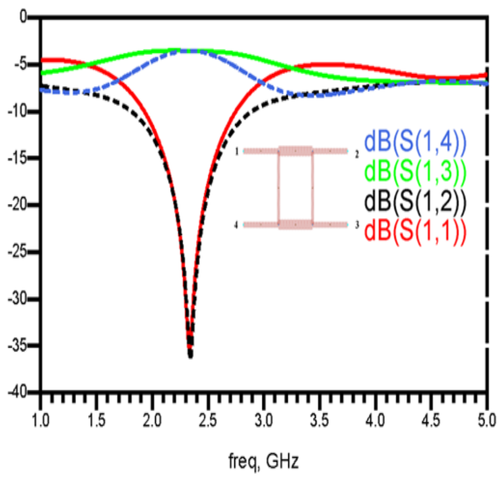


Figure5. Sij (Coefficient of reflection) parameters in coupler phase(3dB, 90 °) as a function of frequency (Rogers TMM4 substrate).

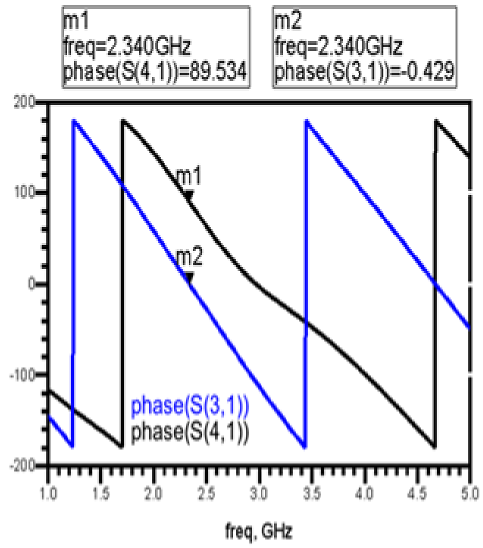


Figure6. Sij parameters in coupler phase(3dB, 90 °) depending on the frequency.

The amplitude Sij parameters of this coupler show an equi-amplitude between the two output channels on the [1.4GHz-3GHz] band. Outside this band, we have degradation of the coupler operation. Also, these results show that we have a poor adaptation (S11 = -25.56dB) and insufficient insulation (S21 = -18.2dB). In terms of phase, the output signals on the ports 3 and 4 are in quasi-quadrature phase. The phase difference is 88 ° at the frequency 2.34 GHz.

IV.4.2 Case of theFlame Resistant (FR4) substrate

Table 2. Coupler parameters.

Parameter	L1	W1	L2	W2	f_r	Z_0	$Z_0/2$
Value	56 mm	4 mm	50 mm	6.4 mm	2.34	50Ω	35.35Ω

This coupler is characterized using the Rogers TMM4 substrate (εr = 4.3, h = 1.6 mm, tgδ= 0, 018).

The simulation results of the hybrid coupler (3 dB, 90 °) are represented in the figures below.

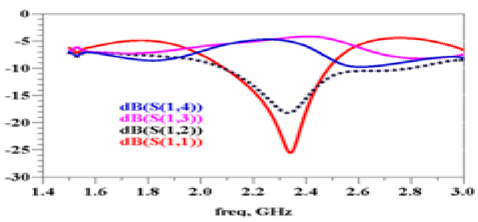


Figure 7. Sij parameters in phase of the coupler (3dB, 90 °) as a function of the frequency (substrate FR4).

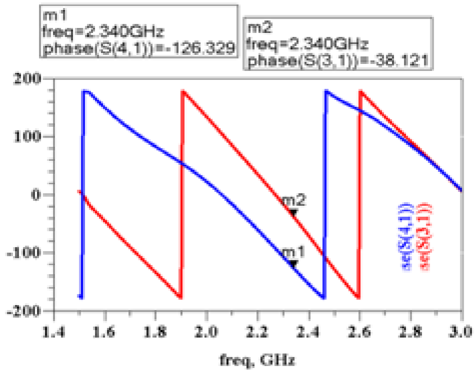


Figure8. Sij parameters in phase of the coupler (3dB, 90 °) as a function of the frequency (substrate FR4).

The amplitude Sij parameters of this coupler show an equi-amplitude between the two output channels on the [1.4GHz-3GHz] band. Beyond this band, we have a deterioration in the operation of the coupler. Also, these results show that we have a poor adaptation (S11 = -25.56dB) and insufficient insulation (S21 = -18.2dB). In terms of phase, the output signals on ports 3 and 4 are in quasi-quadrature phase. The phase difference is 88 ° at the frequency 2.34 GHz.

IV-4-3 Choice of substrate

The table below presents the results obtained for the two types of substrate.

Table 3. Comparative table of couplers.

Type ofsubstrate	Frequency (GHz)	Isolation (dB)	Coupling (dB)	Phase shifter (degree)
TMM4	2,34	-36,725	-35,195	90
FR4	2,34	-18,2	-25,56	88

We observe in Table 3 that the phase shift obtained for the FR4 substrate coupler does not reach 90° in our study. This phase shift is due to the poor coupling and the existing bad insulation between the inputs of this coupler. The coupler designed on TMM4 substrate has an excellent phase shift and a very good insulation, it can easily be used to perform the phase shift of the signals.

From the results of Table 3 and the analysis made, our choice is taken for a coupler on substrate TMM4 for the continuation of the works.

TMM4 Microwave Materials are thermo-hardened ceramic polymer composites designed for high reliability strip line and micro-tape applications. In addition the electrical and mechanical properties of TMM4 has many advantages for ceramic microwave circuits

V. DESIGN OF THE 3DB HYBRID COUPLER, 90 ° WITH THREE BRANCHES

To have a 3dB hybrid coupler, 90° to three brains, we cascaded three hybrid couplers 3dB, 90° on the same substrate. As for the first coupler we realize our model using Agilent ADS software.Referring to Fig. 9, a signal applied to port1 also divides between the output ports 2 of the first coupler (C1) with a phase shift of 90°. If the two output ports of the coupler (C1) are correctly adapted, almost all the signal applied to the port1 is transmitted to the inputs of the couplers (C2) and (C3). The outputs of the coupler (C1) will constitute inputs for the couplers (C2) and (C3). The signals at the inputs of the couplers (C2) and (C3) will also be divided between ports 3 and 4 for the coupler (C2) and between ports 6 and 7 for the coupler (C3) with a phase shift of 90°. Ports 2, 5 and 8 will receive negligible powers and will be isolated.

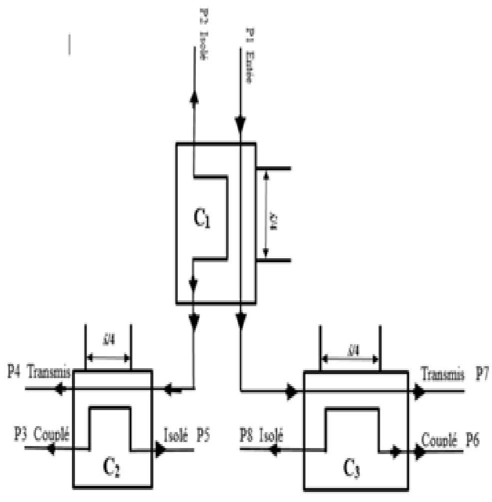


Figure9. Internal diagram of the 3dB hybrid coupler.

Figure 9 shows our power phase shifter or Agilent ADS software under the Momentum interface.

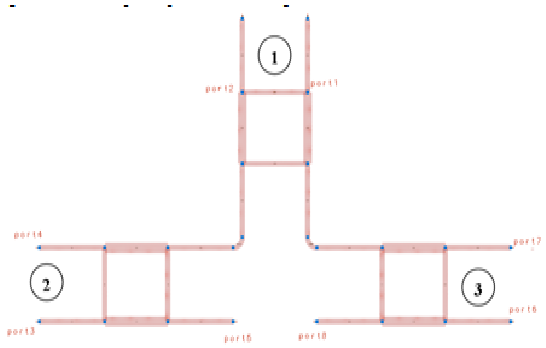


Figure10. Layout of the new phase shifter under Momentum.

Our phase shifterconsists of three inputs as shown in Figure 10 above. If this phase-shifterisfed to the port1 of the input 1, the transmitted outputs willbe the ports 4 and 7 on the other hand the coupled outputs are the ports 3 and 6.The ports 2, 5 and 8 willthenbeisolated.

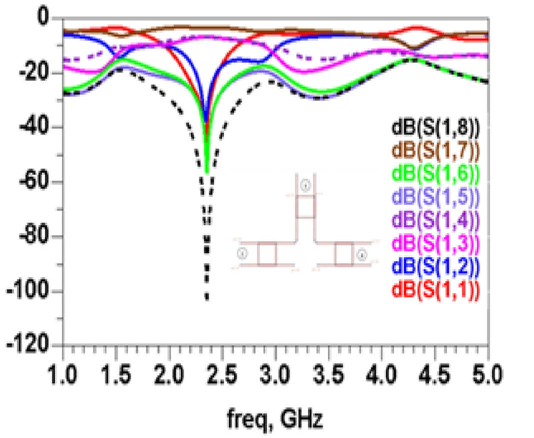
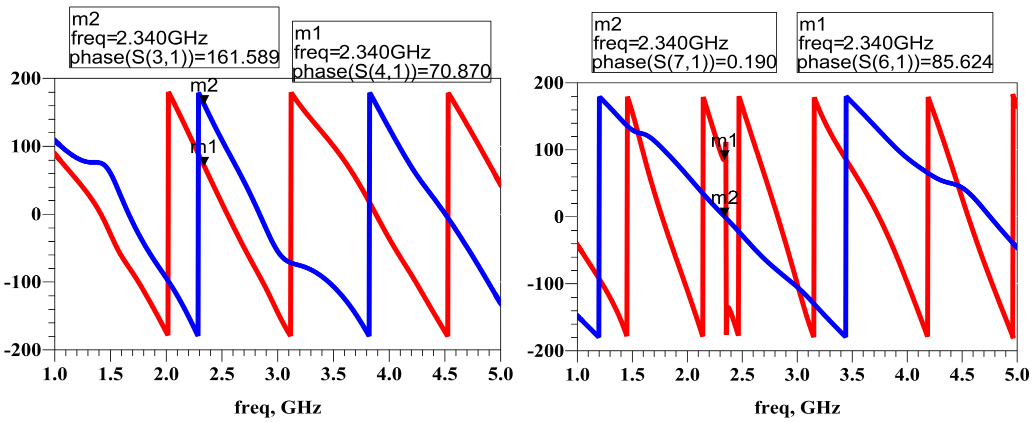


Figure 11. Sij parameters in the coupler phase as a function of frequency.

The input of our phase shifter is port 1 and the outputs port3, 4,6 and 7 (see figure10). Ports 5 and 8 are grounded. The input of our phase shifter can be chosen arbitrarily except ports 5 and 8. The results show that we have an excellent adaptation to inputs 2 and 3 respectively S44 = -38.1dB and S77 = -36.965dB. It also has a very good isolation at the inputs 2 and 3, S43 = -34.842dB for the input 2 and an isolation that does not satisfy us at the input 3 of the coupler is S76 = -105.358dB.



a) **b)**

Figure12. Sij parameters in coupler phase in Frequency function:

a) port34, b) port67.

Regarding the phase, Figure 12 shows the phase shift at the inputs 2 and 3. Between the ports 3 and 4 we observe a phase shift of 90° and at the ports 6 and 7 we have 86° while we waited to obtain a phase shift of 90°.

Table 4. Coupler results.

Specifications	**Entry 2**	**Entry 3**
Frequency(GHz)	2,34	2,34
Phase shift (°)	90	86
Isolation (dB)	-34,842	-105,358
Coupling (dB)	-38,09	-36,965
Directivity (dB)	6,83	
Dimension (mm)	129x74	

VI. CONCLUSION

A 3 dB hybrid 3-way coupler was designed and simulated. Its different parameters have been studied and presented. This global simulation of the coupler focuses on the losses of the device. Indeed, if the coupler was without loss, the output phases 2 and 3 would indicate a phase of 90°. During the simulation we have at the input 3 a phase of 86° at the working frequency, we can therefore estimate the maximum losses in the coupler at 4°, a minimum efficiency of 85% at 2.34 GHz this due the low coupling and a good enough isolation at this input. On the other hand, the input 2 has an excellent phase shift and a very good isolation between the ports. The phase-shifter makes it possible to feed 4 antennas out of phase with each other by 90° in order to have circular polarization, thus the combination of 3 couplers causes a circular polarization by arranging the antennas on these input ports, which optimizes the performance of network coverage and accordingly the radio channel, knowing that the modeling tool is the ADS software.

REFERENCES:

[1]. Bandwidth Optimization Method for Reflective-Type Phase Shifters Daniel Müller , Alexander Haag, AkankshaBhutani, Axel Tessmann, ArnulfLeuther,Thomas Zwick, Senior Member, IEEE, and Ingmar Kallfass. · December 2017

[2]. S. Koenig et al., “Wireless sub-THz communication system with high data rate,” Nature Photon., vol. 7, no. 12, pp. 977–981, Dec. 2013.

[3]. R. J. Emery and A. M. Zavody, “Atmospheric propagation in the frequency range 100-1000 GHz,” Radio Electron. Eng., vol. 49,nos. 7–8, pp. 370–380, Jul./Aug. 1979.

[4]. N. Sarmah, P. R. Vazquez, J. Grzyb, W. Foerster, B. Heinemann, and U. R. Pfeiffer, “A wideband fully integrated SiGe chipset for high data rate communication at 240 GHz,” in Proc. 11th Eur. Microw. Integr.Circuits Conf. (EuMIC), 2016, pp. 181–184.

[5]. Y. Chun and J. Hong, “Compact wideband branch-line hybrids,” IEEE Trans. Microwave Theory Tech., vol. 54, no. 2, pp. 704–709, Feb. 2006.

[6]. H.-J. Song et al., “Demonstration of 20-Gbps wireless data transmission at 300 GHz for KIOSK instant data downloading applications with InP MMICs,” in IEEE MTT-S Int. Microw. Symp. Dig., May 2016, pp. 1–4.

[7]. D. Müller, A. Tessmann, A. Leuther, T. Zwick, and I. Kallfass, “A h-band vector modulator mmic for phase-shifting applications,” in IEEE MTT-S Int. Microw. Symp. Dig., May 2015, pp. 1–4.

[8]. X. Zou, C.-M. Tong, C.-Z. Li, and W.-J. Pang, “Wideband hybrid ring coupler based on half-mode substrate integrated waveguide,” IEEE Microw. Wireless Compon. Lett., vol. 24, no. 11, pp. 748–750, Nov. 2014.

[9]. D. Deslandes and K. Wu, “Integrated microstrip and rectangular waveguide in planar form,” IEEE Microw. Wireless Compon. Lett., vol. 11, no. 2, pp. 68–70, Feb. 2001. [10] Y. Liao, “Microwave Devices and Circuits”, Third edition, Pear-son Publications, 2003.

[10]. R. Garg and A. S. Natarajan, “A 28-GHz low-power phased-array receiver front-end with 360° RTPS phase shift range,” IEEE Trans.Microw. Theory Techn., vol. 65, no. 11, pp. 4703–4714, Nov. 2017.

[11]. W. Che, K. Deng, E. Yung, and K. Wu, “H-plane hybrid ring of high isolation in substrate-integrated rectangular waveguide (SIRW),” Microw.Opt. Techn. Lett., vol. 48, no. 3, pp. 502–505, Mar. 2006.

[12]. S. Y. Zheng, S. H. Yeung, W. S. Chan, K. F. Man, and K. S. Tang, “Design of broadband hybrid coupler with tight coupling using jumping gene evolutionary algorithm,” IEEE Trans. Ind. Electron., vol. 56, no. 8, pp. 2987–2991, Aug. 2009.

[13]. Z. C. Hao, W. Hong, J. X. Chen, H. X. Zhou, and K. Wu, “Single-layer substrate integrated waveguide directional couplers,” Proc. Inst. Electr. Eng., vol. 153, no. 5, pp. 426–431, Oct. 2006.

[14]. T. Djerafi, J. Gauthier, and K. Wu, “Quasi-optical cruciform sub-strate integrated waveguide (SIW) coupler for millimeter-wave systems,” in IEEE MTT-S Int. Microw. Symp. Dig., May 2010, pp. 716–719.

[15]. M. Bozzi, A. Georgiadis, and K. Wu, “Review of substrate inte-grated waveguide (SIW) circuits and antennas,” IET Microw. An-tennasPropag., vol. 5, no. 8, pp. 909–920, Jun. 2011.

[16]. T. Djerafi and K. Wu, “Super-compact substrate integrated wave-guide cruciform directional coupler,” IEEE Microw. Wireless Compon. Lett., vol. 17, no. 11, pp. 757–759, Nov. 2007.

[17]. “Advanced Design System” (AgilentTechnology), http://www.agilent.com

[18]. C. Quan, S. Heo, M. Urteaga, and M. Kim, “A 275 GHz active vectorsum phase shifter,” IEEE Microw. Wireless Compon. Lett., vol. 25, no. 2, pp. 127–129, Feb. 2015.

[19]. Y. Du, W. Su, X. Li, Y. Huang, and J. Bao, “A novel MEMS distributed phase shifter for D-band application,” in Proc. IEEE Int. Conf. Microw.Millimeter Wave Technol. (ICMMT), vol. 1. Jun. 2016, pp. 542–544.

[20]. R. Garg and A. S. Natarajan, "A 28-GHz low-power phased-array receiver front-end with 360° RTPS phase shift range," IEEE Trans.Microw. Theory Techn., vol. 65, no. 11, pp. 4703–4714, Nov. 2017.

[21]. Mohajer, M., M. Faraji-Dana, and S. Safavi-Naeini, "Effects of resonance-based phase shifters on Ka-Band phased array antenna performance for satellite communications," Progress In Electromagnetics Research B, Vol. 60, 259–274, 2014.

[22]. Chakraborty, A. and B. Gupta, "Paradigm phase shift," IEEE Microwave Magazine, Vol. 18, No. 1, 22–41, Jan.–Feb. 2017.

[23]. F. Meng, K. Ma, K. S. Yeo, S. Xu, C. C. Boon, and W. M. Lim,"Miniaturized 3-bit phase shifter for 60 GHz phased-array in 65 nm CMOS technology," IEEE Microw. Wireless Compon. Lett., vol. 24, no. 1, pp. 50–52, Jan. 2014.

[24]. Vilenskiy, A. R. and M. V. Makurin, "Analog varactor phase shifter," 2017 Progress In Electromagnetics Research Symposium — Spring (PIERS), 3820–3825, St Petersburg, Russia,May 22–25, 2017.

[25]. Khalid S. Ahmad, ''Miniaturized Hybrid Rat-Race Coupler of a 2.5 GHz Loaded by Resistors'', Journal of networks, vol. 8, no. 7, july 2013

[26]. T.Jayachitra,V.K Pandey and Anshuman Singh, ''Design of Hybrid Coupler'', Copyright to IJAREEIE, Vol. 3, Special Issue 3, April 2014.

Richard Essomba Mbondjo" Optimization of the radio channel Interface using a 3dB, 90 ° hybrid phase shifter with three branches." International Journal of Engineering Research and Applications (IJERA), Vol. 09, No.07, 2019, pp. 49-57