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Computer-Aided Design and Analysis of Different Configurations of Singly - Balanced Microstrip Diode Mixers Using the Modified MSDES and ADS Packages

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***Abstract*—The aim of this paper is to introduce the computer aided design and analysis of different configuration of singly-balanced Microstrip diode mixers using the recent MSDES program developed by the author and the recent ADS package. The design stages of the Microstrip Mixers including the design of hybrid couplers, Design of matching circuit that matches the diode input impedance to the coupler, and design of Lowpass filter that passes the IF output signals are introduced. The Teflon substrate with substrate parameters er = 4.3, H = 1.35 mm and T = 0.035 mm is used for the mixer circuit design and analysis. The ADS layouts and the applications of the designed Microstrip mixers are presented. Key Words: Microwave Circuits and systems, Computational Microstrip Circuit Design, Microwave Circuits analysis**

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I. INTRODUCTION

Recently many works have been performed for the design and fabrications of the individual parts of the microwave transceiver circuit such as amplifiers, oscillators and mixers using Microstrip technique [1-6]. In the beginning of 1990, the works of fabrication of a complete Microstrip transceiver has been started especially for the military applications. Figure 1 shows the block diagram of transceiver. It comprises a 4-GHz Microstrip negative-resistance oscillator (NRO), 4-GHz broadband Microstrip amplifier (BMA), a 7-dB power splitter using Microstrip branch coupler (MBC), singly balanced diode mixer (SBDM) with 4-port/5-port rate-race, Lange coupler or rectangular branch coupler, Microstrip Lowpass filter (LPF) and TRS [1-2].

For Singly-balanced diode mixer The input signals for the rate-race, Lange or branch-line coupler are: 1) the reference LO input signal comes from 2.4 GHz NRO through the coupled port of 9dB MBC and 2) the received RF signal comes from antenna through TRS and 2.4 GHZ BMA [7-15]. The IF output signal is extracted from the mixer output through Microstrip low-pass filter (LPF). The design of the different configuration of single-balanced diode mixer is performed completely with the aid of the full-scale computer simulation program developed by the author [16-18] while the analysis and optimization are performed using the ADS2017 software [19]. The Microstrip substrate parameters with 50-Ω normalized impedance are: relative permittivity (ε_r) = 4.3 , substrate height (H) = 1.58 mm, and conductor thickness (T) = 0.035 mm.

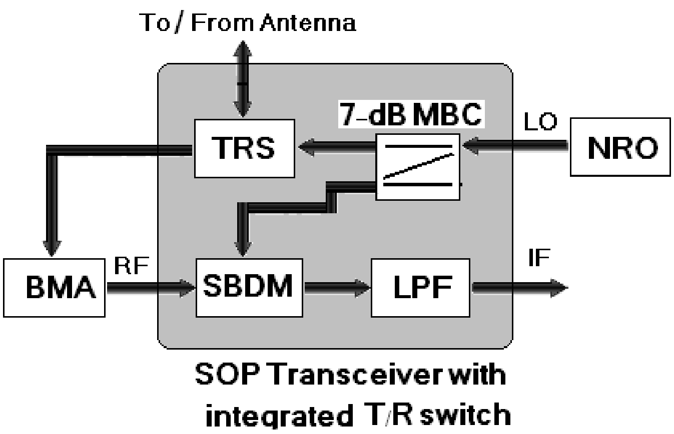


Fig. 1: Block diagram of L-band sensor including SOP-HMIC transceiver with integrating TRS.

II. DESIGN OF MICROSTRIP SINGLY-BALANCED DIODE MIXER.

The design of a Microstrip mixer is performed using the developed full-scale computer simulation program. The design is performed for a singly balanced diode mixer with the following two stages [9-14]: 1) Design of hybrid coupler (rate-race or Lange coupler) , 2) Design of matching circuit that matches the diode input impedance to the coupler.

A. Design And Analysis Of 4-Port Rate-Race Coupler

The rate-race coupler is designed for the coupling factor C = 3 dB at the operating frequency of 2.4 GHz. As a result of the developed program, the parameters of the rate-race are [9-14]: total length of the rate-race line = 106 mm, length of ($\frac{1}{4}\lambda_{g}$) circular lines (R) = 17.8 mm, length of ($3/4\ \lambda_g$) circular lines = 53.4 mm, width (WR) of rate-race lines = 1.57 mm and impedance of circular lines = 70. 75 Ω. Figure 2 and 3 show the ADS Schematic diagram of 2.4 4-port/5-port rate race couplers. Figure 4 shows layout of the 4-port/5-ports rate-race coupler operated at 2.4 GHz. Figures 5 show $S_{11}S_{21}$, S_{31}, and S_{41}, versus frequency for the 4-ports rate race couplers operated at 2.4 GHz using ADS2017 software. Figures 6 show $S_{11}S_{21}$, S_{31}, and $S_{41,}$ S_{51}, versus frequency for the 5-ports rate race couplers operated at 2.4 GHz using ADS2017 software. Figures 7 through 10 show the phase difference and power ratio between port 3 and 3 versus frequency of the 2.4 GHz 4-port/5port Rate-race couplers. It is seen that the values of S_{21} and S_{31} for the directed (port 2) and coupled (port 3) ports equal to 3dB while the port 4 is isolated (S_{41} = -50 dB). It also seen that the phase difference and power ration between port 2 and 3 are 0 degree and 0dB respectively.

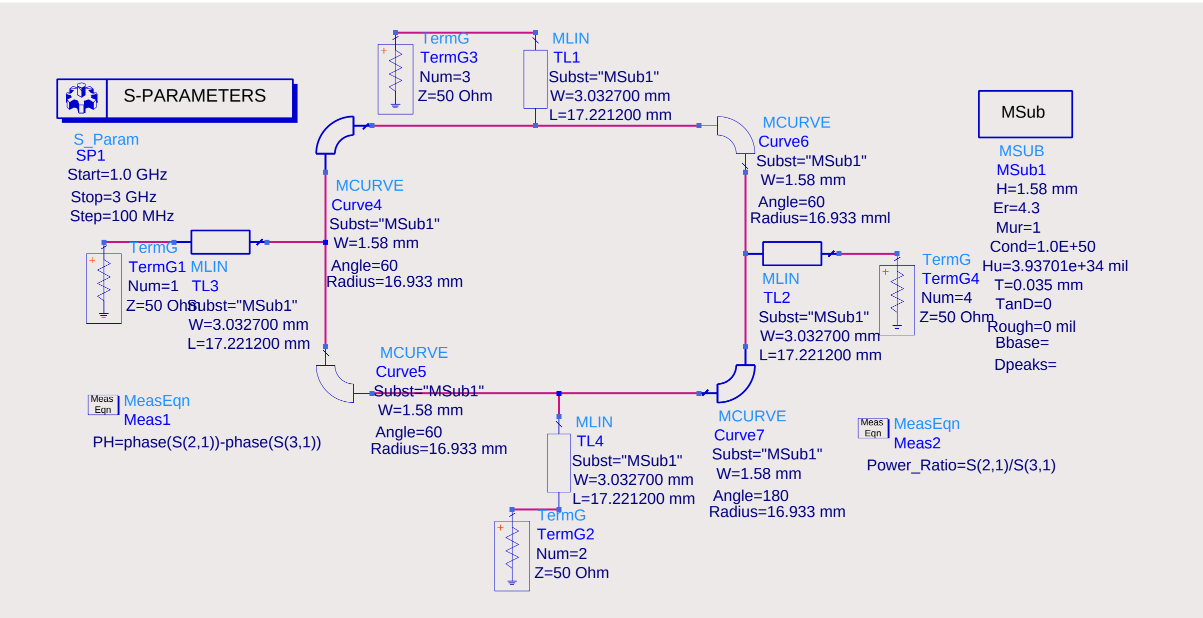


Fig. 2: ADS-Schematic diagram of 2.4 GHz 4-port Rate-race coupler

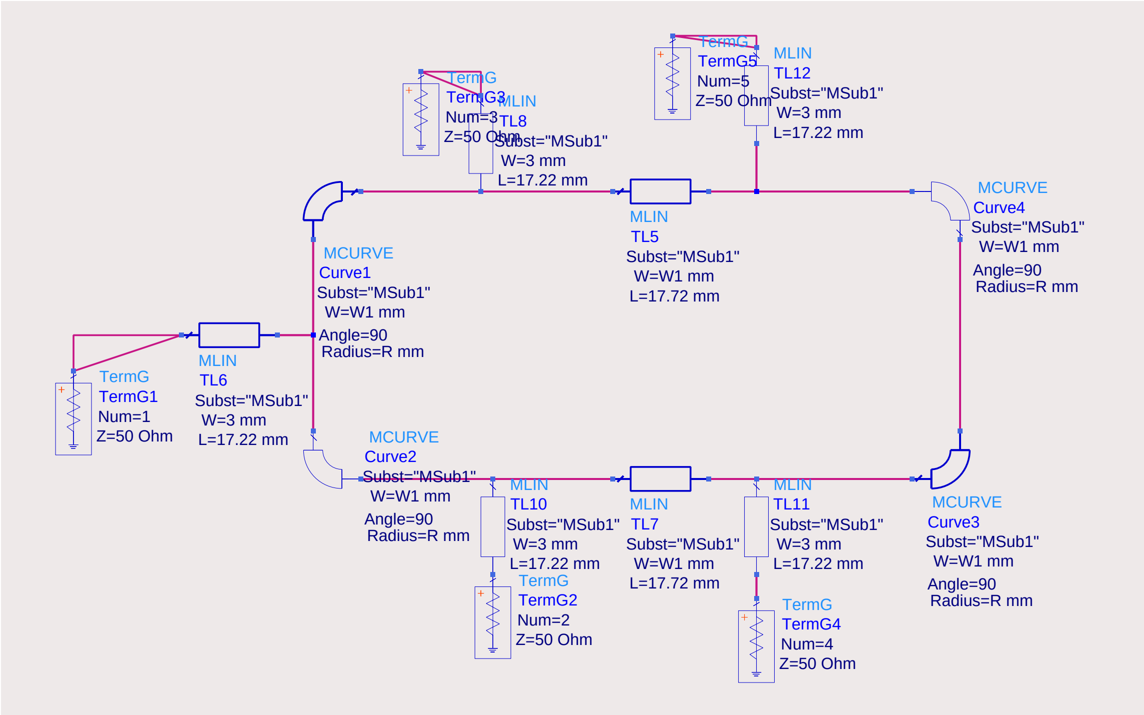


Fig. 3: ADS-Schematic diagram of 2.4 GHz 5-port Rate-race coupler

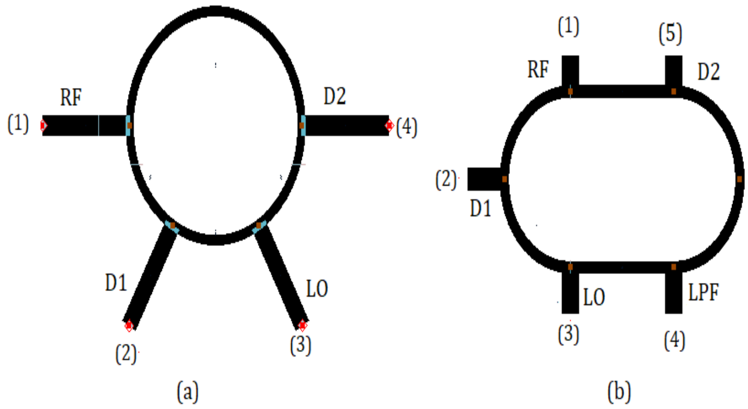


Fig. 4: ADS-layout of 2.4 GHz 4-port (a) and 5-ports (b) Rate-race couplers

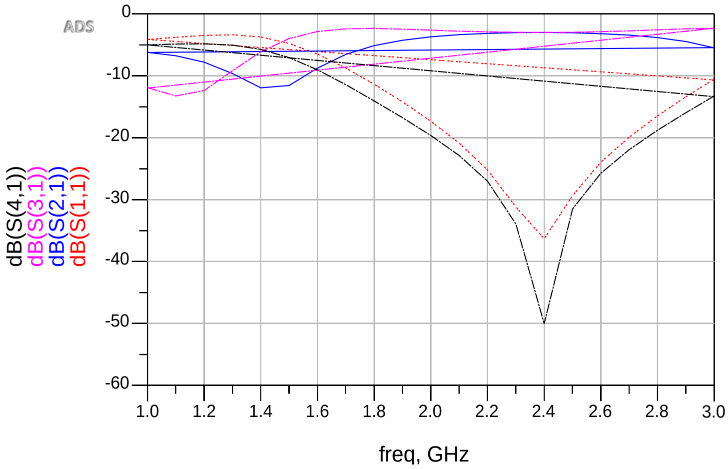


Fig.5: $|S_{11}|$, $|S_{21}|$ and $|S_{31}|$ and $|S_{41}|$, $|S_{11}|$ in (dB) versus frequency for the 2.4 GHz Rate-race coupler

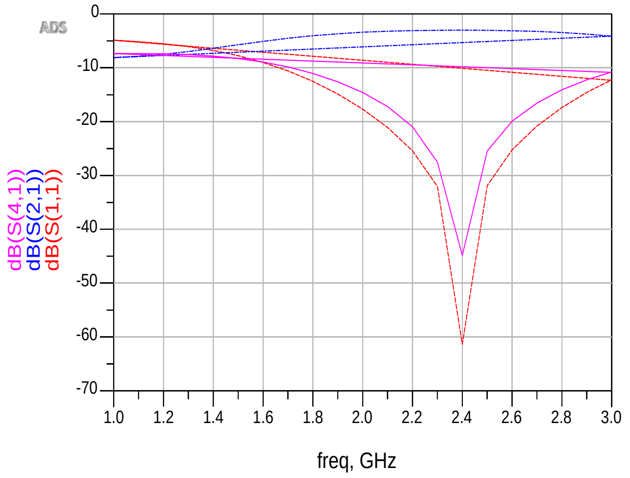


Fig. 6: $S_{11}S_{21}$, S_{31}, and $S_{41,}$ S_{51}, versus frequency for the 5-ports rate race couplers operated at 2.4 GHz using ADS2017 software

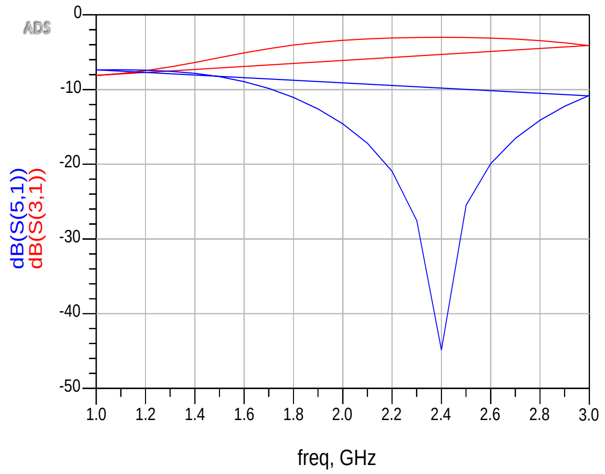
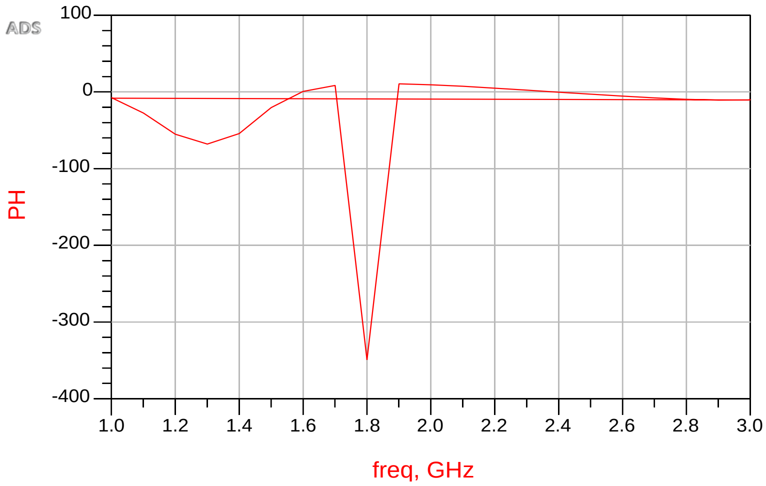


Fig. 7: Phase difference between port 3 and 3 versus frequency of the 2.4 GHz 4-port Rate-race Coupler



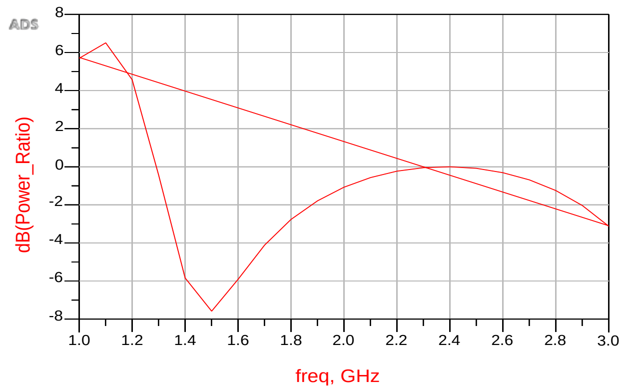


Fig. 8: Output power ration between port 3 and 3 versus frequency of the 2.4 GHz 4-port Rate-race Coupler

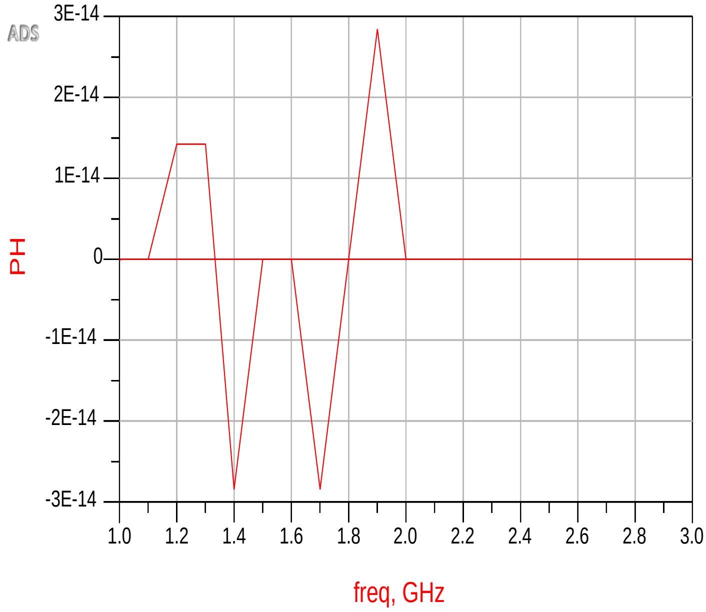


Fig. 9: Phase difference between port 3 and 3 versus frequency of the 2.4 GHz 5-port Rate-race Coupler

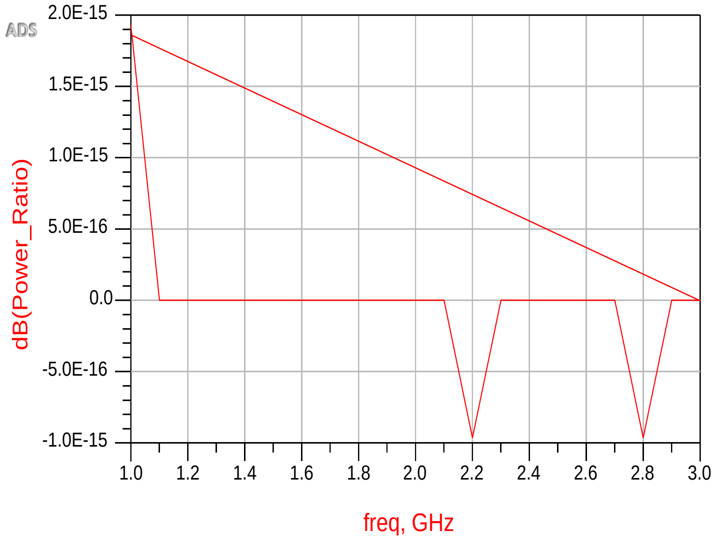


Fig. 10: Output power ration between port 3 and 3 versus frequency of the 2.4 GHz 4-port Rate-race Coupler

B. Design And Analysis Of 4-Port Branch-Line Coupler

The branch-line coupler is designed for the coupling factor C = 3 dB at the operating frequency of 2.4 GHz. As a result of the developed program, the parameters of the rate-race are [9-14]: Width , length and impedance of series line are 5.15 mm, 16.92 mm and 35.3 Ω respectively. Width , length and impedance of branch line are 2.99 mm, 17.32 mm and 50 Ω respectively.. Figures 11 and 12 show the ADS Schematic diagram and layout of 2.4 branch-line couplers.

Figure 13 shows $|S_{11}|$, $|S_{21}|$ and $|S_{31}|$ and $|S_{41}|$, in (dB) versus frequency for the 2.4 GHz for branch-line Coupler. Figure 14 shows phase difference between port 2 and 3 versus frequency of the 2.4 GHz rectangular. Figure 15shows Output power ration between port 2 and 3 versus frequency of the 2.4 GHz branch-line coupler

It is seen that the values of S_{21} and S_{31} for the directed (port 2) and coupled (port 3) ports equal to 3dB while the port 4 is isolated (S_{41} = -35 dB). It also seen that the phase difference and power ration between port 2 and 3 are 90 degrees and 0 dB respectively

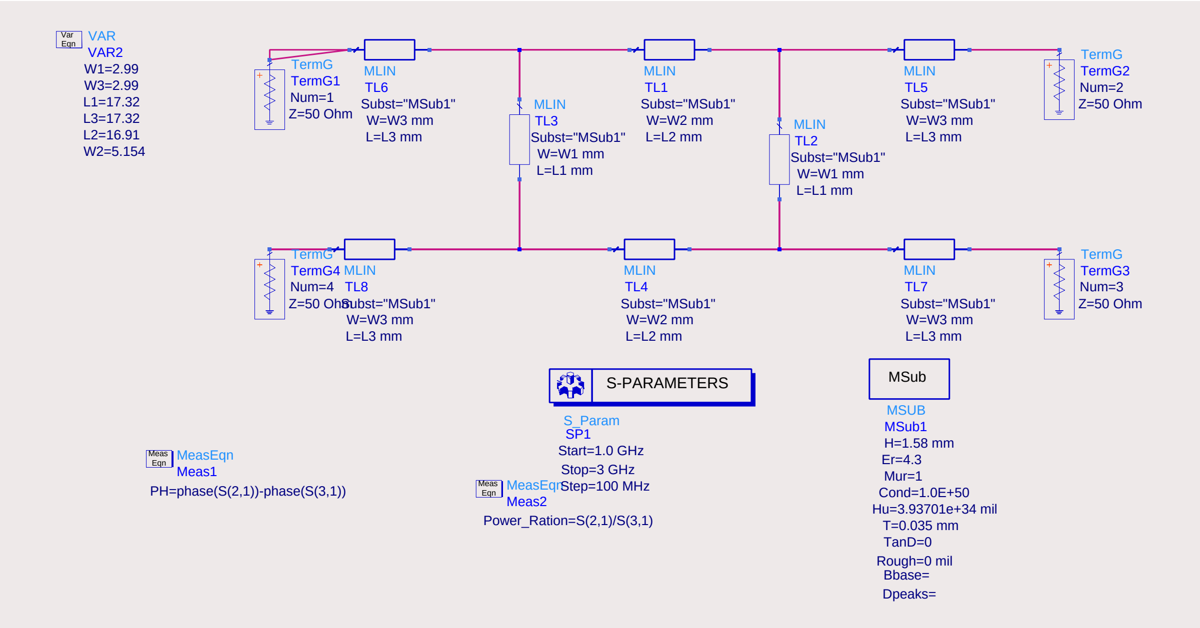


Fig. 11: ADS-Schematic diagram of 2.4 GHz branch-line Coupler

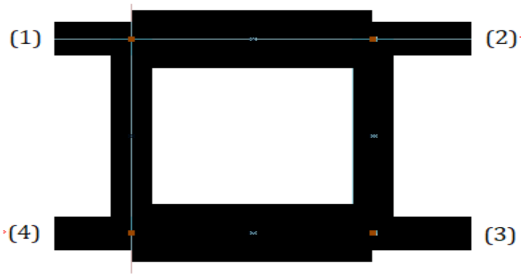


Fig. 12: ADS-layout of 2.4 GHz rectangular branch-line Coupler

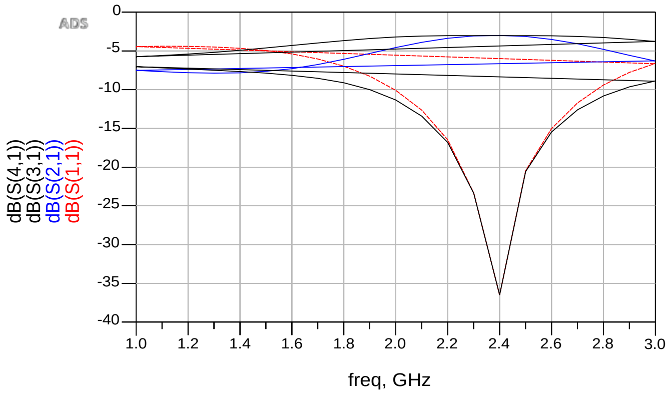


Fig.13 $|S_{11}|$, $|S_{21}|$ and $|S_{31}|$ and $|S_{41}|$, $|S_{11}|$ in (dB) versus frequency for the 2.4 GHz Rectangular branch-line Coupler

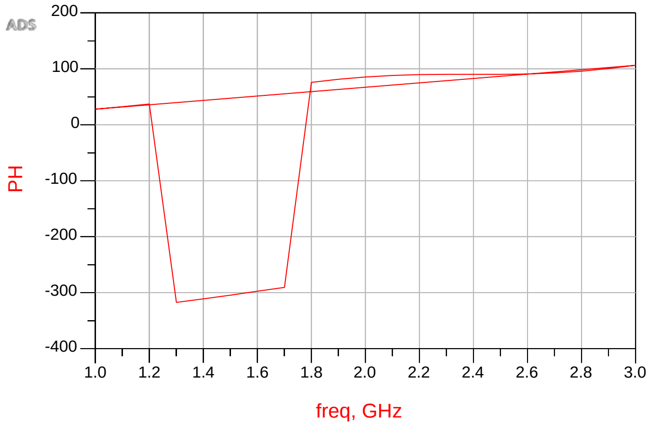


Fig. 14: Phase difference between port 2 and 3 versus frequency of the 2.4 GHz rectangular branch Coupler

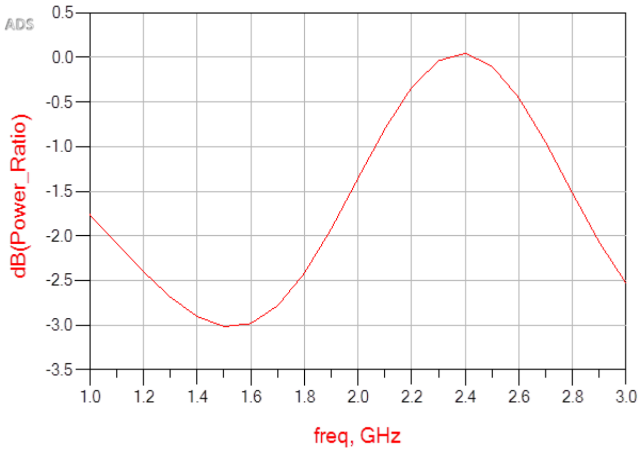


Fig. 15: Output power ration between port 2 and 3 versus frequency of the 2.4 GHz Rectangular branch-line coupler

C. *Design And Analysis Of Lange Coupler*

The Lange coupler is designed for the coupling factor C = 3 dB at the operating frequency of 2.4 GHz. As a result of the developed program and the optimization process using ADS 2017 the parameters of the Lange are [9-14]: Strip Separation n =0.113 mm, Strip width = 0.36mm Coupled line length = 15.214 mm. Figures 16 and 17 show the ADS Schematic diagram and layout of 2.4 Lange Coupler. **Figure 18** shows $|S_{11}|$, $|S_{21}|$ and $|S_{31}|$ and $|S_{41}|$, in (dB) versus frequency for the 2.4 GHz for Lange Coupler. Figure 19 shows phase difference between port 2 and 3 versus frequency of the 2.4 GHz Lange coupler. Figure 20 shows Output power ration between port 2 and 3 versus frequency of the 2.4 GHz Lang coupler

It is seen that the values of S_{21} and S_{31} for the directed (port 2) and coupled (port 3) ports equal to 3dB while the port 4 is isolated (S_{41} = -35 dB). It also seen that the phase difference and power ration between port 2 and 3 are 90 degrees and 0 dB respectively

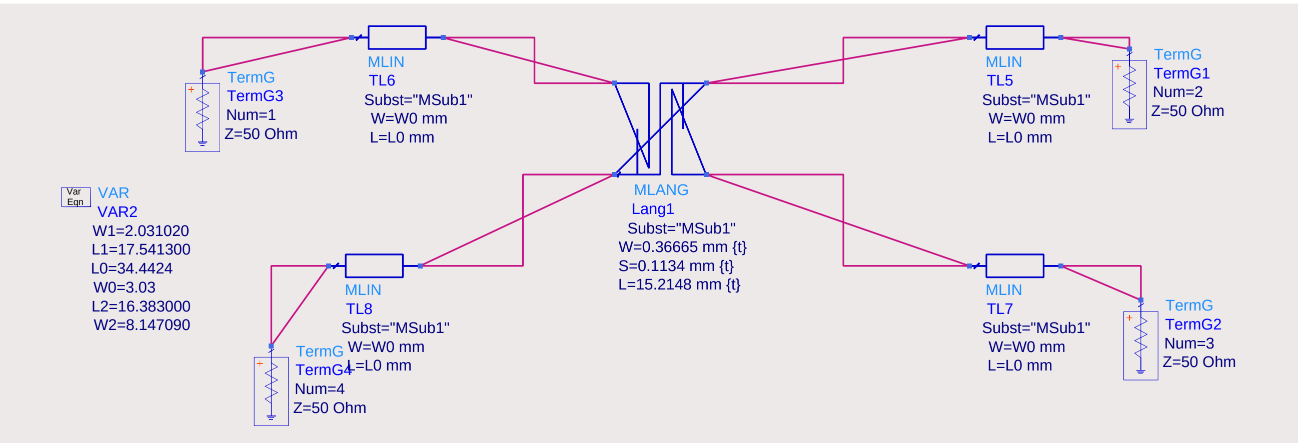


Fig. 16: the ADS Schematic diagram of 2.4 Lange Coupler.

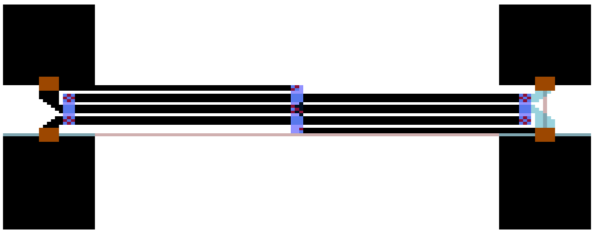


Fig. 17: the ADS Layout of 2.4 Lange Coupler.

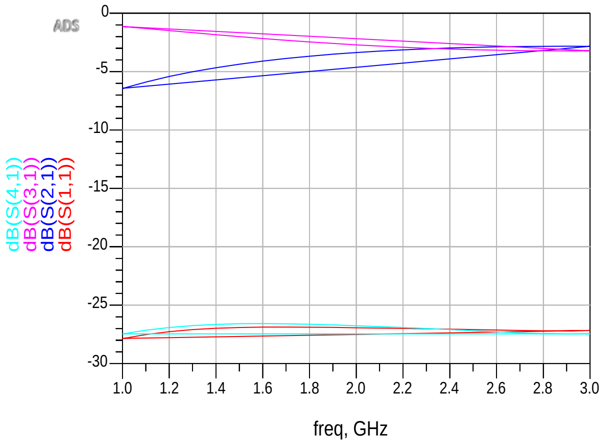


Fig. 18: $|S_{11}|$, $|S_{21}|$ and $|S_{31}|$ and $|S_{41}|$, in (dB) versus frequency for the 2.4 GHz for Lange Coupler.

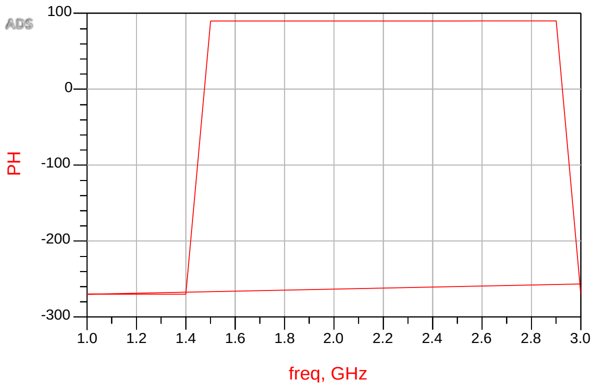


Fig. 19: The phase difference between port 2 and 3 versus frequency of the 2.4 GHz Lang Coupler.

Fig. 20: Output power ration between port 2 and 3 versus frequency of the 2.4 GHz Lang coupler

D. Design Of Diode Matching Circuit

Using the Schottky barrier diode (MMD101) model in ADS $Z_{in} = 103+j120,63\ \Omega$. For the calculated normalized impedance and the input reflection coefficient, the lengths of and widths of the diode matching circuit are: length of series line = 24.5647 mm, length of open circuit single stub = 11.62. Figure 21 shows the schematic diagram of diode matching circuits. Figure 22 shows $|S_{11}|$, and $|S_{21}|$ in (dB) versus frequency for the diode matching circuit.

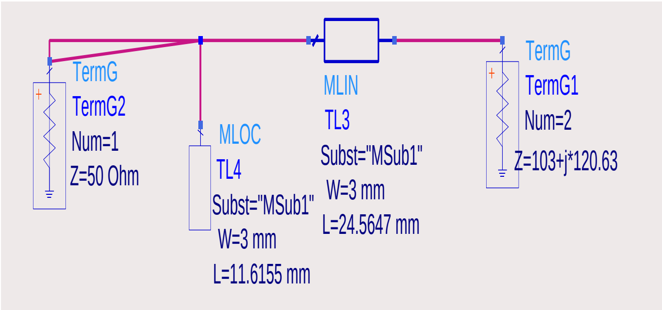


Fig. 21: the ADS schematic diagram of diode matching circuits.

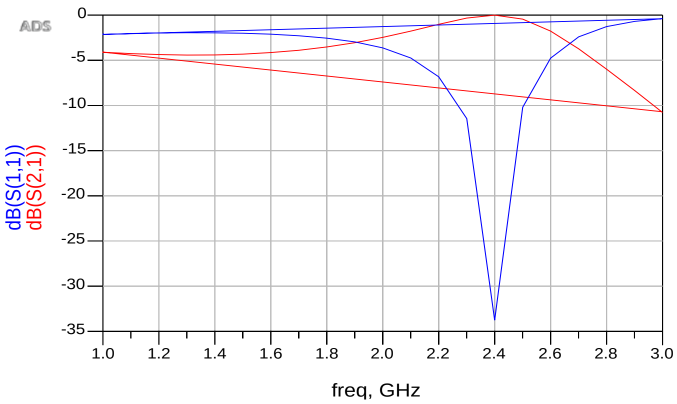


Fig. 22: $|S_{11}|$, and $|S_{21}|$ in (dB) versus frequency for the diode matching circuit.

E. Design Of LPF

The maximally flat Lowpass prototype filter is used in the design of the LPF with the following specifications :[9-13, 22-23]: the operating frequency, f_o, = 2.4GHz, the cut-off frequency, f_c = 0.8 GHz, the characteristic impedance of the series inductive is 120Ω, and the characteristic impedance of the shunt capacitance is 20Ω. One section maximally flat LPF is considered. As a result of our developed program, length (L_L) and width (W_L) of the inductive Microstrip line are 18.189 mm and 0.358 mm, respectively . Length (L_C) and width (W_C) of the capacitive Microstrip line are 32.055mm and 7.4936 mm, respectively . The attenuation at the operating frequency is 43.62 dB. The properties of a Microstrip LPF are analyzed by computing the electromagnetic field distribution in the device across a spectrum of frequencies (1– 10) GHZ. Figure 23 shows the ADS Schematic diagram of the the designed maximally-flat LPF. Figure 24 shows S_{21} (dB) versus frequency for the designed maximally-flat LPF.

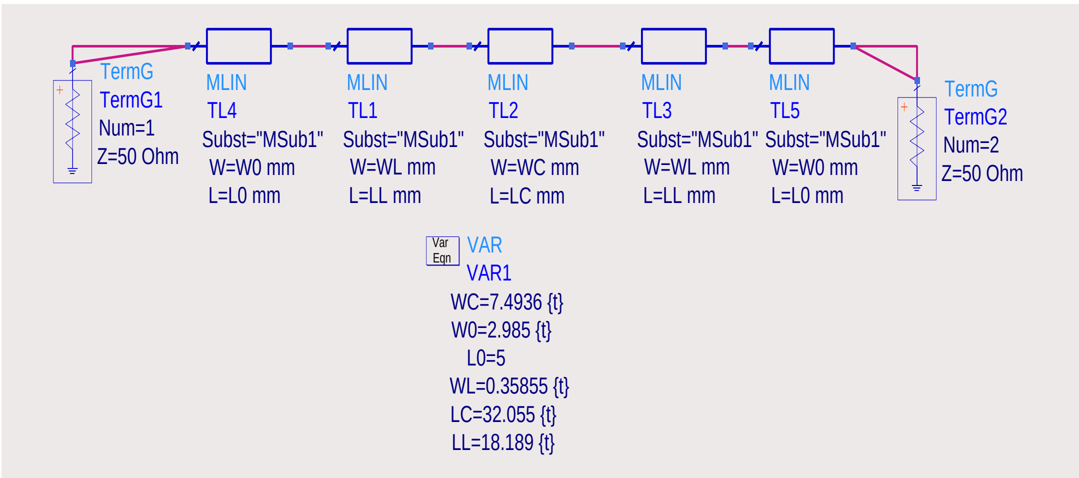


Fig. 23: The ADS Schematic diagram of the designed one-section maximally flat LPF

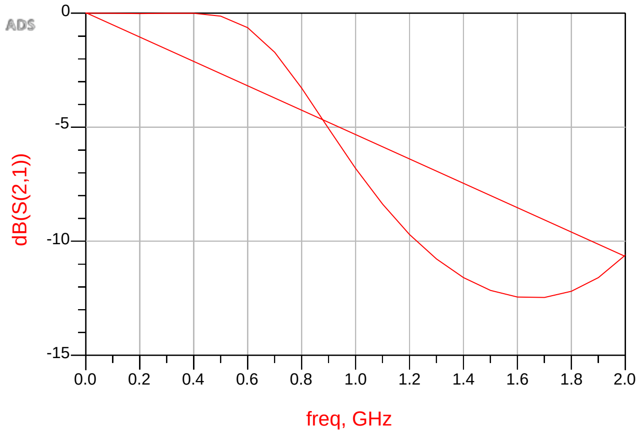


Fig. 24: S_{21} (dB) versus frequency for the designed maximally-flat LPF

III. FINAL SCHEMATIC DIAGRAM AND LAYOUT OF THE DESIGNED SINGLY-BALANCED DIODE MIXER WITH LPF

The final schematic diagram of the designed singly-balanced mixer using rate-race coupler is analysed and optimized using ADS2017 software [30-33]. Figure 25 and 26 show Schematic diagram and layout of the designed Singly-balanced diode mixer with LPF using branch line coupler. Figure 27 and 28 show Schematic diagram and layout of the designed Singly-balanced diode mixer with LPF using 5-port rate-race coupler. Figure 29 and 30 show Schematic diagram and layout of the designed Singly-balanced diode mixer with LPF using Lange coupler

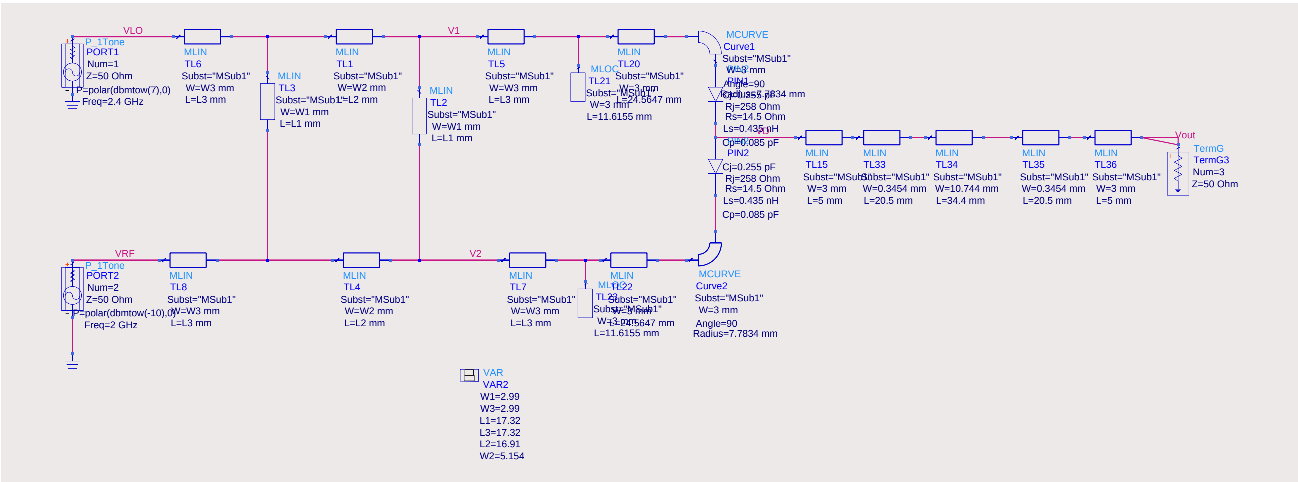


Fig. 25: ADS Schematic diagram of the designed Singly-balanced diode mixer with LPF using branch line coupler.

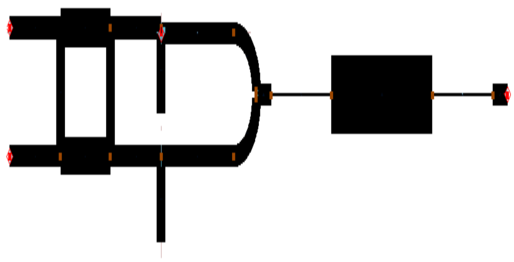


Fig. 26: ADS Layout diagram of the designed Singly-balanced diode mixer with LPF using branch line coupler.

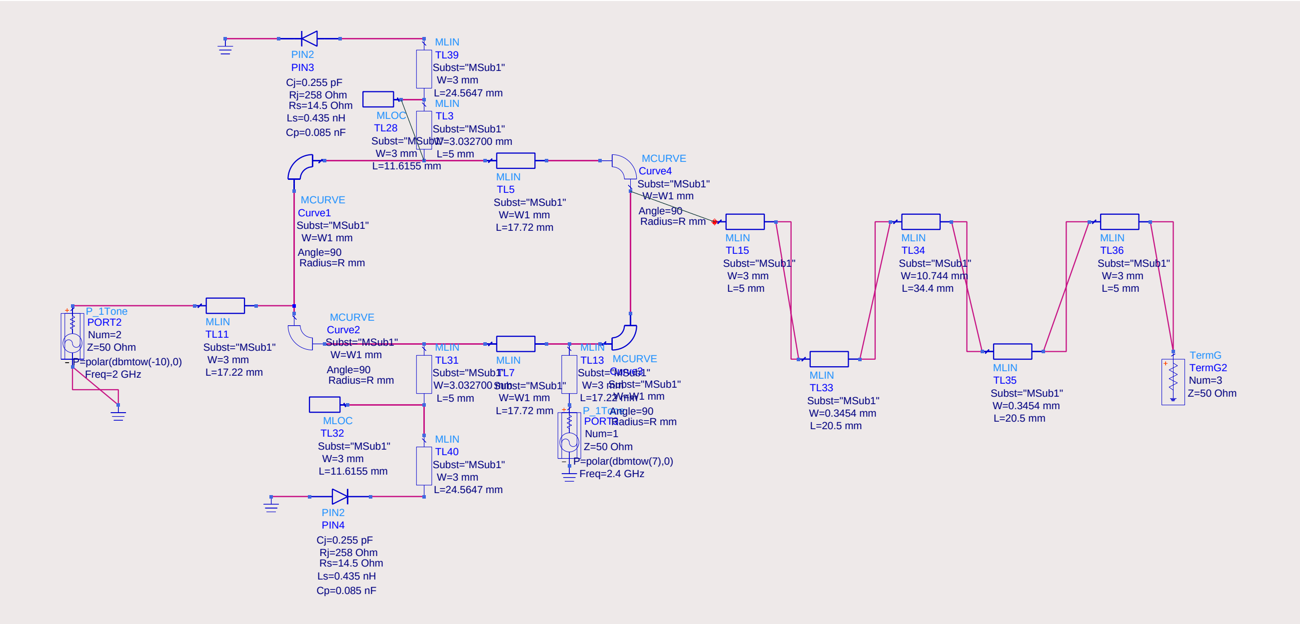


Fig. 27: ADS Schematic diagram of the designed Singly-balanced diode mixer with LPF using 5-port rate-race coupler.

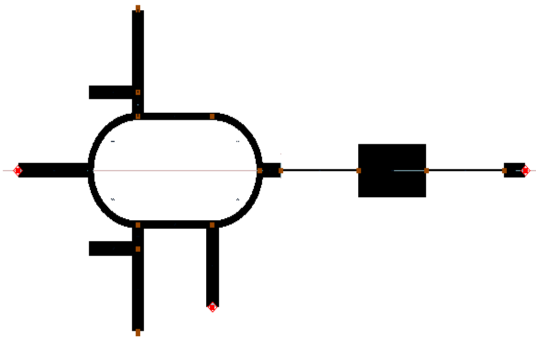


Fig. 28: ADS Layout diagram of the designed Singly-balanced diode mixer with LPF using 5-port rate-race coupler.

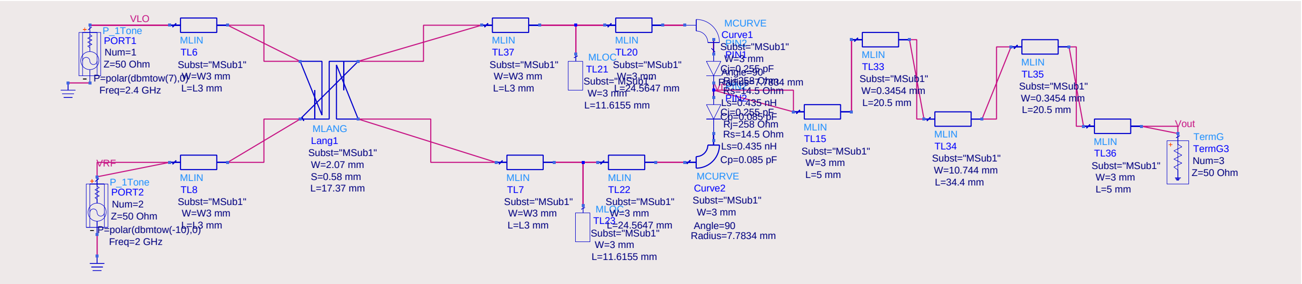


Fig. 29: ADS Schematic diagram of the designed Singly-balanced diode mixer with LPF using Lang coupler.

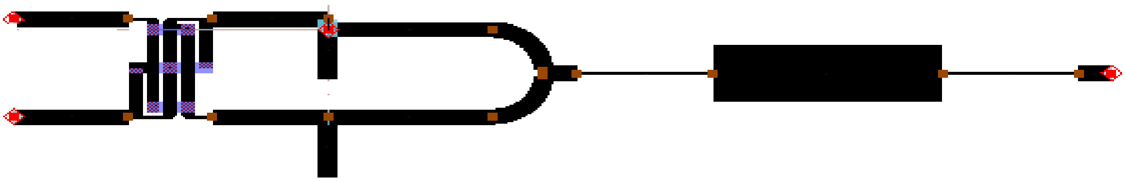


Fig. 30: ADS Layout diagram of the designed Singly-balanced diode mixer with LPF using Lange

IV. CONCLUSION

Distributed microwave integrated circuits have been increasingly adopted in many electronic systems such as communication, radar, electronic warfare, navigation, surveillance, and weapon guidance systems. These systems are mostly military in nature and have been supported strongly by the defense community. The objective of this work is to present a complete design, analysis and optimization of different configurations of Microstrip singly-balanced diode mixers. The configurations singly-balanced diode mixer using either rate-race, branch-line coupler or Lange coupler in addition with a maximally-flat LPF. A full-scale computer simulation program developed by the author is used for the designed configurations. The designed configurations are analyzed and optimized using the ADS2017 package. The complete design and analysis of the individual components are presented. The complete layouts of the designed configurations are introduced. The designed configurations can be used in many applications, including: wireless communications, radar systems (ground based, airborne, personal vehicles), target detection and identification, deep space Communications, and radio spectrometry. As a future work a complete circuit simulation using the most recently new approaches for coupling FDTD with circuit functionality, device physics (drift-diffusion and hydrodynamic particle transportation) and the thermodynamic effects can be performed.

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