Coupled Line Coupler for Use in RF Meters

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***Abstract*—This paper is the final project for EENG430 (Passive RFMW). It will focus on the structure and design of coupled line couplers through using Advanced Design System (ADS 2020) software. The coupled line coupler in discussion has a coupling coefficient of 6 dB respectively. This will be modeled through microstrip line technology and will utilize a coupled outlet port, a through port, and then an isolated port. The center frequency will be tuned to 2.45 GHz accordingly and all the other values such as even and odd impedance will be calculated through the coupled coefficient. Using a characteristic impedance of 50 ohms, a λ/4 wavelength, and FR4 substrate, will allow ADS LineCalc to find the lengths, widths, and distance in between the coupled lines. Then S-Parameter simulations will be run to ensure proper results at the center frequency. Altogether, the design will be tuned in the schematic form then translated to the momentum layout to produce the proper output for use in RF power meters or VSWR meters.**

***Index Terms*— ADS, Coupled Line Coupler, Microstrip line, Power, S-Parameters, and Coupling**

I. Introduction

Coupled Line Couplers (CLC) are a specific type of directional couplers that are used in passive devices which includes array antennas, filters, modulators, and power amplifiers. A CLC consists of a four-port network that has an input port, a through port, a coupled port, and an isolated port. It utilizes a pair of 2 unshielded transmission lines in the center that utilizes electromagnetic fields for a power trade between the lines, otherwise known as coupling. These devices are used to divide or combine the power but are mostly designed for low power level splitting [1].

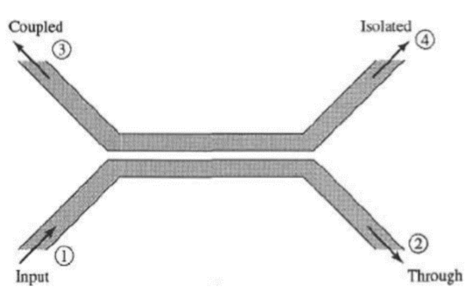

Fig. 1 Typical Design of Coupled Line Coupler

Regarding the design of a CLC, there are two types. There are backward and forward wave couplers. Figure 1 demonstrates a backward wave coupler, as the coupling port (output) is close to the input port. This type of backward wave coupler will be utilized for this specific design in ADS.

In addition, the current flow of the coupled line can flow in different modes. As this coupler has electromagnetic properties, there are two modes that it can undergo which are even and odd. First, the odd mode current is otherwise known as the odd mode characteristic impedance (Z0o) where current flows down a conductor with a contra-flow current back up the other conductor. Ultimately, this is caused by the displacement current coupling from the two conductors, and it will be equal in amplitude but opposite in direction. Figure 2 below, shows the odd mode of excitation [2].

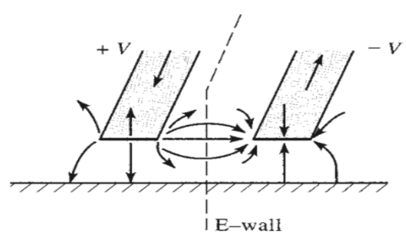

Fig. 2 Odd Mode Excitation

On the contrary, there is even mode excitation which means it is equal in amplitude and in the same direction. This means that there is a single current flow from the displacement current between the center conductor with the same polarity. It has a common ground the components share and therefore is named the even mode current, or the even mode characteristic impedance (Z0e). Figure 3 below, shows the even mode of excitation [2].

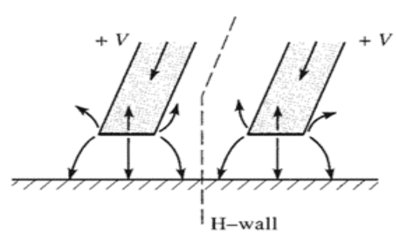

Fig. 3 Even Mode Excitation

It is important to note that CLC requires both even and odd excitation because this generates coupling. Without both excitations there would be no power being coupled from the energized transmission line to the passive transmission line.

Next, to calculate the even and odd impedances of a single section coupler, it will require the following two equations [2].

$$Z_{0e} = Z_0\sqrt{\frac{1+C}{1-C}} \quad (1)$$

$$Z_{0o} = Z_0\sqrt{\frac{1-C}{1+C}} \quad (2)$$

For Equation 1 and 2, Z_0 is the characteristic impedance and C is the value of the voltage coupling coefficient of the coupler which is less than 1 in value.

Altogether, these concepts are necessary for designing a successful backward coupled line coupler through using microstrip technology at a specified coupling factor using ADS software. Along with simulations of both schematic and momentum layout models is necessary to be analyzed for proper results. The following sections will show the step-by-step process for designing a proper CLC that can be integrated into radio frequency power meters or voltage standing wave ratio meters. Section II will begin with the design procedure of the coupled line coupler along with the tuning and optimization used, Section III will talk about the simulation results, Section IV will analyze the results of the scattering parameters, and Section V will conclude the findings from this project.

II. DESIGN OF COUPLED LINE COUPLER

A. *Specifications*

The design of the CLC is bounded by design specifications that must be followed. For this project, the coupled line coupler will use the transmission strip line form and use 1-ounce copper cladding (Thickness: 0.035 mm) as the conductor material. The substrate material will be the FR4 with 62 mil laminate (1.574 mm). The design frequency of the coupler will operate at a center frequency of 2.45 GHz with a characteristic impedance of 50 ohms and a λ/4 wavelength. It can be noted that there is not much data on realistic tolerances for CLCs, so it can be presumed as 0.0001 mil resolution tolerance. In this case, the coupling factor chosen was 6 dB because it is at the absolute minimum for fabrication methods and the closest to ideal coupling. Next, since the parameters are chosen, the even and odd impedances can be calculated by hand and then run through LineCalc to get the length, width, and distance. It could otherwise be done through design graphs, however, due to estimation and difficulty of hand calculation, LineCalc will produce better results computationally. Then through modeling it schematically and in momentum methods, it can be fine tuned and optimized for desired results.

Before constructing the design of the CLC, it is important to understand the circuit configuration of the CLC first. Figure 4 shows the configuration of the single section coupler's circuit [3].

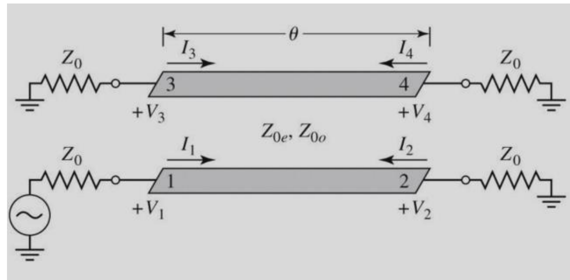

Fig. 4 Coupled Line Coupler Circuit Diagram

To see how the parameters are laid out for the design, Table I is also generated for easy readability of the different specifications.

TABLE I

DESIGN PARAMETERS

Parameter	**Specification**
Coupling Factor (dB)	6
Characteristic Impedance (Ω)	50
Center Frequency (GHz)	2.45
Microstrip Substrate	FR4
Substrate Dielectric Constant (ε_r)	4.6
Substrate Thickness, H (mil)	62
Copper Cladding (μm)	35
ADS Transmission Line	MSCLIN

Once the parameters and specified values were chosen, the next steps for the design are to calculate the values of the different impedances for Z0e and Z0o. Using Z0 and the coupling factor of 6 dB from Table 1, the values can be calculated from using Equations 1 and 2. However, the only unknown is the coupling coefficient (C) which is determined through using the coupling factor. It is normalized by using Equation 3 below, where CF stands for the coupling factor chosen [1].

$$C = 10^{-CF/20} \qquad (3)$$

Now that all the equations are defined, the values for the specific CLC at 6 dB can be calculated and are shown as follows.

C = 0.5012

Z0e = 86.74 Ω

Z0o = 28.82 Ω

These values are completely defined, so the impedances along with the other parameters are entered into the ADS LineCalc tool to generate the dimensions of the microstrip line quarter wave values. Figure 5 below shows the LineCalc tool with the arbitrary dimensions to visually demonstrate the length, width, and distance for the microstrip coupled line (MSCLIN). Then Table II shows the values generated from LineCalc before being tuned.

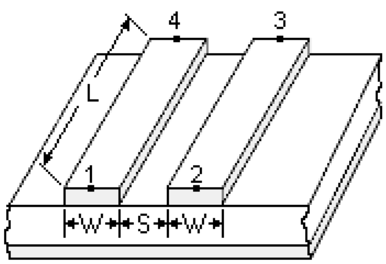

Fig. 5 LineCalc MSCLIN Component Diagram

TABLE II

LINECALC DIMENSIONS FOR CLC

Width (W)	70.134646 mil
Length (L)	691.133858 mil
Spacing (S)	3.297795 mil

B. *Basic Design in ADS*

After getting the specifications, the circuit schematic was built around the pair of microstrip lines. This is the basic schematic that a single CLC follows. From there the design will get more complicated with more transmission lines and bends connecting them. In Figures 6 and 7 show the basic schematic and the generated layout that is the base of any usable CLC.

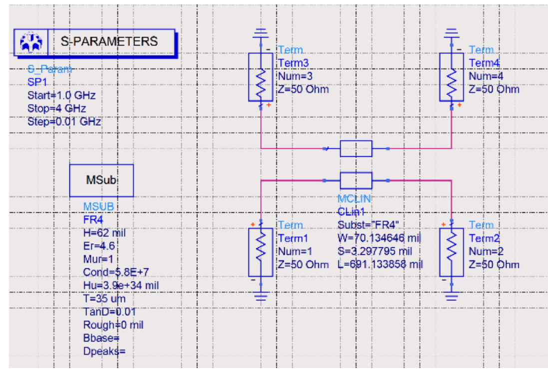

Fig. 6 Schematic of Basic CLC

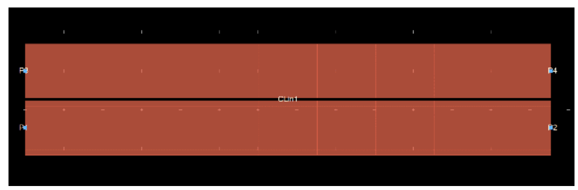

Fig. 7 Generated Layout of Basic CLC

C. *Final Design in ADS*

To make a CLC that could be found in a VSWR meter or a RF power meter, there needed to be adjustments to the basic schematic done for the CLC in Figure 6 and 7. To create a CLC that would be used for RF purposes, there must be additional bends and transmission lines attached to the coupled lines. Figure 8 below shows what typical CLC couplers look like in application, so this design will be modeled after it in ADS software [4].

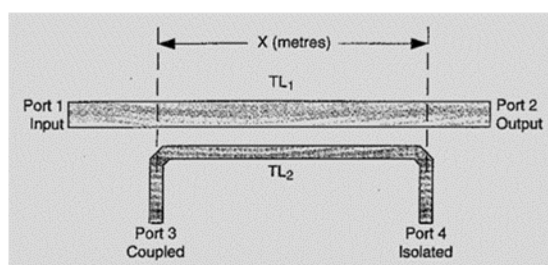

Fig. 8 Directional Coupler Used for Power Meters

However, this design should work conceptually, there needs to be tuning and optimization integrated into the design to ensure the proper scattering parameters. Altogether, after a good amount of fine tuning, the new lengths, widths, and spacing values were produced. It can be seen in Table III.

TABLE III

DIMENSIONS FOR CLC

Width (W)	49.2 mil
Length (L)	447 mil
Spacing (S)	2.5 mil

The values from Table III were achieved through tuning the original values from Table II. With the addition of more lines and bends in the schematic, created new responses that had to be changed accordingly. This was achieved by utilizing variables for the widths, lengths, and distance between the coupled lines. As well as variables for the microstrip lines for the top and bottom sections. Once that was tuned after testing multiple responses, the desired schematic and generated layouts were created and are shown in Figures 9 and 10.

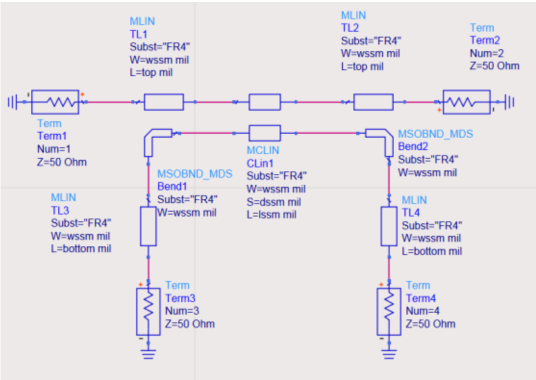

Fig. 9 Schematic of CLC

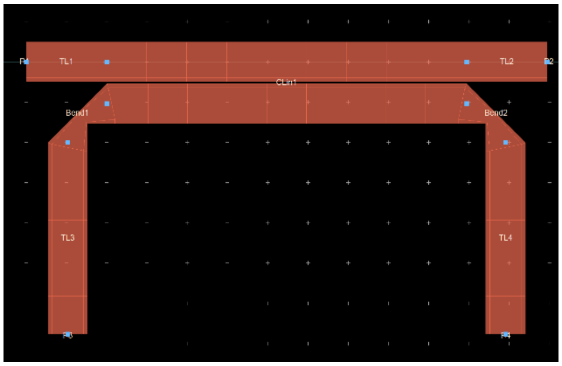

Fig. 10 Generated Layout of CLC

III. SCHEMATIC AND MOMENTUM SIMULATIONS

After the layouts and circuits were completed, it was time to simulate the parameters desired. It was necessary to complete both schematic and momentum simulations which can be shown in Figures 11 and 12. Note that the schematic simulation is the ideal, theoretical transmission of the circuit, while the momentum simulation is running with the substrate which is closer to real-life, actual simulation.

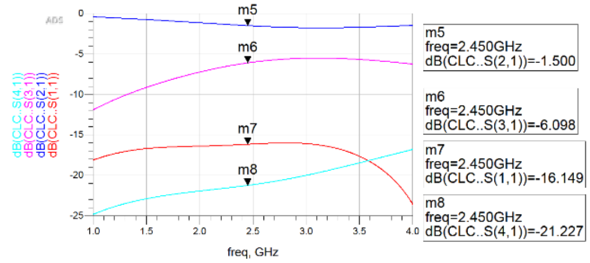

Fig. 11 S-Parameters for Schematic Simulation

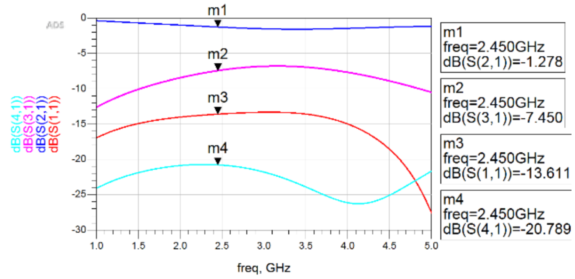

Fig. 12 S-Parameters for Momentum Simulation

IV. ANALYSIS

To completely understand the values of the S-Parameters, Table IV is formulated to compare both schematic and momentum values, so it can be easily comparable. In addition, markers were placed at 2.45 GHz for the center frequencies for both plots.

TABLE IV

RESULT COMPARISON OF SIMULATIONS AT 2.45 GHz

[S]	Schematic	Momentum
S_{11} (dB)	-16.149	-13.611
S_{21} (dB)	-1.500	-1.278
S_{31} (dB)	-6.098	-7.450
S_{41} (dB)	-21.227	-20.789

It can be noted that both scattering parameters are similar in curved line shape and values. The coupling between S_{21} and S_{31} is under coupled but around 6 dB. It can be noted that ideal coupling would only occur if S_{21} and S_{31} were touching [5]. However, this will never occur as there is space in between the coupling lines, however, it shows good matching, as S_{31} reads at -6 dB. In addition, S_{11} for port 1 has a little reflection and S_{41} for port 4 has decent isolation from the coupled lines. However, it is important to note that the schematic design was optimized and tuned accordingly to see good results in coupling and other parameters.

On the other hand, the generated layout with the FR4 substrate, showed different results. It can be shown it does not quite reach the exact -6 dB coupling between S_{21} and S_{31}, however, it is relatively close, so it was deemed acceptable. In addition, the S_{11} for the momentum is a bit off and could be possibly lower and less curved. Then S_{41} was isolated, but it was a bit inaccurate as it should produce a straighter line.

The difference in results is due to EM simulation being more accurate than the simple model-based circuit simulation. This only includes nodal connections and is the theoretical function of the circuit. However, the planar electromagnetic (EM) simulation considers the substrate chosen along with the internal circuit interactions. This allows more in-depth, complex designing of the coupled line coupler, which should model the actual performance of this coupler in real life. This EM simulation will consider the physical properties, the different components, and the interactions between the parts within the coupler. This includes power losses, material differences, and connectivity of the ports.

For the design itself, it is important to note that the spacing designated is quite small which could lead to harder fabrication. Also, that 6 dB is a relatively small coupling factor which makes it even more precise. Normally for manufacturing purposes, 20 to 30 dB CLC's are commonly fabricated, but for proof of concept, this was designed for 6 dB. Ultimately, the design of this CLC is intricate and will need more precision tuning and optimization if fabricated.

V. CONCLUSIONS

In this report, a coupled line coupler has been designed using ADS 2020 software. Based off certain given parameters for this microstrip configuration, a successful CLC has been designed based off couplers found in RF power meters and VSWR power meters. Overall, it can be noted that the coupling coefficient correlates to the spacing in between the coupled microstrip lines. Also, fine tuning the widths and lengths is important to achieving the right scattering parameters. It can be noted that although, this is not a perfected design, it has generated relatively accurate results to show the progress of this project. Furthermore, additional research can be done to perfect the coupling of the MCLIN, and the other transmission lines and bends. Thus, this project was completed through reading published journals, class lecture notes from Dr. Payam Nayeri, the Microwave Engineering Textbook by David M. Pozar, and other online help forums.

REFERENCES

[1] David M. Pozar, "Microwave Engineering", fourth edition, John Wiley & Sons. Inc, 1998.

[2] S. Babani, J. S. Kazaure, T. A. Danladi, and A. L. Umar, "Design and Simulations of Coupled-Line Coupler with Different Values of Coupling Efficiency," International Journal of Electrical, Electronics, and Data Communication, vol. 3, no. 8, pp. 14–17, Aug. 2015.

[3] P. Nayeri, "PRFMW_Lecture12_DirectionalCouplers_partI," Canvas Mines.[Online].Available: https://elearning.mines.edu/courses/25863/files/2224328?module_item_id=266765. [Accessed: 06-Dec-2020].

[4] "RF Directional Couplers," Electronics World, Aug-1999. [Online]. Available: http://techdoc.kvindesland.no/radio/ymse1/20061216154203574.pdf. [Accessed: 06-Dec-2020].

[5] "Coupled Line Couplers," Microwaves101. [Online]. Available: https://www.microwaves101.com/encyclopedias/coupled-line-couplers. [Accessed: 06-Dec-2020].