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Development of Scalar Network Analyzer Based on Dual Channel Microwave Generator

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Abstract

Microwave technologies are rapidly evolving, requiring sophisticated signal processing and control technology. This research develops a Scalar Network Analyzer (SNA) using a Dual Channel Microwave Generator (DCMC) to overcome standard SNAs' frequency ranges, signal processing inefficiencies, and lack of dual channel capabilities. Low frequency (5 GHz) coupled line couplers will improve DCMC feedback systems. The project will provide a precise measuring system for transmission (S21) and reflection (S11). Microstrip-fabricated couplers can function at 5 GHz with a coupled loss < 10 dB. Simulation results for the coupler usingthe SynthNV microwave generator with dual channels indicated S11 at -18.965 dB, S21 at -2.473 dB, S31 at -9.561 dB, and S41 at -5.149 dB. The prototype integrated with DCMC has -0.099 dB at 2.8 GHz and -14,457 dB at 3.208 GHz. Adding a DCMC to the SNA framework improves microwave system accuracy, reliability, and efficiency, enabling future technology advances.

1. Introduction

The advancement of microwave technologies has been pivotal in telecommunications, aerospace, medical imaging, and more. Accurate examination and control of microwave signals are essential, driving the need for advanced instruments like a Scalar Network Analyzer (SNA) based on a Dual Channel Microwave Generator (DCMC) (Babani et al., 2015). Conventional SNAs face constraints such as limited frequency ranges, inefficiencies in processing diverse signals, and the absence of dual channel capabilities (Alazemi & Rebeiz, 2016). This research aims to integrate a DCMC with a directional coupler into the SNA framework, offering extended frequency coverage, improved signal flexibility, and real-time dual channel analysis (Martel et al., 2020). By incorporating these advanced features, this innovation could revolutionize microwave technology in various fields, providing engineers, researchers, and industry experts with a powerful tool for precise signal analysis and optimization. This development promises to enhance the accuracy, reliability, and efficiency of microwave systems, ultimately contributing to significant technological advancements (Vitanawasam et al., 2019).

Current SNAs and DCMCs face several limitations in meeting the complex needs of modern microwave systems. Our university lacks a coupler, crucial for precise measurements and seamless connections in laboratory setups, hindering ongoing experiments (Dai et al., 2019). Additionally, our SNA cannot accurately measure the reflection coefficient (S11), impacting our ability to assess signal integrity and system performance. The high cost of integrating a DCMC with an SNA is another significant barrier, making this technology inaccessible to smaller labs and projects with limited budgets (Lonappan et al., 2016). Addressing these issues is vital for advancing microwave signal processing and achieving reliable and comprehensive data in our research. We are exploring potential collaborations and alternative methodologies to overcome these constraints, ensuring our work continues effectively and contributes to the scientific community (Cuper et al., 2019).

2. Methodology

The framework of this project outlines the entire workflow, from the initial design of the scalar network analyzer to the integration of the dual channel microwave generator as a feedback system, as illustrated in Fig. 1(a). The design phase includes developing a coupled line coupler, which involves several essential components. These components range from the microstrip coupler and mathematical modeling to selecting the type of PCB, SMA connectors for the transmission lines and PCB, and finally, the fabrication process, as shown in Fig. 1(b). The project will employ CST software to simulate the coupled line coupler. The first step is installing CST software on the laptop to facilitate the simulation. Key features will be incorporated into the CST software to develop the coupled line coupler, as depicted in the block diagram of the system in Fig. 1(c). This comprehensive approach ensures a systematic progression from design to simulation, ultimately achieving the project objectives.

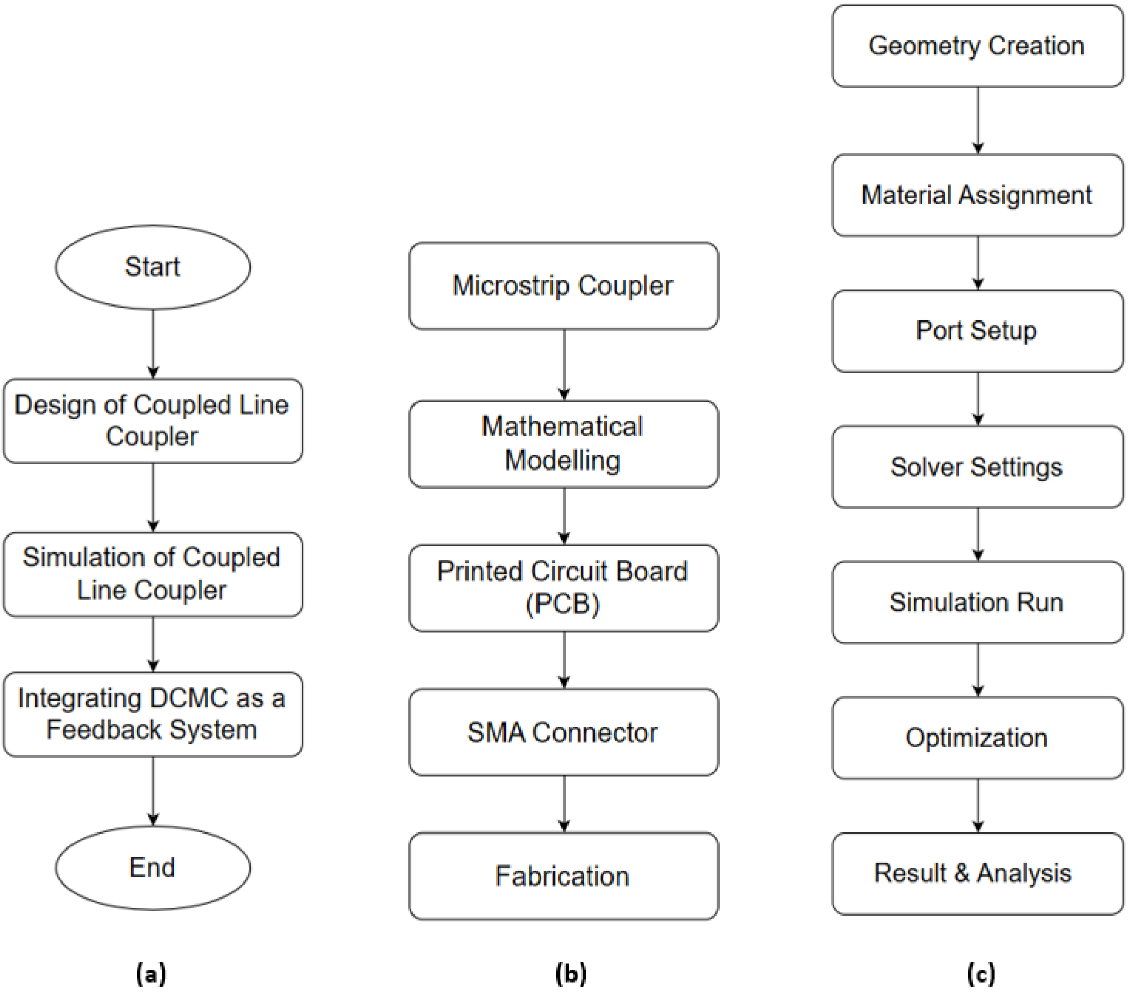


Fig. 1 *Block diagram (a) The workflow for the project; (b) Block diagram of the coupled line coupler; (c) Block diagram of the system*

2.1 Microstrip Coupled Line Coupler

This project utilizes a microstrip coupled line coupler, also known as a multisection coupled line coupler, as the foundation for the scalar network analyzer. Unlike traditional couplers limited by the need for a quarter wavelength, this design uses multiple connected line segments to enhance bandwidth. However, this increases the electrical length, reducing the coupling factor. The design can extend the calculation techniques used for single section couplers as shown in Fig. 2.

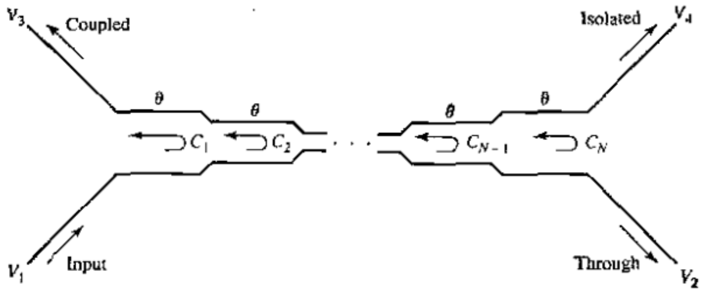


Fig. 2 *An N-section coupled line coupler*

2.2 PCB (RO3003)

RO3003, developed by Rogers Corporation, is an advanced circuit board material ideal for high-frequency applications like RF and microwave technology. It offers stable electrical properties across various frequencies and temperatures, essential for precision applications. With a dielectric constant (Dk) of 3.00 ± 0.04 and a low dissipation factor (Df) of 0.0010 at 10 GHz, RO3003 ensures high performance and reliability. It also boasts excellent thermal conductivity, a high Tg above 280°C, and minimal water absorption, making it suitable for challenging environments. RO3003's low coefficient of thermal expansion (CTE) enhances dimensional stability, crucial for multi-layer circuit boards.

2.3 SMA Connector

The SMA connector, particularly the female type, is a coaxial RF connector characterized by its internal threaded design. It provides a reliable connection point for mating with male SMA connectors or cable assemblies, commonly used in circuit boards, antennas, and test equipment. These connectors offer flexibility in installation, available in panel-mounted or PCB-mounted variants for different applications shown in Fig. 3.

Fig. 3 *SMA connector (female)*

2.4 Fabrication

PCB fabrication involves creating printed circuit boards through several stages: design, material selection, substrate preparation, copper cladding, imaging, etching, drilling, surface finishing, inspection, and assembly. For this project, manual etching of RO3003 with sandpaper is used. This process involves carefully abrading the copper layer to expose the circuit layout, ensuring precise removal of unwanted copper while preserving the circuit's integrity. Despite being labor-intensive and time-consuming, this method allows for detailed etching of complex designs on RO3003 material as shown in Fig. 4(a) and (b).

(a)

(b)

Fig. 4 *Fabrication and etching (a) Fabrication flow; (b) Etching process*

2.5 Integrating DCMC

A closed loop configuration is essential to integrate a coupler with a dual channel microwave generator, establishing a feedback system. This setup allows part of the generator's output to be fed back into the system for real-time monitoring, control, and additional processing. By analyzing feedback information, the system can implement modifications or corrective measures, enhancing the stability, accuracy, and optimization of the generated microwave signals.

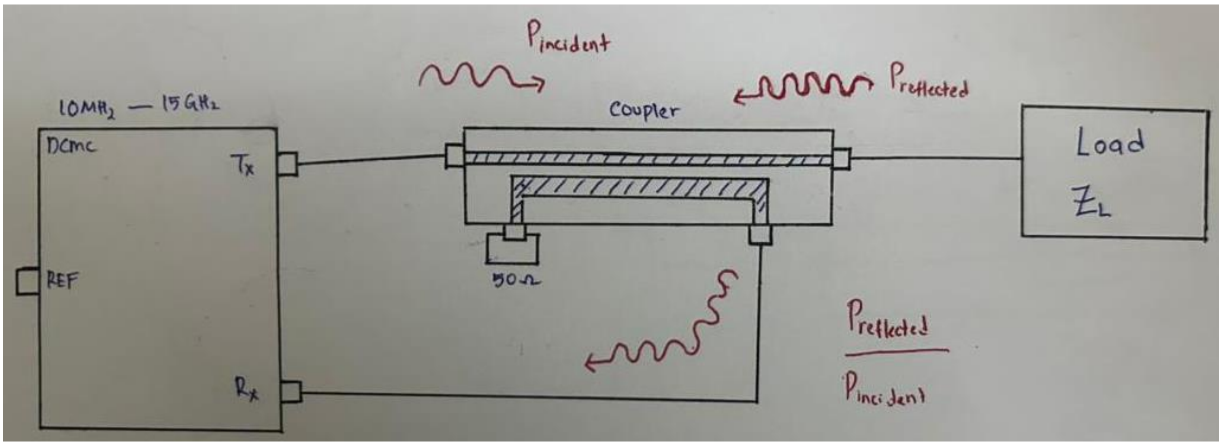


Fig. 5 *Integrating DCMC*

3. Result and Discussion

This section primarily emphasizes the evaluation of the functionality of both hardware and software. The design for this system is based on two essential points:

i. Designing and developing hardware in the CST Studio Suite software.
ii. Designing and integrating prototype with DCMC for SNA.

3.1 Dimension of Substrate

Before running the simulation, it's crucial to create the coupler in CST Studio Suite with precise measurements. The RO3003 substrate has a length of 80mm, width of 34mm and height of 1.52mm. these dimensions ensure accurate physical representation as illustrated in Fig. 6(a) and Fig. 6(b). The bottom cladding made of annealed copper measures 80mm x 34 mm with a thickness of 0.0175mm, serving as the foundational plane as illustrated in Fig. 6(c). The primary microstrip line is 80mm long and 3mm wide, optimizing signal transmission as illustrated in Fig. 6(d). The second line is designed using coupled line coupler calculations. Accurate dimensions and material properties are vital for faithful simulation, ensuring optimal impedance matching and minimal signal loss as illustrated in Fig. 6(e). The gap between the transmission lines varies for different simulations and the coupler port connections are defined for port 1, 2, 3 and 4 each with specific functions as illustrated in Fig. 6(f).

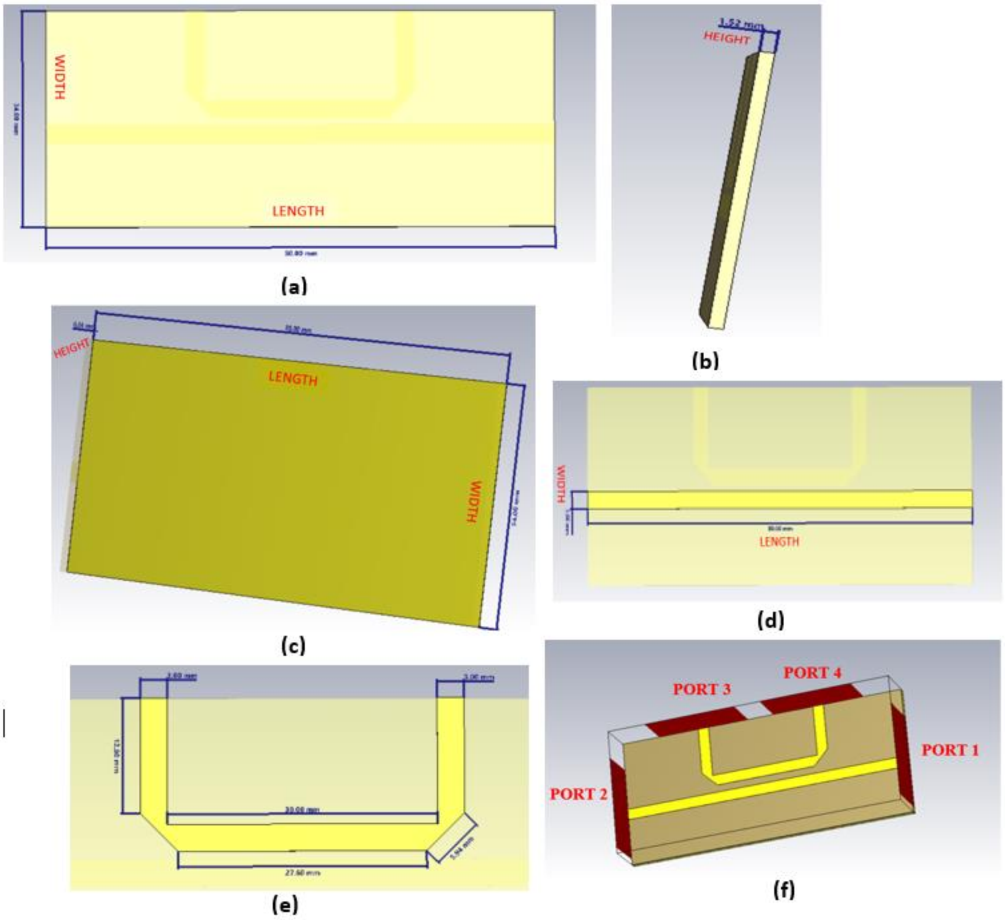


Fig. 6 *Substrate (a) Length & Width; (b) Height; (c) Bottom Cladding; (d) First Stripline; (e) Second Stripline; (f) Port*

3.2 Prototype of Coupler

Fig. 7 shows the directional coupler prototype with successful connections between the microstrip line and SMA connectors. The copper microstrip line on the RO3003 substrate matches the simulated dimensions, ensuring accurate electrical properties. SMA connectors between the female pin and microstrip line and secure grounding via the copper layer at the bottom. This meticulous installation maintains signal integrity, allowing precise measurements with Scalar Network Analyzer. Proper positioning and attachment ensure low signal degradation and consistent impedance matching.

Fig. 7 *Coupler Prototype*

3.3 Data of Prototype

Fig. 8 shows the crucial data of the prototype under load, highlighting the effective frequency range and key performance metrics. This data includes the S21 transmission coefficient, which measures the proportion of the transmitted signal to the input signal, crucial for evaluating signal transmission and system efficiency. By analyzing S21 across the designed frequency range, we can identify frequencies with optimal transmission, indicating good impedance matching and effective performance. Based on the fig.8 the frequencies with minimal reflection can be identified by the points where the S21 values are closest to 0 dB, as this suggests the least amount of signal loss at 3500 MHz to 4000 MHz where at these points, the S21 values are relatively higher compared to other frequencies, indicating better transmission and minimal reflection. Thorough testing under various stress level confirms the coupler's effectiveness and operational capabilities within its designated range.

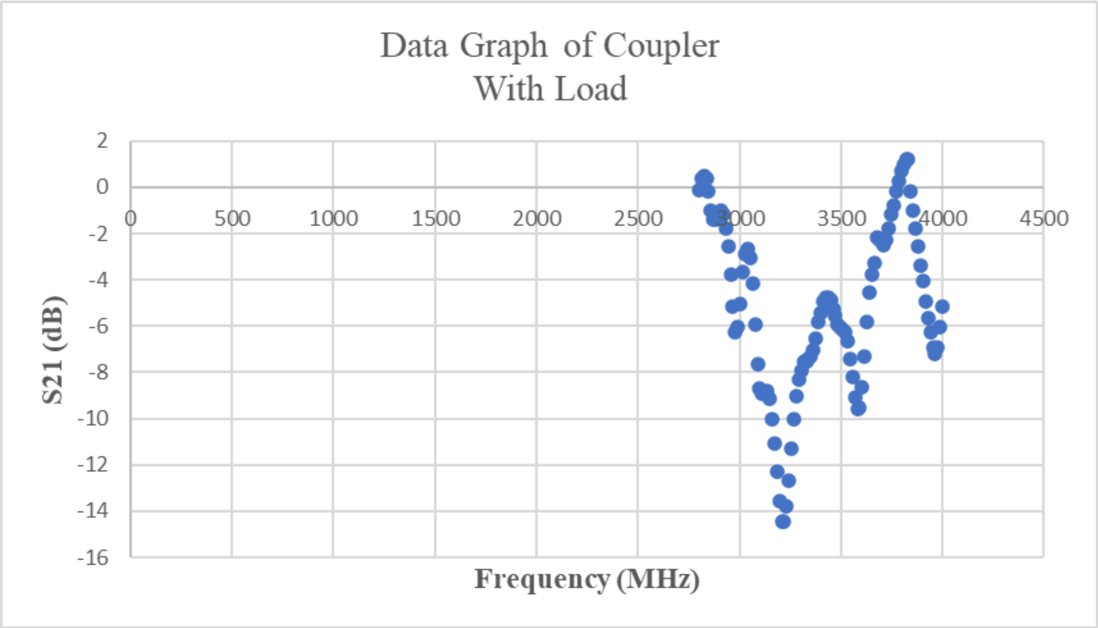


Fig. 8 *Data Graph of Coupler with Load*

3.4 Prototype of Coupler

Fig. 9 shows the S-Parameters of a coupler from 4 GHz to 6GHz, highlighting key performance metrics. The S11 reflection coefficient shows excellent impedance matching at 5.8 GHz with a value of -18.97 dB. The S21 transmission coefficient remains constant at around -2.47 dB, indicating uninterrupted signal transmission. The S31 decreases to -9.56 dB at 5.6 GHz, demonstrating effective coupling while the S41 drops to -5.15 dB at 5.8 GHz, suggesting high isolation and minimal signal leakage. Overall, the coupler performs excellently between 5.6 GHz and 5.8 GHz, making it suitable for high performance applications within this frequency range.

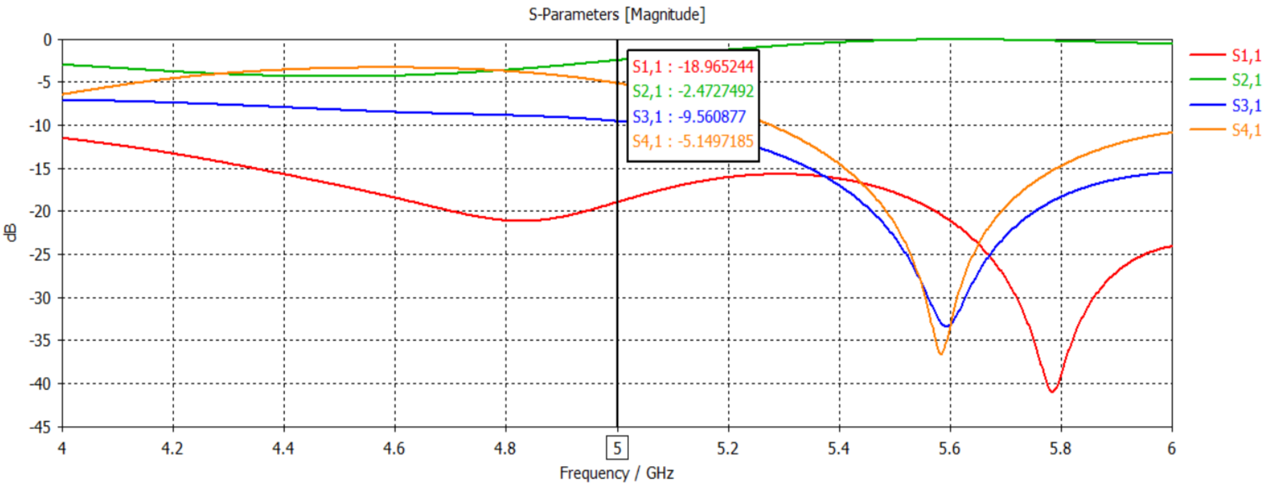
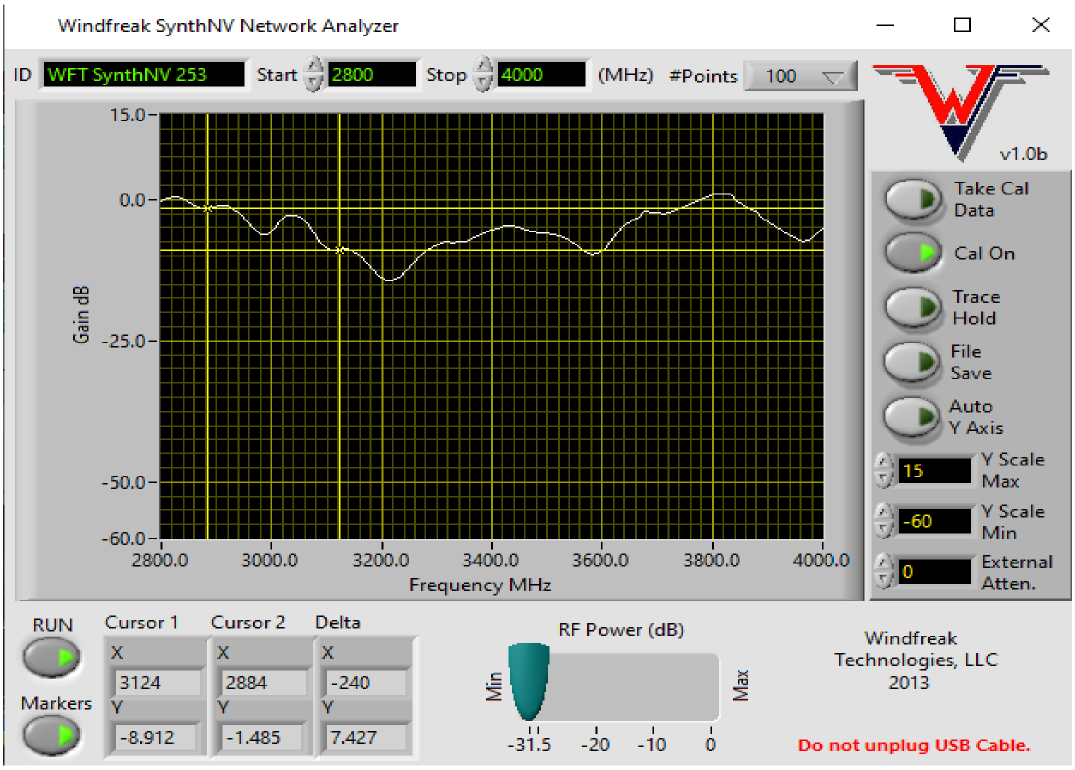


Fig. 9 *Coupler (Length = 80mm) (Gap = 1mm) Simulation Graph*

3.5 Coupler Integrate with DCMC

Fig. 10 shows the results of coupler calibrated with DCMC with a load attach to the coupler. After calibrating the coaxial cable and the coupler, it is important to connect a load to port 2 and the load is a wide band antenna that is suitable for this project. The system starts operating at 2.8 GHz with a reflection coefficient of -0.099 dB. The best return loss of -0.990 dB is achieved at 2.908 GHz, showing that the system performs efficiently. However, at 3.208 GHz, there are significant deteriorations in the return loss, reaching to -14.457 dB. This suggests the presence of resonances or disturbances in the coupler. These fluctuations may be caused by various unpredictable factors, highlighting the complexity of the system's behavior or caused by people when designing and fabrication of the coupler manually without any machines.


Windfreak SynthNV Network Analyzer

ID WFT SynthNV 253 Start 2800 Stop 4000 (MHz) #Points 100

Y Scale Max 15

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Cursor 1	Cursor 2	Delta
X	X	X
3124	2884	-240
Y	Y	Y
-8.912	-1.485	7.427

Windfreak
Technologies, LLC
2013

Do not unplug USB Cable.

Fig. 10 *Coupler Integrated with DCMC*

4. Conclusion

The creation of an SNA using DCMC and coupler marks a significant advancement in microwave technology. The dual channel microwave generator allows simultaneous real-time analysis on two channels, expanding frequency range and signal adaptability which is vital for applications in various field of engineering. The project had three main goals: to produce a low-frequency (5 GHz) coupled line coupler, combine it with the DCMC to form a feedback system and develop a comprehensive measuring system for S21 and S11 coefficient. Using microstrip technology and a Multisection coupled line coupler approach, the research overcame challenges like the absence of coupler and limited VNA measurement capabilities. This novel dual channel technology promises significant improvements in the precision and efficiency of microwave signal measurements, benefiting various fields reliant on accurate microwave technologies.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author attests to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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