A Dual-Band Integrated Network Analyzer For RF Bio Sensing Application

Mayank Awasthi*, Kunal Wadhwani*, Azeemuddin Syed*, Mohammad Hashmi**
*CVEST, IIIT Hyderabad, Hyderabad, India
**Department of ECE, Nazarbayev University, Nur-Sultan, Kazakhstan
Email: *{mayank.awasthi, kunal.wadhwani}@research.iiit.ac.in, *syed@iiit.ac.in, **mohammad.hashmi@nu.edu.kz

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***Abstract*—RF bio-sensing is often utilized for the detection of bio-samples by using the concept of shift in resonant frequency. It is widely reported that the shift in resonant frequency is narrower compared to the bandwidth of the device used for measuring this shift. As a result, wideband Vector Network Analyzer (VNA) proves to be an overkill and instead a narrowband measurement setup can fulfill this requirement. Therefore, in this paper, an integrated solution for the detection of materials having varying permittivities is presented. A Dual-Band Six Port Reflectometer (DBSPR) is proposed and designed using planer microstrip line technology for the purpose of characterizing the sensor using reflection and transmission coefficient. A Complimentary Split Ring Resonator (CSRR) based sensor having an unloaded resonance frequency of 2.3 GHz is utilized as a test set. The designed DBSPR operates at 1.12 GHz and 2.26 GHz with a 10dB bandwidth of 254 MHz and 215 MHz respectively. The DBSPR and CSRR sensor are integrated using a microstrip line. The integrated device is tested for two different materials having a permittivity of 2.3 and 4.3. A shift of 118 MHz is observed between these materials and thus shows the potential usefulness of the proposed setup.**

Keywords*—*dual band, six port reflectometer, bio-medical

I. Introduction

A lot of research emphasis is placed now a days on the development of biosensors for characterization of materials. These sensors are based mostly on Complementary Split Ring Resonator (CSRR) and Defected Ground Microstrip line Structure (DGMS). The sensors are then characterized by S-parameters for the detection material. Among the earlier reports, sensors based on CSRR and interdigital-capacitor-shaped defected ground structure (IDCS-DGS), and a comparison was made between the two for different types of materials with a permittivity ranging from 2.17-10.2 [1]. It was observed that for change in permittivity, the shift in resonant frequency was lesser as compared to the bandwidth of the device used for the measurement of the shift. Subsequently, bio-chemical microwave-based sensor was designed and the process of obtaining real and imaginary parts of the permittivity through shifts in resonant frequency (Δf) for S_{21} was explained [2]. It is important to notice that while the material under test, i.e., glucose, remained same in the experiment, the change in concentration of glucose resulted in the shift of resonant frequency, which was again narrower compared to the bandwidth of measurement device. There are a number of reports which show the importance of shift in resonant frequency for S_{21} parameter in the measurement of complex permittivity [3]-[4].

Generally, biosensors utilize traditional VNAs to measure its S-parameter and to detect the shift in resonant frequency. However, since the shift in resonant frequency is very small, therefore, there is a need for a targeted device specifically made to operate at the resonant frequencies that can measure shifts in resonant frequency accurately as well as affordably. There have been several previous works such as a

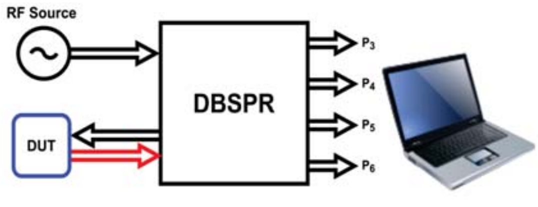

Fig. 1 Basic Block diagram of proposed daul-band integrated network.

reflectometer that operates at 2.4 GHz and utilizes AD8302 to measure the reflection coefficient [5]. However, AD8302 itself consists of active components like mixer and log amplifiers, which makes the device complex and expensive. A high-frequency wideband VNA that operates from 4-32 GHz seems exciting [6]. It consists of multichannel receivers, Low Noise Amplifiers (LNA), and micromixers for the down-conversion of signals. However, it may constrained by complex structure, may be prone to errors, and cost ineffective. Therefore an alternative VNA for 50-100 GHz designed using heterodyne architecture seems promising [7]. However, the operating frequency was very high for biosensors like CSRR, DGMS, and IDCS-DGS based sensors mentioned earlier.

To address the above concerns, concept of six-port technique and an arbitrary Six Port Reflectometer (SPR) to measure reflected power and its phase at 10 GHz using waveguide components can be a suitable candidate [8]-[10]. However, the frequency is very high and use of waveguide

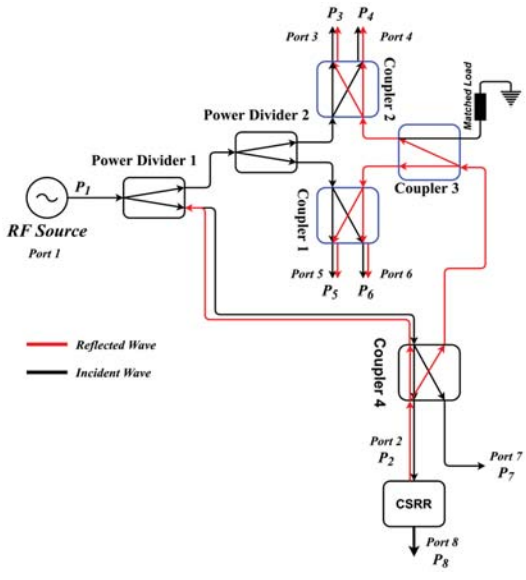

Fig. 2 Architecture of proposed DBSPR integrated with CSRR.

increases its size for biomedical applications. An SPR that operates at three different frequencies i.e, 6.6 GHz, 19.7 GHz, and 32.4 GHz has been presented in [11]. However, it has been mentioned that the tri-band nature of the SPR was a result of the periodic nature of microstrip transmission lines. This paper, therefore, makes use of the concept of SPR and report the Dual-Band Six Port Reflectometer (DBSPR) explicitly designed for two frequencies and its integration with a CSRR based RF biosensor for the detection of shift in resonant frequency at lower frequencies. The dual-band nature of the DBSPR does not depend on the periodic nature of transmission lines which increases its practical application. The advantages of using DBSPR include its capability of measuring the shift in resonant frequency, handling high power, affordable cost, and portability.

II. PROPOSED DESIGN AND EQUATIONS

Fig. 1 shows the basic block diagram of the proposed integrated network analyzer. The designed system consists of DBSPR as measurement device and CSRR based RF biosensor as Device Under Test (DUT). Fig. 2 presents the detailed architecture of designed DBSPR integrated with a CSRR. The DBSPR consists of two 3dB equal split dual-band power divider and four dual-band quadrature hybrid couplers. The power divider design utilizes a two-section coupled line technique [13], and the couplers were designed using the Pi-stub concept [14]. The input signal (shown by the black line in Fig. 2) is given through port 1 in Power Divider 1, and it gets divided into two parts one goes towards the Coupler 4 connected with DUT, and another goes to the Power Divider 2. Furthermore, if port 2 is not matched, then the incoming signal gets reflected (shown by the red line in Fig. 2) to the Coupler 3 which further divides the reflected signals into two parts for Coupler 1 and Coupler 2. The signal travels through Coupler 1 and Coupler 2 with an introduction of phase shift (90^0) in the signal for Port 3 and 5. The same process is repeated for the signal coming from Power Divider 2 in Coupler 1 and Coupler 2, phase shift of 90^0 was added for Port 4 and Port 6. Both the signals superposed at four ports Port 3-Port 6, by implementing the following formula in (1), the magnitude of the reflection coefficient (S_{11}) can be obtained.

$$|S_{11}| = \frac{|(P_3 - P_4) + j(P_5 - P_6)|}{P_7} \tag{1}$$

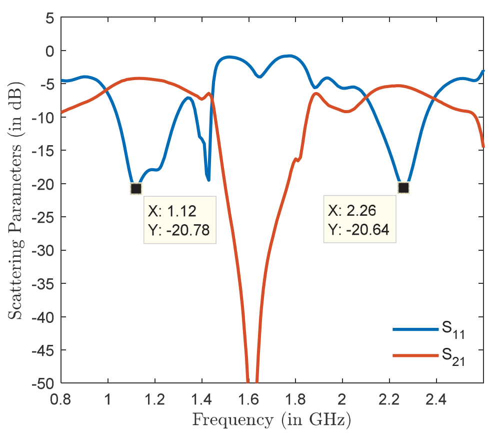

Fig. 3 S-parameter of DBSPR simulated using AWR.

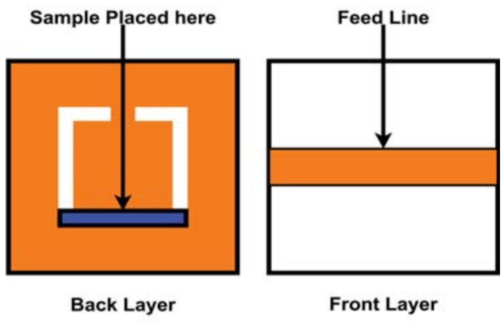

Fig. 4 CSRR based RF biosensor.

Where, P_7 is the incident power and P_3, P_4, P_5 and P_6 are power received at port 3, 4, 5, and 6, respectively.
It should be noted that the phase of the reflection coefficient can also be found using (1). However, this paper only focuses on the magnitude. The magnitude of S_{21} can be directly obtained by measuring the ratio in (2).

$$|S_{21}| = \frac{P_8}{P_7} \tag{2}$$

Where, P_8 is the power received at port 8 as shown in Fig. 2.

III. SIMULATION AND RESULTS

The DBSPR and CSRR sensor has been designed and simulated for two operating frequencies centered at 1.1 GHz and 2.3 GHz. The proposed integrated system was simulated using RT/Duroid5880 as a substrate. The required parameter for RT/Duroid5880 are as follows: dielectric constant $\varepsilon_r = 2.2$, substrate thickness $h_s = 1.575$ mm, loss tangent $\tan\delta = 0.0037$, and copper thickness T = 0.035 mm. The DBSPR and CSRR biosensor has been designed and simulated in AWR's Microwave Office (AXIEM) and CST Microwave Studio, respectively. Furthermore, DBSPR and biosensor were integrated using microstrip line and materials of different permittivity were placed over it for testing and verification using CST 3D EM-Simulations.

A. *Dual-Band Six Port Reflectometer*

Fig. 3 shows S-parameter of the designed and simulated DBSPR. It has been observed that $|S_{11}|$ of -20.78 dB and -

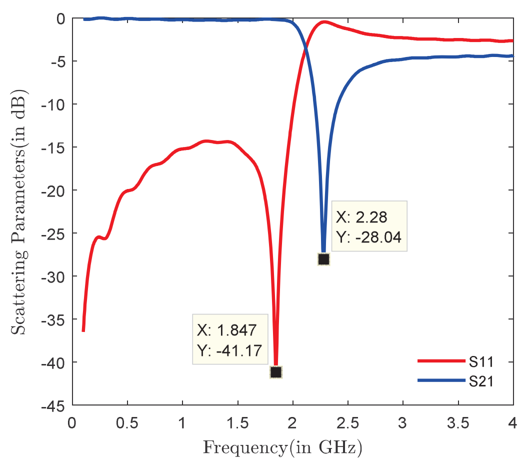

Fig. 5 S-parameter of RF biosensor simulated using CST.

20.64 dB was obtained for 1.12 GHz and 2.26 GHz of frequency with a -10 dB bandwidth of 254 MHz and 215 MHz respectively. Moreover, the DBSPR consists of very high transmission zero of less than -50 dB that makes it work specifically in its two operating bands only.

B. *CSRR based RF biosensor*

The CSRR based RF biosensor has been designed to operate at a frequency of 2.3 GHz. Fig. 4 shows the two layers of designed RF biosensor. Fig. 5 shows the S-parameters of the RF biosensor. It can be noticed from Fig. 5 that $|S_{21}|$ of -28.04 dB at 2.28 GHz of frequency and $|S_{11}|$ of -41.17 dB at 1.847 GHz of frequency has been achieved when simulated in CST Microwave Studio. The CSRR will be used as test set for the detection of two different materials.

C. *Integrated DBSPR and CSRR sensor*

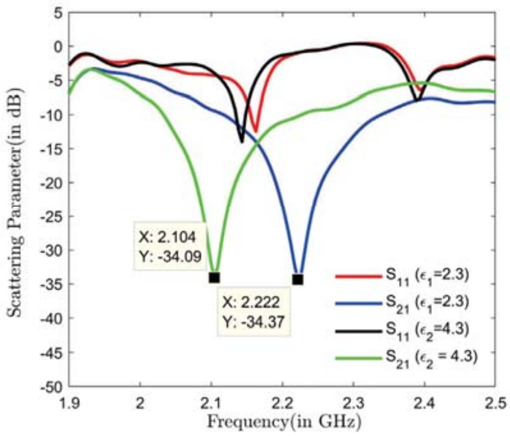

Fig. 6 S-parameter of RF biosensor using proposed Integrated Network Analyzer for two different materials.

Fig. 6 shows S-parameters of CSRR RF biosensor obtained after integrating it to the DBSPR. The integration and simulation were done in CST Microwave Studio. To verify the concept, two simulations were done keeping the volume of following material constant:

1) Sensor with material 1 ($\varepsilon_1 = 2.3$)

2) Sensor with material 2 ($\varepsilon_2 = 4.3$)

where, ε_n denotes permittivity of material 'n'.The selected materials have a constant permittivity in the operating band of DBSPR. In Fig. 6, $|S_{21}|$ of -34.37dB and -34.09dB was observed at 2.222 GHz and 2.104 GHz for material 1 and material 2, respectively. Also, a shift of 118 MHz in resonant frequency was obtained when the sample was changed from material 1 to material 2.This shows that the shift in resonant frequency is narrower with respect to the bandwidth of DBSPR and hence, the DBSPR is suitable for its measurement.

IV. Conclusion

An integrated network analyzer utilizing the DBSPR and CSRR as RF biosensor explicitly designed for the detection of materials with different permittivity has been presented. The system has been designed to operate at 1.1 GHz and 2.3 GHz. The simulations carried out for two cases, mimicking the change of material on RF biosensor, demonstrate a shift of 118 MHz for S_{21} parameter. It is identified that the SPR is suitable to measure the shift in resonant frequency accurately. Moreover, it is a cost effective solution considering that it is an all-passive design. Future work includes designing a multiband integrated system and utilizing it for the measurement of change in concentration

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