Microwave Based Approach for Noninvasive Cholesterol Measurement

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***Abstract*—Heart problems have become very common these days, major reason to heart attack is the disturbed Cholesterol level present in the human blood. Till date there is no other way to measure Cholesterol except blood invasion technique. This paper presents non-invasive method to check Cholesterol using a microstrip antenna, structures a rectangular patch. The proposed antenna is utilized to estimate cholesterol levels by sensing variations in dielectric properties of blood. Results are determined by experimenting frequency response of antenna and cholesterol measured using available invasive technique, enabling a non-invasive approach for cholesterol Monitoring.**

***Index Terms*—Noninvasive, Cholesterol, Microwave, dielectric, antenna, VNA.**

I. INTRODUCTION

Nowadays, Heart related issues have become common in all age groups. A certain and precautions need to be taken considering the rising imbalance of cholesterol levels in human body. Cholesterol is a fat-like substance produced by liver and obtained from food, excess levels of this can block blood vessels, increasing risk of heart diseases and stroke [2]. It is present in blood as lipoproteins namely, Low-Density Lipoprotein (LDL-Bad cholesterol), High-Density Lipoprotein (HDL-Good cholesterol) and Triglycerides and each maintaining lipid balance. Cholesterol measurement is essential to access heart health, Monitor the effects of diet and medication and guide proper treatment. However, most existing methods are invasive involving needle pricks that may cause pain, minor skin damage and risk of infection. Therefore, there is a need for safer and more comfortable alternatives for regular cholesterol monitoring.

Most common method to check cholesterol is the blood sample test which undergoes chemical procedure and identifies the result, this is also termed as invasive technique. But this method is painful, time consuming also not suitable for continuous monitoring. As high values of cholesterol lead to serious diseases like heart problems, stroke, organ damage etc., it is essential to monitor cholesterol time to time. At present there are other methods to measure cholesterol like Optical Methods Including- Raman Spectroscopy, Infrared Spectroscopy [2]. but these techniques are way costlier. Other non-invasive methods include E-nose systems, electrical sensors, biosensors and non-optical methods. Major loop hole of these techniques is: accuracy parameter, device usability, cost and complexity which still remains unsatisfied, limiting the reliability.

This paper focuses on microwave-based non-invasive technique for monitoring blood parameter. Microwaves are electromagnetic waves in the frequency range of approximately 300MHz to 300GHz, they interact with biological tissues based on their dielectric properties such as permittivity. Variation in Cholesterol affect the properties and results in changing electromagnetic response [3]. Microwave sensing techniques provide non-destructive evaluation with deep penetration and sensitive towards change in tissue composition, making them suitable for analyzing physiological parameters.

Organization of the paper is subjected to five different sections; section III onwards, technical details and mathematical co-relation is discussed. Whereas section IV describes methodology, block diagram and antenna fabrication procedure. Explanation of dataset generation and software terminology is done in section V. At the end of paper an affirmative conclusion in coined in section VI.

II. LITERATURE REVIEW

Previous studies reveal that microwave and electromagnetic sensing techniques have gained significant attention for non-invasive biomedical applications due to their high sensitivity to dielectric property variations.

Kim, J., Lee, S., & Park, D. work presents a dual-layer microstrip patch antenna designed for non-invasive glucose monitoring. The antenna operates by detecting variations in the dielectric properties of blood, which cause shifts in resonant frequency and reflection coefficient (S11). The study demonstrates high sensitivity and good accuracy, indicating the potential of microwave sensing for biomedical applications [5].

Rahman, M. M., Islam, M. A., Hasan, M. M., & Rahman, M. approached utilization of infrared (IR) LEDs and photodiodes for near-infrared (NIR) sensing of cholesterol levels. The reflected optical signal is processed using a microcontroller and correlated with cholesterol concentration in blood. The system provides high accuracy, rapid measurement, and real-time monitoring capabilities while avoiding invasive blood sampling [6].

Joseph, A., & Devakumar, A. combines optical, dielectric, and spectroscopic techniques to estimate glucose and cholesterol levels non-invasively. Different sensing mechanisms such as absorption, scattering, capacitance, and photoacoustic effects are analyzed to determine analyte concentration. The approach offers continuous monitoring and is suitable for wearable healthcare applications [7].

Kim, J., Jeon, S., Lee, M., & Park, D. designed a smart contact lens integrated with a biosensor is used to measure cholesterol concentration from tear fluid. The sensed data is wirelessly transmitted using Near Field Communication (NFC) technology to an external device for monitoring. The study demonstrates the feasibility of wearable and continuous cholesterol monitoring with good biocompatibility [8].
Aristovich, E. investigated cholesterol sensing using electromagnetic impedance analysis and finite element method (FEM) simulations. The changes in blood impedance due to varying cholesterol concentration are analyzed using AC electrical models. The results confirm that cholesterol-induced dielectric variations can be detected through electromagnetic sensing, supporting the development of practical non-invasive cholesterol sensors [9].
Although several non-invasive cholesterol measurement techniques have been proposed, but not accepted worldwide. Many methods require complex optical systems, wearable devices, or sophisticated signal processing. Therefore, there is a scope for a simple, compact, and cost-effective microwave sensing technique. The proposed microstrip patch antenna-based sensor addresses this gap by utilizing cholesterol-induced dielectric variations in biological tissues for non-invasive cholesterol estimation.

III. TECHNICAL SPECIFICATION

In electromagnetic sensing applications, characterization of dielectric properties of biological tissues over a broad frequency range (10 Hz to 100 GHz) is accepted on the basis of Cole-Cole formulation [1]. The Gabriel model framework provides frequency dependent values of permittivity and conductivity with the help of multi-term Cole-Cole model [10].

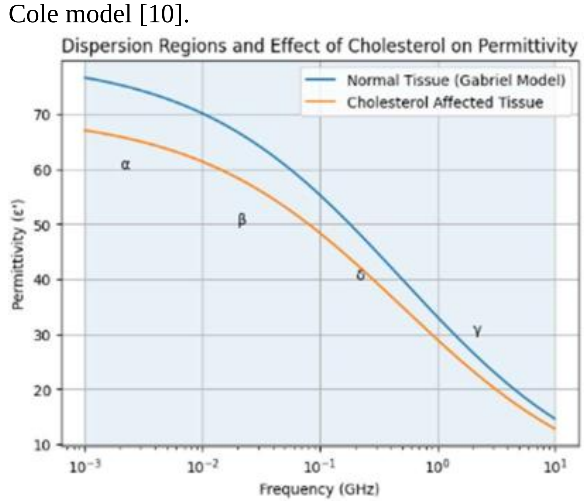

Fig. 1[Effect of cholesterol on permittivity]

In Fig. 1shows variation of real permittivity (ε ‘) with frequency, defining dispersion regions α, β, δ, and γ based on Gabriel model. For blood-based studies the transition from β-region to δ-region lies within the microwave frequency range. An increase in cholesterol concentration alters membrane structure and reduces the effective water mobility in tissues, resulting in a decrease in permittivity and conductivity.

These dielectric variations can be detected indirectly using microwave sensing techniques based on the Gabriel model.

$$\varepsilon^*(\omega) = \varepsilon_\infty + \sum (\text{dispersion terms}) + \frac{\sigma}{j\omega\varepsilon_0} \qquad (1)$$

Therefore, higher water content gives higher dispersion strength (Δε), faster relaxed behavior in the γ-dispersion region, and greater conductivity (σ). Gabriel model enables indirect estimation by allowing comparison between measured deviation and dielectric properties.

In the field of Bio electromagnetics, a concept of Specific Absorption Rate (SAR) is learned, which tells the rate at which electromagnetic energy is absorbed by human body tissue when introduced to radio frequency signals. Around 1 mW power and short exposure durations are used to maintain safety standards. Human fingers are considered more suitable due to accessibility, sufficient blood supply and tissue thinness that allows effective penetration of microwave signals. 1GHz to 5GHz frequency range is selected because it provides adequate penetration while interacting with body tissue.

IV. METHODOLOGY

A human subject is considered where blood parameters are measured using both conventional and proposed technique. At first the antenna is connected to a Vector Network Analyzer (VNA) and the subject is asked to place their fingers on the radiating surface of sensing antenna. For reference, subject's blood is also collected immediately using regular invasive method.

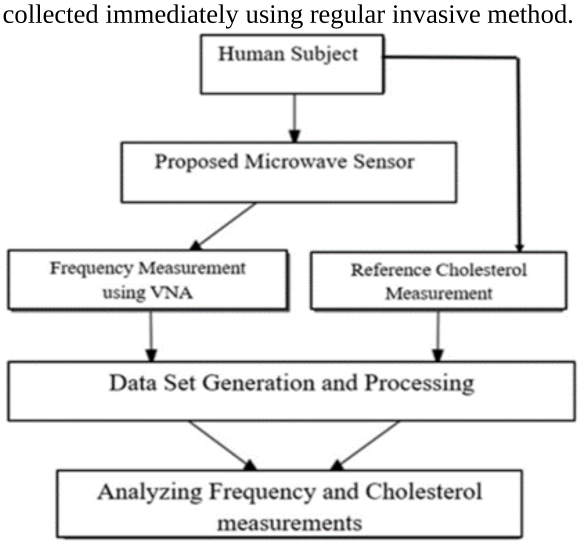

Fig. 2 [Block Diagram]

The proposed system uses a microstrip rectangular patch antenna as the primary sensing element for non-invasive cholesterol estimation. The antenna consists of a metallic radiating patch on one side of a dielectric substrate and a ground plane on the other side. Its planar structure allows direct contact with human skin and is highly sensitive to variations in the dielectric properties of biological tissues. The dielectric behavior of tissues can be represented using the Cole–Cole and Gabriel models [2], and since the effective permittivity of blood is approximately 4.4, FR4 with a similar dielectric constant is selected as the substrate material to achieve better electromagnetic interaction with the tissue [11].

For the conducting material, copper metal is used for the radiating patch. Considering conductivity, radiation efficiency, cost, availability, and ease of fabrication, copper is selected as the most suitable conducting material. The antenna is designed to operate at 2.4 GHz, which lies in the Industrial, Scientific, and Medical (ISM) band. This frequency range is highly sensitive to dielectric properties and can effectively detect tissue changes associated with cholesterol, providing good impedance matching.

a) Antenna design

A standard transmission line model equations as described by C. A. Balani's is used to design a rectangular patch microstrip antenna. The Widths

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (2)$$

εr is the dielectric constant of the substrate with c as the speed of light, fr being the resonating frequency. Effective dielectric constant is stated as

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-1/2} \qquad (3)$$

Substrate thickness is the height (h). Considering the fringing effect an extended length is calculated using

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad (4)$$

The effective length is:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \qquad (5)$$

and the actual patch length is:

$$L = L_{eff} - 2\Delta L \qquad (6)$$

b) Fabrication process

1. The antenna is implemented on an FR4 substrate of thickness 1.6 mm and dielectric constant approximately 4.4
2. Artwork generation: length and width in mm designed.

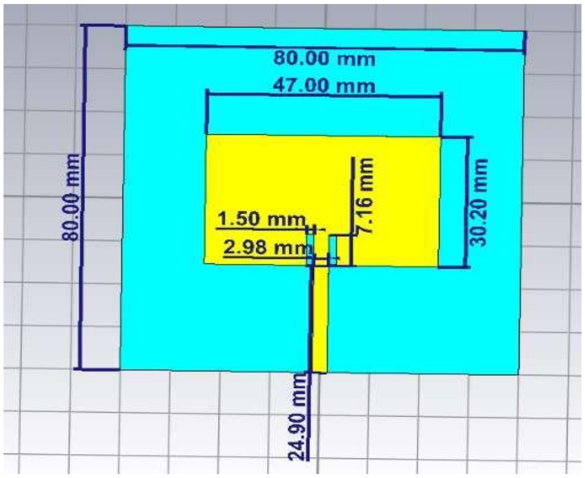

Fig. 3 [Artwork generation]

3. The antenna layout is transferred onto a copper-clad PCB using ironing, where the printed pattern protects the copper.
4. Chemical etching: The board immersed in Ferric Chloride ($FeCl_3$) which removes unwanted copper and forms the desired antenna structure.
5. After etching, a functional PCB-based microstrip antenna is obtained with SMA connector to provide an RF interface between the antenna and the Vector Network Analyzer (VNA).

Fig. 4 [Fabricated Antenna at 2.4GHz]

c) Frequency Measurement

A device is used to measure electrical parameters of RF and microwave circuits called as Vector Network Analyzer (VNA). It measured scattering parameter (S11) and VSWR of 1.05 of the signals which becomes easier to record high frequency antenna. S-parameter is used to describe signal transmission and reflection. Therefore, changes in blood properties are indicated by the frequency shifts in reflected signal of the person who has placed his/her fingers on the proposed antenna. Changes in blood composition, such as variations in cholesterol levels, affect the permittivity of blood due to changes in lipid profile properties.[12] This results in measurable frequency shifts in the antenna response which is then referred to the data samples of actual blood reports done using conventional clinical testing of cholesterol (Invasive method).

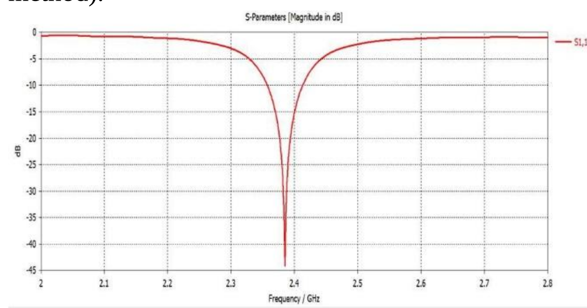

Fig. 5[Simulated result S11 parameter]

Fig. 6 [Practical result S11 parameter]

It was observed that antenna exhibits a resonating frequency around 2.4 GHz lying within the intended operating range for sensing cholesterol. The minimum S11 value was observed approximately -21 dB, indicating good impedance matching at resonating frequency. The sharp resonance observed in the S11 curve confirms the stable operation and high frequency selectivity of the antenna.

d) Dataset Generation

A proper guidance from healthcare professionals and necessary ethical consideration was taken during the process of generating dataset. Each participant included in the study is treated as an individual subject. The cholesterol levels of the subjects were measured using standard invasive methods, and the corresponding resonant frequency shifts were recorded using the microwave sensor connected to a Vector Network Analyzer (VNA). A total of 50 subjects were included in the dataset covering a range of cholesterol levels for effective analysis. Subjects with other major health conditions were excluded to avoid disturbance while conductance of the activity. The final dataset was used to analyze the relation between cholesterol levels and frequency shifts for non-invasive sensing

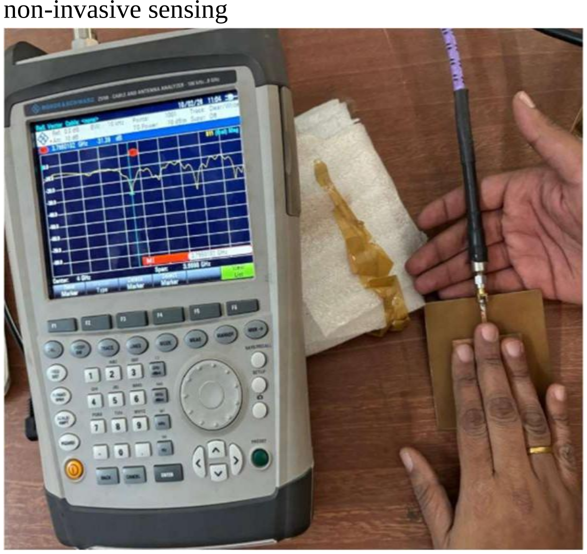

Fig. 7 [Recording resonant frequency shift]

V. RESULTS

Based on the experimental dataset, a quantitative relationship between cholesterol levels and microwave sensor response has been established. The results indicate that variation in cholesterol concentration significantly affect the dielectric properties of biological tissues, particularly lipid and blood, as described by frequency-dependent Gabriel and Cole-Cole models [3].

An increase in cholesterol leads to structural changes in cell membrane, reduced water content and restricted ionic movement. It caused a measurable shift in antenna's resonating frequency and reflection coefficient (S11).

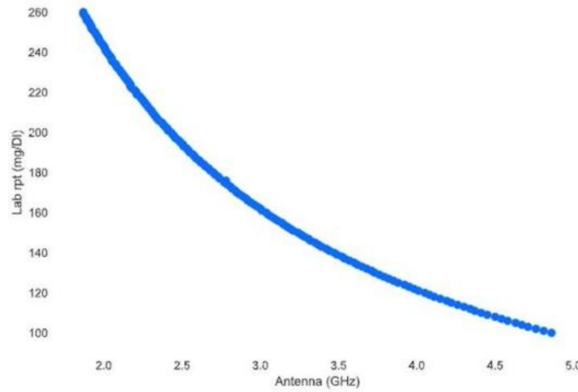

Fig. 8 [Relation between sample cholesterol values and frequency responses of antenna]

A monotonic and consistent trend was observed which enabled the application of regression analysis (polynomial regression) to model the functionality of non-invasive approach.

In polynomial regression, the dependent variable (cholesterol level) is expressed as a higher-order function of the independent variable (frequency)Fig. 7.

Applicability of "Python" language was used to process the data coding part Fig. (8) including libraries pickle, NumPy, flask, easyOCR etc.

Fig. 8 [Python Coding]

$$\frac{(HS_1\ GHz) \times (HS_1\ mg/dL)}{(HS_2\ GHz)} = (HS_2\ mg/dL) \quad (7)$$

Eq. (7) demonstrates the mathematical correlation between frequency response of HS1 (Human Subject-1 and its respective cholesterol value (mg/dL).

By using the measured frequency response of a reference subject, the cholesterol level of an unknown subject (Human Subject-2) is estimated through the established frequency–cholesterol relationship, enabled non-invasive cholesterol prediction.

Fig (9). Shows estimated cholesterol level of subject's result with the value of 184.86 mg/dL for 2.665 GHz frequency.

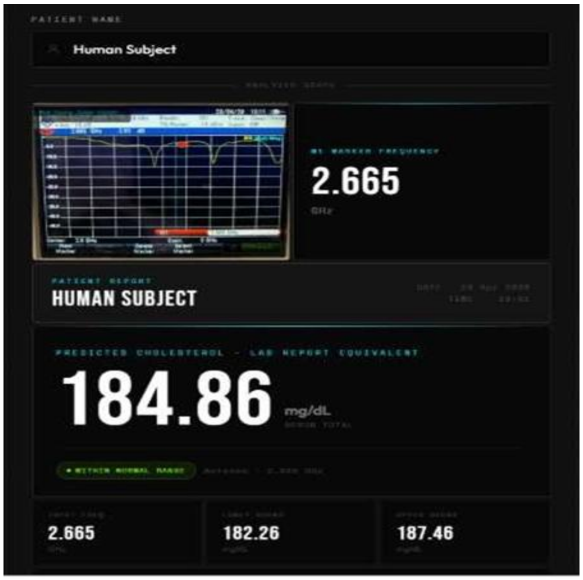

Fig. 9 [Final output]

VI. CONCLUSION

The presented work demonstrates the feasibility of a non-invasive cholesterol estimation system based on microwave sensing using a rectangular microstrip patch antenna operating at 2.4 GHz. The dielectric properties of biological tissues were analyzed using the Gabriel and Cole-Cole dielectric models [], which establish the relationship between tissue permittivity, conductivity, and frequency. Experimental observations confirmed that an increase in cholesterol concentration leads to reduced water content and ionic mobility, resulting in a decrease in tissue permittivity and a corresponding shift in the resonant frequency of the antenna.

The proposed antenna fabricated on an FR4 substrate (εr = 4.4, thickness = 1.6 mm) exhibited good impedance matching with a measured return loss (S11) of approximately

-21 dB at 2.4 GHz, indicating efficient power transfer and stable resonance characteristics. A dataset comprising cholesterol measurements from 50 human subjects was analyzed, and a consistent relationship between cholesterol concentration and resonant frequency shift was observed. Polynomial regression was employed to model this nonlinear relationship and predict cholesterol values from the measured frequency response. Furthermore, a user-friendly software interface was developed in which the frontend accepts the measured resonant frequency, while the backend processes the data using the trained polynomial regression model to estimate cholesterol levels automatically. The interface also displays the minimum and maximum cholesterol range considering tolerance limits, thereby improving the practical usability of the system.

Overall, the obtained results demonstrate that microwave sensing combined with dielectric modeling and machine learning provides a promising, low-cost, and non-invasive approach for cholesterol monitoring. The proposed technique eliminates the need for repeated blood sampling and has the potential to be developed as a portable point-of-care diagnostic device for future healthcare applications.

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