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Comparative Analysis of Multi-Substrate Materials in Microstrip Antenna Models for Broadband Wireless Communications

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Abstract

Multi-substrate antenna material is a combination of more than one primary antenna base material where this substrate material can determine the quality of antenna performance. A quantitative empirical approach is carried out to achieve maximum performance by processing the dielectric constant of the substrate to obtain other antenna parameters. This aims to increase the stability of the antenna gain and produce a large bandwidth. The results show that diamond has a bandwidth of 75 MHz with a maximum gain of 4.228 dBi and a VSWR of 18.017. While epoxy FR-4 produces a bandwidth of 57 MHz with a maximum gain of 3.444 dBi and a VSWR of 2.011, the quartz material produces a bandwidth of 80 MHz with a maximum gain of 4.426 dBi and a VSWR of 10.884. The conclusion is that FR-4 epoxy substrate performs better than diamond and quartz. It is hoped that the results of this research will impact the development of a smart antenna system.

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INTRODUCTION

The development of human activities that are increasingly dynamic, so communication is needed with each other easily anywhere. Therefore, communication technology devices such as smartphones are needed, built with a transmitter, antenna, and receiver system, which are very important to support continuous communication. The antenna is part of this technological device. Of course, it is needed to carry information through the medium of an electromagnetic [1]. Many antenna models have been developed with various approaches, including microstrip models such as array antenna models, reconfigurable antenna models, and smart antennas [2], [3]. The consideration for choosing this microstrip model is because it is simple in design and easy to integrate with other systems in a low-cost [4], [5]. This type of antenna has three main elements: the ground plane, substrate, and patch. Substrate material usually affects the antenna's performance because the characteristics and dimensions of this substrate can also affect the accuracy of the measurement results of antenna parameters [6].

The problem that often occurs is that the composition of the substrate arrangement is not ideal, so there are differences in the final results of calculations and measurements. The results of prior research using ferrite as a base material can provide an increase in antenna gain through the simulation results approach but have not been realized in the hardware [7]. Another research with epoxy material provided optimal results for determining antenna frequency allocation even though the gain was low [8]. However, almost all substrate materials can work at a wide band frequency even though the gain is relatively low. Usually, the standard criteria are that a

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substrate must possess a dielectric constant value which indicates the conductivity level of the material. The greater the value of this constant, it is possible that the antenna gain will increase, and the working frequency of the antenna will be more accurate [9], [10].

The difference in results on these substrate materials is obtained because the constituent materials are not ideal and are influenced by the dielectric constant value and the strip-type [11] so a systematic and careful calculation is needed. The method approach in realizing the antenna in this research uses a multi-substrate material which is a variation of the basic materials of diamond, epoxy Fr-4, and quartz. This type of substrate can provide increased antenna power gain for a wide frequency range, although in terms of price, it is pretty expensive, and the manufacturing process is not simple and needs to be done carefully [12]. The use of multi-substrates in the antenna design in this study was carried out to support performance improvements in broadband wireless communication systems that require consistency and stability in transmitting information [13], [14]. Problems that occur in broadband communication are usually changing in power levels due to the effect of multiple paths (multipath) transmission and the appearance of signal attenuation due to obstructions along the transmission path [15], [16].

On the other hand, the microstrip antenna does not provide a considerable power gain for all existing models. Still, there is a chance that this type of antenna can produce a stable gain over a long period if the choice of substrate material is suitable [17]. Therefore, the main objective of this research, in principle, is to obtain a substrate material specification that is of good quality and able to ensure the consistency of the microstrip antenna gain stability within a certain period, which is applied explicitly to broadband wireless communication systems through modification of the primary material of the antenna substrate. To obtain the suitability of the material, the research phase begins with determining the criteria for broadband wireless communication to be applied, then adjusting the quality testing and calculation of each antenna's multi-substrate material to match the requirements for this type of broadband communication [18], [19].

METHOD

The method used in this research is empirical and quantitative by first identifying each substrate's dielectric coefficient value. The stages of this method are used based on the design flow diagram shown in Figure 1. Furthermore, the calculation process is carried out to obtain the antenna dimensions by calculating the length and width of the radiator (patch).

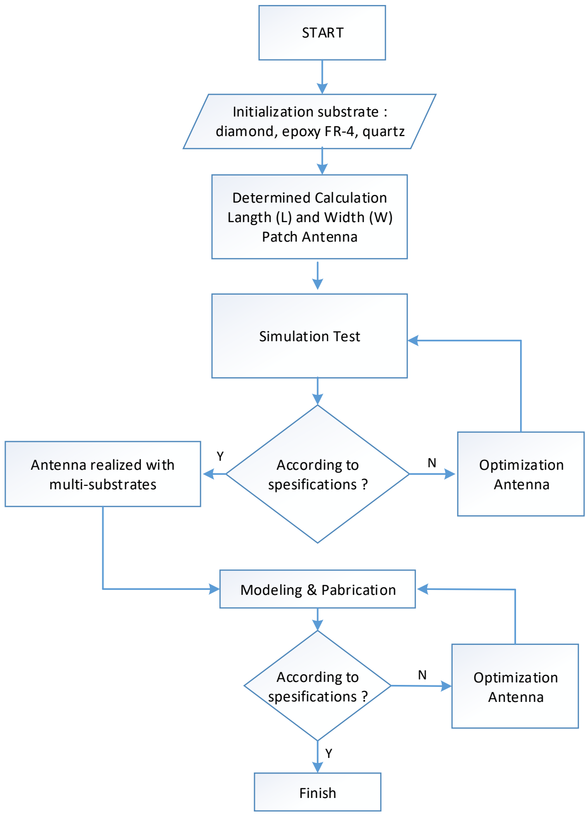


Figure 1. Flowchart of Multi-Substrate Microstrip Antenna Design using Quantitative Empirical Method

The criteria that need to be considered regarding the method used for the design of this antenna broadband wireless are [12][13]:

- The patch height of the microstrip antenna (t) must meet the requirements $t \ll \lambda_0$.
- Microstrip antenna substrate height (h) must meet the requirements $h \ll \lambda_0$ or $0.003\lambda_0 \leq h \leq 0.05$.
- The patch antenna length (L) must meet the requirements $\frac{\lambda_0}{3} \ll L \ll \frac{\lambda_0}{2}$ (for rectangular patch models).
- The material used for the microstrip antenna substrate must have a dielectric constant (ε) value of $2{,}2 \leq \varepsilon \leq 12$.

RESULTS AND DISCUSSION

The selection of three types of basic materials, diamond, epoxy FR-4, and quartz, is the majority of essential materials for making all antenna models. The multi-substrate performance capability of this antenna, when applied to wireless communication at the GSM 1.8 GHz frequency as a public service technology platform, will show the difference. This happens based on the difference in the dielectric coefficient of each substrate, such as diamond having $\varepsilon_r = 5{,}68$, epoxy FR-4 $\varepsilon_r = 4{,}3$, and quartz $\varepsilon_r = 3{,}75$. The impact on strengthening the antenna's radiation power is where the epoxy material can radiate a strong transmit power of 88.9%. Meanwhile, diamond and quartz can only radiate a strong emitting power of 18.1% and 34.1% of the total emitted power.

Modeling Results

The results of modeling the antenna microstrip broadband for wireless communications are shown in Figure 2.

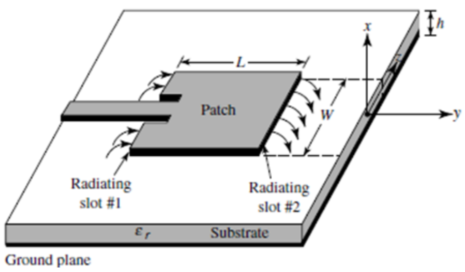


Figure 2. Model of Antenna Microstrip for Broadband Wireless Communication

The calculation of the length (L) and width (W) of this patch antenna must first find the specifications for the primary substrate material, namely the dielectric thickness (h) and the dielectric constant. The thickness of the substrate has enough impact on changes in bandwidth and strengthening so that its thickness can be calculated using equation 1 [20], [21].

$$h \leq \frac{0{,}3\ x\ c}{2\ \pi\ f_r\ x\ \sqrt{\varepsilon_r}} \quad (1)$$

h shows the thickness of the substrate, which is influenced by the frequency of the antenna (fr), the dielectric constant of the material (ε_r), and the speed of light waves in free space (c), changes in the length and width of the microstrip patch can also affect the difference in the frequency bandwidth of the antenna. Therefore, the arrangement must be made carefully where the approach used to find the length and width of the microstrip antenna must refer to changes in length and width whose values can be calculated using equations 2 and 3.

$$W = \frac{c}{2xfr} x \sqrt{\frac{2}{\varepsilon r+1}} \quad (2)$$

$$L = L_{eff} - 2\Delta L \quad (3)$$

The effective dielectric constant (ε_{reff}), the effective length of the material (L_{eff}), and the length of the substrate (ΔL) are obtained based on the initial information provided by the manufacturer, which is closely related to the specifications of the material used.

Calculation Results

Using the above equation, the antenna calculation approach is taken from the substrate dielectric coefficient value data. The results are shown in Table 1.

Table 1. Antenna Calculation Results

Parameter Substrate	Calculation Results (*mm*)		
	Dimond	**Epoxy**	**Quartz**
Thickness (*h*)	3,26	3,75	4.017
Substrate Width (*Wg*)	62,14	72,54	76,94
Substrate Length (*Lg*)	53,72	61,81	66,24
Feeder Thickness (*hi*)	0,10	0,10	0,10
Patch Length (*L*)	34,13	39,29	42,14
Patch Width (*W*)	44,55	50,02	52,84
Feeder Length (*li*)	17,08	19,64	21,03
Feeder Width (wi)	5,11	7,46	8,62

Table 1 shows that the quartz substrate produces the results of the calculation of material parameters above diamond and epoxy so that it has the potential to increase antenna gain more significantly than the other two substrate materials. This statement is also reinforced by the results of previous studies, which showed that quartz could increase the antenna gain level higher throughout its working frequency range [22], [23].

Simulation Results

Simulations are carried out as a standard reference to describe the quality of the antenna to be realized. The main parameters measured were VSWR, gain, and frequency bandwidth for each type of substrate use.

VSWR

The results of the comparison of the VSWR multi-substrate microstrip patch antenna are shown in Figure 3.

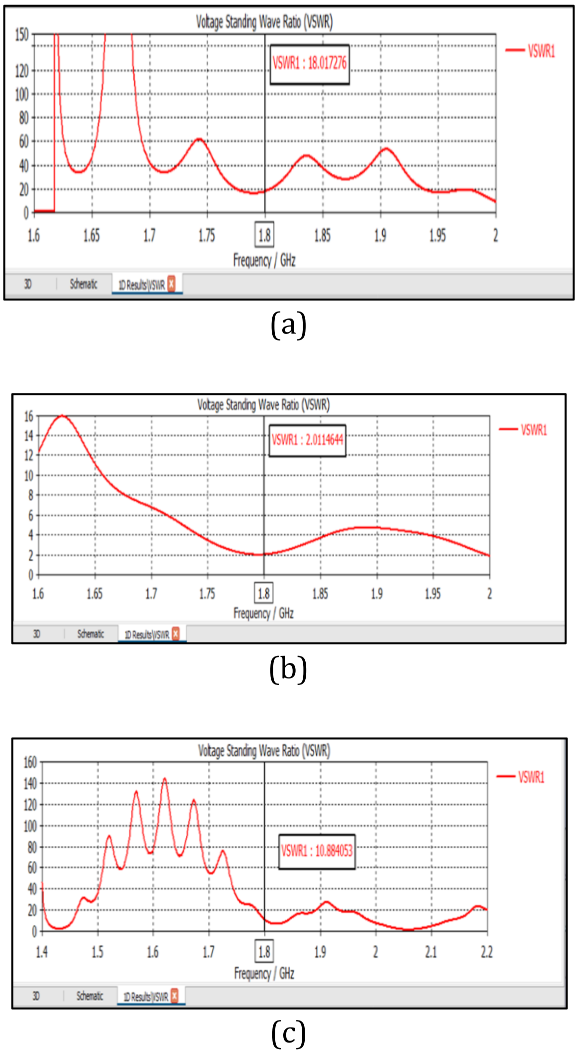


Figure 3. Simulation Results of VSWR; (a). Diamond, (b). Epoxy FR-4, (c). Quartz

The VSWR value of the antenna, if it is assumed to work at a frequency allocation of 1.8 GHz, shows that the epoxy substrate is closer to the best value of 2.011 compared to diamond and quartz, which respectively produce a VSWR of 18.170 and 10.884. The quality of the Fr-4 epoxy substrate, along with the microwave frequency between 900 MHz to 2.3 GHz, has a VSWR value close to the tolerance value, which is between 1 to 2 [24], [25].

Gain Antenna

The results of the gain comparison for the multi-substrate material of the microstrip patch antenna are shown in Figure 4.

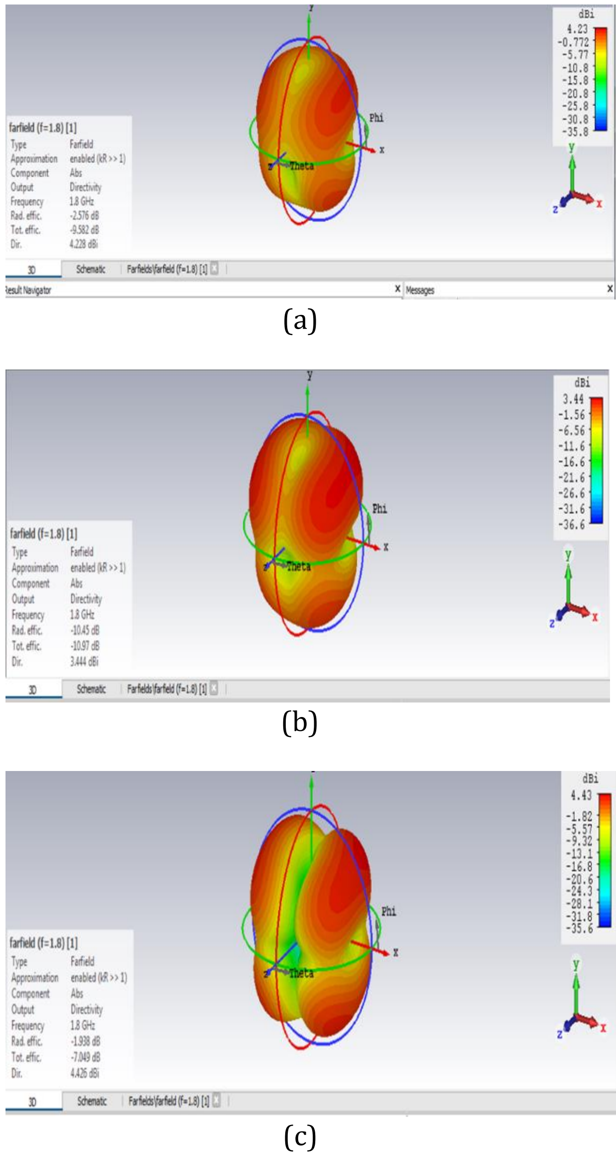
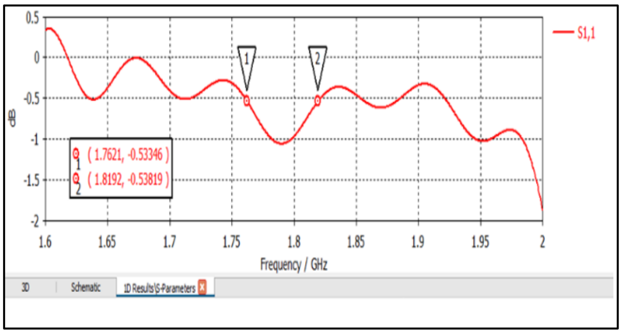


Figure 4. Calculation Results of Gain Antenna; (a). Diamond, (b). Epoxy, (c). Quartz

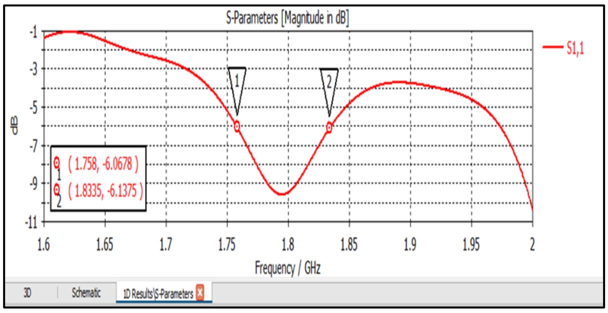
The gain results for each type of substrate are, on average, above three dBi, allowing the antenna to produce an even more significant gain. Diamond and quartz substrates have a maximum gain of above four dBi but do not look stable. They often change over time when compared to epoxy substrates. This change will increase with the magnitude of the frequency shift so that it also has an impact on the strength of the radiated power [12], [17].

Bandwidth Antenna

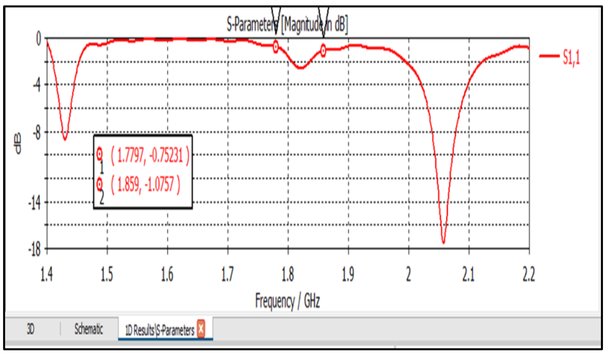
The results of the comparison of the frequency bandwidths for each unique antenna substrate material for the microstrip patch model are shown in Figure 5.



(a)



(b)



(c)

Figure 5. Simulation Results of Bandwidth Antenna; (a). Diamond, (b). Epoxy, (c). Quartz

The bandwidth for these three substrates shows that the most considerable bandwidth is obtained when the antenna is composed of quartz base material at 80 MHz, and the smallest bandwidth when the antenna uses epoxy FR-4 is 57 MHz. Diamond and quartz substrates are mainly applied for frequency allocation above 10 GHz because they can produce a reasonably wide bandwidth [17], [23].

CONCLUSION

Substrate materials with different dielectric constant values are sufficient to give different results on the gain, VSWR, and bandwidth. Epoxy Fr-4 substrate material is better used to realize a microstrip antenna operating at a broadband wireless communication frequency.

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