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Radiation Characteristics of a Planar Strip Dipole Antenna and a Slot Dipole Antenna for THz Applications

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Abstract

The development of a THz system often requires a device that is used to radiate or detect THz waves. One way to fulfill this requirement is to use an antenna. Therefore, we need to consider the radiation characteristics of an antenna working in the THz region. In this paper, we present simulation study of two dipole antennas, i.e. a planar strip dipole antenna and a slot dipole antenna. The simulation results show that a planar strip dipole antenna has a better radiation efficiency (more than 95%) compared to the slot dipole. It also shows that an efficiency of more than 98% can be achieved when using silicon dielectric substrate. Furthermore, a return loss characteristic of 38,752 dB can be achieved by using a silicon dielectric substrate and a metal layer of Au for the planar slot dipole antenna.

Abstrak

Ciri-Ciri Radiasi Antena Dwikutub Bilah Planar dan Antena Dwikutub Celah untuk Aplikasi THz. Pengembangan sistem THz seringkali harus didukung oleh alat khusus yang digunakan untuk memancarkan atau mendeteksi gelombang THz. Salah satu cara untuk memenuhi fungsi ini adalah dengan menggunakan antena. Oleh karena itu, ciri-ciri radiasi antena yang berfungsi di zona THz harus diperhatikan. Makalah ini menyajikan hasil kajian simulasi dari dua jenis antena dwikutub, yaitu antena dwikutub bilah planar dan antena dwikutub celah. Hasil simulasi menunjukkan bahwa antena dwikutub bilah planar memiliki tingkat efisiensi radiasi yang lebih tinggi (lebih dari 95%) daripada antena dwikutub celah. Ditunjukkan pula bahwa tingkat efisiensi sebesar lebih dari 98% dapat tercapai dengan penggunaan substrat dielektrik silikon. Selain itu, karakteristik kembali rugi sebesar 38.752 dB dapat tercapai dengan penggunaan substrat dielektrik silikon dan lapisan logam Au pada antena dwikutub celah planar.

Keywords: antenna, dipole, strip, slot, THz

1. Introduction

In the spectrum of electromagnetic radiation, the THz frequency lies between the infrared and millimeter regions. Figure 1 shows the position of THz waves in the electromagnetic spectral range. It appears that the THz frequency region is in transition between the electronic and photonic domain [1]. This gives a certain approach to study the use of a frequency range extending from 0.3 THz to 3 THz.

Utilization of the THz frequency is still rare, except in astronomy and related fields [2]. This is due to lack of equipment to generate and detect THz waves [3]. However, the presence of femtosecond laser technology and photoconductive antennas in the 1980's led to THz technologies that could be used in various applications, such as medical science, pharmacology and security. In fact, there are a lot of research activities on semiconductor devices that can work at frequencies up

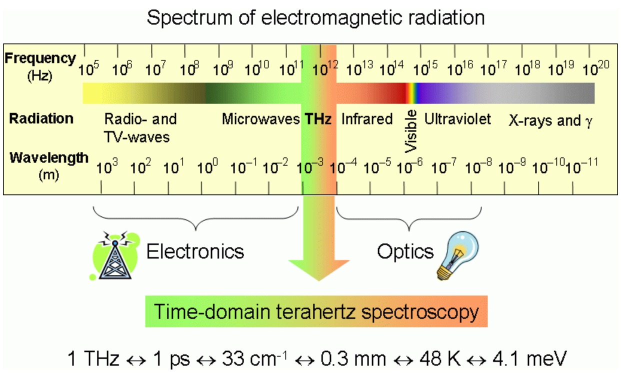

Figure 1. Spectrum of Electromagnetic Radiation [1]

to 1 THz [4-5]. Si-CMOS technology is considered to be unsuitable for applications in the THz wavelength due to the lossy nature of the substrate, providing a possible power gain at frequencies above 100 GHz [6-7]. Many studies recommend THz applications in telecommunication systems as a solution to fulfill the demand for high data access in the future [8-11].

The implementation of THz technology will depend on the ability of a tool to detect and radiate THz waves. One component that can be used to receive and transmit THz waves is an antenna. The antenna itself acts as an interface with free space as well as a transducer of electrical energy to electromagnetic wave energy and vice versa. Many researchers have discussed the use of antennas as part of the THz system as both a detector and transmitter [12-17]. This paper discusses the design and simulation of a planar strip dipole antenna and a slot dipole antenna by varying dielectric substrate, i.e. Roger T5880 and silicon, and metal layers of dielectrics, i.e. cobalt (Co) and gold (Au). Benchmarking the performances of some antenna designs can be used as to determine the type of antenna by considering the performance needed and the utilization of certain materials.

2. Methods

This study conducts the simulation by specifying the resonant frequency at 1 THz. It is done to provide an alternative use of antenna applications that utilize a frequency of 1 THz. First, a resonant frequency of antenna is determined by giving an appropriate match impedance to the feeding system. The other physical parameters will be determined in order to obtain the performance of the antenna, such as Bandwidth, Gain, Radiation Pattern, Directivity, and Efficiency.

The antenna is designed by using the basic shape of the half-wavelength dipole antenna to determine the initial dimension. The antenna uses two models of dipole antennas, i.e. a planar strip dipole antenna and a slot dipole antenna.

Figure 2 and Figure 3 show initial designs of a planar strip dipole antenna and a slot dipole antenna respectively. The antennas have dimensions of 15 ×160 μm (0.1 λ_o × 0.53 λ_o), where λ_o is the wavelength in free space at a frequency of 1 THz. The simulation uses a discrete port to provide input to the strip dipole antenna. Moreover, the slot dipole antenna design uses the feeding of a stripline form that is located in the dielectric element. Table 1 shows the values of variables used in the simulation.

In this simulation, the antenna design is conducted by using three factors, i.e. types of antenna, substrate, and metal layer. Each factor has two conditions. The types

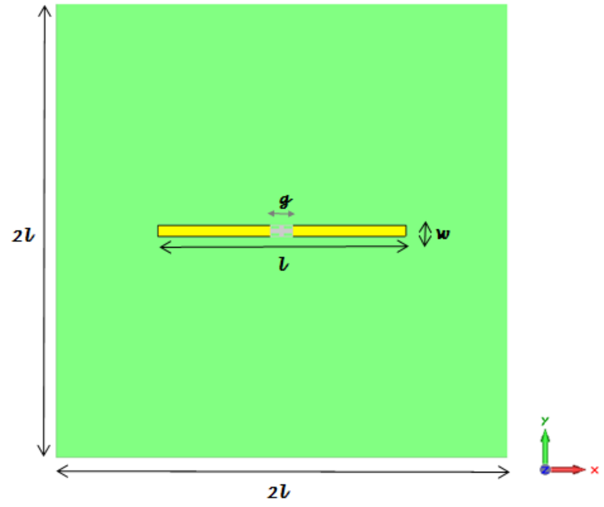

Figure 2. Geometry of Strip Planar Dipole Antenna

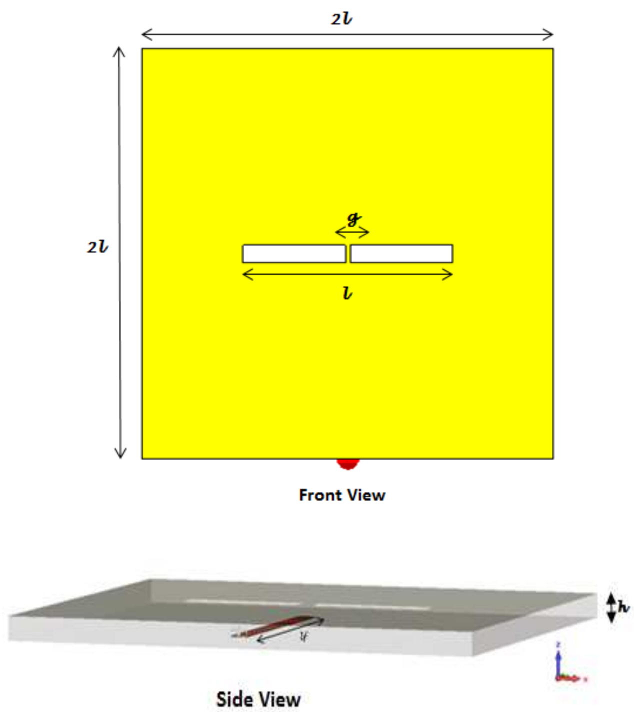

Figure 3. Geometry of Slot Dipole Antenna

Table 1. Antenna Dimension

Variable	Planar Strip Dipole Antenna (μm)	Slot Dipole Antenna (μm)
L	160	160
W	15	15
G	10	10
H	13	13
Lf	-	150
ε_r (Roger RT5880)	2,2	
ε_r (Silicon)	11,9	

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of antenna are planar strip dipole antenna and slot dipole antenna. The dielectric substrates are Roger RT5880 substrate with ε_r = 2.2 and thickness (h) = 13 µm, which is a material often used in the manufacture of microwave antennas, and silicon substrate with ε_r = 11.9 and thickness (h) = 13µm. There are also two types of metal layers used: Au and Co.

This paper will show 6 simulation results with some provisions. The antenna should be in the resonant frequency of 1 THz. The simulation conducts the characterization of the variable dimensions in order to get the resonant frequency. The characterization is conducted on the three variables: length (l), width (w), and length of feeding (lf) of the slot dipole antenna.

3. Results and Discussion

The simulation is conducted by using CST EM-3D simulation software, Microwave Studio 2011, which uses the FDTD method. The characterization is carried out for the variables l, w, g, and lf where the initial condition is shown in Table 1. The characterization is carried out to obtain the best match between feeding line and dipole antenna. After getting the antenna design with optimum matching impedance, it continues to simulate the radiation characteristics of the antenna. There are several radiation characteristic parameters compared in this designs, i.e. Return Loss, Directivity, Radiation Pattern, Radiation Efficiency, and Bandwidth.

Planar strip dipole antenna. Figure 4 shows the return loss characteristics for the four-antenna design with variations on the substrate and the metal layers. These results are also the best results from the characterization of variable length (l) and width (w). Dimension values with the best results can be seen in Table 2. The value of S_{11} parameter below -10 dB is often used for determining the impedance matching and bandwidth of the antenna.

Figure 4 shows that there are similar results when simulating the two antennas with dielectric substrate of Roger T5880. A better matching condition is obtained when the dielectric substrate of silicon is applied. The best matching condition is obtained when the simulation uses a silicon dielectric substrate and Au metal layer.

Table 2. Summary of Simulation Results

Substrat	Metal Layer	Size (µm) L	Size (µm) w	S11 (dB)	Range Bandwidth (GHz)	Bandwidth (GHz)	Main Lobe Directivity (dBi)	Main Lobe Direction (degree)	Radiation Efficiency (%)	Total Efficiency (%)
Planar Strip Dipole Antenna										
Roger T5880	Copper (Co)	102	5	-20.55	939.13-1077.8	138.67	2.22	102	96.59	95.73
Roger T5880	Gold (Au)	102	5	-20.26	940.68-1080.2	139.52	2.18	101	96.03	95.13
Silicon (Si)	Copper (Co)	59	20	-27.85	912.37-1114.7	202.33	2.28	180	98.64	98.48
Silicon (Si)	Gold (Au)	49	19	-38.75	935.22-1080	144.78	2.15	111	98.06	98.06
Slot Dipole Antenna										
Silicon (Si)	Copper (Co)	96	8	-34.00	974.68-1021.1	46.42	5.79	180	72.48	72.44
Silicon (Si)	Gold (Au)	96	8	-13.39	995.38-1008.2	12.82	4.12	134.000	33.37	31.83

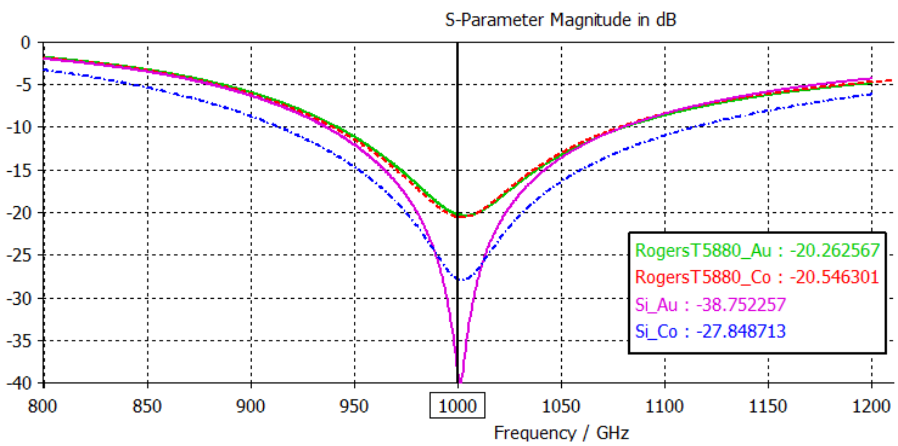


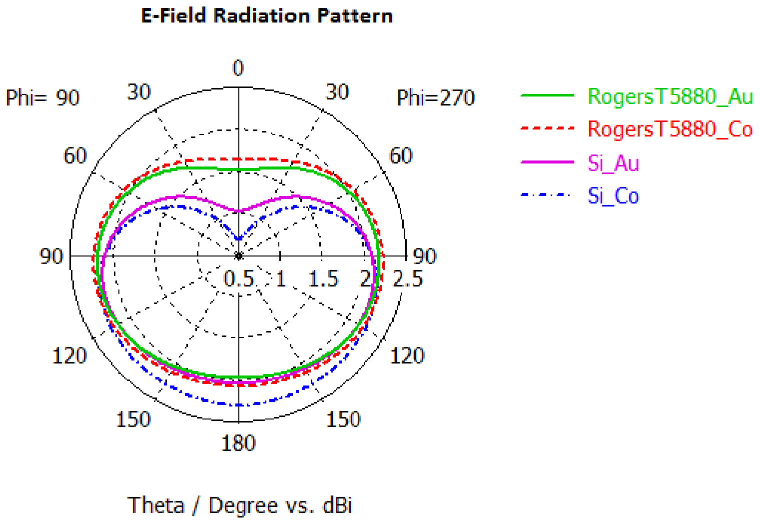
Figure 4. S11 Parameter of Planar Strip Dipole Antenna

Figure 5 illustrates the radiation patterns of the four designs of planar strip dipole antennas. It appears that in general the main beam (main lobe) of the E-field leads downward. This indicates that the direction of emission of electromagnetic waves moves in the direction of the substrate which is more radiated than into free space.

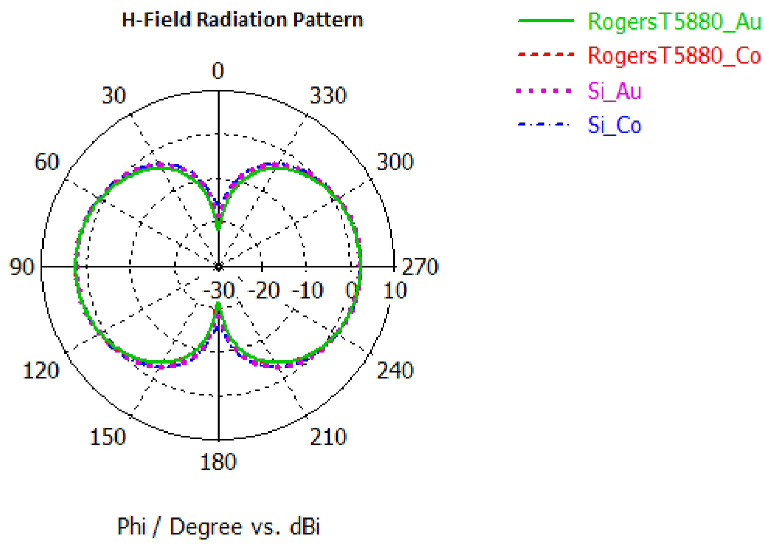
The comparisons shown in Figure 5 illustrate the influence of changes in dielectric substrate and metal layer used. E-field radiation patterns from four antennas have different shapes between each other. Figure 5 (a) shows that the radiation pattern is more directive when using silicon dielectric substrate compared to when using Roger RT5880 dielectric substrate. The back lobe side level is also reduced when using silicon as a dielectric substrate. The highest directive level is 2.28 dBi in the direction of 180° when simulating the antenna using the silicon dielectric substrate and Co metal layer. At the same time, the H-fields from the four designs are similar to each other as shown in Figure 5 (b).

Slot dipole antenna. The microstrip slot antenna is another antenna used in the microwave frequency range because of its ease of fabrication. It also has the more mature results of these two types of antennas. This simulation intends to see the performance characteristics of a slot dipole antenna at a resonant frequency of 1 THz.

The simulation is conducted for the slot dipole antennas using a dielectric substrate of silicon. There are two kinds of metal layers used—Au and Co. Figure 6 and Figure 7 are the simulation results for a slot dipole antenna with metal layers of Au and Co respectively.



(a)



(b)

Figure 5. Radiation Pattern of Planar Dipole Antenna

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These results are obtained by performing a characterization of the half-wave dipole dimensions variable as shown in Table 1. Antenna dimensions and other parameters of the simulation results are shown in Table 2.

Figure 6 shows the return loss characteristic (S_{11}) curve. Generally, it shows the results of the resonant frequency of 1 THz. The matching condition of the antenna using Co is -40.00 dB appears better than the antenna using Au which is -13.39 dB. By considering the bandwidth limit at -10 dB, it seems that the bandwidth of the first antenna is wider (up to 46.42 GHz) than the second antenna at 12.82 GHz. The differences of the metal layer will produce the difference performance of the slot dipole antenna.

Figure 7 compares the radiation pattern for both slot dipole antennas. Figure 7 (a) shows the benchmarking between the E-field for both slot dipole antennas. There is a main lobe and a back lobe in the antennas' radiation. The back lobe causes the transmitting power to decrease in the main direction of radiation.

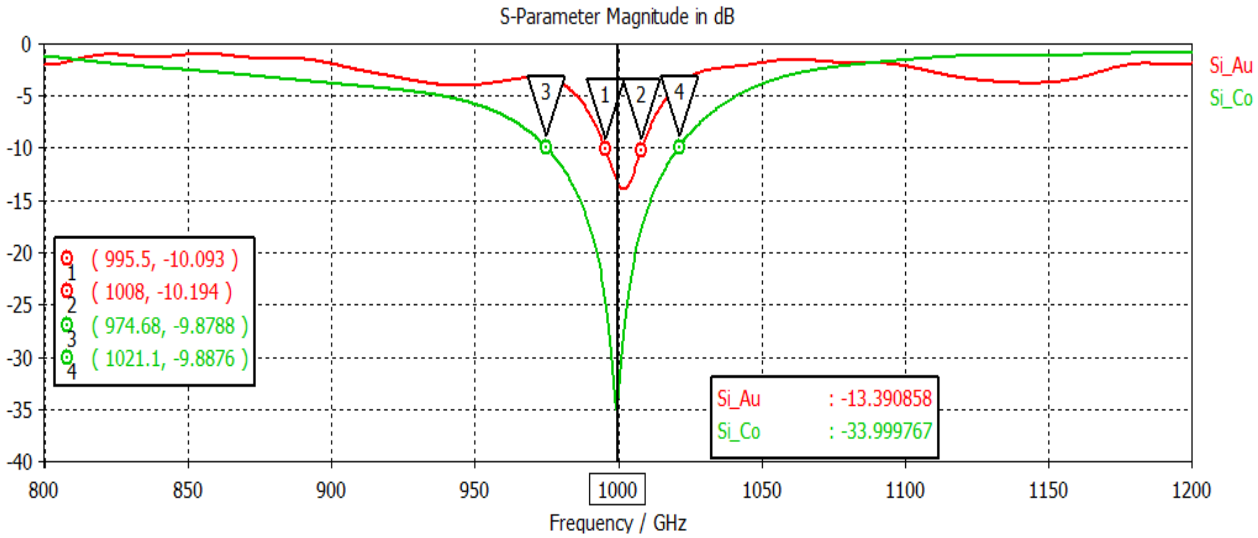
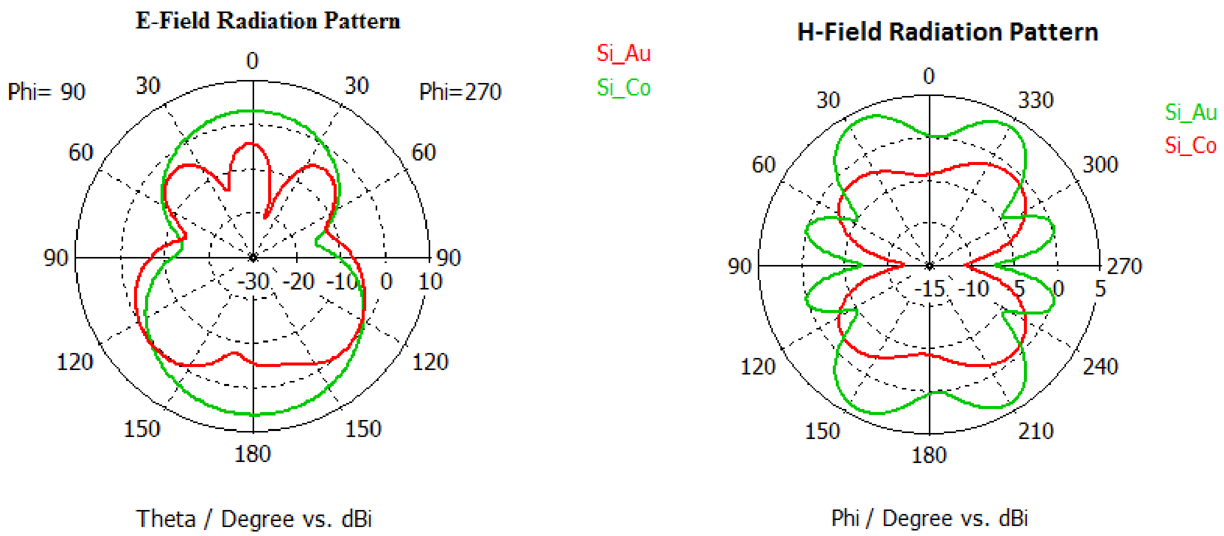


Figure 6. S11 Parameter of Slot Dipole Antenna



(a) E-Field radiation pattern

(b) H-Field radiation pattern

Figure 7. Radiation Pattern of Slot Dipole Antenna

The radiation pattern of the antenna with the Co layer is more directive than the other antennas. The gain of the antenna using the Co layer also has a higher gain: 5.79 dBi in the 180° heading. Furthermore, Figure 7(b) shows H-field radiation patterns. The antenna using the Au layer has more side-lobes compared than the antenna using Co.

From the simulation, it is found that the dimensions and materials used can be adjusted to obtain the desired antenna performance. The overview of simulations results for six designs can be seen in Table 2, including directivity, radiation efficiency, and total efficiency. These are important to know in designing antennas.

In the previous chapter the antenna design simulation using different dielectric substrates were carried out. First, the simulation was conducted using a material commonly used in the design of the antenna in the microwave range, namely Roger RT5880 with permittivity values ε_r = 2.2. Subsequently, the simulation was conducted by using a substrate of silicon with permittivity values ε_r = 11.38.

The simulation results show that there is an increased performance in the efficiency of the antenna by using the higher permittivity value of dielectric substrate. The values in Table 2 show that the planar strip dipole antenna that uses a substrate of Roger T5880 has 96% radiation efficiency and total efficiency of about 95% for both Au and Co. The simulation using silicon dielectric substrate has radiation efficiency and total efficiency of about 98%. This means that there is an increase in the efficiency of the antenna, either when transmitting or receiving waves.

In addition, the use of a dielectric substrate with a higher value also improves the return loss characteristic (S_{11}). The bandwidth becomes wider as well. Table 2 shows that the antenna with the Roger T5880 substrate has an S_{11} about -20 dB, while the design using the silicon dielectric substrate can improve the matching condition up to -27.8 dB. The value can be raised up to -38.7 dB when using a metal layer of Au.

The results for the slot dipole antenna indicate that this design may be used in THz applications. However, the performance parameter is worse than the planar strip dipole antenna. There are back lobes and side lobes in the radiation pattern curve that reduce the efficiency of radiation.

4. Conclusions

Utilization of THz waves of course requires careful attention to obtain the optimum design. An antenna that can serve as the interface between device and atmosphere is expected to have good characteristics. This will determine the level of precision in its application. The 1 THz antenna design in this simulation yielded a significant performance improvement with the use of high dielectric value materials, namely silicon, compared with a material commonly used in the microwave antenna, Roger T5880. The values of radiation efficiency and total efficiency in the use of silicon substrate reached more than 98%, higher than with Roger T5880. The return loss characteristic (S_{11}) from the simulation also shows better results on its matching condition, -38.75 dB, by using silicon dielectric substrate and the metal layer of Au. Future studies will lead to the design of an antenna with optimum performance as an interface to a variety of applications in sensing and imaging.

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