

Dielectric Property Effect with Dielectric Constant for Millimeter Wave Antenna Design

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Abstract

The millimeter Wave transmission provides large bandwidth for data transfer which can satisfy the 5th generation mobile network architecture three main features: High data rate, Low latency, Mass Connectivity. Due to the high propagation attenuation characteristic of millimeter Wave, the Directivity of Antenna Array greatly increase the transmitting distance. The antenna dimensions are designed relative to wave length for better radiation performance. In millimeter Wave bands, the wave length is under millimeter scale which the antenna can be integrated to Package called AiP (Antenna in Package)

This article will discuss the influence of substrate material property for antenna behavior. The Dielectric Constant (Dk) of air is closed to 1, use substrate with low DK for Antenna in Package results better expression to increase Gain and Wider bandwidth. However, the wave length is also affected by Dielectric Constant, since the wavelength is inversely proportional to the square root of the Dk, the substrate with high Dk reduces the AiP size obviously. In this paper, we will provide the comparison of antenna performance for Low/High Dk by Patch Antenna which consider single antenna and antenna array.

In the simulation, the result shows the difference between High and Low Dk. When Dielectric Constant increases to 6 from 3, the width of single antenna can be reduced 30% and in contrast the peak gain is 15% higher with low Dk. For handheld devices such as smartphone, the internal space is limited, the size of antenna becomes critical. With the help of pattern design to enhance antenna performance. The high Dk material can be the choice of antenna for handheld devices.

Key words

5G, Millimeter Wave, Patch Antenna, High Dielectric

I. Introduction

With the development of communication technology, data transmission has grown exponentially, the evolution of wireless data and the growing popularity of smart devices have led to a large-scale surge in mobile data traffic. Mobile users and related industries require faster data processing speeds and higher traffic speed.

The fifth generation of new radio (5G NR) technology is being actively researched to meet customers and new business models, some frequency bands of 5G reach 28GHz (mmWave) above, the higher frequency range provides wider bandwidth for larger amount of data.

When the frequency reaches the millimeter wave band, the antenna can be designed into a package (Antenna in Package,

AiP), since the antenna size becomes small enough due to the shorter wavelength, thus providing better integration of mobile devices. [1]

Most designers understand that by using a substrate material with a higher Dielectric constant value, the size of the microwave circuit can be miniaturized. The circuit size decreases as the Dielectric constant value of the substrate material increases, allowing the millimeter-wave antennas integrate into mobile devices more favorable[2]-[3].

In this paper, the relationship between substrate material dielectric constant and mmWave antenna dimensions would be discussed.

II. Structure & Design of the Antenna

The antenna is designed at 28GHz band of the 5G mobile by using 3-layer metal stack-up with an 18 μ m copper thickness for each layer. Two substrate materials are chosen and designed: first is a relative permittivity of 3.4 and loss tangent of 0.0044, and second is a relative permittivity of 6.3 (High Dk) and loss tangent of 0.009. The relative permittivity (Dk) of material will determine the antenna size and the thickness of the resonate gap of the antenna which should be thick enough to get better performance of the antenna, as like bandwidth and gain. However, it is well known that the dimension and thickness of practical portable devices is limited.

Therefore how to choose suitable material properties is very important and this study will be shown the relations between the antenna size, thickness of the resonate gap, and the permittivity of the dielectric materials. Figure 1 is shown the stack up of the antenna, the function of M2 is similar to the traditional patch antenna. Because the impedance bandwidth of the traditional patch antenna is narrow, the stacked patch M1 is used to improve the impedance bandwidth. It is an effective and simple method to improve the impedance bandwidth by using stacked patch [4] which can couple and generate the additional current, that result in wider impedance bandwidth. The reference ground for patch antenna and the feeding via is on M3. In order to purely explore the relationship between the antenna and the material properties, it uses the feeding via to simplify the design of the transmission line.

The thickness between M1 and M2 is kept on around 500 μ m, and the resonate gap between M2 and M3 is optimized with different relative permittivity of 3.4 and 6.3 by Ansys HFSS simulation tool. The position of the feeding via, dimensions of the patch antenna and stacked patch should also be tuned and optimized to obtain wider impedance bandwidth and antenna gain. After the optimized patch size, and stacked patch size, and feed point location as well as the thickness of the resonate gap are fine-tuned, the next step is to arrange and compare the 1 $\times$ 5 antenna array with material permittivity 3.4 and the 1 $\times$ 7 antenna array with material permittivity 6.3 in the same antenna module size. Table I is showed the optimized values of the patch size, stacked patch size, and the thickness of the resonate gap for two material Dk of 3.4 and 6.3. The width of the single antenna and the thickness of the resonate gap are decreased 30% and 22% individually as increased the material Dk from 3.4 to 6.3. As can be seen from Figure 2, the left draw is the 3D model in the electromagnetic simulation software, and the right draw is showed that the impedance match are both designed at 28GHz band, the bandwidth of return loss below -10dB with material permittivity 3.4 is 3.9GHz from 26.1GHz to 30GHz, and with material permittivity 6.3 is 4.4GHz from 25.6GHz to 30.3GHz. The difference of the

impedance bandwidth is within 0.5GHz.

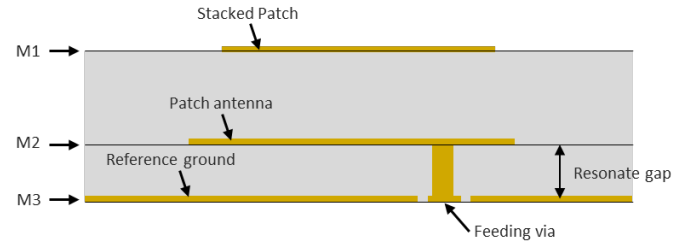


Figure 1. The stack up of the antenna

Table I. The optimized values of the single antenna.

Material Dk/Df	3.4 / 0.0044	6.3 / 0.009
Patch Size(mm x mm)	2.53 x 2.53	1.79 x 1.79
Stacked Patch Size (mm x mm)	2.35 x 2.35	1.73 x 1.73
The thickness of resonate gap (μ m)	250	196

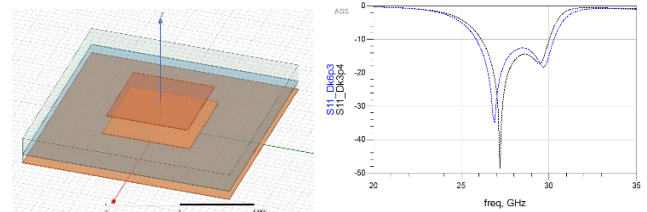


Figure 2. The impedance match of the single antenna

The Figure 3 is shown the antenna gain pattern with different Dk material. The peak gain with Dk 3.4 material is 6.63dBi which is 11% better than 5.9dBi with Dk 6.3 material. Therefore, summary the above descriptions and simulation results: design antenna with higher material Dk can obtain the advantages of smaller antenna size and thinner thickness of resonator gap.

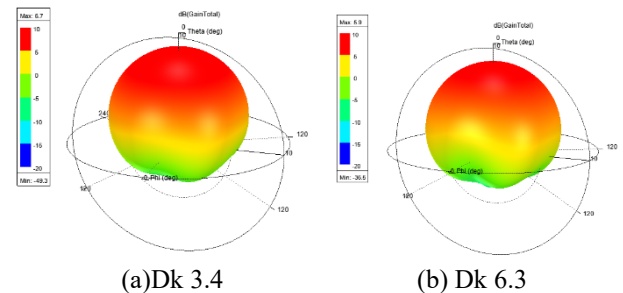


Figure 3 Antenna patterns

III. Antenna Array

As mentioned in part II, this section will discuss and evaluate the performance of the antenna in the same antenna module size, including the peak gain, impedance bandwidth, and the radiation angle for 70% and 90% power.

In Figure 4, within the limited antenna array module size, the antenna array quantity with Dk 3.4 material is 1×5 , and the pitch between the antennas is 2.9mm; the antenna array quantity with material Dk 6.3 is 1×7 , and the pitch between the antennas is 2.1mm. The antenna pitch in the antenna array is relative to half-wavelength and inversely proportional to the square root of the Dk [5]. The antennas can be excited by individual ports without connecting to each other through transmission line in Ansys HFSS setting environment, therefore it could only consider the performance of the antennas. Figure 5 is showed the impedance match at 28GHz band for all array ports with the two material Dk. The maximum bandwidth among this port with material Dk of 3.4 is 4.2GHz from 25.8GHz to 30GHz, and with material Dk of 6.3 is 4.7GHz from 25.6GHz to 30.3GHz. The difference of the impedance bandwidth is also 0.5GHz for antenna array comparisons.

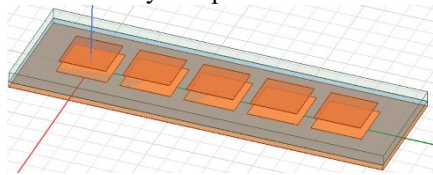


Figure 4(a) 1×5 Antenna array with material Dk of 3.4

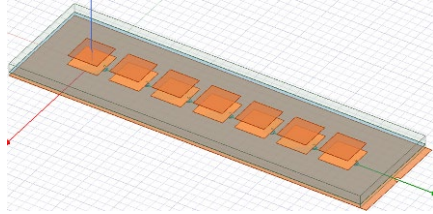


Figure 4(b) 1×7 Antenna array with material Dk of 6.3

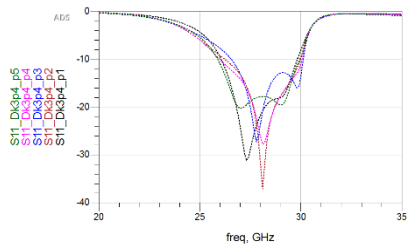


Figure 5(a) 1×5 impedance match of the Antenna array with material Dk of 3.4

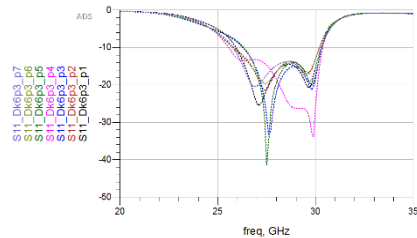


Figure 5(b) 1×7 impedance match of the Antenna array with material Dk of 6.3

For the comparison of antenna gain, the peak gain of 1×5 antenna array with material Dk of 3.4 is total 10.6 dBi which

is better 0.009 dBi than 1×7 antenna array with material Dk of 6.3, as showed in Figure 6. The performance between the both antenna arrays is very close. On the other hand, the gain of the antenna array could be compensated by increasing the quantities of the antenna with higher material Dk in the same module length[6]. However, what is the benefit of increasing the number of antennas? In the Table II, it obviously shows the advantage – wider radiation range. The radiation angle with 1×7 antenna array is wider $10^\circ \sim 12^\circ$ than 1×5 antenna array for 70% and 90% power radiation, but it needs more control ports of the antenna module IC.

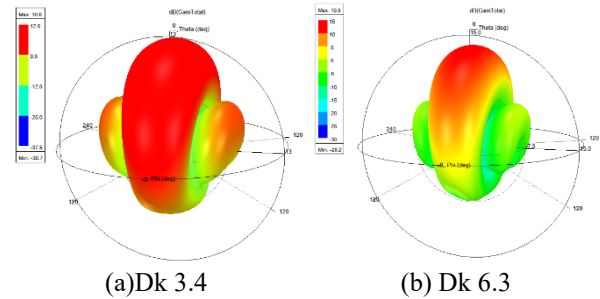


Figure 6 Antenna array patterns

Table II The comparison of the radiation angle

Material Dk/Df	3.4 / 0.0044	6.3 / 0.009
Antenna Array	1×5	1×7
Radiation Angle (90% Power Radiation)	$-56^\circ \sim +56^\circ$	$-60^\circ \sim +60^\circ$
Radiation Angle (70% Power Radiation)	$-61^\circ \sim +61^\circ$	$-66^\circ \sim +66^\circ$

IV. Conclusion

In this paper, we design and simulate a patch antenna with two material Dk of 3.4 and 6.3 at millimeter wave 28GHz band in 3-layer stack-up structure. Design with higher material Dk of 6.3 can obtain the advantages of smaller 30% width of the single antenna and thinner 22% thickness of resonator gap, but in contrast the peak gain is 15% higher with low Dk of 3.4. The gain of the antenna array could be compensated by increasing the quantities of the antenna with higher material Dk in the same dimension. Design antenna with proper selection of high Dk material can help to reduce the size of the antenna module and increase the radiation angle.

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