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5G Yarıklı Panyon Anten Tasarımı

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MAKALE BİLGİSİ

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Papyon anten
Milimetre dalgabandı
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28 GHz anten

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ÖZET

Bu çalışmada, bir yarıklı papyon antenin yeni bir tasarımı önerilmiştir. Önerilen anten çalışma frekansı, milimetre dalga bandı ve 5G teknolojileri için aday bir standart olan 28 GHz'dür. Önerilen anten, iki farklı taban malzeme kalınlığı için beş farklı taban malzemesi kullanılarak tasarlanmış ve benzetimi yapılmıştır. Elde edilen sonuçlar optimum bir tasarım elde edilene kadar karşılaştırmış ve test edilmiştir. Önerilen antenin boyutları, parametrik optimizasyon tekniği kullanılarak en küçük boyutu yüksek verimlilikle elde etmek için ayrı zamanlarda eniyilenmiştir. Geri dönüş kaybı, duran dalga oranı, üç boyutlu kutupsal grafiği ve anten kazancı hesaplanmıştır. Benzetim sonuçları, önerilen tasarımın 28 GHz'de iyi ışıma özelliklerine sahip olduğunu göstermiştir. Önerilen tasarım, gelecek 5G cihazlarında kullanılabilir.

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5G Slotted Bow-Tie Antenna Design

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ABSTRACT

In this paper, a new design of a slotted bow-tie antenna is proposed. The proposed antenna operating frequency is 28 GHz which is a candidate standard for millimeter waveband and 5G technologies. The proposed antenna has been designed and simulated using five different substrate materials for two different substrate thicknesses. The obtained results are compared and tested until an optimal design is reached. The dimensions of the proposed antenna are optimized at separate times using the parametric optimization technique to get the smallest size with high efficiency. The return loss, voltage standing wave ratio, the 3D polar plot and the gain of the antenna were simulated. Simulation results demonstrate that the proposed design has good radiation characteristics at 28 GHz. Proposed antenna design can be used for future 5G devices.

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1. INTRODUCTION *(GİRİŞ)*

Existing mobile communication systems and commercial applications today use the spectrum below 3 GHz. With the proliferation of smart phones and other mobile data devices like netbooks, tablets, etc., below 3 GHz spectrum has become increasingly crowded. A vast amount of spectrum in the 3–300

GHz range remains unexploited for wireless applications. In order to tackle the exponential increase of mobile data traffic and to satisfy the users' high data rate demand, the use of 3–300 GHz spectrum is highly desirable [1].

The 12–300 GHz spectrum is generally referred to as millimeter-wave (mmWave) band. To overcome the issues mentioned above, mmWave technology which is candidate for fifth generation (5G) systems [2] has recently been proposed. However, electronic components such as antennas used in 5G systems are too big in size and consume too much power. Also, the low efficiency of antenna devices is another challenge with mmWave band. Hence, it is essential to design reduced size antennas with high gain and bandwidth [1], [3–5].

Today, Bow-tie antenna design has become a topic of concern in radar and sensor systems because of the advantages such as basic geometry, broadband characteristics, ease of fabrication, low profile, omni directivity, and high radiation efficiency [6], [7]. The dimensions of the bow-tie antenna are sensitive to the operation frequency. Therefore, it is difficult to obtain the desired frequency especially for 5G band. But, there is still a big question which frequency band will be used for 5G. In relation to this, in recent years, South Korea, US, and Japan have agreed to use 28 GHz band as an international standard for 5G network [8].

Hence, the main objective of this paper is to investigate, design, simulate, and optimize bow-tie antennas for 5G devices operating at 28 GHz. In this paper, a new slotted Bow-tie antenna is designed and its dimensions are optimized to get the smallest size. For the proposed antenna, five different substrates (Arlon CuClad 217, Rogers RT/duroid 5880, FR4_epoxy, Neltec NH9294, and Nelco N4000-13) with two different substrate thicknesses (1.57 and 0.635) are compared for the optimal design at 28 GHz.

2. NEXT GENERATION 5G WIRELESS COMMUNICATION *(YENİ NESİL 5G KABLOSUZ İLETİŞİM)*

5G is the key technology for next generation wireless communication and lies in exploring unused mmWave band. Today, academia and research groups are collaborating in different aspect of 5G systems to support enormous demands on data traffic. 5G will have various benefits which includes: wider coverage area, capacity enhancement, higher data rate, lower end-to-end connectivity and massive device connectivity [2]. 5G technology will help subscriber administration tools for the fast action, most likely, will present a large broadcasting data (in Gigabit), which can support more than 60,000 connections, support heterogeneous services (including private network) and provide uniform, uninterrupted, and consistent connectivity across the world [9]. 5G will be significantly quicker than 4G, supporting for greater productivity overall intelligent devices with a general download speed of 10.000 Mbps. Extra, with greater bandwidth, comes quicker download speeds and the capability to run more multiple mobile internet applications. However, 5G will require more cost to implement and during the latest mobile phones will apparently have it integrated, other handsets will be considered out of date [5]. Also, a strong wireless internet connection will depend on the number of devices connected to one channel.

3. SLOTTED BOW-TIE ANTENNA *(YARIKLI PAPYON ANTEN)*

The basic bow-tie antenna comprised of two identical triangle slots meet from the head in microstrip patch antenna design [10]. However, slotted bow-tie antenna is a bow-tie antenna model which depends on the requirements such as, the frequency or time domain usage. Slotted bow-tie antenna has always been attractive for implementation in many applications such as ground filtering radar, the mobile devices, bio-medical, and Wi-Fi applications [11–24]. In this paper, a new slotted bow-tie antenna is designed for frequency domain applications to increase the antenna bandwidth.

In the design case, two parameters are important: slot width and location. The general location of the feeding slot is in the middle of the antenna (between the two triangles), the novelty of this study is the change of the position of the feeding slot toward one of the triangles. The microstrip feeder is connected to one side of the antenna. The dimensions values (outside width, inside width, tri-length, substrate length, substrate width, and substrate thickness) of the antenna are optimized to reach the optimal design. Figure 1 depicts the geometry of a slotted bow-tie antenna.

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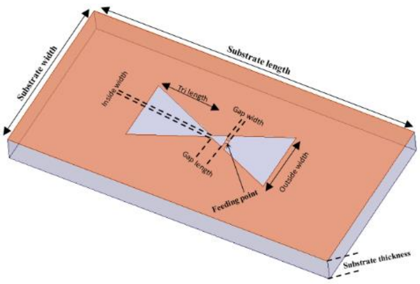

Figure 1. Slotted bow-tie antenna dimensions *(Yarıklı papyon anten boyutları)*

Optimal slot width and location can be obtained by performing a parametric study. The lack of closed form formula for the designs and the variety of the designs lead the designer in using optimization methods and algorithms. Therefore, numerical techniques remain another option for analysis and synthesis of the antennas. The Ansoft HFSS simulation program offers an optimization technique that can help with improving the solution result in parametric way. In parametric analysis and optimization of Ansoft HFSS, different design variable variations of the design process are considered and each of the design variable is computed to minimize the cost function. For the bow-tie antenna design problem, the design parameter and the variation of the design parameter are first defined and then performance characteristics with respect to the variations in design are analyzed. If the solution accuracy is not being satisfied, search region is restricted or enlarged and optimization starts again to minimize the cost function.

4. ANTENNA DESIGN *(ANTEN TASARIMI)*

To simplify the slotted bow-tie antenna structure and to improve the return loss given in [6], the slot shape is modified and optimized. The antenna dimensions are miniaturized to more than half. The new antenna geometry is shown in Figure 2.

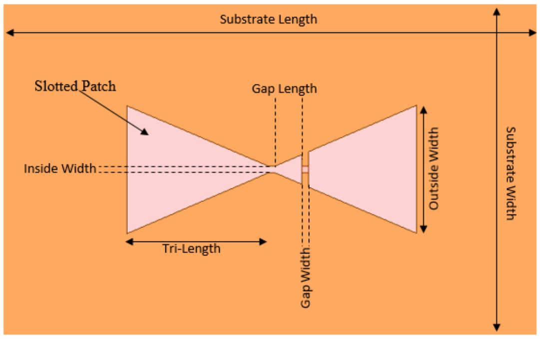

Figure 2. Proposed slotted bow-tie antenna geometry *(Önerilen yarıklı papyon anten geometrisi)*

The main modifications applied to this antenna geometry are replacing the slot position on the antenna surface and using 50Ω microstrip line to feed the antenna instead of the CPW feeding line. Because the CPW feeding structure usually gives a multi-band or tri-band frequency results and this can be another study to merge the ultra-wide band and mmWave band or maybe merge another different wide bands of radiation in one antenna, while in this paper the aim is to get a fix 28 GHz of frequency. The performance results of the proposed bow-tie antenna design are presented in the next section.

5. SIMULATION RESULTS AND DISCUSSION *(SİMÜLASYON SONUÇLARI VE TARTIŞMA)*

In this study, bow-tie antenna design in [6] is taken as reference and the frequency range of the reference design is 6–7 GHz. The dimensions of the reference antenna parameters are listed in Table 1 and the simulated return loss (S_{11}) of the reference antenna is shown in Figure 3.

The purpose this paper is to improve the reference antenna by using the slot technique for higher frequency bandwidth. The frequency region that looking for the design is 28 GHz. For this reason, the geometry of the proposed antenna is first optimized and then improved at various times until it reaches the optimal design.

Table 1. The dimensions of reference design [6] *(Referans tasarımın boyutları)*

The variables	Elements Values(mm)
Outside Width	11.5
Inside Width	0.5
Arm Length	16.75
Feeding Gap Length	2.7
Substrate Length	23
Substrate Width	37
Substrate Thickness	19.5

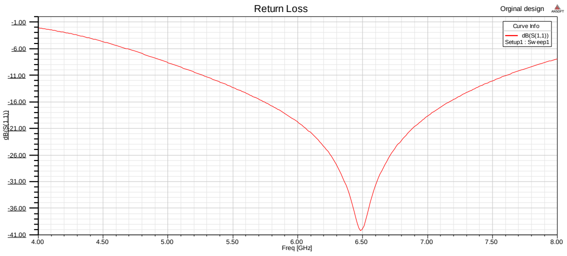

Figure 3. S_{11} plot of the reference design *(Referans tasarımın S_{11} grafiği)*

To get better return loss and antenna performance at 28 GHz, five different substrates with different dielectric constants (Arlon CuClad 217, Rogers RT/duroid 5880, FR4_epoxy, Neltec NH9294, and Nelco N4000-13) are studied separately. Each of five different substrates is also examined with two different substrate thicknesses of 1.57 mm and 0.635 mm which are commonly used in implementation. The most benefit of the bow-tie antenna is its omnidirectional radiation pattern. The slope and width of these parameters should be optimized to achieve a better return loss and voltage standing wave ratio (*VSWR*) results.

The first design starts by using the 1.57 mm of thickness for each kind of substrates with other dimensions trying to simulate at 28 GHz and then the antenna design is developed by reducing the thickness to 0.635 mm. The first optimized dimensions are listed in Table 2.

Table 2. The first dimensions of the proposed antenna *(Önerilen antenin ilk boyutları)*

The variables	Elements Values(mm)
Outside Width	2.9
Inside Width	0.2
Arm Length	3.1
Feeding Gap Width	0.2
Feeding Gap Length	0.6
Substrate Length	10
Substrate Width	10
Substrate Thickness	1.57

The dimensions shown in Table 2 are tested with the same substrates, but the results are unsatisfactory. The S_{11} solution results are critical at 28 GHz frequency as can be seen in Figure 4.

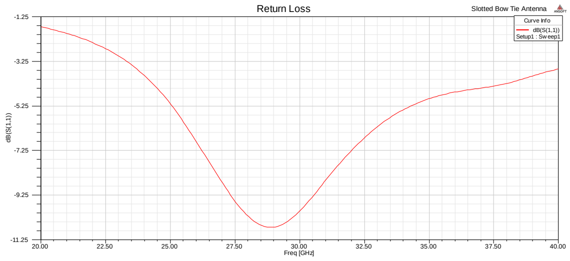

Figure 4. S_{11} plot of for the first optimized dimensions *(İlk eniyilenmiş boyutlar için S_{11} grafiği)*

The dimensions are optimized again using parametric optimization technique to improve the S_{11} result and the new dimensions are given in Table 3.

The new values show promising results with the five types of substrates. The simulation results of the five substrates for 1.57 mm substrate thickness are shown in Figures 5–9.

Using Arlon CuClad 217 substrate material with dielectric constant Ɛr = 2.17, the result is 32 GHz at –40 dB as shown in Figure 5.

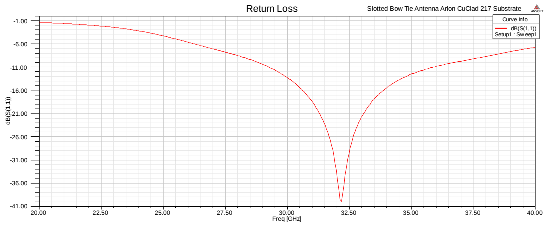

Figure 5. S_{11} result using Arlon CuClad substrate *(Arlon CuClad taban malzemesi için S_{11} sonucu)*

Table 3. The first optimization dimensions *(İlk eniyileme boyutları)*

The variables	Elements Values(mm)
Outside Width	1.9
Inside Width	0.1
Arm Length	2.1
Feeding Gap Width	0.1
Feeding Gap Length	0.5
Substrate Length	10
Substrate Width	10
Substrate Thickness	1.57

Using Rogers RT/duroid 5880 substrate material with Ɛr = 2.2. The result is 32 GHz at –38 dB as shown in Figure 5.

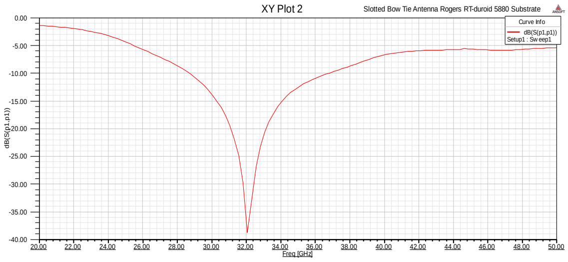

Figure 6. S_{11} result using Rogers RT/duroid 5880 substrate *(Rogers RT/duroid 5880 taban malzemesi için S_{11} sonucu)*

Using FR4_epoxy substrate material with Ɛr = 4.4 the result is 24.3 GHz at –54 dB as shown in Figure 7.

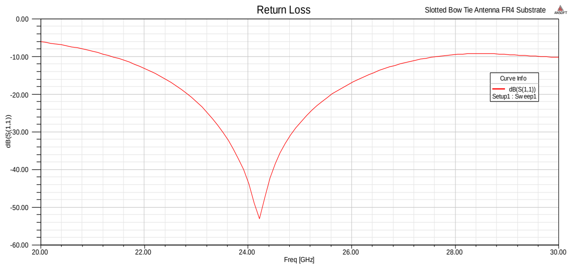

Figure 7. S_{11} result using FR4_epoxy substrate *(FR4_epoxy taban malzemesi için S_{11} sonucu)*

Using Neltec NH9294 substrate material with Ɛr = 2.94, the result is very close to the aim of this antenna at 28 GHz for 5G applications and millimeter waves bands. The result is 28.72 GHz at –33 dB as illustrated in Figure 8.

Using Nelco N4000-13 substrate material with Ɛr = 3.5, the result is 24.8 GHz at –45 dB as shown in Figure 9.

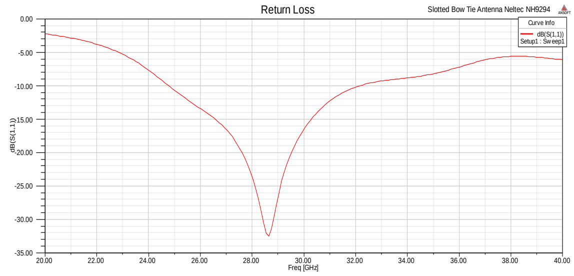

Figure 8. S_{11} result using Neltec substrate *(Neltec taban malzemesi için S_{11} sonucu)*

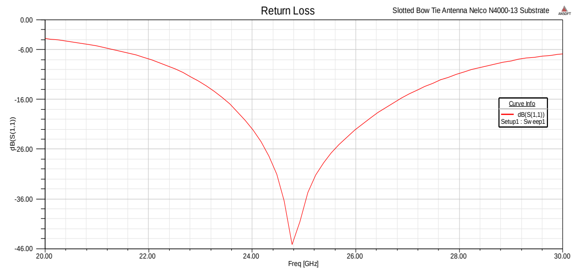

Figure 9. S_{11} result using Nelco substrate *(Nelco taban malzemesi için S_{11} sonucu)*

For 0.635 mm substrate thickness, the return loss (S_{11}) results of the five substrates are given in Figures 10–14, respectively. The S_{11} plot of Arlon CuClad 217 substrate material with Ɛr =2.17 is shown in Figure 10.

The S_{11} plot for Rogers RT/duroid 5880 substrate material with Ɛr = 2.2 is given in Figure 11.

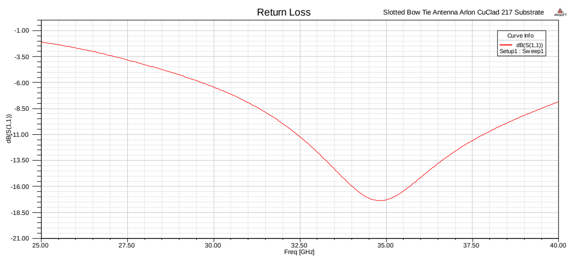

Figure 10. S_{11} result using Arlon CuClad substrate *(Arlon CuClad taban malzemesi için S_{11} sonucu)*

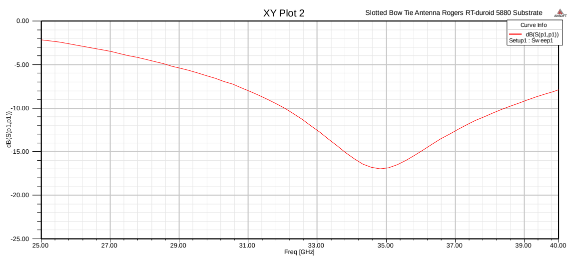

Figure 11. S_{11} result using Rogers substrate *(Rogers taban malzemesi için S_{11} sonucu)*

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The return loss result for FR4_epoxy substrate material with $\varepsilon_r = 4.4$ is shown in Figure 12.

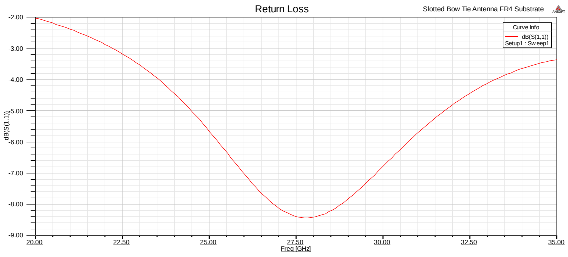


Figure 12. S_{11} result using FR4_epoxy substrate *(FR4_epoxy taban malzemesi için S_{11} sonucu)*

The return loss result for Neltec NH9294 substrate material with Ɛr = 2.94 is shown in Figure 13 which is very close to the aim of 28 GHz for 5G applications and millimeter waves bands.

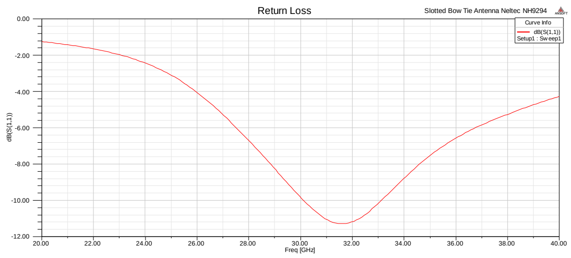


Figure 13. S_{11} result using Neltec substrate *(Neltec taban malzemesi için S_{11} sonucu)*

Using Nelco N4000-13 substrate material with Ɛr=3.5 the result is shown in Figure 14.

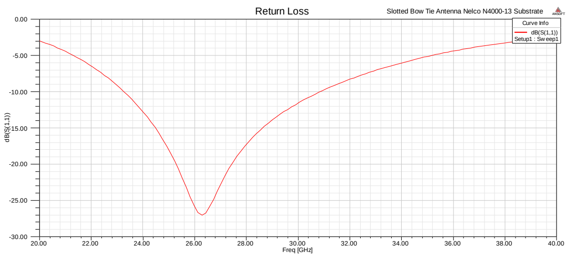


Figure 14. S_{11} result using Nelco N4000-13 substrate *(Nelco N4000-13 taban malzemesi için S_{11} sonucu)*

By changing the substrate thickness 1.57 mm to 0.635 mm while keeping the other dimensions without any change, as it is seen from the Figures 10–14, all the antennas improved their frequency but lost their gain except Nelco N4000-13. Also, from the results shown in Figures 5–14, Nelco substrate has the best result using 0.635 mm thickness. As a next step, the dimensions are re-optimized for Nelco substrate to obtain the closest value to 28 GHz frequency without exceeding the boundaries of the slotted bow-tie antenna shape.

The solutions are sensitive to the dimension values of the antenna. For this reason, changing the dimension values influences the solution strongly. By varying the substrate width three times, different S_{11} results are obtained and these are shown in Figure 15.

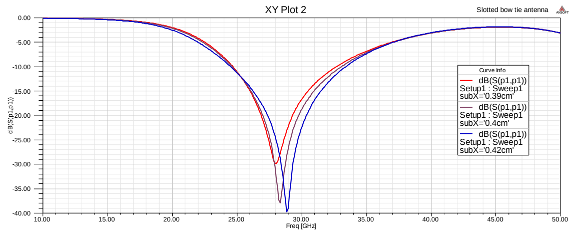


Figure 15. Three different S_{11} results with three different substrate widths *(Üç farklı taban malzemesi için üç farklı S_{11} sonucu)*

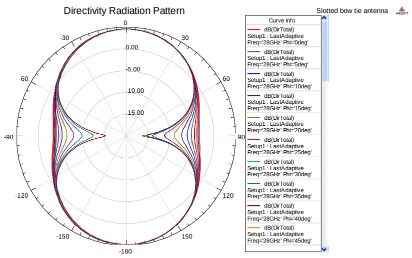
As Figure 15 demonstrates, changing the dimensions gives different results. So, the new designed dimensions that give a sharp 28 GHz with Nelco N4000-13 for 0.635 mm of thickness are listed in Table 4.

S_{11}, *VSWR*, radiation pattern, and Gain Total results for the optimal slotted bow-tie antenna design are given in Figures 16–19. From the Figures 16–19, S_{11} solution result of the proposed bow-tie antenna has a sharp 28 GHz at –30 dB, VSWR result is below 2, has a good directivity and radiation toward theta.

Table 4. The final dimension values obtained *(Elde edilen son boyut değerleri)*

The variables	**Elements Values(mm)**
Outside Width	1.9
Inside Width	0.1
Arm Length	2.1
Feeding Gap Width	0.1
Feeding Gap Length	0.5
Substrate Length	3.9
Substrate Width	6
Substrate Thickness	0.635

Especially, as can be seen from Figure 18, the Bow-tie antenna has an omni directivity in different angles at 28 GHz of gain. Figure 19 is given to explain the Gain Total. In electromagnetics, an antenna's power gain which combines the antenna's directivity



and electrical efficiency is a key performance number and describes how well the antenna converts input power into radio waves headed in a specified direction. From Figure 19, it is seen that all the power gain directed toward Theta which means an optimal gain with optimal design.

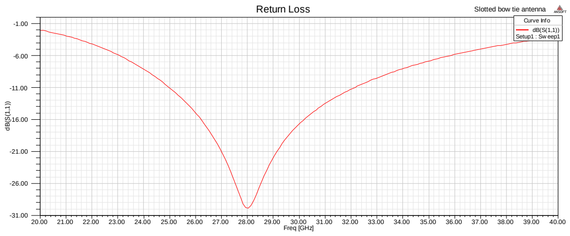


Figure 16. S_{11} result for the optimal design *(Optimal tasarımın S_{11} sonucu)*

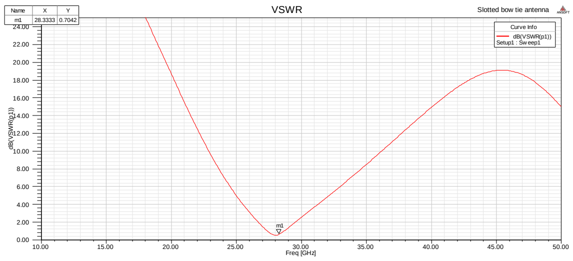


Figure 17. *VSWR* result for the optimal design *(Optimal tasarımın duran dalga voltaj oran sonucu)*

Figure 18. Simulated radiation pattern for the optimal design *(Optimal tasarımın ışıma diyagramı)*

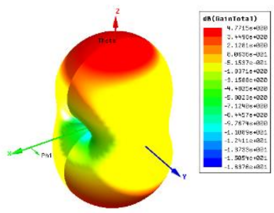


Figure 19. Gain Total result for the optimal design *(Optimal tasarımın toplam kazanç sonucu)*

6. CONCLUSION *(SONUÇ)*

A novel slotted bow-tie antenna is proposed in this paper. The frequency band for the design of the proposed antenna is selected as 28 GHz which is candidate for next generation 5G devices and applications. In the designs, various substrate materials such as Arlon CuClad 217, Rogers RT/duroid 5880, FR4_epoxy, Neltec NH9294, and Nelco N4000-13 have been used, and their performances to reach the optimal result have been investigated. Also, each of the substrate has been analyzed for two different thickness values.

It is worth emphasizing that among the substrates, the Nelco substrate material with substrate thickness of 0.635 mm shows the best choice to reach the optimal solution which has sharp 28 GHz. The dimensions values of the antenna design with Nelco substrate material are then optimized again. Finally, the proposed antenna has good performances operating at 28 GHz that achieves a return loss of –30 dB, VSWR of below 2, a good directivity, and the radiation pattern of the proposed antenna has a good matching over the required frequency. Proposed design can find applications in 5G systems. Future work will be to optimize the proposed antenna by using several meta-heuristic techniques. Also, the proposed antenna will be fabricated and experimentally verified.

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