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Use of Microstrip Antennas in Aerospace Applications: L5 Band Satellite Communication Example

Özgür DÜNDAR[1] Mustafa Furkan ATEŞ[2*]

[1] Necmettin Erbakan Üniversitesi, Havacılık ve Uzay Bilimleri Fakültesi, Havacılık ve Uzay Mühendisliği, Konya, Türkiye

[2] Maverik Dream Works, Konya, Türkiye

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ABSTRACT

Today, microstrip antennas are preferred in many aerospace applications such as high-performance vehicles, aircraft, military aircraft, Unmanned Aerial Vehicles (UAVs), spacecraft, radar systems, satellite and missile applications. In this study, the use of microstrip patch antennas in the aerospace industry and especially in global positioning systems (GPS) has been investigated and a sample microstrip patch antenna design has been realized in the GPS L5 security band. The designed antenna with high gain and circular polarization is simulated with High Frequency Structural Simulator (HFSS) and the results are analyzed. Numerical analysis of the simulations showed that at the center frequency of 1176 MHz, the S11 value was -38.85 dB, the bandwidth was 54 MHz and the gain was 6.07 dBm. As a result of these values, it is concluded that it can be used in the global positioning L5 security band.

Havacılık Uygulamalarında Mikroşerit Anten Kullanmı: L5 Band Uydu Haberleşme Örneği

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ÖZET

Günümüzde mikroşerit antenler, yüksek performans gerektiren araçlarda, uçaklarda, askeri uçaklarda, İnsansız Hava Araçlarında (İHA), uzay araçlarında, radar sistemlerinde, uydu ve füze uygulamaları gibi pek çok havacılık alanında tercih edilmektedirler. Bu çalışmada, Mikro şerit yama antenlerin havacılık sektöründe kullanım alanları ve özellikle küresel konumlama sistemlerinde (GPS- Global Positioning System) kullanımı araştırılmış ve GPS L5 güvenlik bandında örnek bir mikroşerit yama anten tasarımı gerçekleştirilmiştir. Tasarımı gerçekleştirilen yüksek kazançlı ve dairesel polarizasyonlu anten High Frequency Structural Simulator (HFSS) program ile simüle edilerek sonuçlar incelenmiştir. Yapılan simülasyonların nümerik analizinde neticesinde 1176 MHz merkez frekansında, S11 değerinin -38.85 dB olan, band genişliğinin 54 MHz ve kazancının ise 6.07 dBm olduğu görülmüştür. Elde edilen bu değerler neticesinde küresel konum belirleme L5 güvenlik bandında kullanılabileceği sonucuna varılmıştır.

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***Sorumlu Yazar:** Özgür DÜNDAR, *odundar@erbakan.edu.tr*

GİRİŞ

Communication can be broadly defined as the transfer of information as electromagnetic energy from one point to another. Information transfer within the communication system is achieved by modulating the information into an electromagnetic wave, which acts as the carrier of the information signal (Balanis, 2005). When the modulated carrier reaches the desired destination, the original information signal is demodulated and re-acquired. In today's modern communication systems, antennas are the most important components of communication links (Karaaslan et al., 2013). Antennas are especially indispensable elements of aviation communication systems.

In today's communication technologies, Microstrip Patch Antennas are often preferred in outdoor applications due to their superior characteristics. Furthermore, because of their benefits—including low cost, high performance, ease of installation and production—microstrip patch antennas have gained popularity among microwave antennas. These advantages can be found in a variety of aerospace fields, including automobiles, military aircraft, spacecraft, Unmanned Aerial Vehicles (UAV), radar systems, satellites, and missile applications that demand high performance (Balanis, 2005). This is because they provide a thin planar configuration that can be very easily assembled and integrated without causing drag for vehicle surfaces such as aircraft or missiles. The ease of fabrication using printed circuit boards, easy assembly of the antenna to the rest of the circuit board, and the flexibility to add hardware to make such active antennas make microstrip antennas a special and preferred choice for any aircraft or missile application, given their aerodynamic properties (URL 1).

The use of internet in the cabin during flight is a new and developing technology today, and its use in the aviation industry is becoming more popular and available day by day. Especially in air travel, people want to be able to use their mobile devices. There are many studies, examples and productions that allow passengers to use their mobile phones in the aircraft.

In their study in 2023, Dündar & Koyuncu designed a microstrip patch antenna that can be integrated into mobile personal devices such as mobile phones, tablets, laptops, etc. and can communicate simultaneously with both 4G (LTE) and 2.4 GHz WiFi wireless communication bands during the journey. As a result of the design and simulations with the HFSS program, it was observed that with a gain of 3.085 dBm at the center frequency of 2.5720 GHz and a bandwidth of 2.453 - 2.703 MHz, passengers can communicate with both the 2600 MHz FDD and TDD band used for 4G - LTE mobile network communication and 2.4 GHz WiFi channels 9-14 during in-flight travel (Dündar & Koyuncu, 2023).

There are also studies on next generation 5G communication for in-flight internet use. Dündar et al. developed a microstrip patch antenna system in their 2021 study that may be utilized as an access point on Airbus A321 aircraft and offers internet connectivity in the 5GHz band. Additionally, a simulation of electromagnetic field emission and the installation of the intended antennas inside the aircraft cabin were done. The IEEE 802.11 ac/ax standard was followed in the design of the microstrip antennas. Using FR-4 dielectric material, 4 antennas and 5300 MHz (CH 60) center frequency are used to deliver 5GHz WiFi internet service. The intended antennas are utilized as access points and have fiber connections between them. The HFSS simulation tool was used to simulate the electromagnetic field emission of the antennas installed within the cabin (Dündar et al., 2021).

Sreejith et al. carried out antenna design studies in the Ku band range for use in airline aircraft. In order to use the system more effectively, they designed a circular microstrip array antenna with dual polarization. It is also aimed to minimize the negative impact on aircraft aerodynamics by creating the antenna design in a foldable structure. RO4003C (ε_r=3.55) was selected as the patch layer of the 8x8 antenna. Simulation results show that the antenna has a bandwidth of 750 MHz and inter-port isolation is better than 25dB (Sreejith et al., 2022).

In 2023, Banerjee and colleagues from the University of San Diego designed a microstrip array antenna for dual-band communication in the K-/Ka band frequency range. This antenna can radiate in the frequency range of 22.55-23.55 GHz and 25.5-27.5 GHz. Similar to the other study, Banerjee opted for an 8x8 type antenna design. The antenna has a gain of 21 dBi at 23.05 GHz and 22.3 dBi at 26.5 GHz, according to simulation studies (Banerjee et al., 2023).

In another study, Martinez et al. developed an 8x8 microstrip array antenna system at Ku band frequency. The distinguishing feature of this study is that the antenna structure is bendable. The most important reason for choosing this type of structural material is that the antenna should not have a negative aerodynamic effect when the antenna is mounted on the airplane. The designed antenna was also manufactured and tested with the bendable structure. In addition, the simulation program was used to place the antenna on the aircraft model and analyze the radiation pattern (Martinez-Vazquez et al., 2021).

Another issue that needs to be investigated in phased array antenna or moving antenna systems is the ability of antenna systems placed on vehicles such as airplanes, automobiles, ships, etc. to track the satellite. In this regard, in moving antenna systems, the antenna platform should be motorized, and satellite tracking should be realized while the vehicles are in motion with motor control with reference to the satellite tracking signal. In this type of antenna systems, signal level and antenna pattern changes with antenna offset angle are analyzed (Tsuji et al., 2014).

In the paper published by Zhang et al. we can examine the design of a 4x4 phased array antenna at Ka band frequency. In this study, a system was built that has a gain of 6 dBi at 35 GHz. It is evident that the aperture microstrip antenna logic is used to realize the design and that the antenna system is constructed using microstrip feed. According to (Zhang et al., 2016), this indicates that the antenna radiation produces better outcomes, with an S_{11} value of -35 dB.

Lightweight and aerodynamic, microstrip antennas are used in aircraft radar systems. In this way, they can increase safety measures by monitoring the aircraft's surroundings. Wide coverage can be achieved by placing microstrip antenna arrays on some low-profile curved surfaces. These surfaces can be assembled into shapes that match the fuselage, wing or skeleton of an aircraft or missile, thus increasing the use of this type of antenna for many applications. The single curved surface can also be used as an approximate shape that fits into the aircraft wing, fuselage or outer compartments. Such a design also prevents detection by the enemy in all defense applications, including radar and communication systems (URL 2).

Chen et al. created a microstrip beam array antenna for a missile in their 2018 work. The S11 reflection parameter is 1GHz bandwidth at 34.02–35.05 GHz, and the antenna center frequency is 34.5 GHz. With a diameter of only 16 mm, the antenna is 50% smaller than a typical array antenna. The angle between the antenna beam angle and the normal is 35°, and the antenna beamwidth is 36°. Within the 36° to 72° angle of incidence of the fuze, the antenna's main beam can be vertically illuminated towards the ground target.

Geolocation has been one of the most important needs from past to present. While different primitive methods were used in the past, the most up-to-date Global Satellite Positioning Systems (GNSS) are used today. GNSS allows us to determine the latitude, longitude, altitude, speed and time information of any point in the world with a certain accuracy by using satellites positioned globally on the earth orbit.

GNSS is mainly based on satellites. GNSS receivers take into account the arrival time of the position orbit signal from the satellite and calculate the distance to the satellite and the delay time of the signal. The signal from a single satellite is not sufficient for position determination. If signals from at least 3 satellites are received to determine the position, the GNSS receiver can determine the position on the earth. However, since the satellite and GNSS receiver clocks are not synchronized, it is necessary to receive time information from another satellite.

Global positioning systems (GPS) have a wide range of uses but can be categorized under 2 main headings. These are civilian and military uses. In military use, there are many areas of use such as intercontinental missiles, positioning in manned and unmanned land, air (UAV, UCAV) and sea vehicles. Civilian uses are very wide and include GPS aircraft tracking, aviation, intelligent navigation systems, autonomous vehicles, cartography.

The electromagnetic waves sent by GPS satellites undergo bending as they pass through the atmosphere. Since the L1 and L2 bands have different wavelengths, they are diffracted at different rates. By calculating the difference and reducing the effect of atmospheric distortion, much more precise location information can be obtained. While an accuracy of 98 m can be achieved by using only the L1 band, it is possible to achieve an accuracy of less than 1 m with the joint use of the L1 and L2 bands. As part of the modernization of GPS, a new frequency allocation was made for GPS in 2009. This signal, called L5, started to be broadcast over Block IIF satellites in 2009, mainly for the purpose of safe navigation of aircraft (Erdemir, S., 2013).

In GPS measurements, electromagnetic waves are used to transmit data from satellites to users. Each GPS satellite has three basic frequencies, L1 (1575.42 MHz), L2 (1227.60 MHz) and L5 (1176.45 MHz) for civilian use. Microstrip patch antennas with small size, high transmittance interlayer and circular polarization are a favorite choice for GPSs and are widely used in positioning systems. Single band, two band and three band microstrip patch antenna designs are available in the literature.

In 2002, Chih-Ming SU and Kin-Lu WONG designed a dual-band coaxial line fed microstrip patch antenna using FR-4 dielectric material operating in L1 and L2 bands. They obtained bandwidths of 15 MHz and 17 MHz and gains of 1.5 and 4.5 dBi, respectively (Su & Wong, 2002).

In 2004, Xiang-Fei PENG et al. designed a compact dual band antenna. The antenna designed in this study is stacked, coaxially fed and operates in L1 and L2 bands. The antenna was designed and analyzed with Ansoft HFSS software. They used a dielectric material with a coefficient of 12 for the bottom layer and 9.2 for the top layer. As a result of the analysis, they obtained bandwidth values of 20 MHz, 16 MHz and gain values of 2.4 dBi and 4.5 dBi for L1 and L2 bands, respectively (Peng et al., 2005).

Onur AKTAŞ, in 2019, designed, analyzed and produced a GNSS antenna that can operate in the L1 band and a GPS antenna that can operate in the L1 band. They designed the antenna with the CST program. They used RO3003 as dielectric material. By increasing the thickness of the dielectric layer, they achieved a bandwidth of 70 MHz in the L1 band (Aktaş, 2019).

In Cemal ŞEN's study in 2020; they designed stacked microstrip antennas operating in L1, L2 and L5 bands. The antennas were optimized using the MWS module of the CST program. They designed 6 designs, one single layer microstrip antenna for each band, one double layer microstrip antenna operating simultaneously in L1 and L2 bands and 2 stacked microstrip antennas operating simultaneously in L1, L2 and L5 bands. The designed antennas are fed by coaxial line. . In this antenna, they obtained a gain of 3.28 dB, 2.49 dB and a bandwidth of 41 Mhz and 53.4 Mhz, respectively. They used FR-4 dielectric material for the antenna operating in L1, L2 and L5 bands. The antenna gains were found to be 1.59 dB, 2.57 dB and 1.615 dB, respectively (Şen, 2020).

In 2020, Mishra et al. realized a circularly polarized planar antenna covering the global positioning system L1, L2 and L5 bands. An internal feed line excites an elliptical patch, which makes up the antenna. In order to achieve dual-band response covering the L1, L2, and L5 bands, two concentric ring slots are etched into the ground plane. To achieve circular polarization, load two slots on the elliptical patch and integrate a quarter-wavelength spring with an internal feed. To cover the GPS L5 band, the quarter-wavelength spring also broadens the lower resonant band's impedance bandwidth. The antenna also meets the criterion of 1 dBi gain flatness of the GPS antenna. A prototype of the antenna has been fabricated and the experimental results are in good agreement with the simulated results (Mishra et al., 2020).

METHOD

Microstrip Patch Antenna Design

Because of their small size, light weight, and ease of integration with portable devices, planar circularly polarized (CP) antennas are widely used in modern wireless communication systems, biomedical equipment, radio frequency identification (RFID) devices, and satellite positioning systems. According to (Kumar et al., 2017), the CP antenna offers steering flexibility between the transmitter and receiver in addition to mitigating the effects of multipath fading. Widely used navigation systems such as BeiDou Navigation Satellite System (BDS), Galileo, Global Positioning System (GPS), Global Navigation Satellite System, and Quasi-Zenith Satellite System use L-band right-handed circular polarization (RHCP) antennas for their operation (Babakhani et al., 2017). The L band (1-2 GHz) is divided into five sub-bands: L1 (1575.42 MHz), L2 (1227.6 MHz), L3 (1381.05 MHz), L4 (1379.913 MHz) and L5 (1176.45 MHz) for various operations of GPS (Mishra et al., 2020).

In April 2014, the US Air Force decided to broadcast civil navigation (CNAV) messages on L2C and L5 signals. For this purpose, some updates were made in the GPS control section (URL 3).

L5 is a third civil GPS signal designed to meet the demanding requirements for life safety and other high-performance applications. The frequency of the L5 signal is 1176 MHz. L5 is broadcast in a radio band reserved exclusively for aviation safety services. In the future, it is planned to use L5 together with L1 C/A. With the use of L5, it is aimed to increase the accuracy of the system as well as the capacity utilization and fuel efficiency on airlines, railways, maritime roads and highways (Koca & Ceylan, 2018).

The designed antenna has been realized in the L5 band at the center frequency of 1176 MHz and within the scope of the Computer Aided MVA Design course. The design started with the selection of the substrate material and FR4 material was chosen for its easy accessibility and low cost. The relative dielectric constant εr=4.4, the loss tangent tanδ=0.02 and the dielectric base thickness h=1.6 mm was chosen for high bandwidth. In order to calculate the antenna dimensions in the following steps, the constant of the dielectric material will be calculated using the material thickness. The patch width is denoted by W and is calculated using Equation 1 as follows.

$$W = \frac{c_0}{2f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}} \quad (1)$$

In the related equation, c0 is the speed of light and fc is the center frequency. For a center frequency of fc=1176 MHz, the antenna width W=77.625 mm. According to these values; since the condition W/h≥1 is satisfied, the effective dielectric constant εreff is calculated using Equation 2.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{W}\right]^{-1/2} \quad (2)$$

For ε_r=4.4, h=1.6 mm and W=77.625 mm; ε_{reff}=4.222 was obtained.

$$L_{eff} = \frac{c_0}{2f_c\sqrt{\varepsilon_{reff}}} \quad (3)$$

When the effective length L_{eff} is calculated with the formula given in Equation 3 and using the values $c_0 = 3x10^8\ m/s$, ε_{reff}=4.222 and . f_c=1176 MHz; L_{eff}=63.563 mm.

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

$$L = \frac{c_0}{2f_c\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (5)$$

When calculating the microstrip antenna patch length L and fringe value ΔL, L=60.550 mm from Equation 5 using the values of W, c_0, ε_{reff}, f_c, L_{eff} and h found above. As a result of all the calculations, the patch dimensions were determined as W=77.625 mm and L=62.075 mm.

Table 1
Antenna Parameters

Parameter	Value
Dielectric Material	FR-4
f_c	$1176\ MHz$
c_0	$3x10^8\ m/s$
ε_r	4.4
W	$77.625\ mm$
L	$60.550\ mm$
ε_{reff}	4.222
L_{eff}	$63.563\ mm$

The physical parameter values of the designed antenna are summarized in Table 1.

RESULTS

According to the physical parameters of the antenna given in Table 1, the coaxial fed patch antenna design was simulated with the HFSS simulation program and numerical analysis was performed. Images of the designed microstrip patch antenna are given in Figure 1.

When the simulations of the designed antenna made with the HFSS Program are examined, it is seen that the center frequency in the S11 graph is 1176 MHz and the return loss S11 value is -38.85 dB. The related graph is shown in Figure 2. The region where the S11 parameter, which is the relative expression of the reflection coefficient or return loss, is below -10 dB is considered as the efficient radiation region for antennas. When we look at the area below the -10 dB reference value, it is seen that an antenna with a bandwidth of 54 MHz was designed.

On the other hand, when the gain graph of the designed microstrip antenna in Figure 3 is examined, both the radiation pattern image is seen and the gain of 6.07 dBm is simulated as a three-neck image by the HFSS program.

Figure 1
General View of the Designed Microstrip Antenna

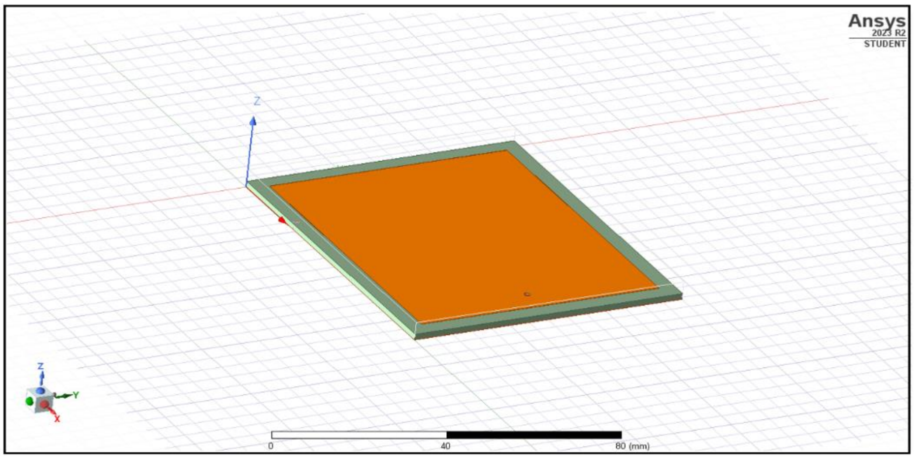


Figure 2
Microstrip Patch Antenna S11 Parameter Graph

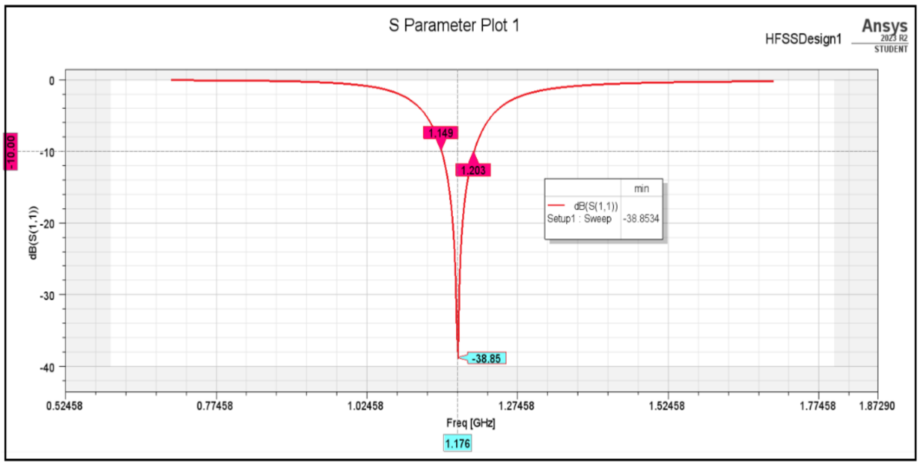
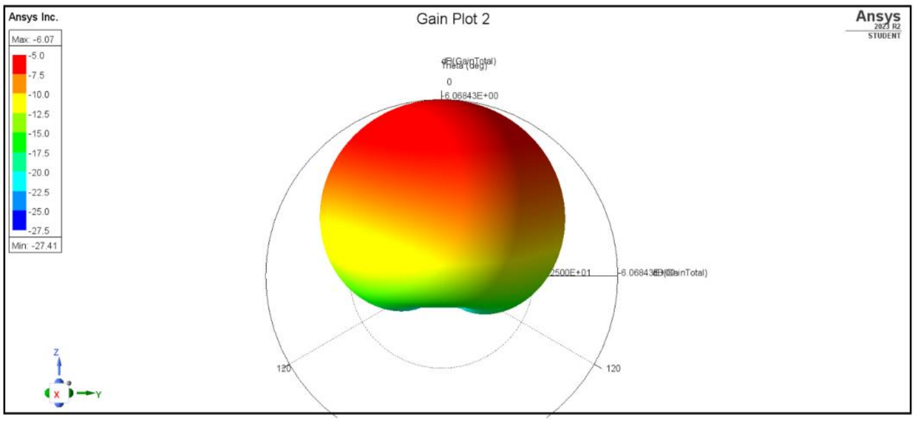


Figure 3
Microstrip Patch Antenna Gain Graph



CONCLUSION

The aim of this study is to design a high gain microstrip patch antenna for use in the L5 GPS band, which is broadcast in the radio band reserved for aviation security services.

As a result of the design and numerical analysis of the simulations made with the HFSS program, it was seen that at the center frequency of 1176 MHz, the S11 value was -38.85 dB, the bandwidth was 54 MHz and the gain was 6.07 dBm. As a result of these values, it is concluded that it can be used in the global positioning L5 security band.

Since this study was carried out as a student project within the scope of Computerized Microstrip Antenna Design course, an L5 band micro strip antenna was designed as an example. The main objective is to design a tri-band micro strip antenna that covers L1, L2 and L5 bands simultaneously. This study is a preliminary work towards this goal. Triple band is set as the target for further studies.

Ethics Committee Approval

This study did not use human or animal subjects that require ethics committee approval. The research was conducted on publicly available data sets, literature reviews or theoretical analyses. In accordance with ethical rules, academic integrity and scientific ethics were fully complied with at every stage of the research process. Therefore, ethics committee approval was not required.

Author Contributions

Research Design (CRediT 1) Özgür DÜNDAR (%60) – Mustafa Furkan ATEŞ (%40)

Data Collection (CRediT 2) Özgür DÜNDAR (%50) – Mustafa Furkan ATEŞ (%50)

Research - Data Analysis - Validation (CRediT 3-4-6-11) Özgür DÜNDAR (%60) – Mustafa Furkan ATEŞ (%40)

Writing the Article (CRediT 12-13) Özgür DÜNDAR (%60) – Mustafa Furkan ATEŞ (%40)

Revision and Improvement of the Text (CRediT 14) Özgür DÜNDAR (%50) – Mustafa Furkan ATEŞ (%50)

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Conflict of Interest

There is no conflict of interest between the authors.

Sustainable Development Goals (SDGs)

Sustainable Development Goals: 11 Sustainable Cities and Communities

Sustainable Development Goals: 15 Terrestrial Life

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