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A Novel Tooth Slot Integrated Microstrip Patch Antenna for IoT and Wireless Systems

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ABSTRACT :

A technique to design a wideband, low-profile microstrip patch antenna is presented in this paper. The proposed antenna features a tooth-like slot on the patch and uses an inset-fed microstrip line. By exciting two resonant modes, the design achieves bandwidth enhancement while maintaining a compact profile, with a total substrate thickness of only $0.033\lambda_0$. A single antenna element and a 2×2 array operating at 10 GHz were fabricated using standard PCB processes. The single-element prototype achieves a -10 dB return loss bandwidth of 10.5% and a peak gain of 9.4 dBi. The 2×2 array demonstrates a slightly wider bandwidth of 10.6% and a gain of 15.1 dBi. The antenna design offers advantages including low profile, low fabrication cost, ease of integration with planar circuits, and excellent performance in terms of gain and bandwidth, making it suitable for high-frequency wireless applications.

Key words: Tooth slot, Wideband, Antenna array, Dual-mode excitation

1. Introduction

Microstrip patch antennas have gained widespread popularity in modern wireless communication systems due to their advantages such as low profile, light weight, ease of fabrication, and compatibility with printed circuit board (PCB) technology. However, conventional microstrip patch antennas suffer from narrow bandwidth and limited gain, which can restrict their use in broadband and high-frequency applications, such as in radar systems, satellite communication, and emerging Internet of Things (IoT) networks.

To address the bandwidth limitation, various techniques have been explored, including the use of slots, parasitic elements, stacked patches, and electromagnetic bandgap (EBG) structures. Among these, introducing slots into the radiating patch is a simple yet effective method to excite multiple resonant modes and thereby enhance the impedance bandwidth. Additionally, compact and low-profile antenna designs are increasingly in demand for integration into modern compact wireless devices.

In this work, we propose a novel microstrip patch antenna with a *tooth-shaped slot* and an *inset-fed microstrip line*, aimed at achieving wide impedance bandwidth and high gain while maintaining a low-profile structure. The proposed antenna operates at 10 GHz and is fabricated using a standard PCB process. By exciting two closely spaced resonant modes, the design achieves over 10% bandwidth for a -10 dB return loss, with a profile of only $0.033\lambda_0$.

Furthermore, a 2×2 antenna array is developed based on the same element, which demonstrates improved gain and slightly broader bandwidth. The design offers a promising solution for applications requiring compact, wideband, and high-gain antennas with low manufacturing cost and easy integration into planar RF systems.

2. Literature survey

Microstrip patch antennas have been extensively studied due to their compact size, ease of fabrication, and suitability for planar and conformal applications. However, their inherently narrow bandwidth and moderate gain limit their use in broadband wireless systems. Numerous techniques have been proposed to overcome these limitations.

In [1] by Balonis, a slot-loaded patch antenna was introduced to improve bandwidth by exciting multiple resonant modes. The introduction of U-shaped and E-shaped slots in the radiating patch has shown effectiveness in broadening impedance bandwidth [2], [3]. While these methods enhance bandwidth, they often lead to increased surface area or complexity in the feed network.

Stacked patch structures and the use of parasitic elements were discussed in [4] and [5], which provided high gain and bandwidth improvement but resulted in increased antenna profile and fabrication complexity. Similarly, electromagnetic bandgap (EBG) and defected ground structures (DGS) have been employed to reduce mutual coupling and improve radiation performance [6], but at the cost of increased design and integration challenges.

Inset-fed microstrip designs have also gained attention for their simplicity and impedance matching capability. In [7], inset feeding was combined with slot techniques to achieve a moderate bandwidth improvement while keeping the structure compact.

Mohammad et al. [8] introduces a truncated patch with capacitive feed and a central slot to excite multiple resonant modes (TM_{10}, TM_{02}, TM_{12}), achieving a broad impedance bandwidth from 5 to 12.5 GHz. The design maintains a compact profile with a substrate thickness of $0.033\lambda_0$.

Tapas et al.[9] Presents an 'S'-shaped slotted ground microstrip patch antenna operating from 9.12 GHz to 31.67 GHz. Incorporating a Frequency Selective Surface (FSS) beneath the antenna enhances the peak gain from 3.9 dBi to 9.4 dBi, suitable for high-frequency wireless applications.

Jiawang [10] proposes a slot-monopole hybrid antenna design that achieves a 76.5% impedance bandwidth (20–44.78 GHz) and a peak gain of 6.1 dBi. The design is cost-effective and robust against substrate losses, making it ideal for millimeter-wave vehicle communication systems.

Despite these advancements, a low-profile, wideband, and high-gain solution that can be easily fabricated using PCB technology remains desirable. The proposed tooth-slot microstrip patch antenna in this paper addresses these challenges by introducing a novel slot geometry that excites dual resonant modes, leading to bandwidth enhancement without compromising the profile or manufacturability.

3. Proposed structure

Tooth Slot Loading Technique incorporate small teeth or slots along the antenna edges (like a slot dipole or patch antenna). These “teeth” alter the current path, increasing effective electrical length.This method improves bandwidth or miniaturizes the antenna.Fractal shaped tooth slots (e.g., Koch, Sierpinski) in patch or slot antennas can also be incorporated.This method enhances multi-band behavior and improves impedance bandwidth. This is given in Figure 1.

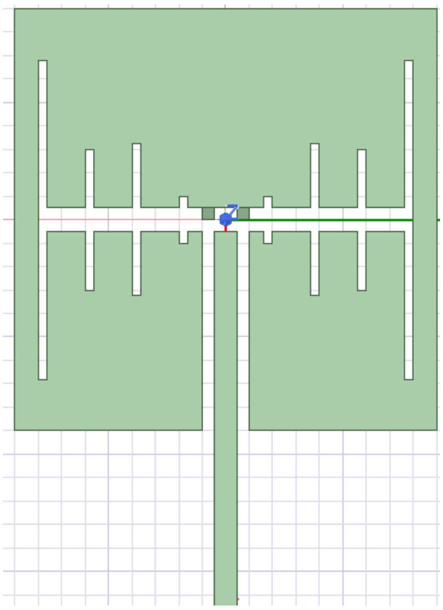


Figure 1: Simple tooth slot antenna

The same structure is arranged in array configuration as 2x2 as shown in Figure 2. Arrays of slot antennas with tooth-shaped slots for increased directivity or gain. *Linear, planar, or conformal arrays can be inserted* based on application. The spacing between elements typically is about 0.5 to 0.7λ. In this project it is fixed as 0.55 λ. To avoid grating lobes,adjusting spacing can fine-tune the beam width and side lobe levels.

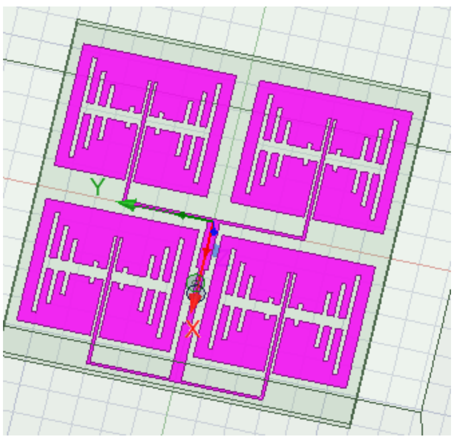


Figure 2: 2x2 structure of tooth slot antenna

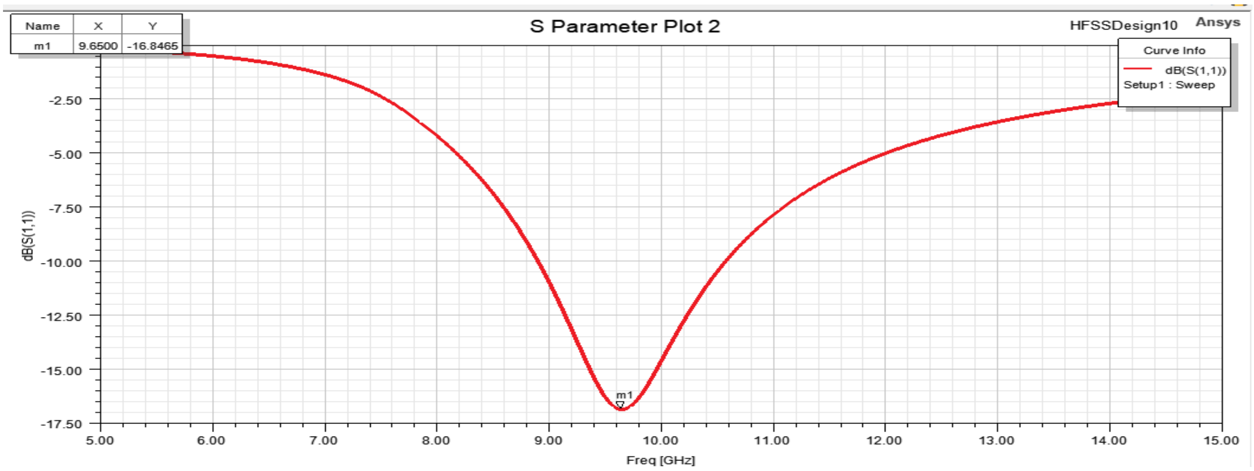
4. Results and Discussion

4.1 Return loss:

Return Loss (RL) is a measure of ***how much power is reflected back*** from the antenna input (typically at the feed point) due to ***impedance mismatch***. It tells you how efficiently the antenna accepts the power from the transmitter.
Return Loss (dB) = $-20 \log_{10}|\Gamma|$

Where:

- Γ is the ***reflection coefficient*** (ratio of reflected voltage to incident voltage).
- RL is in ***decibels (dB)***.



4.2 VSWR

VSWR (Voltage Standing Wave Ratio) is a measure of how efficiently radio-frequency power is transmitted from a power source (like a transmitter) through a transmission line (like a coaxial cable) into a load (like an antenna).

VSWR=1+|Γ|/1−|Γ|

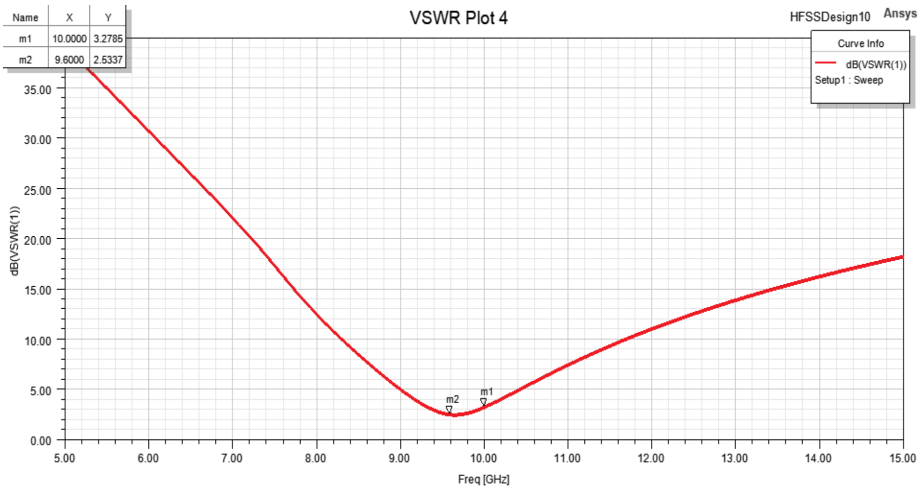


Figure 3: VSWR

4.3 Radiation pattern

2D radiation pattern
There are four types of radiation pattern. Which are E plane and H plane Azimuth and Elevation plane.

Table 1: Radiation pattern angles

Plane	Description	Typical Cut
E-Plane	Plane of the electric field	For a dipole: vertical plane (ϕ = 0°)
H-Plane	Plane of the magnetic field	For a dipole: horizontal plane (θ = 90°)
Azimuth	Horizontal plane (constant elevation, usually θ = 90°)	Common for omnidirectional patterns
Elevation	Vertical plane (constant azimuth, usually ϕ = 0°)	Shows how signal rises or falls

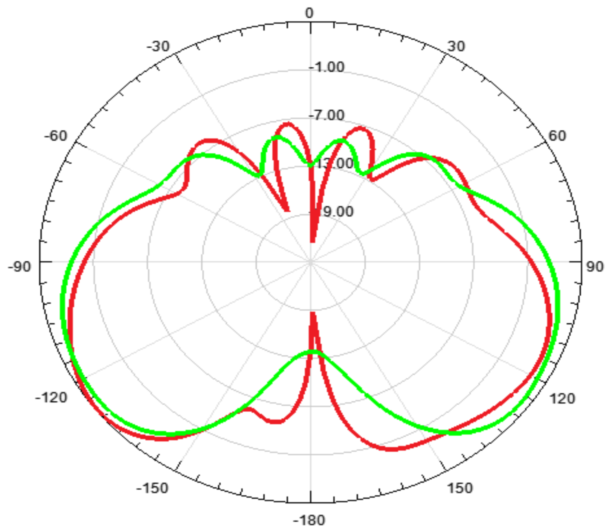


Figure 4: 2D radiation pattern

3D radiation pattern

Radiation pattern uses *spherical coordinates*:

- *θ (theta):* Elevation angle (0° to 180°)
- *φ (phi):* Azimuth angle (0° to 360°)

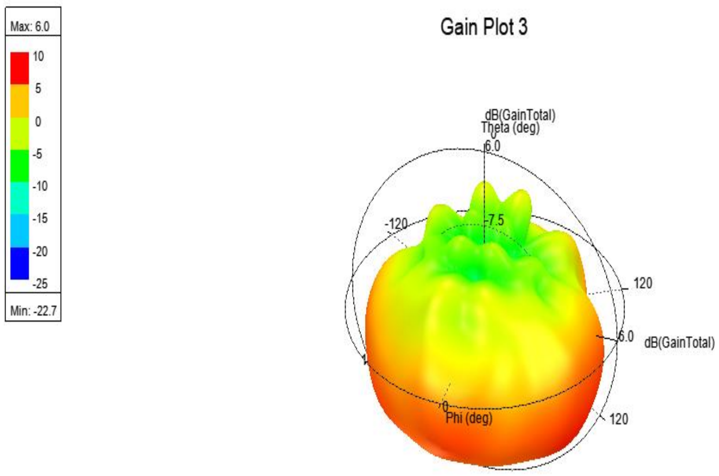


Figure 5: 3D radiation pattern

5. Conclusion

The tooth-slot 2x2 array antenna demonstrates a promising approach to achieving enhanced antenna performance through the integration of tooth-shaped perturbations on slot elements combined in an array configuration. The introduction of teeth along the slot edges effectively modifies the current distribution, resulting in improved bandwidth and gain compared to conventional slot antennas.By arranging these modified slot elements in a 2x2 planar array, the antenna achieves increased directivity and higher overall gain due to constructive interference among elements. The array configuration allows for beam shaping and improved radiation efficiency while maintaining a compact and low-profile structure. This design approach balances complexity and performance, making the tooth-slot 2x2 array antenna suitable for modern wireless communication systems, radar, and sensing applications where compact size, high gain, and reliable impedance matching are critical.

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