Supplementary Information (SI) for Journal of Materials Chemistry C.

Supporting Information

Plasma-Activated Copper-Alkanolamine Precursor Paste for Printed Flexible Antenna: Formulation, Mechanism, and Performance Evaluation

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Section 1 Antenna Design Processes

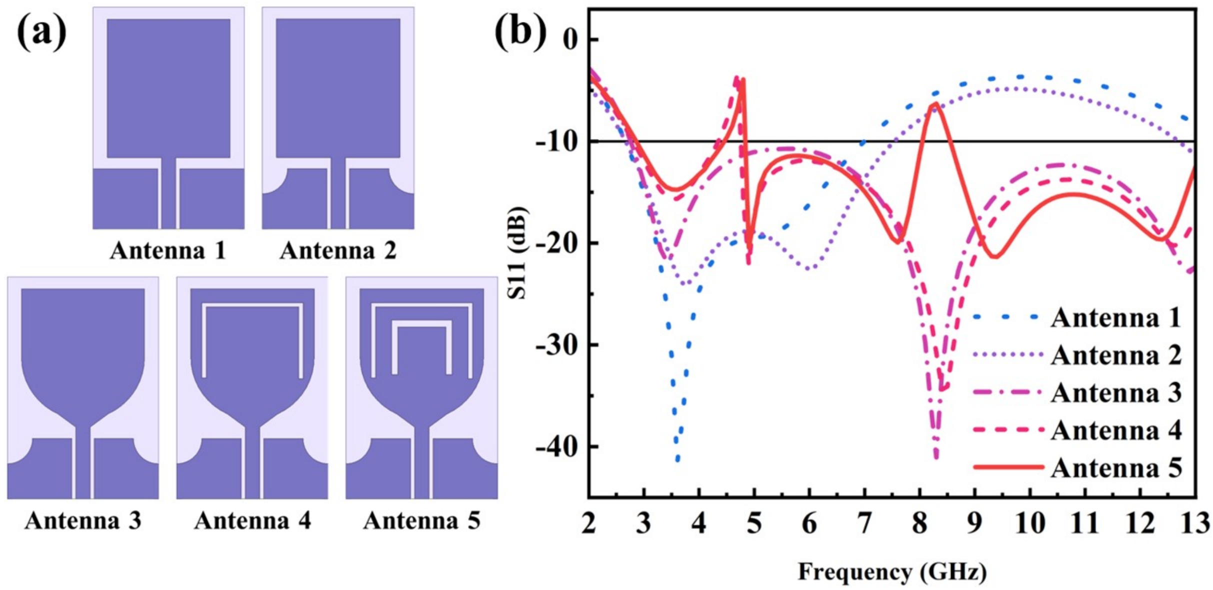

Figure S1. (a) Design processes of the proposed antenna and (b) the return loss values at each stage

The antenna was designed on a polyethylene terephthalate (PET) substrate. The permittivity (ε_r), dielectric loss tangent (tanδ), and thickness of PET were 4, 0.01, and 0.12mm, respectively. The design went through five stages of structural evolution before reaching its ultimate structure, as seen in **Figure S1a**, where the lavender and dark purple portions are the PET substrate and conductive copper pattern respectively. Parametric analysis is performed using ANSYS HFSS, a 3D electromagnetic simulation software.

These evolutionary stages were used to improve the performance of the antenna, especially bandwidth and impedance matching.

Antenna 1, a rectangular microstrip patch antenna with a size of 22×15×0.12 mm^3, served as the initial structure. However, due to its limited bandwidth, this structure was unable to meet the ultra-wideband requirements.

Antenna 2 was created by cutting a 1/4 circle in the ground plate of Antenna 1 to increase the resonance point and broaden the bandwidth. From **Figure S1b**, it can be seen that Antenna 2 contains two resonance points, and the bandwidth is broadened by 0.5 GHz.

Antenna 3 was obtained by changing the shape of Antenna 2's rectangular radiation patch to a gradient structure to further broad the bandwidth. As shown in **Figure S1b**, Antenna 3 achieves signal radiation in the targeted ultra-wideband frequency band, with S11 parameter less than -10dB in the range of 2.9~14GHz.

In order to achieve the notch performance, two half-wavelength slots were introduced sequentially on the radiation patch of Antenna 3. According to reference, a reverse current and a reverse electric field can be created at the slotting position so that the antenna cannot radiate energy outward, thereby resulting in a notch.

The length of the slot can be calculated from the notch center frequency, as shown below.

$$L_{notch} = \frac{c}{2 f_{notch} \sqrt{\varepsilon_{eff}}} \qquad \text{* MERGEFORMAT (1)}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \qquad (2)$$

Where L_{notch} is the inner circumference of the slot; c is the speed of light; f_{notch} is the notch center frequency; ε_r is the relative permittivity of the substrate; ε_{eff} is the effective dielectric constant.

The center frequencies for the Indian National Satellite INSAT band and the International Telecommunication Union ITU band are 4.65 GHz and 8.2125 GHz respectively. According to **Equations 1** and **2**, the theoretical lengths of the slots are calculated to be 20.39 mm and 11.54 mm. The length value on the actual dielectric substrate needs to be simulated and optimized in the HFSS software.

In order to shield the narrowband signal in the INSAT frequency band, a "U" shaped slot was introduced on the radiation patch of Antenna 3 at a distance of 1.37 mm from the top, resulting in Antenna 4 with a notch at 4.45-4.85 GHz. However, this design still suffered from the problem of unshielded signals in the high frequency band. Given that the nested structure would cause interference between the two slots, the second "U" shaped slot was placed 1.3 mm within the first notch structure to create the notch at 8-8.55 GHz, shielding the narrowband signal in the ITU frequency band.

Finally, Antenna 5 achieved the expected ultra-wideband and notch performance. Simulation results showed that the antenna effectively shields narrowband signals in the INSAT and ITU frequency bands while covering broadband signals.

Cconsidering the coupling and interference between the notch structures, the location and size of the notches were optimized. **Figure S2** show the optimized results of parameters L2 and L3. After optimization, the final parameters of the slot structure were as follows: L2 = 7.1 mm, L3 = 4.75 mm, L8 = 0.65 mm, W1 = 10 mm, W2 = 6 mm, W3 = 0.64 mm, W4 = 0.43 mm.

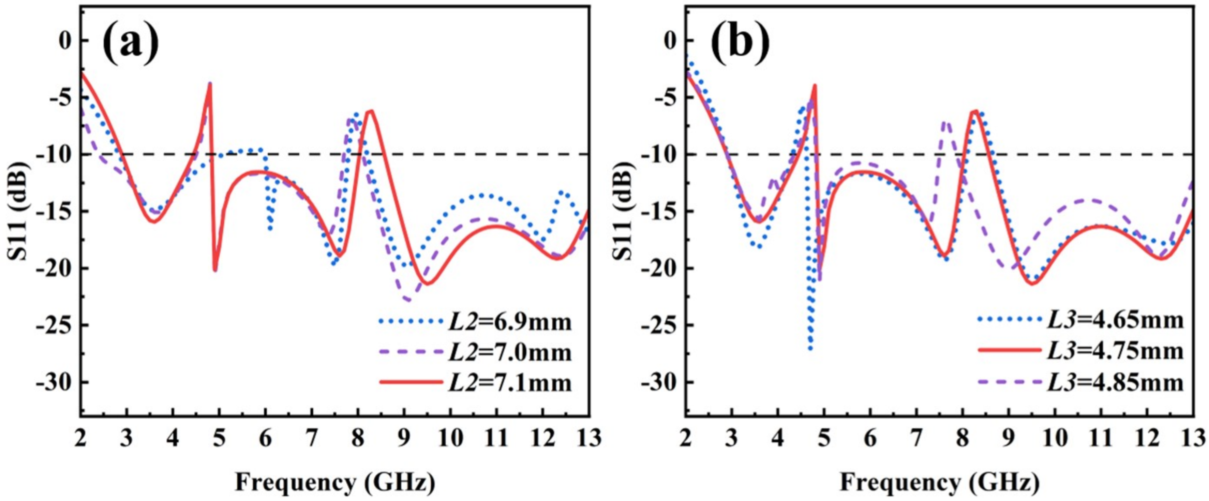

Figure S2. Effect of parameter values on the performance of antenna (a) L2, (b) L3

Section 2. Surface Current Distribution of the Optimized Antenna

The surface current distribution of the antenna at 4.65 GHz, 8.2 GHz, and 9.4 GHz was analyzed by HFSS to illustrate the mechanism of notch generation. As shown in **Figure S3**, different colors indicate the density of the current distribution on the antenna surface, with red and blue representing the maximum and minimum points, respectively. When the center frequency is at 4.65 GHz and 8.2 GHz, a strong half-wave resonance is generated at the notch, with the current concentrated around the "U" shaped notch. The dense current distribution causes the positive and negative currents to cancel each other out, resulting in a reduction in the energy signal radiated outward by the antenna, thereby effectively suppressing the signal transmission in these frequency bands. When the center frequency is at 9.4 GHz, the current is mainly concentrated at the edge, with the current on the radiating patch distributed evenly. Consequently, the antenna can operate in the targeted frequency band, and radiate energy signals well.

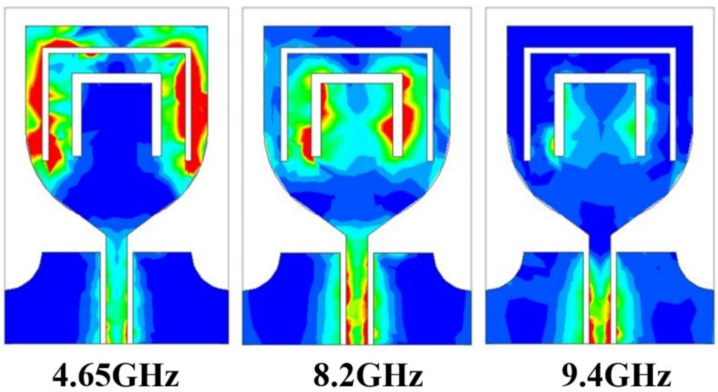

Figure S3. Surface current distribution of the designed antenna at 4.65 GHz, 8.2 GHz and 9.4 GHz