A High Performance Surface-Micromachined Elevated Patch Antenna

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Abstract- In this paper, an air-filled elevated microstrip antenna resonating at 25 GHz based on surface micromachining technology is fabricated and characterized for the first time. The antenna is air-lifted on high-ε_r soda-lime glass substrate and demonstrates a 7% 10 dB bandwidth in measurement. A 10.2 dBi directivity and a nearly frequency-independent broadside radiation pattern over a range of 7 GHz around the center frequency are projected in simulation and currently are experimentally investigated. The elevated patch is fed by a vertical epoxy-core metal-coated micromachined probe and supported by several epoxy posts underneath. By the unique feeding technique we have developed in this paper, the dielectric filled between the patch and the ground is air only and the requirement of low-ε_r substrate for patch antennas and high-ε_r substrate for compact feeding network can be satisfied simultaneously. The performance degradation for traditional microstrip antenna directly built on high-ε_r substrate is alleviated a lot due to the elimination of surface waves in the substrate.

I. INTRODUCTION

Microstrip antennas are widely used in a broad range of wireless communication applications in several different bands such as ISM 2.4 GHz band, IEEE 802.11a 5.8 GHz and LMDS 28 GHz band, due to their low manufacturing cost, relatively good performance and mature optimization tools. As emerging wireless communication and sensor applications in the RF/Microwave/millimeter wave regimes require a high degree of system-level integration, antennas are expected to be easily integrated with other RF parts on a single substrate. For the rest of the RF components/passives, the requirement for compactness is typically achieved utilizing high-ε_r materials. Nevertheless, low-ε_r substrates are preferred for antenna design. Otherwise, microstrip antenna designs show significant performance degradation due to the excitation of surface waves in high-ε_r materials, leading to lower efficiency, reduced bandwidth, degraded radiation patterns and undesired coupling between the various elements in array configurations. This conflict in terms of ε_r requirements can either lead to a hybrid integration solution, that is, microstrip antenna on low-ε_r substrates and other RF parts on high-ε_r substrates, or we can build both antennas and other RF parts on the same substrate with an intermediate ε_r and get a suboptimal component performance instead of best performance for each part.

Many efforts have been put forth to alleviate the problem caused by surface waves. Among them, [1] uses lateral etching to partially remove the silicon underneath the patch to lower the effective dielectric constant. [2] uses metal posts to lift the patch into air and use proximity coupling method to feed the patch. For both [1] and [2], the effective substrate of patch antenna is a mixture of air and high-ε_r materials, so compared to the completely air filled elevated patch proposed in this paper, the antenna performance is not fully optimized.

II. DESIGN OF ELEVATED PATCH

Fig. 1 illustrates the structure of our elevated patch antenna. The patch is fed by a vertical metal-coated epoxy core probe we developed earlier in [3] [4]. The probe is connected with the central conductor of a coplanar waveguide on top of substrate using the effective 3D transition of [3]. The coplanar waveguide feeding scheme is preferred since it is compatible with the assembly of MMIC surface-mount devices and also helps remove the air-dielectric interface between the patch and the ground metal because the coplanar waveguide and the patch antenna can share the same ground on top of the substrate. Unlike the use of metal posts in [2], several polymer posts are used underneath the patch to support the structure. This can avoid coupling between the supporting posts and the radiating structure.

The prototype of the elevated patch is designed and optimized to resonate at the LMDS band of 28 GHz. The final size of the patch is 4.8 mmx5.8 mm. The patch is elevated by 600 μm. The structure is simulated using the FEM based Ansoft HFSS V9.1 software tool and verified by TLM based Microstripes 6.5. Fig. 2 (a) (b) shows the simulated return loss and the 3-D radiation pattern at resonance. Simulation results predict a 7.8% fractional bandwidth around 28 GHz and a nearly frequency-independent radiation pattern from 25 GHz to 32 GHz with a maximum directivity of 10.2 dBi. The main lobe is along the normal direction of the patch and the 3-dB level beam-width is 62 degree in the E-plane. Also, the simulated 3-D radiation pattern has very low side lobe levels and backside radiation (below -20 dB), indicating an improved radiation efficiency due to the elimination of surface waves.

III. FABRICATION

The elevated patch antenna is fabricated by a combination of the epoxy-core conductor technique [5], laser machining, and electroplating bonding [6]. Fig. 3 illustrates the key fabrication steps. After high aspect ratio 600 μm tall polymer is patterned using UV photolithography, a feeding monopole is selectively metallized using photolithography and electro-deposition to provide a signal path from coplanar waveguide (CPW) to the patch (Fig. 3 upper). The metal patch is separately fabricated from a copper sheet with a thickness of 100 μm by laser cut. After gluing the patch to the posts using conductive paste, additional copper electroplating bonding between the feeding monopole and the patch is performed up to 30 μm thick to strengthen the connection (Fig. 3 lower).

IV. MEASUREMENT RESULTS

The fabricated elevated microstrip patch antenna (Fig. 4) was characterized by a 2-port Agilent 8510C vector network analyzer with a probe station. The NIST Multical TRL algorithm [7] was used to calibrate the measurement system. The reference plane was set to the bottom of metal-coated epoxy core probe. The measurement result shows a resonant frequency of 25 GHz for the fabricated patch antenna. The frequency shift is due to small geometry disparity between the fabricated prototype and the simulated one. The 10 dB bandwidth spans from 24.1 GHz to 25.8 GHz, equivalent to a 7% fractional bandwidth. The full radiation pattern is still in investigation.

V. Conclusion

In this work, a novel surface micromachined elevated patch antenna resonating at 25 GHz is reported. The antenna demonstrates increased efficiency, increased bandwidth and improved radiation pattern due to the elimination of surface wave generated in high-ε_r substrate. The fabrication method is also compatible with integration other RF parts on the same substrate, facilitating the application of this antenna in fully integrated SOP-based mm-wave modules.

References:

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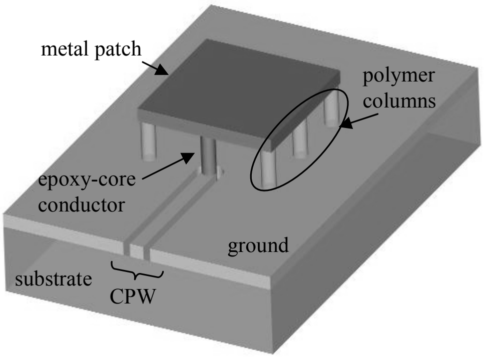
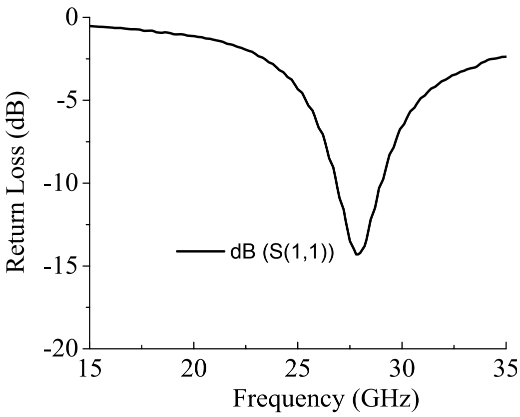
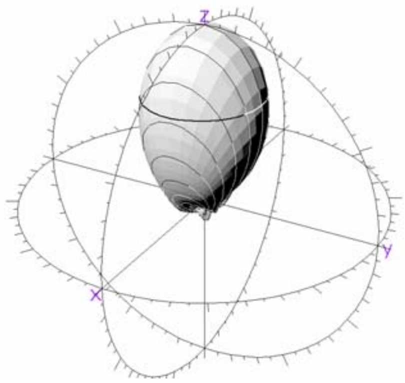


Fig.1. Structure of the proposed elevated patch antenna with CPW-connected probe feeding



(a)



(b)

Fig. 2. Simulated performance of air-filled patch antenna (a) Return loss (b) 3-D radiation pattern at 28 GHz (main beam is along *Z*-direction)

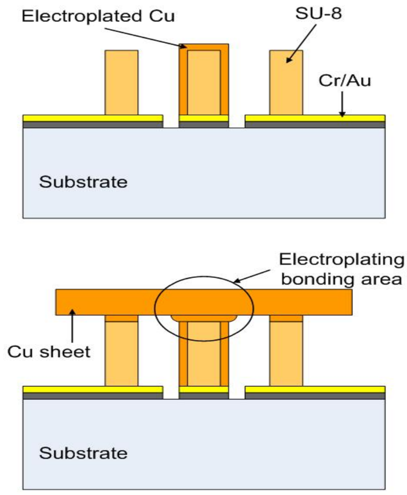


Fig. 3. Fabrication steps of the elevated patch

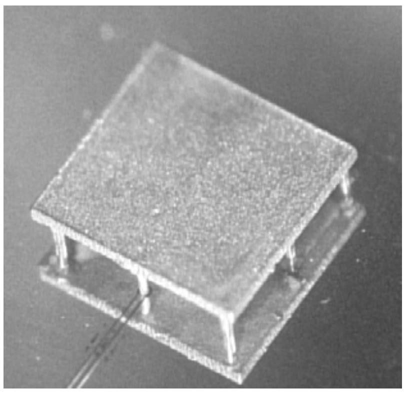


Fig. 4. Photo of the fabricated prototype

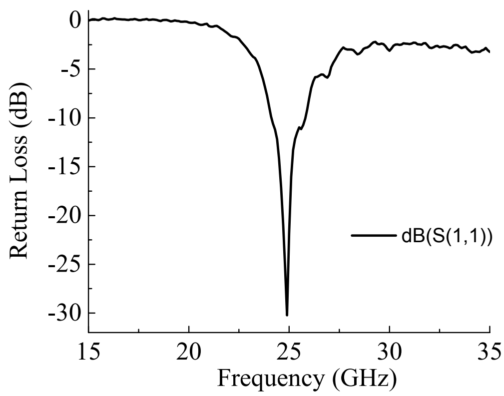


Fig. 5. Measured return loss of the elevated patch