Wideband low-profile low-temperature co-fired ceramic patch antenna with a differential-fed structure

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Abstract: A novel wideband patch antenna with a differential-fed structure is proposed in this study. For this antenna, an H-shaped patch is first adopted to build a compact design. Then, by introducing a via-wall-plate pair as the differential feeding scheme, favourable radiation patterns and enhanced operating bandwidth can be achieved in a low profile. Furthermore, a Marchand balun is incorporated into the overall design to facilitate the test and direct integration with existing single-end radio-frequency circuits. The proposed antenna, which is designed and fabricated, using low-temperature co-fired ceramic technology, could be used to develop a highly integrated system-in-package. The measured results demonstrate that the proposed antenna with a low profile of $0.06\lambda_0$ obtains an impedance bandwidth of 11.2%, a peak gain of 7.1 dBi, and a low cross-polarisation of better than −20 dB.

1 Introduction

The low-temperature co-fired ceramic (LTCC) multilayer technology is an excellent candidate for the production of complex and highly integrated radio-frequency (RF) components [1]. Recently, LTCC antennas have been widely investigated with the increasing demand for integrated, compact and high performance antennas.

The LTCC patch antenna is very attractive due to its well-known merits. However, a conventional patch antenna usually suffers from a limited bandwidth, mainly because of the high dielectric constant of the LTCC materials, thus it is difficult to be directly integrated with wideband systems. To solve this issue, some typical solutions, such as using embedded air cavity [2], adding parasitic elements [3, 4], introducing inner ground plane [5] and so on have been proposed. However, such methods achieve the bandwidth enhancement at the cost of high profile, which is not desirable for many practical applications. Besides, the technique of employing L-shaped probe feeding structure for achieving wideband antenna has also been widely reported [6, 7]. Nevertheless, this approach still suffers from a high profile of $>0.07\lambda_0$, and extra structures have to be constructed to reduce the surface wave losses caused by the thick substrate.

On the other side, LTCC patch antennas with differential-fed scheme are preferable compared to their single-fed counterparts as they can demonstrate a few superior properties, such as low cross-polarisation level, symmetric radiations and so on. This is also highly consistent with the pressing demands for fully integrated and high performance antennas. As such, the LTCC differential-fed patch antenna is becoming a hot spot and receives considerable attentions lately [7, 8]. However, the differential-fed scheme in the aforementioned designs is often implemented through a sub-array manner, which to some extent limits the scope of their interesting antenna elements.

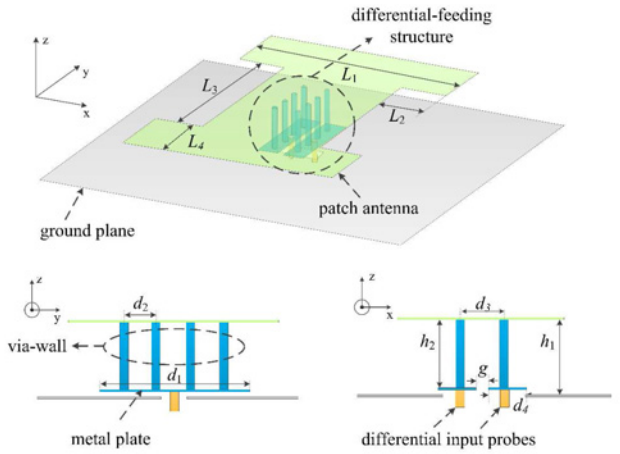
In this paper, a technique to design an LTCC differential-fed patch antenna with wideband performance in a low profile is presented. An antenna prototype is fabricated and measured for the verification.

2 Antenna configuration and working principle

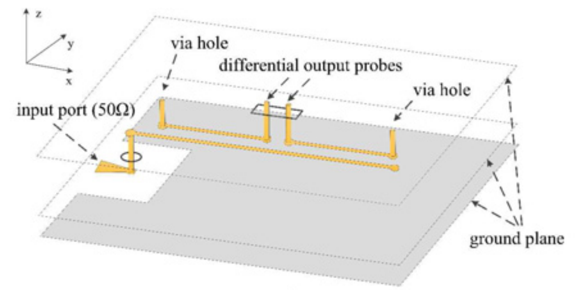
The schematic structure of the proposed LTCC integrated antenna is shown in Figs. 1*a*–*c*, which is divided into two parts of differential-fed patch (12 layers, $0.04\lambda_0$) and Marchand balun (6 layers, $0.02\lambda_0$). The multilayer LTCC substrate used in the design is Ferro A6-M with a dielectric constant $\varepsilon_r = 5.9$ and loss tangent $\tan\delta = 0.002$. The thickness of each substrate layer is 0.1 mm. The differential-fed patch consists of an H-shaped patch and a pair of via-wall-plate feeding structure. Compared to the conventional patch, the H-shaped patch has a smaller size for the same resonant frequency [9]. Thus it is employed here to deliver a more compact design. The differential feeding mechanism is created by a pair of via-wall-plate structures. For one of them, four vias constituting a via-wall is attached on the upper surface of a metal plate, while its lower surface is connected to a single feeding probe. With a pair of such structures, the H-shaped patch can be differentially driven. The differential-fed patch antenna exhibits a wide bandwidth and its working mechanism could be easily explained. Similar with the L-probe scheme [7], the metal plate from the via-wall-plate structure interacting with the H-shaped patch and the ground brings the parasitic capacitance. The capacitance is compensated with the inductance introduced by the feeding probe, thus forming a resonant mode. This resonant mode is then coupled with the patch mode, constituting a dual-mode wide operating band.

However, unlike the L-probe feeding scheme that is hard to work in the low profile, the proposed feeding structure helps the antenna demonstrate excellent performance especially in the case of low profile. Fig. 2 shows the simulated refection coefficient of the proposed antenna for different low profile cases. Note that the Marchand balun is not included in the simulated model here. It is learned that the antenna exhibits >30% impedance bandwidth with a profile of $0.06\lambda_0$ as well as a 19% bandwidth for the proposed profile of $0.04\lambda_0$, and it still operates well even if its overall height is reduced to $0.02\lambda_0$. This phenomenon is partly due to that the long contact between the via-wall and the patch makes the passing currents on the patch more uniform than the L-probe-fed counterpart. The uniform current distribution alleviates the impedance changing, which thereby brings a better impedance matching.

For the facilitation of direct integration with existing single-end RF circuits, a compact Marchand balun is incorporated into the overall design. The balun's differential output probes are directly connected to the differential input probes of the patch antenna as depicted in Fig. 1, while its input port is fixed to the lower edge in order to match with a 50-Ω source.



a



b

parameters	a	b	L_1	L_2	L_3	L_4	g
value (mm)	11.2	9.6	6.3	1.7	5.7	1.35	0.2
parameters	h_1	h_2	d_1	d_2	d_3	d_4	
value (mm)	1.2	1.1	2.1	0.55	0.7	0.6	

c

Fig. 1 *Structure of the proposed LTCC integrated antenna*
a Differential-fed patch antenna
b Marchand balun
c Detailed design parameters

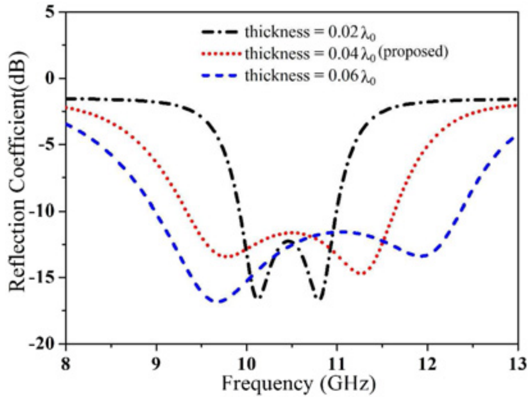


Fig. 2 *Simulated results for different low profile cases*

3 Experimental results

For the verification of the proposed concept, an antenna prototype with overall height of $0.06\lambda_0$ (including a differential-fed patch with $0.04\lambda_0$ thickness and a Marchand balun with $0.02\lambda_0$ thickness) is fabricated and measured. To simplify the test procedure, a conventional PCB board (Rogers 4003C, dielectric constant = 3.38, thickness = 0.813 mm) is used as a ground plane which contains a short microstrip line. One end of the microstrip line is wielded with the input port of the balun while the other end is connected with a feeding coaxial probe. Fig. 3 compares the simulated and measured reflection coefficient and gain of the proposed antenna (the PCB board is included here). It is found that the measured impedance bandwidth for $|S_{11}| < -10$ dB is 11.2%, ranging from 9.88 to 11.05 GHz, which is slightly narrower than the simulation mainly due to the fabrication tolerance. The measured peak gain is 7.1 dBi at 10.8 GHz. Figs. 4*a* and *b* depict the simulated and measured radiation patterns of the proposed antenna at 10.2 and 10.8 GHz. Attributing to the differential feed mechanism, the simulated H-plane cross-polarisation is < -40 dB. Since the cross-polarisation level is very sensitive to the machine error and surroundings of the measurement system, the measured cross-polarisation levels degrade to −20 dB within the 3-dB beamwidth for both *E*-plane and *H*-plane. However, it is still much better than the single-ended patch antenna [8]. As expected, the co-polarisation radiation patterns are symmetric with respect to the boresight within the whole band.

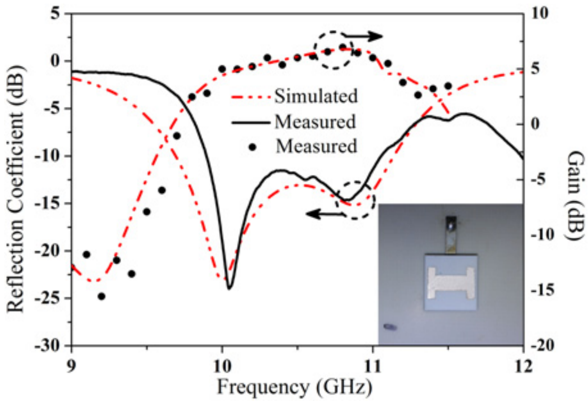


Fig. 3 *Simulated and measured reflection coefficient and gain of the proposed antenna*

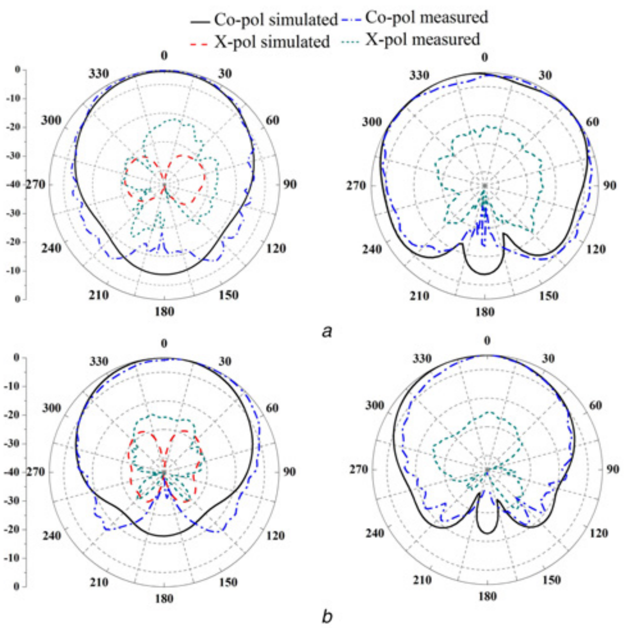


Fig. 4 *Simulated and measured radiation patterns of the proposed antenna*
a At 10.2 GHz, *E*-plane in the left side and *H*-plane in the right side
b At 10.8 GHz, *E*-plane in the left side and *H*-plane in the right side

4 Conclusion

In this paper, an LTCC differential-fed patch antenna has been designed, fabricated and measured. The antenna prototype achieves a wide impedance bandwidth of 11.2% for $|S_{11}| < -10$ dB, a low cross-polarisation of better than -20 dB, and a peak gain of 7.1 dB. The proposed antenna exhibits promising characteristics of low profile, wide impedance bandwidth and high integration, which is suitable for system-in-package applications.

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