Compact microstrip-fed LTCC chip antenna by capacitive coupling

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Abstract: In this paper, a capacitive coupling Low Temperature Co-fired Ceramics (LTCC) chip antenna is designed and fabricated for Wideband Code Division Multiple Access (W-CDMA) mobile handsets applications. The proposed antenna is designed by utilizing the capacitive coupling structure and feeding by a microstrip line. The proposed antenna has the advantage of good gain and easy to impedance matching. The size of the proposed antenna is $3 \times 10 \times 0.94 \text{ mm}^3$. Gain difference by microstrip-fed and CPW-fed is also discussed and comparative results are simulated and demonstrated. Measured results show that the impedance bandwidth for $|S_{11}|$ less than -10 dB covers two bands of W-CDMA, and the omni-directional radiation pattern is realized.

Keywords: LTCC antenna, chip antenna, capacitive coupling structure, microstrip-fed, CPW-fed

Classification: Antennas and Propagation

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1 Introduction

In recent years, mobile handsets such as mobile phones and tablets are receiving a lot of attention. For these handsets, it is attractive to use small and multi-band antennas due to the increasing demand of miniaturization, integration and multi-function.

Low temperature co-fired ceramic (LTCC) technology is especially suitable for the design of small antennas because of its attractive features of high mechanical stability, low fabrication tolerance, and enabling complex three-dimensional structure. A number of methods have been reported to design LTCC antennas. It is possible to decrease the size of antenna by using meander lines [1, 2, 3], helixes [4, 5], or side loaded patches [4, 5]. Complex helical structures can be easily manufactured through LTCC technology to obtain good circular polarization performance [6, 7]. Different LTCC substrate can be used in different layers and embedded air cavities [8] can be utilized to realize a wide impedance bandwidth.

Small antennas are not easily impedance matching due to their high Q factor. In [9], capacitive coupling structure is introduced to tune the input impedance and reduce the size of small antennas. Complex capacitive coupling structure such as three-dimensional capacitive coupling can be easily manufactured by LTCC technology.

LTCC chip antennas are usually fragile and need to be mounted on the dielectric substrate, therefore LTCC chip antennas are usually fed by microstrip line or coplanar waveguide (CPW) instead of coaxial probe (Fig. 2(a)). In [10], LTCC antennas of different suppliers are tested and results show that the gain of microstrip-fed is higher than GCPW-fed, although the paper does not use the same

Fig. 1. Geometry and dimensions of the proposed antenna.

Fig. 2. Feeding methods and photographs of the fabricated antenna.

LTCC antenna for comparison. In order to discuss the gain difference by different feeding methods, microstrip-fed and CPW-fed with the same LTCC antenna are simulated and comparative gain results are demonstrated. Comparative results show that higher gain can be realized by using microstrip-fed.

In this paper, a compact capacitive coupling LTCC chip antenna is proposed and fabricated for Wideband Code Division Multiple Access (W-CDMA) mobile handsets application. Details of the antenna design and measured results are presented and discussed. The gain difference between microstrip-fed and CPW-fed is discussed and the advantage of microstrip-fed is elaborated.

2 Antenna structure and design

Fig. 1 shows the geometry and dimensions of the proposed antenna. The antenna consists of a rectangular patch, a radiation plate, a helix and two meander lines with

a compact size of $3 \times 10 \times 0.94 \text{ mm}^3$. The W-CDMA lower band (1.92–1.98 GHz) and upper band (2.11–2.17 GHz) are generated by the upper meander line, and the lower meander line respectively. The antenna consists of a 10-layer LTCC substrate of FerroA6M (dielectric constant: 5.9), and the thickness of each layer is 0.094 mm. Conductor lines (width: 0.2 mm; thickness: 0.017 mm) are printed inside the antenna to avoid abrasion. A small microstrip-fed rectangular patch is capacitively coupled with the radiation plate to radiate energy. The radiation plate and the rectangular patch are printed on the front and the back of layer 10 respectively. Helical lines are printed on layer 2, 9 and 10. Meander lines are printed on layer 2, 4, 8 and 10. Different conductor lines are connected by via-holes (diameter: 0.1 mm) with small metal circles (diameter: 0.2 mm). Small metal circles are printed on the interface of via-holes, to guarantee a good connection when via-holes are misaligned.

The antenna consists of a helix and two meander lines. The helix is the main working part of the antenna, which will affect two W-CDMA bands. For the purpose of antenna rapid design, dimensions of the helix should be determined at first. Although the helix can resonant independently, the bandwidth is usually very narrow, requiring the meander line to increase the bandwidth. Two W-CDMA bands can be obtained by adjusting the length of two meander lines. Thanks to LTCC technology enables complex three-dimensional structure, meander lines can be folded in different layers to reduce the size.

Critical parameters of the helix are the height H_1 , the width W_1 and the number of turns N . Helical antennas usually have two working modes, the normal mode and the axial mode. In order to obtain the omni-directional radiation pattern, the helix need to work on the normal mode. The normal mode experience formula are given by the following equations [11].

$$\lambda = \frac{c}{f} \quad (1)$$

$$\frac{H_1}{\lambda} < 0.18 \quad (2)$$

$$\frac{W_1}{\lambda} < 0.18 \quad (3)$$

For the proposed antenna, H_1 and W_1 are required to be less than 27 mm to work on the normal mode, while W_1 is required to be close to H_1 for the equal gain in all directions. The resonant frequency of the helix can be reduced quickly by increasing the number of turns N . When designing the proposed antenna, first let the helix resonating at 2.65 GHz, and then linking the meander line with the helix to get two W-CDMA bands. If a smaller meander line is required, the resonant frequency of the helix should be lower by increasing H_1 , W_1 and the number of turns N .

3 Simulation and measurement results

A prototype antenna is fabricated and measured. Fig. 2(b) shows photographs of the fabricated antenna. The antenna is fed by a 50-ohm microstrip line. A test-board (material: FR-4; dielectric constant: 4.4) is used to hold up the antenna and provide the ground plane. The rectangular patch on the back of layer 10 is also used to

connect the microstrip line and the antenna. Dimensions of the test-board and the ground plane are $42 \times 60 \times 1 \text{ mm}^3$ and $42 \times 43 \text{ mm}^2$, respectively.

Fig. 3(a) shows the simulated and the measured $|S_{11}|$ of the proposed antenna. Simulated results are obtained by Ansoft HFSS 13.0. The simulated-10-dB bandwidth of the two W-CDMA bands are both 70 MHz and two resonant frequencies

Fig. 3. Simulated and measured results of the proposed antenna

are 1.95 GHz (f_1) and 2.14 (f_2) GHz respectively. Two measured W-CDMA bands are 90 MHz and 70 MHz and two resonant frequencies are 1.96 and 2.15 GHz. The simulated and the measured results are very close, however two measured resonant frequencies are 10 MHz higher than two simulated resonant frequencies because of the manufacturing error.

Figs. 3(b) and (c) show the simulated $|S_{11}|$ with different length L_1 and L_2 . Turning the rectangular patch width L_1 from 1.2 to 1.8 mm will allow f_1 and f_2 to shift linearly to a lower frequency due to the increase of capacitive coupling between the radiation plate and the rectangular patch. Turning the helix pitch L_2 from 0.4 to 0.45 mm will allow f_1 and f_2 to shift linearly to a higher frequency due to the decrease of the inductance of the antenna.

Fig. 3(d) shows the simulated realized gain of microstrip-fed and CPW-fed from 1.8 to 2.3 GHz. The gain is 0.03 and 0 dBi at 1.96 GHz, 0.52 and 0.42 dBi at 2.15 GHz by microstrip-fed and CPW-fed respectively. The result shows that the gain of microstrip-fed is 0.2 dBi higher than CPW-fed on two W-CDMA bands on the average, and 0.5 dBi higher from 1.8 to 2.3 GHz on the average. The measured gain of the proposed antenna by microstrip-fed is -1.84 dBi at 1.96 GHz and -1.42 dBi at 2.15 GHz. The feed line gap width of the microstrip line is larger than the gap width of the CPW line, which results in more energy being radiated by the gap, therefore the gain of microstrip-fed is higher than the gain of CPW-fed. The size of the LTCC chip antenna is small, so that the gain is usually low. The use of microstrip feed will improve the gain of the LTCC chip antenna.

Fig. 3(e) shows the simulated and the measured x - z and y - z plane far-field radiation patterns at 1.96 and 2.15 GHz. Agreement between the simulation and measurement is also seen. It is observed that the shape of the simulated and the measured radiation patterns are almost the same, which are omni-directional in x - z plane and the shape of figure eight in y - z plane.

4 Conclusion

A capacitive coupling LTCC chip antenna with a compact size of $3 \times 10 \times 0.94 \text{ mm}^3$ has been proposed and fabricated for W-CDMA mobile handsets application. The capacitive coupling structure is easily fabricated by LTCC technology. By introducing the capacitive coupling structure, the size of the antenna is reduced and the resonant frequency is quickly tuned. The reason to use microstrip-fed is elaborated and comparative gain results by microstrip-fed and CPW-fed are demonstrated. It is found that the antenna covers two W-CDMA bands with omni-directional radiation patterns, and 0.2 dBi higher gain is obtained by microstrip-fed compared to CPW-fed on two W-CDMA bands.