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Short communication

The two element antennas using $BiNbO_4$ ceramics as the substrate

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Abstract

A new kind of antenna using high permittivity dielectric materials as the substrate was designed. Its size is 34 mm × 34 mm in square and 1 mm in height. The operating frequency of the array is designed as 3.5 GHz with the bandwidth of 50 MHz at −10 dB attenuation. $BiNbO_4$ ceramic substituted by a little amount of V_2O_5 was chosen as the substrate materials. Bulk ceramics were sintered at 890 °C for 2 h and processed into slices samples. The antenna was made on the substrate by screen-printing technology and the properties were measured using a 8720ES network analyzer. The test results show that 3.07 GHz centre frequency and 34 MHz bandwidth at −10 dB attenuation have been obtained.

Keywords: Antenna; $BiNbO_4$ ceramics; Substrate

1. Introduction

Recent the rapid increase of developments in the wireless communication industry especially mobile communication has strongly influenced on the communication devices. Small antenna, wide-band antenna, multiple-bands antenna and smart antenna become the new research areas of the antenna technology [1–4]. It is challenge to design small antenna with high gain and efficiency.

Microwave dielectric ceramics have the advantage of high permittivity, low dielectric loss and low temperature coefficient. So it can be widely used in the microwave circuit as the resonator, filter, dielectric substrate, dielectric antenna, dielectric waveguide circuit and, etc.

In recent years, the compact internal-type antenna with small size is strongly demanded because the conventional whip and helical type antennas take large volume in mobile equipments. Among various possible internal antennas, the ceramic chip antenna is a good candidate for internal antenna because it offers the advantages of compact size and easy fabrication. Ceramic antennas can be mounted on the circuit board by SMT (Surface Mount Technology) and it can reduce the cost of the installation. A coplanar waveguide feeding antenna (CPWFA) using the ceramic $0.35(Al_{1/2}Ta_{1/2})O_2$–$0.65(Mg_{1/3}Ta_{2/3})O_2$ with permittivity of 26 has been fabricated by Choi [5]. The operating frequency of this antenna is 1.58 GHz, and the size of the antenna is 25 mm × 25 mm × 2 mm. Ghosh [6] reported a patch antenna with a shorting pin using the ceramic $(Ca_{0.05}Mg_{0.95}TiO_3)$ with the permittivity of 18.5. The operating frequency is 1 GHz and the size of the antenna is 17 mm × 8.5 mm × 4 mm. Peng [7] studied a rectangle patch antenna working at the frequency of 2.4 GHz using the microwave ceramic BZN (Bi–Zn–Nb–O) with the permittivity of 90. The whole volume of the patch antenna was reduced efficiently. However, because of the high permittivity, this antenna shows a narrow bandwidth and cannot be used in the actual applications.

In this work, a two-element antenna array has been designed and fabricated. This antenna array is made by screen-printing on the ceramic substrate. $BiNbO_4$ microwave ceramic with high permittivity and low loss is chosen as the substrate. The $BiNbO_4$ ceramic was firstly reported by Kagata [8], many researchers have modified the composition by doping and substituting to get the lower densified temperature and improve the microwave properties. In this work the ceramic with composition of $Bi(Nb_{0.992}V_{0.008})O_4$ reported in our previous work [9] was used. The antenna array is simulated by Ansoft-HFSS. The measured and simulated results correspond with each other well.

2. Experimental

The two elements antenna as shown in Fig. 1 was designed and simulated by HFSS. $BiNbO_4$ ceramic substituted by V_2O_5

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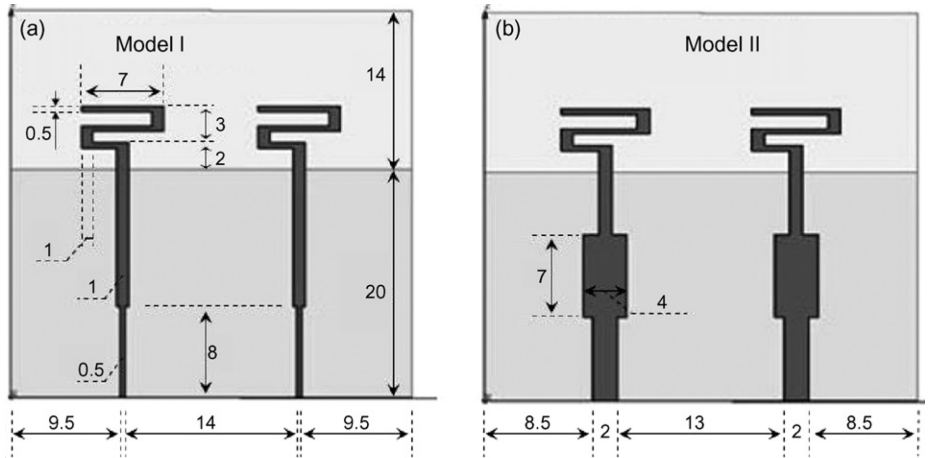

Fig. 1. The geometry of the two-element array printed on the $BiNbO_4$ ceramic substrate.

with formulae of $Bi(Nb_{0.992}V_{0.008})O_4$ was chosen as the substrate. The ceramic substrates were prepared by mix-oxides method and sintered at 890 °C for 2 h. The antennae were printed on the ceramic substrates using silver paste by screen-printing and then sintered at 600 °C for 10 min. The SMA was seamed with the antenna using good soldering tin.

Microwave dielectric properties of ceramic substrates were measured by a network analyzer (8720ES, Agilent, U.S.A.) with a split post-resonator cavity [10,11] and a temperature chamber (DELTA9023, Delta Design, U.S.A.). The S_{11} parameters of the antenna were measured by the 8720ES network analyzer. The temperature coefficient of resonant frequency (TCF) was defined as following:

$$\tau_f = \frac{f_T - f_0}{f_0(85 - 25)} \quad (1)$$

where f_T, f_0 were the $TE_{01\delta}$ resonant frequencies at 85 and 25 °C, respectively.

The patterns of the two elements antenna array were screen-printed on the ceramic substrate and the square resistance of silver paste was about 2.5–4.5 mΩ. The element antenna is meander-line antenna, which can reduce the whole size of the antenna. There is no conductor ground plane on the back of the element antennas, so the radiation pattern of the element antenna is similar with the z-oriented monopole antenna. Because of the high permittivity of the ceramic substrate, the wavelength in the substrate λ_g is more smaller than the λ_0 (wavelength in the air). The distance between the two element antennas can be decided by the theory of antenna array and the simulation. In order to use the 50 Ω coaxial line as the feeding line, two different impedance converters are designed as shown in Fig. 1(a) and (b). The specific sizes of antenna arrays are given. (symmetric and repeating parts are left out) The antenna arrays shown in the Fig. 1 are simulated using the Ansoft-HFSS software.

3. Results and discussions

Table 1 showed the microwave permittivity and dielectric loss of ceramic substrates. Four samples with the same size and materials were prepared and measured. The permittivity was about 43 and Q-values were about 3000, which corresponded

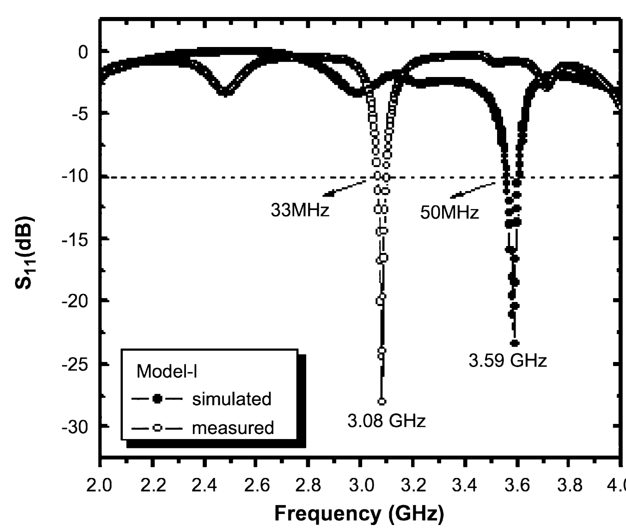

Fig. 2. The simulated and measured S_{11} parameters of the model I.

Table 1
Dielectric property of ceramic substrates

Number	Resonant frequency (GHz)	Permittivity	Dielectric loss (10^{-4})	Q-values	TCF (ppm/°C, 25–85 °C)
1	4.11034	43.2	3.0	3326	+1.2
2	4.11003	43.3	3.4	2890	+0.8
3	4.11540	43.0	3.3	2981	+0.4
4	4.11002	43.1	3.2	3045	+1.5
Average values	4.111	43.2	3.2	3061	+1.0

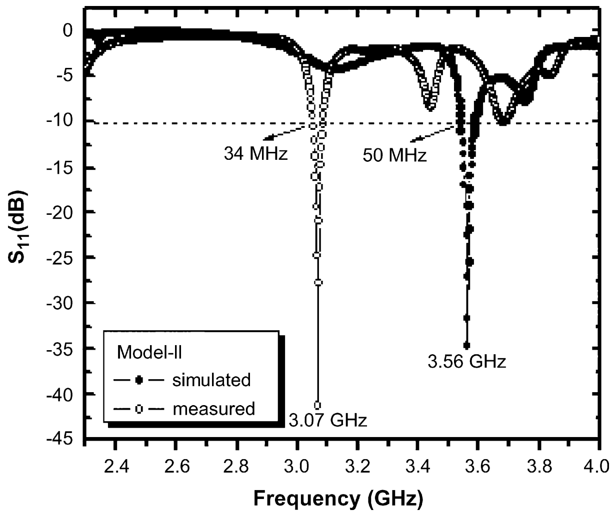

Fig. 3. The simulated and measured S_{11} parameters of model II.

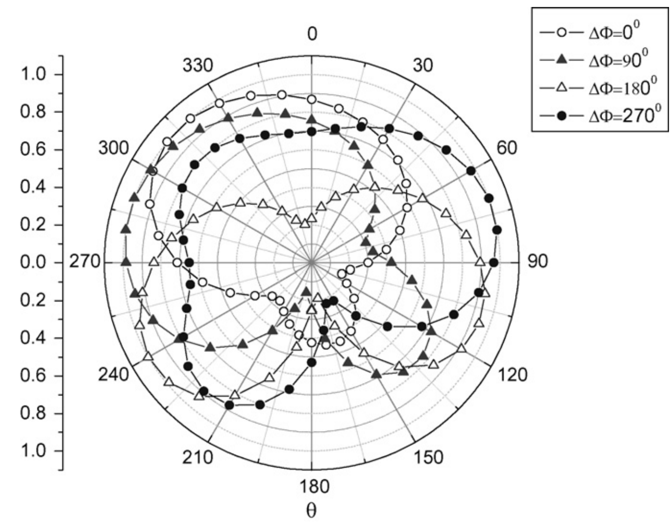

Fig. 4. The simulated radiation pattern of model I.

to that reported in literatures [8,9]. The TCF are all near zero and it is suitable for the application. The average values, 43.2 for permittivity and 3061 for Q-value, were used as the standard parameters for substrates in HFSS simulations.

Fig. 2 shows the simulated and measured S_{11} parameters of the model I. The simulated resonant frequency is 3.59 GHz and the simulated bandwidth is 50 MHz (based on $S_{11} < -10$ dB). The measured result shows that the element antenna resonates at 3.08 GHz and has the bandwidth of 33 MHz.

Fig. 3 shows the simulated and measured S_{11} parameters of the model II. The simulated resonant frequency is 3.56 GHz and the simulated bandwidth is 50 MHz (based on $S_{11} < -10$ dB). The measured result shows that the element antenna resonates at 3.05 GHz with the bandwidth of 34 MHz.

As shown in the Fig. 1(a), the feed port of the left element antenna is port1 and the right one is port2. The V1, V2 are the amplitudes of excited voltage on each port. The $\Phi 1$, $\Phi 2$ are the phases of excited voltage of port1 and port2. In this design we let the $\Phi 1 = 0$, and change the $\Delta\Phi$ ($\Delta\Phi = \Phi 2 - \Phi 1$) from 0° to 270°. The simulated radiation patterns of the antenna array for the model I are shown in Fig. 4, at the operating frequency of 3.5 GHz. From the simulated results of designs, we can see that the radiation patterns of the antenna array consists of two element antennas can be controlled, if the phase of the feed port was changed.

The real photos of antenna samples were shown in Fig. 5. The differences between simulated and measured results were caused mostly by the process parameters. The screen-printing of antenna and the seaming between antenna samples and SMA might bring some negative influence. The simulation using Ansoft-HFSS was also not perfect because of some approximate and simplified assumption and software's own limitation. However the correspondence of the simulated and the measured results were acceptable.

4. Conclusion

Microwave dielectric materials with high permittivity and low loss will play a very important role in antenna application with its special characteristics. In our work, the two element antennas with centre frequency of 3.07 GHz and bandwidth of 34 MHz at −10 dB attenuation were obtained using a substrate with permittivity of 43, size 34 mm × 34 mm × 1 mm. The primary application of $BiNbO_4$ ceramic in antenna will broaden the application field for microwave ceramics with high permittivity and some new progress will be reported in our further work.

Fig. 5. Real photos of antenna samples based on $BiNbO_4$ ceramic substrate.

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