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Dielectric resonator antennas of ZST advanced cerramics

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Investigations on dielectric on compact resonators antennas with enhanced characteristics are described in this paper. The dielectric resonators were of $(Zr_{0.8}Sn_{0.2})TiO_4$ ceramic material (ZST). It is shown that the doping with Mg reduces the sintering temperature and provides a high dielectric constant, low loss and high thermal stability in microwaves. The coupling with an extra resonator can offer a substantial bandwidth enhancement. Moreover, antenna array with four antenna elements provides a higher gain and a more directive radiation pattern.

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1. Introduction

Dielectric ceramics with low-loss, high electric permittivity and enhanced temperature stability are very attractive for the design of compact microwave devices with improved characteristics. The excellent microwave properties of the zirconium tin titanate (ZST) [1, 2] recommend this material for microwave devices [3].

The dielectric resonator antennas provide performances superior to such compact modern devices as microstrip patch antennas [4]. Moreover, conventional antennas printed on high dielectric constant substrates may exhibit a narrow impedance bandwidth and a reduced efficiency due to the conductive losses in the patch and to the losses due to the excitation of the surface waves. It was previously shown that a dielectric resonator antenna (DRA) excited in $HE_{11□}$ and a circular-shaped microstrip patch antenna excited in TM_{11}, both designed for the same frequency, might exhibit almost the same co-polar radiation patterns [5]. However, the DRA exhibits 10 times larger bandwidth, and higher antenna efficiency and a 1 dB higher gain [5].

2. Preparation and microwave characterization of dielectric resonators of Magnesium Doped ZST

$(Zr_{0.8}Sn_{0.2})TiO_4$ undoped ceramic materials (ZST) sintered at $1400^{o}C$ have been previously reported [6, 7]. However, in order to avoid Sn volatilization, the sintering temperature needs to be reduced. In this work, $(Zr_{0.8}Sn_{0.2})TiO_4$ material (ZST) was prepared by solid-state reaction starting from powder oxides ZrO_2, SnO_2 and TiO_2oxydes with purity higher than 99%. In order to reduce the sintering temperature, 2 wt % La_2O_3 and 1 wt % ZnO were added and the powders were ground in distilled water for 24 h in a mill with agate balls before the calcination treatment carried on at $1200^{o}C$ for 2 hours. Then, the calcinated powders were milled for 2 hours and 0.2 wt % MgO was added for a further decrease of the sintering temperature.

3. Microwave dielectric characterization

Microwave dielectric characterization of Mg-doped ZST material uses the resonances of the ZST dielectric resonator, which can be considered as a piece cut from an infinite dielectric waveguide. In opposition to a hollow metallic waveguides, which admit only transverse electric TE and transverse magnetic TM modes, which exhibit no axial component of the electric or magnetic field, respectively, the dielectric waveguides support also the hybrid modes HE. These hybrid modes contain all components of electric and magnetic fields [8].

Let k_0 and β be the total and axial propagations, respectively. For a circular dielectric waveguide of radius a and dielectric constant ε_r , the dispersion equation of the propagation modes along the waveguide is

$$g_1(x,y)\cdot g_2(x,y)-g_3^2(x,y)=0\,, \qquad (1)$$

where x and y are the products between the radius a and the radial propagation constant inside and outside the dielectric waveguide, respectively. The functions $g_1(x,y)$, $g_1(x,y)$ and $g_3(x,y)$ are defined as follows:

$$g_1(x,y)=\frac{J_m'(x)}{x}+\frac{K_m'(y)J_m(x)}{\varepsilon_r yK_m(y)}\,, \qquad (2)$$

$$g_2(x,y)=\frac{J_m'(x)}{x}+\frac{K_m'(y)J_m(x)}{yK_m(y)}\,, \qquad (3)$$

$$g_3(x,y) = \frac{\beta am}{k_0 a\sqrt{\varepsilon_r}} J_m(x)\left(\frac{1}{x^2}+\frac{1}{y^2}\right) \qquad (4)$$

where the $J_m(x)$ are the Bessel functions of the first kind and order m, the $K_m(x)$ are the modified Bessel functions of the first kind and order m, the sign ‘ means first-order derivative. The propagation modes can be indexed by azimuthal and radial number m and n, respectively. The index m is an angular index, and is also called the azimuthal mode number. The number m represents the number of maxima along the resonator circumference. The case $m = 0$ corresponds to the field configuration with cylindrical symmetry. It can be easily seen that, if $m = 0$, then either $g_1(x,y) = 0$ and the fields correspond to a transverse magnetic (TM) mode, or $g_2(x,y) = 0$ and the fields correspond to a transverse electric (TE) mode. In the case $m \neq 0$, a general equation (1) must be satisfied and the field configuration corresponds to a hybrid (HE) mode.

In order to designate the resonances of a dielectric resonator of height h, a third index, i.e. axial number p is used. Indices m, n and p represent the number of field half of wavelength maxima along the resonator circumference, radius and axis, respectively.

The mode chart for the first propagating modes in a dielectric waveguide with $\varepsilon_r = 36.5$ is shown in Fig. 1. The intersections of mode curves with $pa/h = const.$ curves give the DR resonating modes. In the case when the metallic place is distanced from the dielectric resonator, the axial index p can be written as a sum $p = l + \delta$, where l is an integer and δ is a positive, less than unity number. Besides the estimated frequency, for a correct identification, it is required the investigation of the resonance frequency with the distance between the dielectric resonator and the ground plane, as shown in Fig. 2.

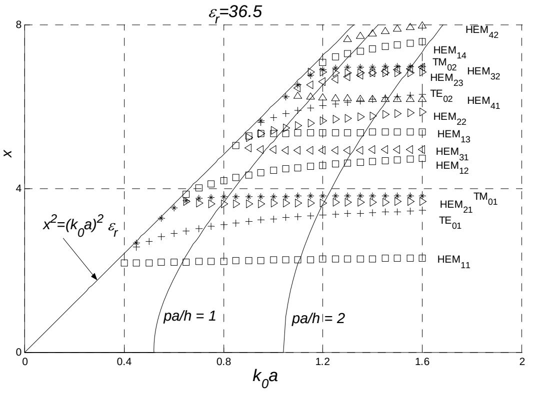

Fig. 1. Chart of the first propagation modes along the axis of a cylindrical dielectric waveguide with $\varepsilon_r = 36.5$. (*) TE modes, (+) TM modes, squares - HEM $_{m\,n\,p}$ modes with m = 1, triangles pointing right - HEM $_{m\,n\,p}$ modes with m = 2, triangles pointing left - HEM $_{m\,n\,p}$ modes with m = 3, triangles pointing up - HEM $_{m\,n\,p}$ modes with m = 4. The intersections of mode curves with pa / h = const. curves give the DR resonating modes.

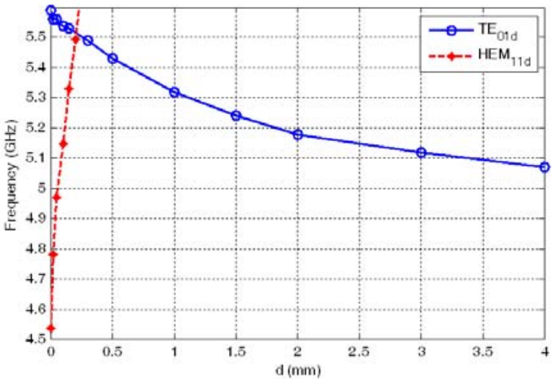

Fig. 2. Resonance frequency of the $TE_{01\delta}$ and $HE_{11\delta}$ modes versus the distance between the resonator and the ground plane.

After the mode identification, the dielectric constant can be found considering any resonance mode of the dielectric resonator. However, in the Hakki-Coleman method, accurate measurements of the losses require a correction for the conductive losses in the metallic plates of the Courtney holder [9].

4. Dielectric resonator antenna (DRA)

Knowing the resonance mode, one can predict the far field radiation when utilizing them as antennas. For examples, the DR excited in $TE_{01\delta}$ radiates as a short magnetic dipole oriented along its axis. While excited in the $TM_{01\delta}$ mode, DR radiates as a short electric dipole.

We investigated a microstrip-fed DRA with a single dielectric resonator shown in Fig. 3. The field configuration and antenna response were obtained by using an electromagnetic simulator [10]. When resonates in the $HE_{11\delta}$ mode, the DR resonates as a horizontal magnetic dipole. The magnetic and electric field of the resonance at 4.8 GHz confirm a distribution specific to the $HE_{11\delta}$ mode with the maximum of the magnetic field perpendicular to the maximum of the electric field as shown in Fig. 4.

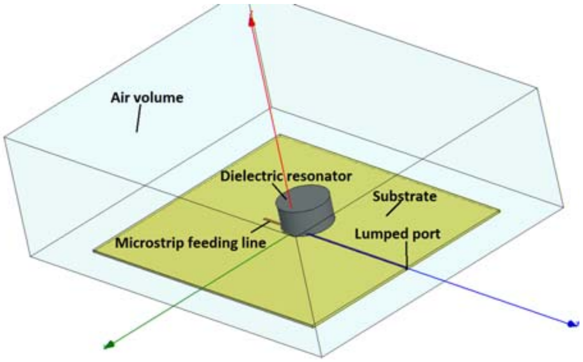

Fig. 3. Geometry of the dielectric resonator antenna

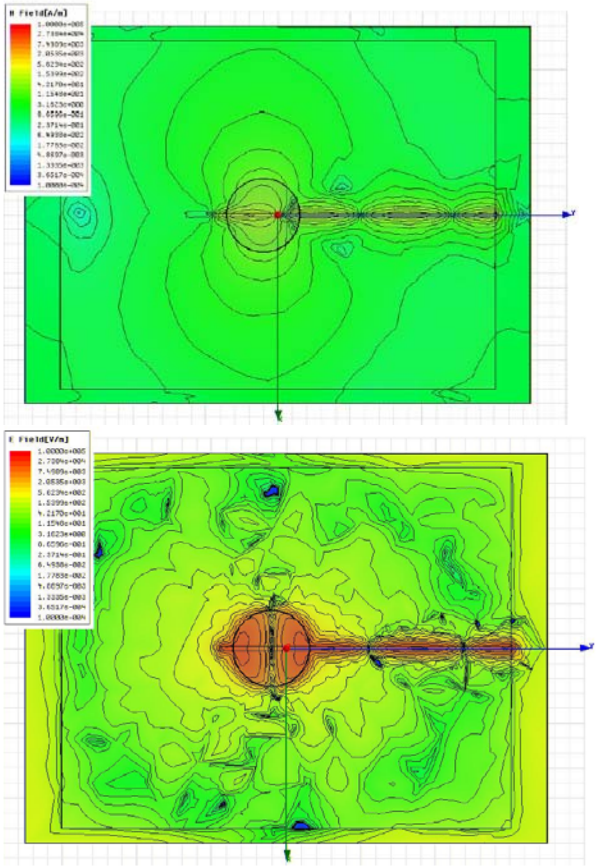

Fig. 4. Field plots for a 1 DRA excited in $HE_{11\delta}$ mode : magnetic field (left), electric field (right).

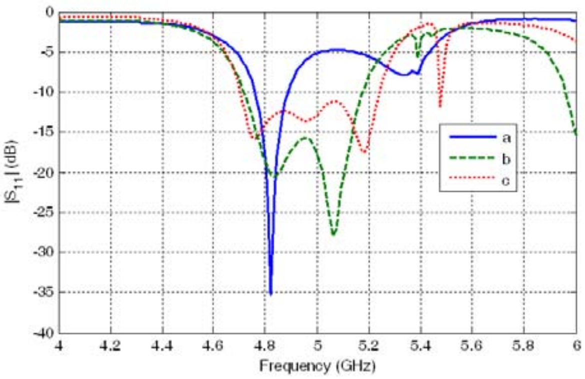

Fig. 5. Measured return loss showing the antenna bandwidth; a) DRA with a single resonator excited in the $HE_{11\delta}$, b) DRA with two coupled DR in a symmetric position, c) DR with two coupled resonators in a non-symmetric position.

The measured reflection loss of the single resonator DRA, which is shown in Fig. 5, exhibits the $HE_{11\delta}$ resonance at 4.8 GHz and a narrow 10dB bandwidth of about 90 MHz. We show that coupling with an extra dielectric resonator can lead to bandwidth enhancement as shown in Fig. 5. When the second dielectric resonator is placed in asymmetric position the 10 dB bandwidth increases to 440 MHz. Furthermore, if the second resonator is placed in a non-symmetric position, a 550 MHz bandwidth is achieved.

5. Antenna array with four DRA

The antenna performances can be significantly improved by using an antenna array with more DRA. The proposed antenna network uses four dielectric resonators excited in $HE_{11\delta}$ mode by using a microstrip network as shown in Fig. 6.

In Fig. 7 are presented the radiation patterns of the single DR antenna showing a maximum gain of 6dB for the main lobe. Due to the characteristics of the $HE_{11\delta}$ mode, the radiation pattern is similar to the pattern due of a magnetic dipole placed horizontally, along the microstrip feeding line. The width of the lobe is about 95^o (for φ = 90^o) and 55^o (for φ = 0^o).

On the other side, the radiation pattern of the DRA array (Fig. 8) exhibits a gain for the main lobe 6 dB higher than the gain for a single DR antenna. Moreover, the directivity is increased, the antenna focusing the energy in a much narrower main lobe. In this case, the main lobe width is 60^o (for φ = 90^o) and 45^o (for φ = 0^o).

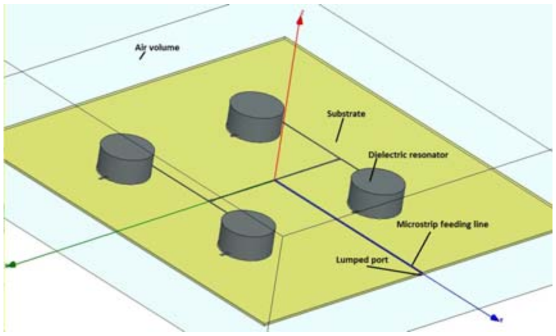

Fig. 6. Geometry of the microstrip fed antenna array with 4 elements.

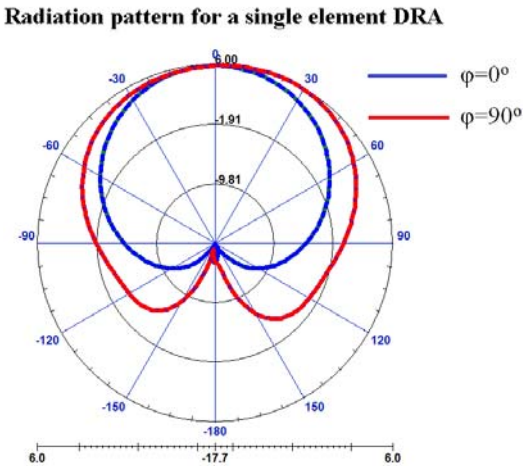

Fig. 7. Antenna pattern of a single DR antenna.

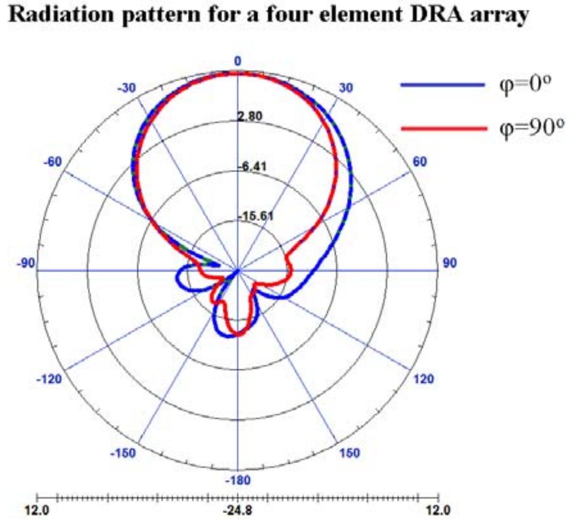

Fig. 8. Antenna radiation pattern of the 4-element antenna array shown in Fig. 6.

6. Conclusions

ZST ceramic resonators are a good choice for high-gain, compact antennas with special characteristics, which do not change when temperature is changed.

Optimal results require careful investigations on the coupling between the resonator and the transmission line as well on mutual coupling between resonators.

The data obtained show that the studied resonator antennas exhibit better characteristics at 4.8 GHz for $HEM_{11\delta}$ mode than for the other investigated modes. Antenna frequency bandwidth is enhanced by adding an extra dielectric resonator to the structure.

An improved gain and a more directive antenna pattern was achieved a array configuration with four elements. The resulted antenna allow high speed data transfer and higher coverage with the same power usage.

Low-cost technologies for producing DRAs of various geometries and new methods for DR excitations will increase the integration in the new telecommunications equipment, where miniaturization and power efficiency is a key element.

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