

# Effect of $\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ : $0 \leq x \leq 1$ Dielectric overlay on the Microstrip Straight Resonator

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## Abstract:

Effect of  $\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ :  $0 \leq x \leq 1$  pellet, in touch overlay on the Ku band resonance characteristics of the Ag thick film microstrip straight resonator is studied. The overlay decreases the resonance frequency, increases the peak transmission and broadens of the resonance curve. The shift in resonance frequency has been used to predict the effective dielectric constant of the multilayer structure. Ceramic composition dependent shift in resonance frequency, broadening of the transmission curve, and increase in peak transmission are observed.

**Keywords** —  $\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ , effective dielectric constant, overlay, straight resonator

## I. INTRODUCTION:

Since the discovery of Ferro electricity in barium titanate ( $\text{BaTiO}_3$ ) in the 1940s, it has been one of the most extensively studied ferroelectric perovskite due to its excellent dielectric, piezoelectric, and ferroelectric properties.[1]

$\text{BaTiO}_3$  has been utilized widely in various electronic components including sensors, electro-optical devices and multi-layer ceramic capacitors (MLCCs).[2,3] Nano-sized  $\text{BaTiO}_3$  materials have been attracting great interest, due to their applications in technical and fundamental research in many areas.  $\text{BaTiO}_3$  nanoparticles are applicable to the miniaturization of microelectronic devices with multilayer ceramic capacitors. Ferroelectrics are being studied as candidates for frequency and phase agile tunable microwave components, such

as tunable filters, tunable oscillators, and phase shifters for application in phased array antennas.[4–10]

However, the relatively large dielectric insertion loss, soft mode effect and limited Q value at high frequency microwave regions limits its overall usefulness. Among the numerous ferroelectric materials, barium strontium titanate  $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$  ~BST has been regarded as a promising candidate for applications in electrically controllable microwave devices.

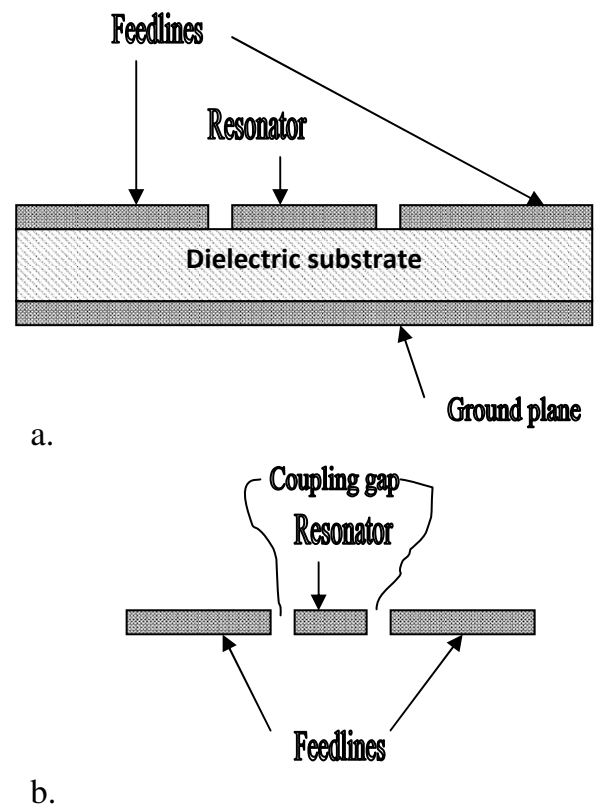
In microwave frequency region, transmission line method, cavity resonator methods are mostly used. To determine dielectric constant an essential part of instrumentation required for such measurements is an appropriate sensor. At present there is no commercially available

equipment capable of measuring directly the relative dielectric constant ( $\epsilon'$ ) and dielectric loss tangent ( $\epsilon''$ ) of materials at microwave frequencies. The usual method of examining the microwave properties of sheet materials is by patterning a simple device such as planar capacitor, co-planer wave guide, microstripsetc and examining their microwave response and evaluating its microwave properties. [11-14] But these methods are destructive, as metal has to be permanently coated on the material.

The use of microwave distributed coplanar sensors by in touch overlay technique is proposed in view of their advantages over other techniques. Desecrate sensors provide measurements in one location, whereas distributed sensors respond to the average values along the sensor, and can be kept in touch with one surface of the test material. This is important is practical application such as moisture content measurement, coplanar sensors can be placed conveniently in contact with one side of the test materials and therefore provide non-distractive measurement of the test dielectric. [15-17]

The microstrip straight resonator is a simple microwave integrated circuit as shown in figure 1. The Q value and resonance frequency of such a circuit is affected by the perturbation. The perturbation can be brought about by use of overlay. The dielectric constant of the overlay

changes the strength of the perturbation, which translates into changes in resonance frequency and peak amplitude of the resonator. The studies in our lab [15–17] on rejection filter, band pass filter, and ring resonator have shown that component characteristics are very sensitive to the type of the overlay. This paper reports the effect of the composition of  $Ba_{1-x}Sr_xTiO_3:0 \leq x \leq 1$  on Ag thick film microstrip straight resonator in the X and Ku band. The changes in resonance frequency have been related to the effective dielectric constant of the overlay BST material.



**Figure 1.:**Microstrip straight resonator:  
**a.**Cross sectional view **b.** Planer view

## II. EXPERIMENTAL

Ferroelectric of composition of  $Ba_{1-x}Sr_xTiO_3$ :  $0 \leq x \leq 1$  was prepared by the Complex Polymerization Method (CPM). The Nanopowders were sintered at  $600^\circ C$ . Formation of nanostructure material was confirmed by XRD. The sintered powders were uniaxially pressed into disks of diameter 13 mm and again sintered at  $500^\circ C$ . The obtained pellet was used as overlay for microwave characterization.

The microstrip straight resonator was delineated by screen-printing the silver paste on 96% alumina substrate. The thick film circuit was fired at  $700^\circ C$ . by conventional thick film firing cycle.

The resonance occurs when length of the resonator is integral multiple of the half wavelength. The length of the resonator is calculated by equations.[18]

$$2(l+l_g) = \frac{n\lambda_g}{2} = \frac{nc}{f_r \sqrt{\epsilon_{r,eff}}}, \quad n = 1, 2, 3 \dots \quad (1)$$

Where  $\epsilon_{r,eff}$  : effective dielectric constant of the substrate.

2l: length of the resonator.

The schematic diagram of the microstrip straight resonator is shown in figure 1. The characterization

of the microstrip components designed was done by measuring transmission and reflection of the microwaves in the frequency range 8 to 18 GHz (X and Ku-bands). The measurements were carried out using Vector Network Analyzer model Agilent Technologies N5230A. The microstrip component was mounted in a resilient MIC (microwave integrated circuit) test fixture. The connection to the coaxial probe of the vector network is achieved using SMA (semi-miniaturized adaptors). For overlay studies the pellet of the composition of  $Ba_{1-x}Sr_xTiO_3$ :  $0 \leq x \leq 1$  was kept as intouch overlay on Ag thick film microstrip straight resonator and  $S_{21}$  measurements were made. The effective dielectric constant of the microstrip component is calculated by using Owen's formula [19]

$$\epsilon_{eff1} = \frac{\epsilon_r + 1}{2} \left[ \left( 1 + \frac{29.98}{Z_0} \left( \frac{2}{\epsilon_r + 1} \right)^{0.5} * \left( \frac{\epsilon_r - 1}{\epsilon_r + 1} \right)^* \right)^2 \right] \left( \left( L_n \left( \frac{\pi}{2} \right) + \frac{1}{\epsilon_r} L_n \left( \frac{4}{\pi} \right) \right) \right) \quad (2)$$

Where  $\epsilon_r = 9.6$ , the dielectric constant of the substrate.

$Z_0 = 50$  ohm

The effective dielectric constant of the multilayer structure (microstripline overlaid with the dielectric) was calculated from the resonance

frequency with and without overlay. By using equation (3)

$$\frac{\epsilon_{eff1}}{\epsilon_{eff2}} = \frac{F_2^2}{F_1^2} \quad (3)$$

Where  $\epsilon_{eff1}$  and  $F_1$  are the effective dielectric constant and resonance frequencies without overlay and  $\epsilon_{eff2}$  and  $F_2$  are the corresponding parameters with the overlay. [20]

### III. RESULTS AND DISCUSSIONS:

The XRD patterns of the samples  $Ba_{0.4}Sr_{0.6}TiO_3$  are shown in the figures 2. The XRD patterns confirm the formation of Nano crystalline powder. All the peaks are ascribed to a tetragonal perovskite structure.

The variation in the transmittance ( $S_{21}$ ) and reflectance ( $S_{11}$ ) with frequency of the designed microstrip ring resonator is shown in figure 3. The resonance (Maximum  $S_{21}$ ) is at 16.58 GHz. The response of the resonator due to the  $Ba_xSr_{1-x}TiO_3$  overlay is shown in the same. From the figure it is seen that, due to the overlay the resonance frequency shifts towards lower frequency side with substantial increase in the peak transmittance. The resonator shows broadband characteristics due to overlay. When the microstrip component is covered by a dielectric material as superstrate or overlay, the fringing field of the microstrip components

interacts with the dielectric, which results in the increased effective dielectric constant of the system, which in turn results in the changes in the characteristics of microstrip component. The impedance, phase velocity and losses change with the dielectric constant, loss tangent and thickness of the overlay material.

Composition of overlay	Resonance frequency (GHz)	Bandwidth (GHz)
No overlay	16.58	0.72
SrTiO <sub>3</sub>	15.20	6.42
Ba <sub>0.2</sub> Sr <sub>0.8</sub> TiO <sub>3</sub>	12.32	3.72
Ba <sub>0.4</sub> Sr <sub>0.6</sub> TiO <sub>3</sub>	8.4.8	1.44
Ba <sub>0.6</sub> Sr <sub>0.4</sub> TiO <sub>3</sub>	12.68	3.96
Ba <sub>0.8</sub> Sr <sub>0.2</sub> TiO <sub>3</sub>	15.38	1.98
BaTiO <sub>3</sub>	13.46	1.44

The straight resonator has four open ends. According to Delinger [20] the open ends of the line excite radiation modes. These ends act like discontinuities having reactive modes associated with it, due to which losses increase in the transmission data ( $S_{21}$ ) of these resonators. The shift in resonance towards the lower frequency side is attributed to the increased effective dielectric constant of the multilayer structure. Due to the dielectric constant of the overlay material the fringing field lines get concentrated, thus increasing the fringing field capacitance which

results in decrease in resonance frequency. The broadening of the resonance curve (increase in band width and decrease in Q value) is due to the lossy nature of the overlay. The thick film microstrip straight resonator is an open circuit so, apart from dielectric losses, radiation losses are also present, the overlay might be suppressing the radiation loss, resulting in increased  $S_{21}$ .

The splitting of resonance curve is due to even and odd modes of coupling. The peak shifting toward lower frequency side is due to even mode of coupling and the peak shifting towards higher frequency side is due to odd mode coupling. The loss value of the odd mode is larger than the even mode. In the coupling sector, the odd mode fields are concentrated and this contributes to the conductor loss. The loss value of the odd mode is larger than the even mode. In the coupling sector, the odd mode fields are concentrated and this contributes to the conductor loss. The even mode contributes more to the frequency dependence of  $\epsilon_{eff}$  than the odd mode [21].

The plot of composition dependent effective dielectric constant of the multilayer structure for the  $Ba_xSr_{1-x}TiO_3$  is shown in figure 4. From the plot it is clear that composition dependent variation in dielectric constant is observed. It is felt that the overlay technique can

be used to predict the dielectric properties of ceramic in the pellet form, using thick film Microstripline components.

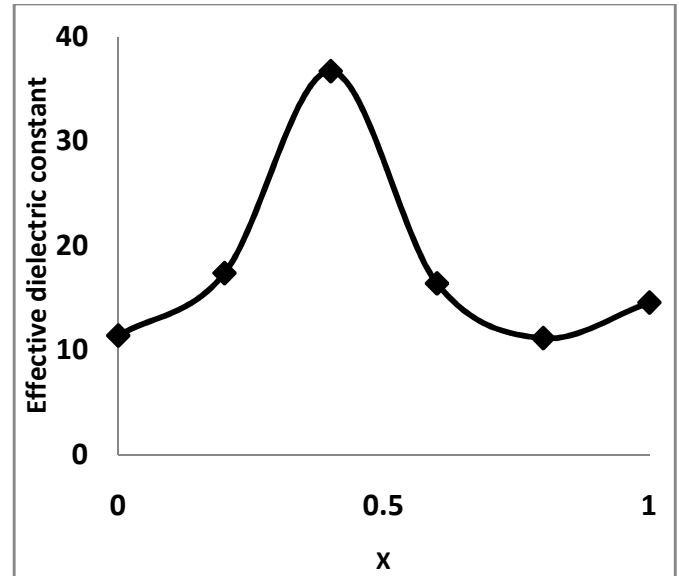


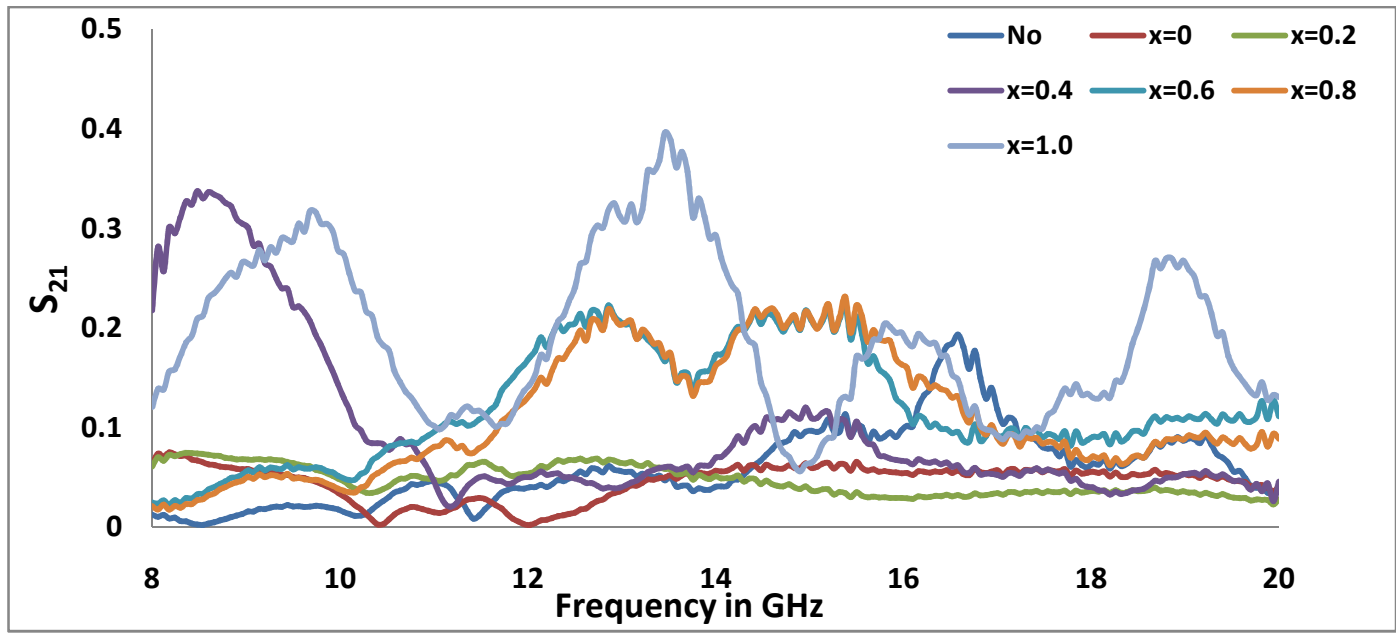
Figure.4: Variation of effective dielectric constant with composition of  $Ba_xSr_{1-x}TiO_3$ , of overlay.

#### IV. CONCLUSIONS

The Ag thick film microstrip straight resonator can be used to predict the properties of dielectric constant of the  $Ba_xSr_{1-x}TiO_3$ . The composition dependent dielectric constant is observed. The overlay of  $Ba_xSr_{1-x}TiO_3$  increases the peak transmission of the microstrip component.

#### V. ACKNOWLEDGMENT:

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**Figure 3:** Variation of transmission coefficient ( $S_{21}$ ) of microstrip straight resonator as a function of frequency, with overlay of  $Ba_xSr_{1-x}TiO_3$

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