Perturbation of Microstrip Straight Resonator due to \( \text{Ni}_{(1-x)}\text{Co}_x\text{Mn}_2\text{O}_4:0\leq x\leq1 \) Thick Overlay

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Abstract:
The effect of \( \text{Ni}_{1-x}\text{Co}_x\text{Mn}_2\text{O}_4:0\leq x\leq1 \) NTC ceramic thick thermistors was synthesized by screen printing and firing. The thick film thermistor was used as in touch overlay on the Ku band Ag thick film straight resonator. The changes in transmission \( S_{21} \) characteristics of the Ag thick film microstrip straight resonator were studied. The overlay decreases the resonance frequency and Q value and increases the peak transmission. The shift in resonance frequency has been used to predict the dielectric constant of the \( \text{Ni}_{1-x}\text{Co}_x\text{Mn}_2\text{O}_4:0\leq x\leq1 \) NTC ceramic thick film.

Key words: Thick film, \( \text{Ni}_{1-x}\text{Co}_x\text{Mn}_2\text{O}_4, \) dielectric constant, overlay

Introduction:
The propagation of electromagnetic waves in dielectrics is accompanied by absorption of energy and variation in the phase of the waves, which depend on permittivity of the medium. The permittivity intern depends other physical properties of the medium such as its moisture content, density and composition. It also varies with frequency and temperature [1]. Recent airborne and deep space applications require the broadband and real time dielectric characterization of the materials at microwave frequencies apart from need of planerisation.

In microwave frequency region, transmission line method, cavity resonator methods are mostly used [2,3]. 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 \( (\varepsilon'') \) and dielectric loss tangent \( (\varepsilon'') \) of sheet materials at microwave frequencies. The usual method of examining the microwave properties of sheet materials is by patterning a simple device such as planner capacitor, co-planer wave guide, microstrips etc and examining their microwave response and evaluating its microwave properties. [4-10] But these methods are destructive, as metal has to be permanently coated on the material.

![Diagram of Microstrip Straight Resonator](image)

**Figure 1:** Microstrip straight resonator:

- **a.** Cross sectional view
- **b.** Planer view along with overlay
The use of microwave distributed coplanar sensors by in touch overlay technique is proposed in view of their advantages over other techniques. Discrete 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 in 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 [11-13].

The end coupled, transmission type straight resonator is a simple microstrip circuit as shown in figure 1. The resonance (maximum transfer of signal) occurs when half-integral multiple of wavelength equals the length of the resonator [14,15]. The Q value and resonance frequency of such a circuit is affected by the perturbation [16,17]. 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 [18-20] on rejection filter, band pass filter, and ring resonator have shown that component characteristics are very sensitive to the type of the overlay. To the authors knowledge there are no reports on the use of Ag thick film microstrip straight resonator to study microwave characteristics of the thick film materials using overlay technique. Ceramics of 3d transition element Mn, Co, Ni, Fe are most widely used as NTC thermistors. For microwave application of the thermistor the microwave properties of the thermistors must be known. This paper reports the effect of the composition of thick film Ni$_{(1-x)}$Co$_x$Mn$_2$O$_4;0 \leq x \leq 1$ on Ag thick film microstrip ring resonator. The changes in resonance have been related to the effective dielectric constant of the overlay thick film.

**Experimental:**

The required thick film Ni$_{(1-x)}$Co$_x$Mn$_2$O$_4;0 \leq x \leq 1$ NTC ceramic was obtained by screen printing and firing the oxalate co-precipitated ceramic powder as described in [21] The microstrip straight resonators as shown in figure 1 was delineated by screen-printing the silver paste on 96% alumina substrate. The thick film circuit was fired at 700°C by conventional thick film firing cycle. The dimensions were calculated using the relation [14,15]

\[
2(l + l_g) = \frac{n\lambda_g}{2} = \frac{nc}{F_r \sqrt{\varepsilon_{r,eff}}} , \quad n = 1, 2, 3... \tag{1}
\]

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

2l: length of the resonator.

$F_r$: is the resonance frequency

For performance evaluation the resonator is mounted in a resilient MIC (microwave integrated circuit) test fixture transmission ($S_{21}$) measurements were made using vector network analyzers (N5230A). For overlay studies the thick film thermistor was kept as in touch overlay on the straight resonator and the transmittance ($S_{21}$) measurements were made.

**Results:**

The variation of the transmittance with frequency of the designed microstrip straight resonator (SR) is shown in figure 2, along with overlay effect. For SR without overlay the resonance frequency is 16.068 GHz with bandwidth 325 MHz. From both the figures 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 thick film overlay.

Since the thick film was deposited on alumina the effect of alumina on characteristics of the straight resonator has also been plotted in figure 2. The value of $S_{21}$ of the thick film straight resonator due to Ni$_{(1-x)}$Co$_x$Mn$_2$O$_4$ thick film lies between 25% to 35% as compared to 22% without overlay.
The value of $\varepsilon_{\text{eff} 1}$ effective dielectric constant of the microstrip component with air as overlay was calculated by using Owen’s formula [22]

$$
\varepsilon_{\text{eff} 1} = \frac{(\varepsilon_{r2} + 1)}{2} \left[ 1 + \frac{29.98}{Z_0} \left( \frac{2}{\varepsilon_{r2} + 1} \right) \times \left( \frac{\varepsilon_{r2} - 1}{\varepsilon_{r2} + 1} \right) \left( \frac{\ln(\pi/2)}{\pi} + \frac{\ln(\varepsilon_{r2})}{\varepsilon_{r2}} \right) \right]^{0.5}
$$

(2)

Where $\varepsilon_{r2} = 9.6$, the dielectric constant of the substrate.

$Z_0 = 50\Omega$. The effective dielectric constant of the multi layer structure (shown in figure 3) was calculated by considering the resonance frequency of the resonator with and without overlay using formula [23].

$$
\frac{f_2^2}{f_1^2} = \frac{\varepsilon_{\text{eff} 1}}{\varepsilon_{\text{eff} 2}}
$$

(3)

Where $f_1$ and $\varepsilon_{\text{eff} 1}$ are resonance frequency and effective dielectric constant respectively without overlay and $f_2$ and $\varepsilon_{\text{eff} 2}$ are the corresponding parameters with the overlay. The calculated values of the effective dielectric constant ($\varepsilon_{\text{ef}}$) as a function of composition of the overlaid thick film obtained are plotted in figure 4. From figure it is seen that the effective dielectric constant of the Ni$_{1-x}$Co$_x$Mn$_2$O$_4;0\leq x \leq 1$ NTC ceramic thick film at Ku band is ~14.5 -15.

The values of resonance frequency, bandwidth, Q value and peak amplitude are tabulated in table 1.
Figure 3: The variation of effective dielectric constant of the microstrip straight resonators as a function of the composition (Ni$_{1.8}$Co$_x$Mn$_2$O$_4$: 0≤x≤1) of thick film overlay.

Table 1: Resonance frequency, peak transmission, bandwidth and Q values of the straight resonators with thick film overlay

<table>
<thead>
<tr>
<th>Composition of the overlaid thick film</th>
<th>Resonance frequency (Hz)</th>
<th>Peak transmission $S_{21}$</th>
<th>Bandwidth (MHz)</th>
<th>Q (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No overlay</td>
<td>16.068</td>
<td>0.34</td>
<td>325</td>
<td>49.4</td>
</tr>
<tr>
<td>Alumina</td>
<td>14.410</td>
<td>0.43</td>
<td>617</td>
<td>23.3</td>
</tr>
<tr>
<td>NiMn$_2$O$_4$</td>
<td>14.946</td>
<td>0.40</td>
<td>552.5</td>
<td>27.0</td>
</tr>
<tr>
<td>Ni$<em>{0.8}$Co$</em>{0.2}$Mn$_2$O$_4$</td>
<td>15.158</td>
<td>0.45</td>
<td>585</td>
<td>25.9</td>
</tr>
<tr>
<td>Ni$<em>{0.6}$Co$</em>{0.4}$Mn$_2$O$_4$</td>
<td>14.394</td>
<td>0.41</td>
<td>617</td>
<td>23.3</td>
</tr>
<tr>
<td>Ni$<em>{0.6}$Co$</em>{0.4}$Mn$_2$O$_4$</td>
<td>14.989</td>
<td>0.41</td>
<td>682</td>
<td>21.9</td>
</tr>
<tr>
<td>Ni$<em>{0.3}$Co$</em>{0.8}$Mn$_2$O$_4$</td>
<td>14.800</td>
<td>0.42</td>
<td>614</td>
<td>24.1</td>
</tr>
<tr>
<td>CoMn$_2$O$_4$</td>
<td>14.833</td>
<td>0.43</td>
<td>194</td>
<td>76.5</td>
</tr>
</tbody>
</table>

Discussion:
When the dielectric material is overlaid on the microstripline, the fringing field of the microstripline interacts with the dielectric materials results in increased effective dielectric constant. The reflective dielectric constant is the dielectric constant experimented for the sensors. In quasi-TEM analysis of microstripline, the effective dielectric constant is the dielectric constant experienced by the sensor (microstrip component). This takes into account the effects of fringing fields in the substrate, the test (overlaid) material, the free space and the geometry of the microstrip component. When the covered sheet material has finite thickness, the energy is distributed in Three different regions shown in figure 4.

The decrease in resonance frequency can be attributed to rise in effective dielectric constant of the microstrip circuit due to overlaid material. The fringing field lines get concentrated,
which increases the fringing field capacitance, which in turn decreases the resonance frequency. The higher effective dielectric constant at higher frequency is due to more interaction of the field with the overlaid material due to smaller size of the resonator. The broadening of the resonance curve (increase in band width and decrease in Q value) is due to the lossy nature of the overlaid material. The thick film microstrip straight resonator is a open circuit so, apart from dielectric losses, radiation losses are also present, the overlay might be suppressing the radiation loss, resulting in increased S21 value.

It is felt that overlay technique can be used to predict the dielectric properties of the thick films using Ag thick film microstrip components.

Conclusion:
The in touch overlay technique has been successfully used to predict the dielectric constant of the Ni_{1-x}Co_{x}Mn_{2}O_{4}; 0\leq x\leq 1 NTC ceramic thick films at Ku band. The overlay decreases the resonance frequency and Q value and increases the transmission at resonance.

References:
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