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Modelling of Discontinuities in $CsNO_3$: PVA Based Multilayer Suspended Microstrip Line

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Abstract— Suspended microstrip line on multilayer Cesium nitrate ($CsNO_3$) – polyvinyl alcohol (PVA) composite film is investigated to determine its dispersion and propagation characteristics. Ansoft HFSS is used to determine the effect of variation in dielectric constant of film on characteristic impedance and effective dielectric constant. Full wave analysis is carried out to extract the electrical equivalents circuits of discontinuities in strip conductor such as step and bend. The result present in the paper can be used in the design of tunable RF integrated circuits (RFICs).

Keywords— Characteristic impedance, effective dielectric constant, discontinuities, composite film, tunable

I. INTRODUCTION

Ferroelectric materials are being widely studied due to their potential use in device applications such as FeRAM and tunable microwave components [1, 2]. Non-linear dielectric response and nonreciprocity under the influence of DC electric field makes these materials useful for such applications. The non linear variation in relative dielectric constant of ferroelectric material with electric field can be used to develop electronically tuneable devices for multiband wireless applications [3-8]. The tunable RF devices developed using ferroelectric films have shown advantages in terms of high speed, higher power handling capabilities, lower cost and size in comparison with other possible solutions (e.g. MEMS).

Since, the design and development of tunable RF front end passive as well as active circuits invariably involves sections of transmission lines and discontinuities; it is essential to model the transmission line structures useful for such applications. Most of the research work reported in the literature is based upon the use of microstrip line [9] or coplanar waveguide [10] for the development of tunable devices using ferroelectric films. Since, suspended microstrip line and inverted microstrip line presents another useful planar transmission line structures (variants of microstrip line) that can be used to develop tunable RFICs; modelling of suspended microstrip line and its associated discontinuities have been focused in the present research work.

In this paper, we report the modeling of suspended microstrip line on multilayer ferroelectric film to determine the variation in characteristic impedance and effective dielectric constant with different dielectric constant of ferroelectric film and frequency and extraction of electrical equivalent circuits for step and bend discontinuities in strip conductor. Full wave FEM (finite element method) based 3D simulator HFSS [11] is used in this modeling.

II. GEOMETRY OF MULTILAYER SUSPENDED MICRO STRIPLINE

The geometry of the structure used in the full wave simulation using HFSS is shown in the Fig. 1. Radiation boundary condition is used to include the effect of open space condition at the top of the suspended microstrip line geometry. The multilayer structure consist of a lossless $CsNO_3$:PVA composite film of thickness 100 µm sandwiched between two dielectric substrates of thickness 254 µm and ε_r= 2.2 and a strip conductor on the top layer having width = W µm and thickness t = 15 µm. An air gap is introduced between the ground plane and dielectric layer (ε_r= 2.2). The physical parameters used in full wave analysis are: side wall separation, a = 5 mm, b = 20 mm, h = 0.708 µm, t_1 = 100 µm, t_2 = 254 µm, t_3 = 100 µm, t_4 = 254 µm, t_5 = and t_6 =15 µm. These parameters are selected to ensure the dominant quasi TEM mode of propagation in this structure. The variation of dielectric constant with bias voltage of $CsNO_3$: PVA composite films have been reported [12].

Suspended microstrip line is a variant of microstrip line which incorporates an air gap between the substrate and the ground plane [13]. The introduction of the air gap results in the reduction of the effective dielectric constant of the propagation medium. This structure permits larger circuit dimensions, leading to less stringent mechanical tolerances and increased accuracy of circuit fabrication as compared with microstrip. The presence of air gap also reduces the conductor loss in the ground plane because most of the electromagnetic energy concentrated in the dielectric substrate**.**

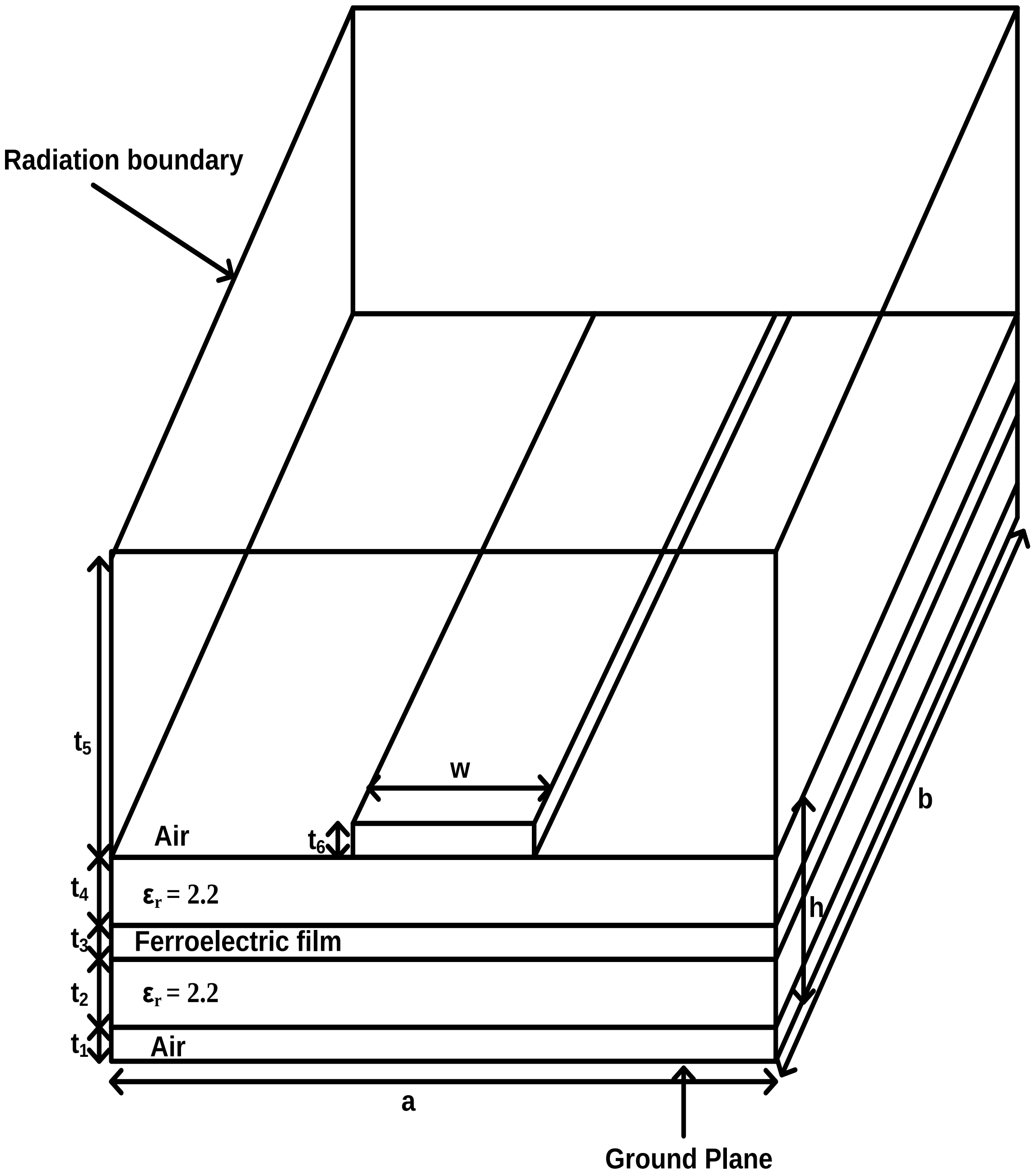

Fig. 1 Geometry of Suspended Microstrip Line on Multilayer Ferroelectric – polymer composite film.

III. CHARACTERISTIC IMPEDANCE AND EFFECTIVE DIELECTRIC CONSTANT OF MULTILAYER SUSPENDED MICROSTRIP LINE

Fig. 2 shows the dispersion characteristics of suspended microstrip line. The ε_{eff} of suspended microstrip line, used in this study, increases with the increase in the frequency from 1 to 20 GHz and it is strongly dependent on dielectric constant the ferroelectric- polymer composite film. For the lower range of ferroelectric film dielectric constant, very little variation in ε_{eff} indicates that the geometry is less dispersive. On the other hand, for the higher values of ferroelectric film dielectric constant, greater variation in ε_{eff} has been observed which shows more dispersion in the electrical characteristics of transmission line. The value of ε_{eff} varies in the range 1.67 – 1.71 for the dielectric constant of ferroelectric – polymer film 5 and from 2 – 2.1 for the dielectric constant of ferroelectric – polymer film 50 with fixed W/h = 1.The frequency dependent variation in the characteristic impedance Z_0 of the suspended microstrip line on multilayer ferroelectric – polymer composite film is shown in Fig. 3. Again, for the lower values of dielectric constant of the ferroelectric film, a negligible variation in Z_0 has been observed; while for larger values of the ferroelectric film dielectric constant, Z_0 decreases with the increasing frequency. For ferroelectric film ε_r = 50, the Z_0 varies from 75 Ω to 78 Ω and for ε_r = 5, Z_o varies from 85 Ω to 87 Ω in the frequency range 1 GHz to 20 GHz. This shows that the electrical properties of the multilayer suspended microstrip line which can be varied by applying electric field of different strengths.

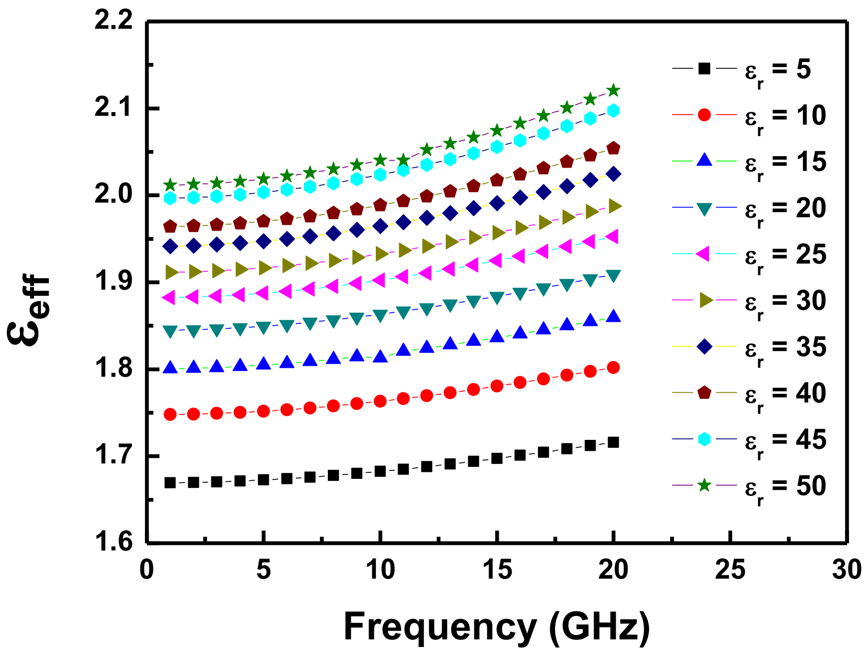

Fig. 2. Variation in effective dielectric constant with frequency for W/h = 1.

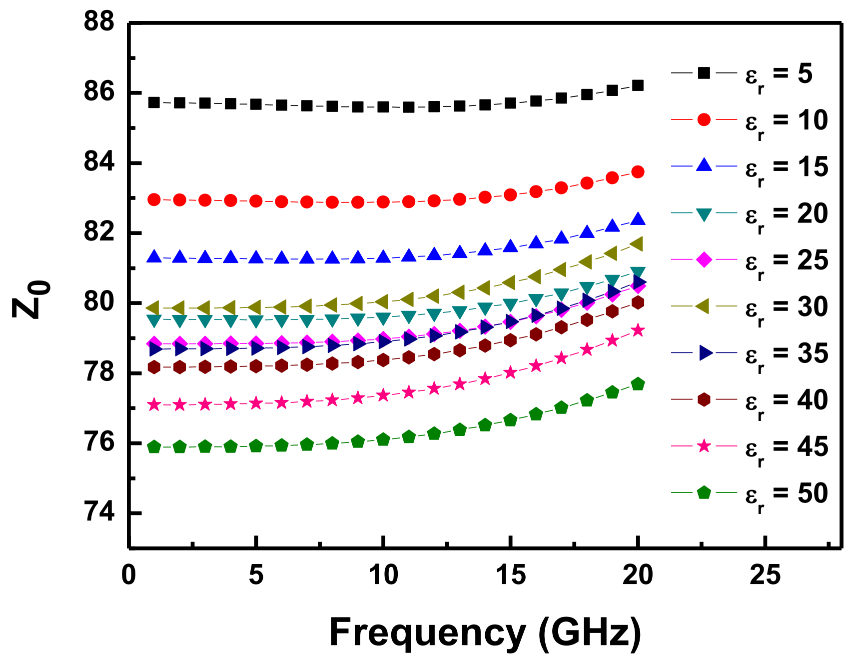

Fig. 3. Variation in characteristic impedance with frequency for W/h = 1

IV. DISCONTINUITIES IN STRIP CONDUCTOR

Passive and active RFICs consist of transmission lines with various types of discontinuities in strip conductor. These discontinuities results from the abrupt changes in the geometry of the strip conductor such as abruptly ended strip conductor, step change in strip conductor width, right angle bend in strip conductor, gap in the strip conductor, slot in the strip conductor [14] etc. Therefore, electric and magnetic fields are modified near the discontinuity. The change in electric field distribution gives rise to an equivalent capacitance and that in the magnetic field result in an equivalent inductance. In the design of RFICs, compensation of discontinuities is widely used to reduce the effects of discontinuity reactance. Characterisation of these discontinuities is essential for the accurate design of RFICs. Since the size of the discontinuities is very small in comparison to the wavelength, they can be modelled using lumped elements. Depending on the type of the discontinuity, the equivalent circuits can be a simple shunt or series element across the line. The component values of an equivalent circuit depend on the parameters of the line and the type of discontinuity, as well as the frequency of operation.

A. Electrical equivalent circuit of step discontinuity

The abrupt change in strip conductor width without any change in substrate thickness and dielectric constant causes the step discontinuities in suspended microstrip line. The geometry and equivalent circuit of double step discontinuity in strip conductor is shown in Fig. 4. The field discontinuities are due to the increase in the current density from wider to the narrower conductor, and due to scattered electric fields on the front edge of the wider conductor. The equivalent circuit parameters are plotted as a function of frequency for different dielectric constant of ferroelectric as shown in the Fig. 5 and Fig. 6.

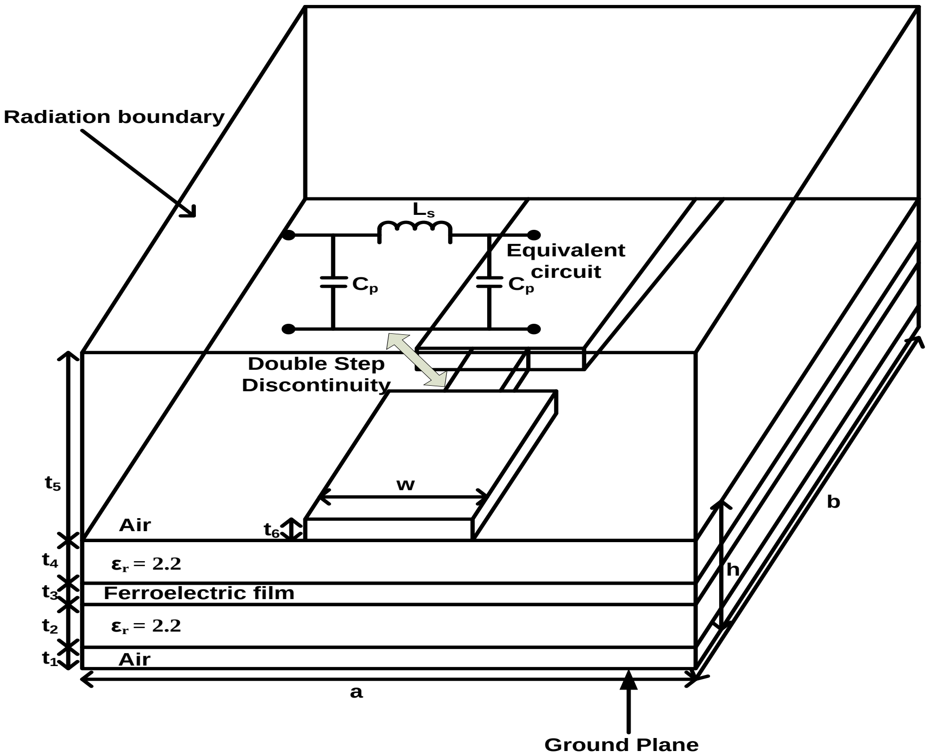

Fig. 4. Double step discontinuity and its equivalent circuit.

The series inductance L_s due to the interruption in the current density at the step from wider to narrower strip conductor, decreases with the increasing frequency while the shunt capacitance C_p due to the disturbance of the electric field near the step, first it increases and then decreases as increasing frequency.

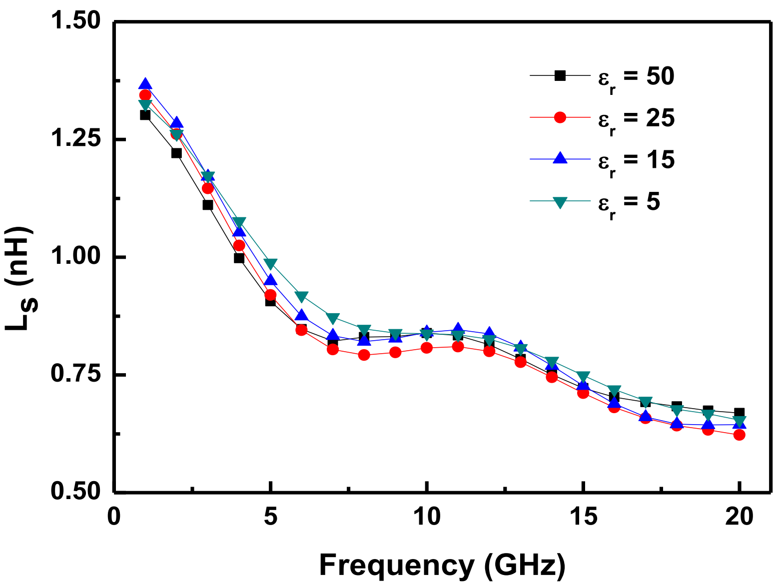

Fig. 5. Variation in equivalent circuit parameters L_s of double step discontinuity with frequency.

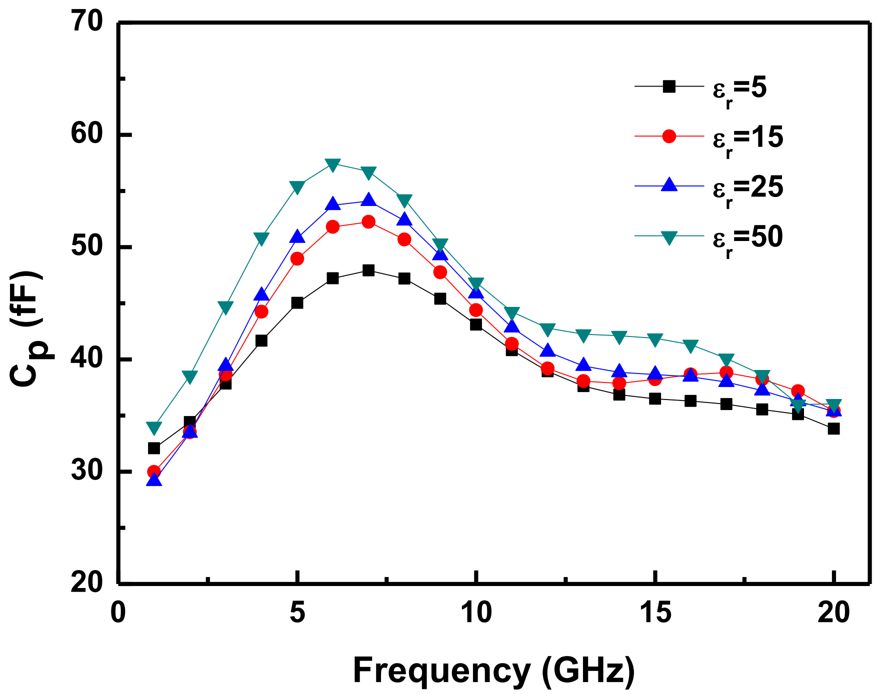

Fig. 6. Variation in equivalent circuit parameters C_p of double step discontinuity with frequency.

B. Electrical equivalent circuit of bend discontinuity

Bend discontinuities are usually right-angle, symmetric changes in direction of the microstrip conductor. The geometry and equivalent circuit of double step discontinuity in strip conductor is shown in Fig. 7.

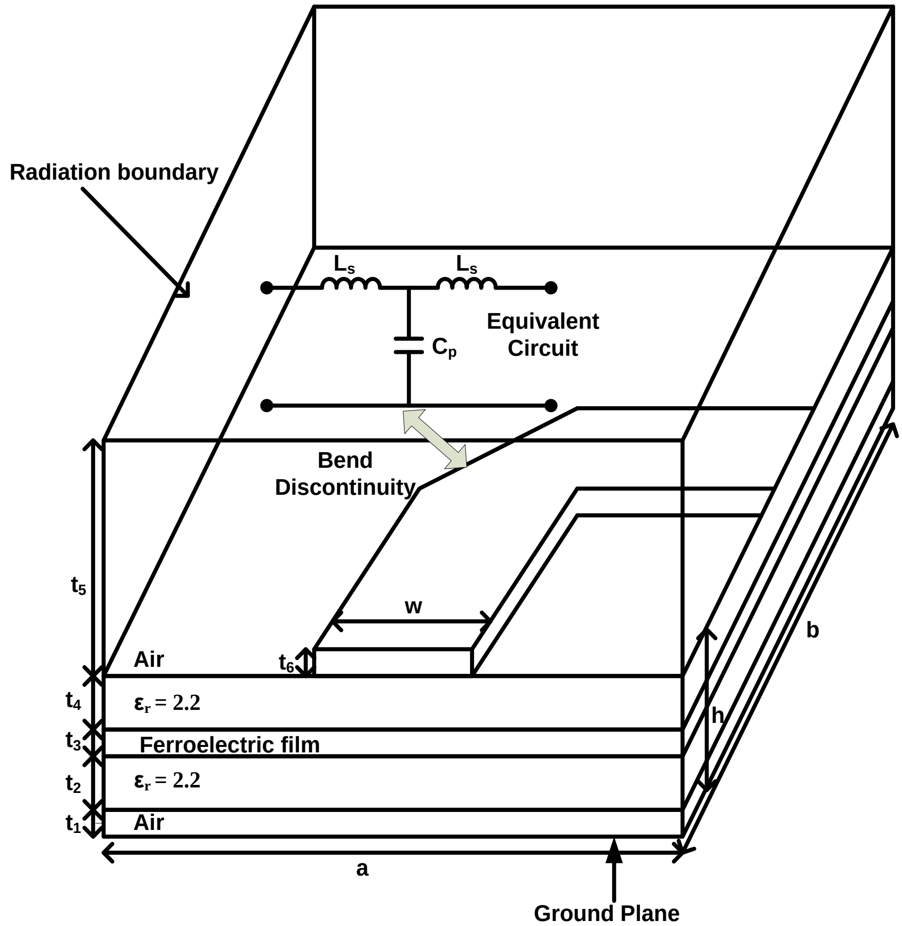

Fig. 7. Bend discontinuity and its equivalent circuit.

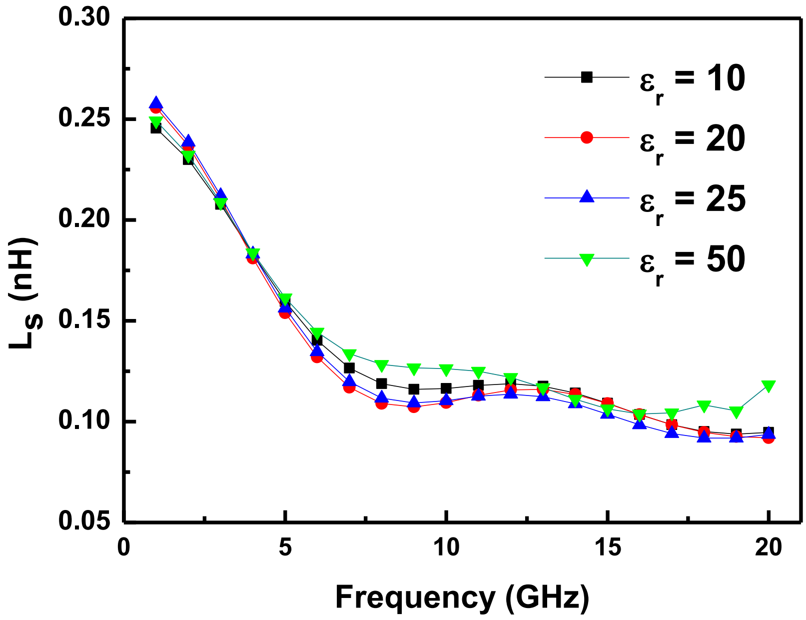

Fig. 8. Variation in equivalent circuit parameters L_s of bend discontinuity with frequency for W/h = 1.

There are field and current discontinuities at the bends, the current lines are concentrated at the inner corner, and there is an extra fringing electric field at the outer corner. The capacitance arises through additional charge accumulation at the corners particularly around the outer point of the bend where electric field concentrates. The inductances arise because of current flow interruption.This is considerable, especially due to the current flows in the outer edges of suspended microstrip. The effect of frequency on parallel capacitance and shunt inductance are shown in Fig. 8 and Fig. 9 respectively.

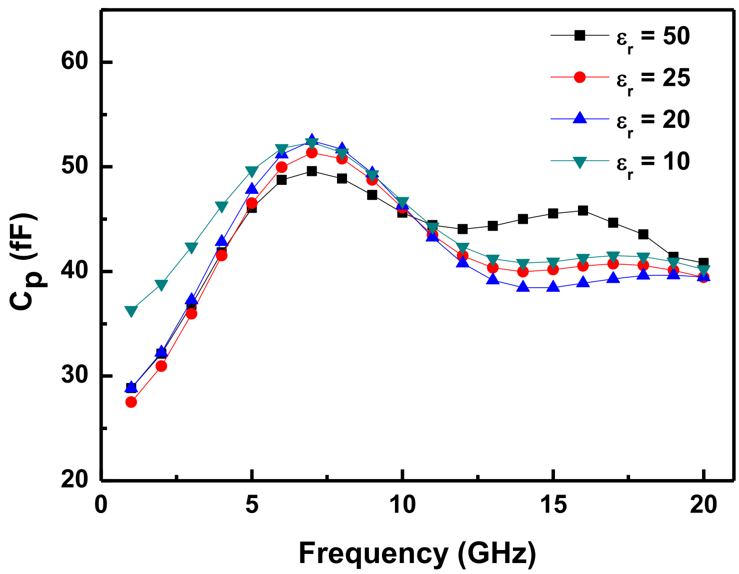

Fig. 9. Variation in equivalent circuit parameters C_p of bend discontinuity with frequency for W/h = 1.

V. CONCLUSIONS

In this paper, we have presented the modeling of multilayer suspended microstrip and its discontinuities. The variation in characteristic impedance and effective dielectric constant and frequency has been calculated and analyzed. The parameter of lumped equivalent circuit for different discontinuities such as step and bend are calculated by using full wave simulator HFSS. The obtained result can be used for the design of passive and active circuit especially tunable component using this transmission line.

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