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# $Ni_{0.1}Co_{0.9}Fe_2O_4$ spinel ferrite as a promising magneto-dielectric substrate for X-band Microstrip Patch Antenna

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***Abstract*— In the present study, the suitability of Ni-Co spinel ferrites as dielectric substrate for microstrip patch antenna has been reconnoitered in X-band frequency range. The scrutinized spinel ferrites with chemical composition $Ni_{1-x}Co_xFe_2O_4$ (x=0.00,0.30,0.60,0.90) were synthesized using Pechini's sol gel method. For the present study, Ansoft Designer SV2 was used to design and analyze the microstrip patch antenna. Simulation of antenna was done at resonant frequency of 10.02 GHz, which makes this research to find application in military and surveillance. Firstly, the antenna dimensions were calculated using resonant frequency and electromagnetic properties of the compositions. The antenna output parameters such as return loss, bandwidth, VSWR (Voltage Standing Wave Ratio), Smith Chart and radiation pattern were subsequently analyzed by the simulation Based on the analysis, Ni-Co ferrite $Ni_{0.1}Co_{0.9}Fe_2O_4$ has come out to be the best alternative out of the studied compositions for its possible usage as efficient dielectric substrate in microstrip patch antenna in 8.2 – 12.4 GHz frequency range.**

***Keywords*— *Ni-Co spinel ferrite; microstrip patch antenna; X-band; VSWR; return loss; miniaturization.***

## I. Introduction (*Heading 1*)

Undoubtedly antennas are the electronic eyes and ears of today's world due to their indubitable place in communication technology. Any type of communication, whether wired or wireless, microwave or optical, involves antenna in one or another form. Antenna is basically a transducer which converts electrical signal to electromagnetic waves and vice-versa. It is an interface between transmitter/receiver and the channel. Its size and characteristics significantly affect the quality of service (QoS) of communication. In last few decades, the communication technology has grown exponentially. Therefore, antenna engineering needs to be reformed accordingly in order to cope up with the prevailing technology [1-2]. It is very interesting to note that lot of work has been done in the field of antenna. Different antennas such as parabolic reflectors, patch antenna, slot antenna, folded dipole antennas have been proposed for different applications. In this revolution of antenna engineering, microstrip patch antennas have emerged out as the most amazing development. These microstrip antennas have wide range of applications in microwave systems including radar, missiles, mobile & satellite communication, navigation, global positioning system (GPS) and biomedical systems, due to their lighter weight, low volume, low production cost, simple planar structure, fabrication ease and conformity [1, 3-4]. These antennas have several technological advantages also such as dual-frequency operation, frequency agility, broad bandwidth, feedline flexibility and beam scanning omnidirectional patterning [5]. Microstrip patch antenna basically consists of a dielectric substrate sandwiched between a comparatively small sized conducting patch on one side and equal sized ground plane on the other side (Fig. 1). The conducting patch can be of any geometry, commonly of rectangular or circular shape [6-7]. Patch dimensions depend on the dielectric constant of substrate and the resonant frequency [8]. This antenna was initially proposed by G.A. Deschamps in 1953 [9], but was popularized by Robert E. Munson and his co-workers in 1970's [10]. Later on, different research groups scrutinized these antennas with different dielectric substrates [11-15].

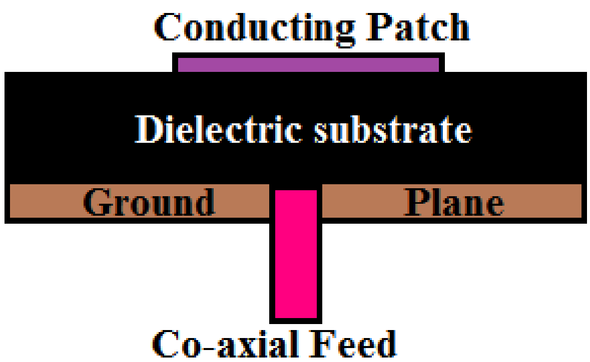


Fig. 1 Structure of Microstrip Patch Antenna

The role of dielectric substrate is very crucial in the design of microstrip antenna. Properties of antenna such as dimensions, efficiency, bandwidth and quality factor depend on the dielectric constant of dielectric material. The height of antenna can be miniaturized by factor $n = \sqrt{\mu_r \varepsilon_r}$ by use of suitable dielectric materials [1, 16]. The miniaturization factor n is also known as refractive index of the material [17]. But the miniaturization should not be done at the cost of compromise with the performance. High dielectric materials, a common choice for miniaturization, don't serve the purpose here as their usage also leads to degradation of pattern and radiation efficiency [12]. In this situation, materials with magneto-dielectric properties are required which allow both reduced antenna size and increased bandwidth [18-19]. Polycrystalline ferrites, having high electrical resistance, good chemical stability and mechanical strength can be employed in these applications [20]. Among magneto-dielectric materials, spinel ferrites come out to be better choice in comparison to hexaferrites due to their lower sintering temperature and low production cost [21-22].

In the present work, Ni-Co spinel ferrites are scrutinized in X-band frequency range for their possible application in miniaturization of antenna. The reason behind choosing X-band for this study is that this band is a popular radar frequency sub-band used in civil, military, air traffic control, defense tracking, vehicle speed detection and weather monitoring applications. The samples under investigation were prepared using sol-gel auto-combustion route. The structural and X-band electromagnetic characterization of these samples has already been reported [23]. In this communication, the X-band complex permittivity and permeability values of the compositions was used to determine the antenna parameters. Then, the performance of the simulated antenna in terms of output parameters such as return loss, 10 dB bandwidth, VSWR, Gain, beam width and radiation pattern is analyzed in the frequency range 7 GHz to 13 GHz.

## II. DESIGN PROCEDURE

### A. *Selection of the material for substrate*

The material to be used for dielectric substrate must fulfill three essential conditions:

1. Resonant frequency of the antenna ($f_r$): $f_r$ must lie within the limits of frequency band for which antenna is being designed. Since, the present antenna is simulated for X-band, hence the resonant frequency of material must lie between 8.2 GHz and 12.4 GHz. The resonant frequency selected for the present design is 10.02 GHz.
2. Permittivity ($\varepsilon_r$) and permeability ($\mu_r$): Material with low permittivity is considered to be better for the design as it provides better efficiency, higher bandwidth, lower quality factor and high radiated power [24]. The use of magneto-dielectric material instead of pure dielectric material helps to minimize the size of antenna. In the present case, spinel ferrites with chemical formula $Ni_{1-x}Co_xFe_2O_4$ (x =0.0, 0.3, 0.6, 0.9) are used as magneto-dielectric substrate for the antenna. The electromagnetic properties, which are used for the simulation of antenna have already been reported elsewhere [23]. As reported in that research, all compositions have real part of permittivity in 5.14-5.69 range, making these spinel ferrites suitable for the antenna design.
3. Dielectric constant: Material with low dielectric constant is considered to be better for the design as it provides better efficiency, higher bandwidth, lower quality factor and high radiated power [24]. In the present case, four spinel ferrite compositions with chemical formula $Ni_{1-x}Co_xFe_2O_4$ (x =0.0, 0.3, 0.6, 0.9) are used as substrate for the antenna. All compositions have dielectric constant in 5.14-5.69 range, making them suitable for the antenna design.
4. Substrate thickness (h): Thick substrate increases the fringing field at patch periphery and increases the radiated power [24]. Also, the height of substrate with feed should lie in X-band frequencies. Hence, the height of substrate is chosen to be 2 mm.

### B. *Determination of patch dimensions ($L_{pat}$ and $W_{pat}$)*

The rectangular microstrip patch antenna is designed by using selective four ferrite samples (NC 0.00, NC 0.30, NC 0.60 and NC 0.90) as substrate. The parameters required for design rectangular patch antenna such as are permittivity ($\varepsilon_r$), dielectric loss tangent (tan $\delta_e$), permeability ($\mu_r$) and magnetic loss tangent (tan $\delta_m$) at operating frequency 10.02 were determined using Vector Network Analyzer (VNA) and are presented in Table 1 [23]. Using the values of $\varepsilon_r$ and $\mu_r$ the length of antenna is determined by formula [25]: $L_{pat}=c/2f_r \sqrt{\mu_r\varepsilon_r}$, where c is the velocity of light in free space. The width ($W_{pat}$) of the antenna is optimized to suppress higher modes of excitation by simulation using Ansoft Designer SV2 [26].

### C. *Determination of substrate ($L_{sub}$ and $W_{sub}$) and ground plane dimensions ($L_g$ and $W_g$)*

For practical considerations, it becomes necessary to have finite ground plane. The dimensions of substrate are equal to that of ground plane and are calculated using equations [27]: $L_{sub} = L_g = 6h + L_{pat}$ and $W_{sub} = W_g = 6h + W_{pat}$,where, h is the substrate thickness. The dimensions of patch are picturized in Fig. 2 and are listed in Table 1.

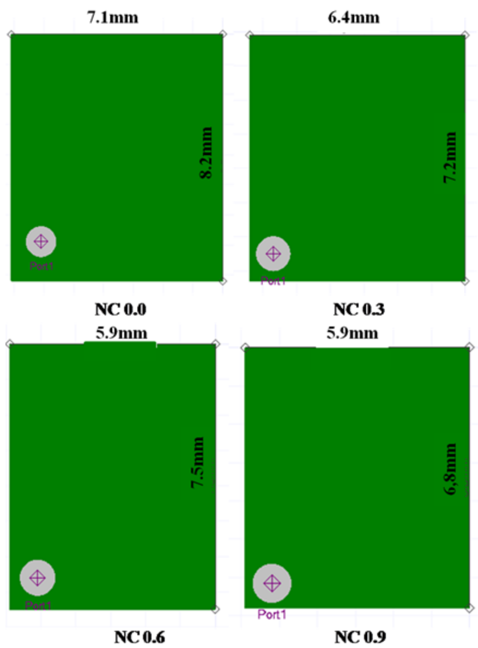


Fig. 2 Geometry of designed antenna

For feeding the microstrip antenna, there are several methods such as feed line, co-axial cable feed, probe feeding, aperture fed, proximity fed etc. But the most common is coaxial probe method due to its different advantages such as easy fabrication, better matching, low spurious radiation etc. The antenna, simulated in the present work, is excited by using coaxial feed technique. The feeding locations for impedance matching of 50 ohms with input impedance are optimized by rigorous trial and error method [28]. Thus the design input parameters of antenna such as permittivity ($\varepsilon_r$), dielectric loss tangent (tan $\delta_e$), permeability ($\mu_r$) and magnetic loss tangent (tan $\delta_m$) at operating frequency 10.02 (fr) are tabulated in Table 1.

TABLE I. ELECTROMAGNETIC PARAMETERS AT RESONANT FREQUENCY, DIELECTRIC SUBSTRATE DIMENSIONS (L & W) AND COAXIAL FEED LOCATION FOR THE ANTENNAS SIMULATED USING SPINEL FERRITE COMPOSITIONS

| Composition | $f_r$ (GHz) | ε' | tan $\delta_e$ | μ' | tan $\delta_m$ | L mm | W mm | Feed Point |
|---|---|---|---|---|---|---|---|---|
| **NC 0.00** | 10.02 | 5.14 | 0.052 | 0.851 | 0.121 | 7.1 | 8.2 | -6.1, -6.9 |
| **NC 0.30** | 10.02 | 5.153 | 0.068 | 1.156 | 0.214 | 6.4 | 7.3 | -5.7, -6.5 |
| **NC 0.60** | 10.02 | 5.444 | 0.07 | 1.186 | 0.136 | 5.9 | 7.4 | -5.1, -6.6 |
| **NC 0.90** | 10.02 | 5.689 | 0.242 | 1.22 | 0.009 | 5.9 | 6.8 | -5.2, -6.1 |

## III. RESULTS AND DISCUSSION

The electromagnetic parameters of the spinel compositions at the resonant frequency 10.02 GHz have been tabulated in Table 1. These parameters for NC 0.90 composition are also plotted in Fig. 3 [23]. The spinel composition NC 00.90 has observed the highest value of permittivity and permeability at the resonant frequency of 10.02 GHz, which has made this composition to be capable of being simulated as the smallest antenna with dimensions 5.9 mm × 6.8 mm. These dimensions are in accordance to the formula provided in Eq. 1.

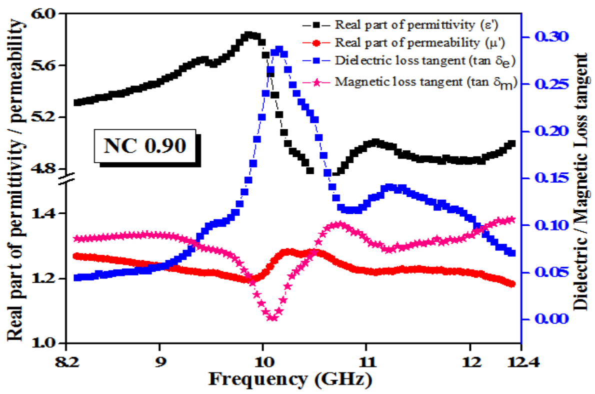


Fig. 3 Electromagnetic parameters of NC 0.90 composition in X-band

The value of miniaturization factor (n) are determined using the experimental values of permittivity ($\varepsilon_r$) and permeability ($\mu_r$) using formula: n= √ ($\mu_r\varepsilon_r$). Its variation w.r.t. frequency for the prepared compositions in X-band is provided in Fig. 4. These values. It can be clearly seen that values of n for NC 0.00 is smaller in comparison to other three doped compositions. Values of n for NC 0.30, NC 0.60 and NC 0.90 lies in range 2.4 – 2.6 while that for NC 0.00 remains close to 2.

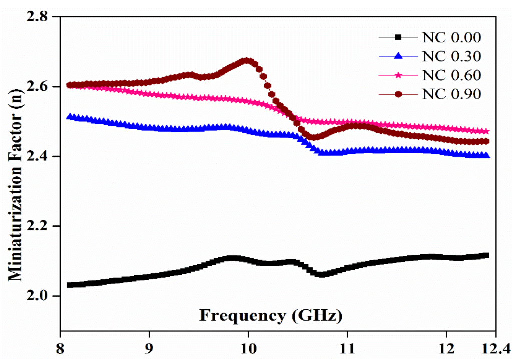


Fig. 4 Variation of miniaturization factor with frequency for ferrite compositions with frequency

The variation of simulated return loss with frequency is presented in Fig. 5. From this figure, it can be inferred that the designed antennas are resonant near the designed operating frequency of 10.02 GHz. The lowest return loss has been observed for the antenna on NC 00 ferrite substrate, owing to its better impedance matching obtained in this composition in comparison of other compositions. The % bandwidth for -10 dB return loss for antennas is provided in Table 2. The highest % bandwidth of 51.00 GHz is observed for an antenna on NC 0.90, whereas it is nearly equal for antennas on other ferrite substrates. The enhancement of bandwidth was also reported for Ni-Zn ferrites [10] and Cd – ferrite [13].

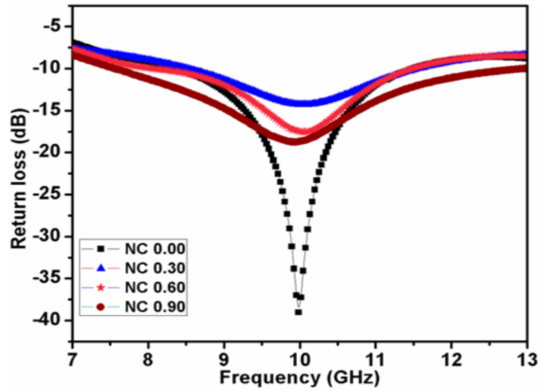


Fig. 5 Variation of simulated return loss with frequency.

TABLE II. OUTPUT PARAMETERS: RETURN LOSS ($R_L$), % -10DB BANDWIDTH, VSWR, GAIN AND BEAM WIDTH OF THE SIMULATED ANTENNAS GOVERNING THE UTILITY OF THE SIMULATION

| Composition | $f_r$ (GHz) | $R_L$ (dB) | % BW (GHz) | VSWR | Gain | Beam Width |
|---|---|---|---|---|---|---|
| **NC 0.00** | 10.00 | -39.50 | 28.58 | 1.027 | 0.67 | 88˚ |
| **NC 0.30** | 10.08 | -17.47 | 27.36 | 1.47 | 0.50 | 85˚ |
| **NC 0.60** | 10.07 | -14.20 | 30.33 | 1.31 | 0.55 | 88˚ |
| **NC 0.90** | 9.94 | -18.72 | 51.00 | 1.26 | 0.42 | 90˚ |

The variation of voltage standing wave ratio (VSWR) with frequency in the range of 7 to 13 GHz is presented in Fig. 6. VSWR is a measure of how well the antenna is attached to the cables or how much power is reflected back into the cable. Ideally, value of VSWR should be 1. And in

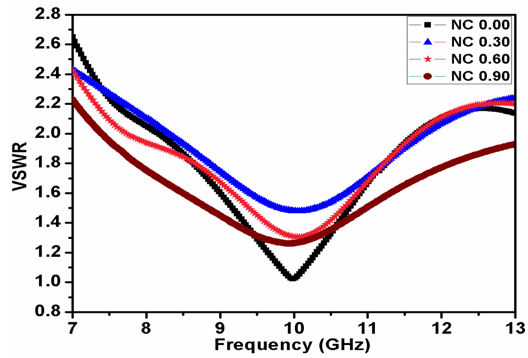


Fig. 6 Variation of simulated VSWR with frequency

our study, VSWR values for 4 compositions have been close to unity at operating frequency, which shows better optimization at feed location. The VSWR for NC 0.90 antenna has low value as compared to other doped compositions. Although the value of gain is minimum for this composition, the highest beam width of 90˚ is achieved by this composition.

The Smith charts and radiation patterns of all antennas are analyzed by simulation. The characteristic Smith chart for antenna NC 0.00 and NC 0.90 are presented in Fig. 7, which shows the variation of impedance with frequency in the range of 7-13 GHz. From Fig. 7, it is seen that impedance shows only inductive loading throughout the range of 7-13 GHz. The reactive impedance of antenna simulated using NC 0.00 is nearly equal to normalized impedance over the studied frequency range. The VSWR at resonant frequency from smith chart is 1.027.

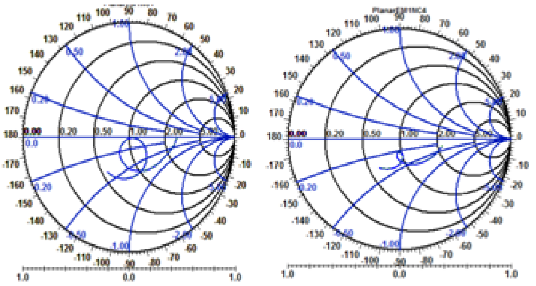

Fig. 7 Characteristic Smith chart of antenna NC 0.00 and NC 0.90

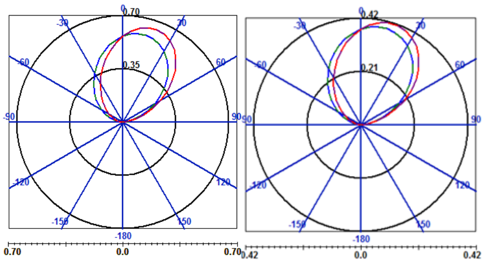

Fig. 8 Representative Radiation pattern of antenna NC 0.00 and NC 0.90

The representative 2D polar radiation patterns of NC 0.00 and NC 0.90 are shown in Fig. 8. From radiation pattern, the values of maximum gain and beam width are calculated for all antennas and are tabulated in Table 2. The maximum gain (0.67) at operating frequency 10.02 GHz has been obtained for composition NC 0.00, while maximum beam width has been obtained for composition NC 0.90. The beam widths of all the antennas lie in 85˚-90˚ range.

## IV. Conclusion

The performance of microstrip patch antenna using Ni-Co spinel ferrites as dielectric substrate has been analyzed in X-band using Ansoft Designer SV 2.2. Using the electromagnetic properties, antenna dimensions have been determined. Antenna simulated using undoped composition has achieved the return loss of -39.5 dB. But the composition NC 0.90 has emerged as the best out of all the four compositions as it has got maximum -10 dB bandwidth % of 51%, maximum beam width of 90˚ and VSWR of 1.26. Also, the antenna fabricated using NC 0.90 has got minimum dimensions (5.9 mm × 6.8 mm) due to its favorable electromagnetic properties. Thus, this composition $Ni_{0.1}Co_{0.9}Fe_2O_4$ can be employed as a promising magneto-dielectric substrate for X-band Microstrip Patch Antenna where bandwidth is a primary issue and gain is a secondary issue.

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