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 δ_e	μ'	tan δ_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.

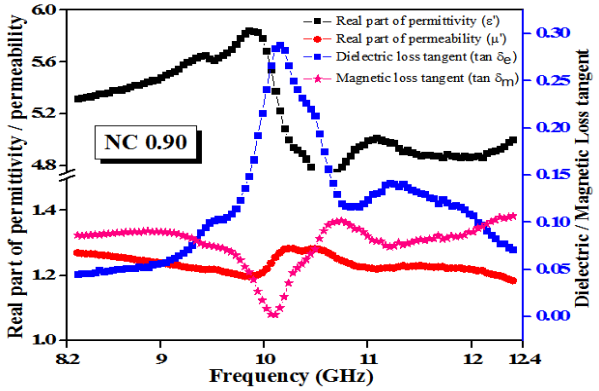

Fig. 3 Electromagnetic parameters of NC 0.90 composition in X-band

The value of miniaturization factor (n) are determined using the experimental values of permittivity (ε_r) and permeability (μ_r) using formula: $n = \sqrt{(\mu_r \varepsilon_r)}$. 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.

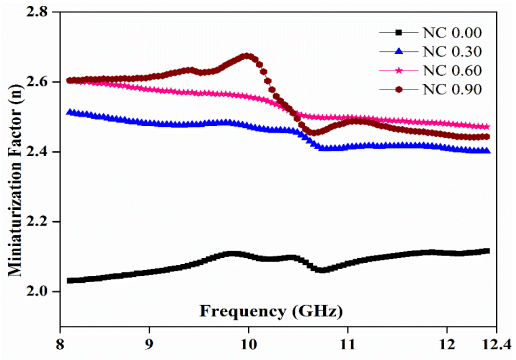

Fig. 4 Variation of miniaturization factor with frequency for ferrite compositions with frequency

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].

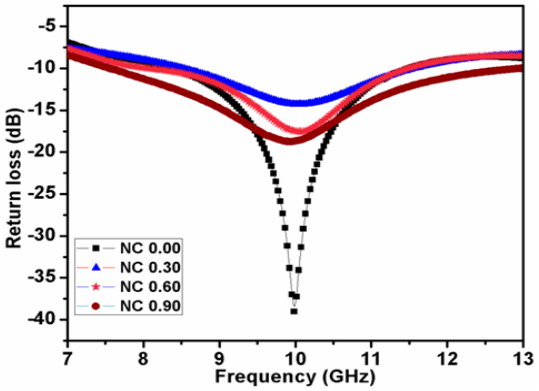

Fig. 5 Variation of simulated return loss with frequency.

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

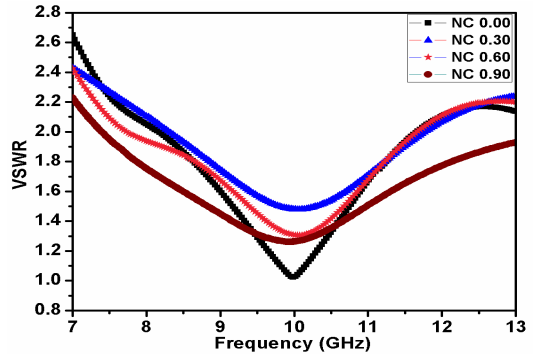

Fig. 6 Variation of simulated VSWR with frequency

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.

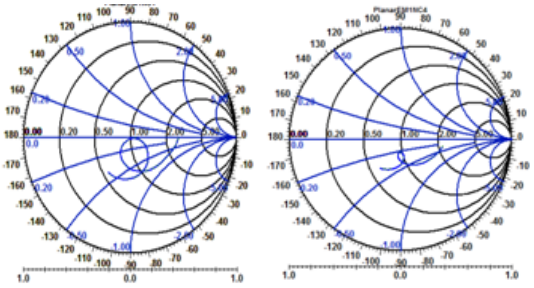

Fig. 7 Characteristic Smith chart of antenna NC 0.00 and NC 0.90

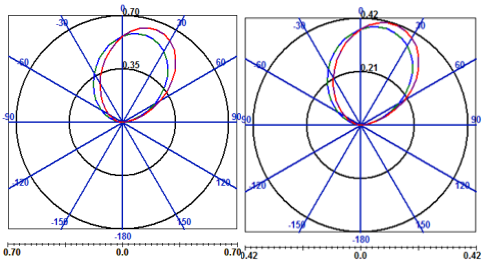

Fig. 8 Representative Radiation pattern of antenna NC 0.00 and NC 0.90

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 $Ni_{0.1}Co_{0.}9Fe_2O_4$ 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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