Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Fabrication and Characterization of 20 MHz Quarter Wave Helical Resonator

To cite this article: Joydip Nandi *et al* 2020 *J. Phys.: Conf. Ser.* **1451** 012005

Fabrication and Characterization of 20 MHz Quarter Wave Helical Resonator

Joydip Nandi[1,2*], Parnika Das[1,2], A K Sikdar[1], Ashif Reza[3], Anuraag Misra[1,2]

[1]Variable Energy Cyclotron Centre,1/AF Bidhannagar, Kolkata-700064, INDIA.
[2]Homi Bhabha National Institute, BARC training School Complex, Mumbai-400094,INDIA.
[3]Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai -400005, INDIA.

*Corresponding author E-mail: j.nandi@vecc.gov.in

Abstract. To increase the signal to noise ratio, helical resonator is generally employed in between trap signal pick up electrode and Low noise amplifier having high input impedance. Based on available literature and simulation study,a 20MHz Helical resonator was designed and fabricated. The measured resonant frequencyand quality factor of the fabricated resonator is 19.67 MHz and 1030 respectively. Simulation results are found in good agreement with the fabricated resonator parameter. Effect of material's conductivity on the quality factor of the resonator is also studied.

Keywords: Electrical Conductivity; Helical Resonator; Penning Ion Trap; Quality factor;

1.Introduction

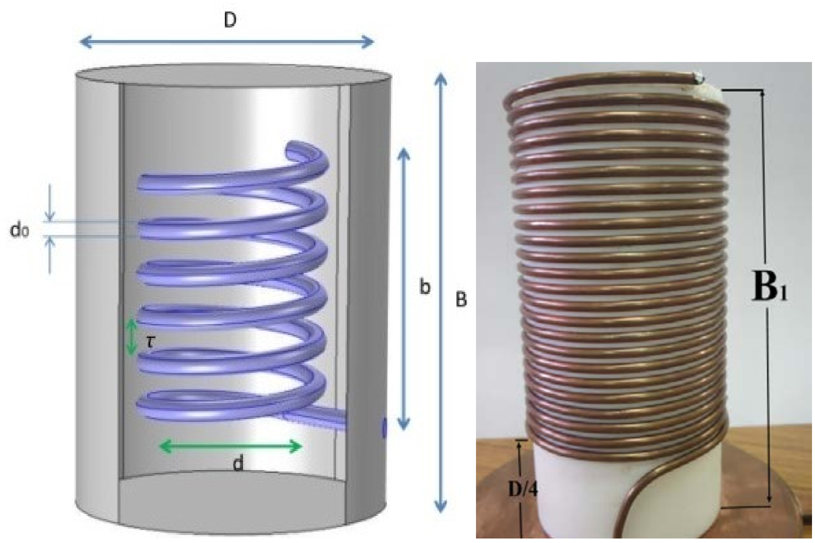
Helical resonator is used in the design of ahigh frequency filter [1-2] in the communication systems due to reasonably high quality factor in a confined volume of space. In ion trapping experiment, the signal from trapped charged particles is generally very feeble. Helical resonatorfinds its application in enhancing signal to noise ratio. Itis also usedin studying the frequency dependent dielectric properties [3].In the Paul trap [4-5],high amplitude RF signal is given through ahelical resonatorwith impedance matchingbetween signal source and ion trap [6].In the Penning Ion Trap, helical resonator is used for the signal detection in resonant detectiontechnique [4,7-9]. Here the resonant transfer of energy between the resonator and the trapped particles, results in dip in the output signal of Low Noise Amplifier.As the size of the helical resonators are comparatively smaller and have predictable parameters at low temperatures, it finds wide application in cryogenic setup.

Helical resonator is a kind of transmission line resonator with helical inner coil with one end shorted with the outer shield. In the short circuit conditions, load impedance is zero. From the transmission line theory, it can be explained that significant amplitude of the wave will be reflected from the short circuit termination and results in standing wave within the resonator volume. Helical structure of the inner conductor will decrease the physical dimension and the electrical length will be nearly equals to quarter wavelength. As an example for 20MHz resonator with 100mm outer shield diameter, quarter wave coaxial resonator will have a length of 3.75 meter with a quality factor as 1878 [10].For the same diameter of the outer conductor and similar resonating frequency, quarter wave helical resonator will be about 132 mm length with a quality factor 880 according to Ref [11].

Considering the above characteristics of a helical resonator, a 20MHz resonator was designed and studied [12]. In this report helical resonator has been fabricated as per design [12] and measured frequency and quality factor is compared with design parameters.

2.Fabrication and Measurement

Helical resonator was initially designed, where the helix was connected with the side wall as shown in Fig-1(a) [12]. In this fabricated resonator, the helical structure is brazed with the bottom plate as shown in Fig. 1(b).



(a) (b)

Fig.1: (a) Initial Design where the Helix was connected to side wall (Representative figure showing less number of turn in the coil). (b) Fabricated Helical coil is shorted in the bottom plate.

Dimension of the fabricated resonator and resonating parameter is given in Table 1. The fabricated resonator connected with two SMA ports shown in Fig.2(a). Both the SMA ports are weekly coupled to the resonator. Measurement of resonant frequency was done by exciting one SMA port from signal generator (AFG-3252C, Tektronix). Output was taken from another SMA and further amplified by ZFL-1000LN+ amplifier. This amplifier shows constant gain of 25dB in our region of interest. The output of the amplifier is connected to the RF port of the Oscilloscope (MDO3032, Tektronix made) as shown in Fig. 2(b). For a fixed amplitude of the function generator, frequency of excitation was varied. We found maximum strength of amplifier's output at 19.67 MHz and from the difference of 3dB frequency, measured quality factor is 1030.

Table1. Design parameter of Fabricated resonator (With copper shield, copper coil and teflon core).

Designed Parameter	Values
Inner Diameter of the Cylindrical Shield (D)	101mm
Axial Pitch of the Helix (τ)	3.4mm
Number of turns	24
Helix diameter	55mm
Length of the Cylinder (B)	132mm
Height of the Teflon Cylinder (B_1)	106.8mm
Thickness of the Teflon Cylinder	3mm
Inner Diameter of the Teflon	49mm
Presence of Groove on the core Material	Yes
Depth of the Groove	1mm
Helical Coil Shorted in	Bottom plate
Simulated Resonating Frequency	20.468
Simulated Quality Factor	1041
Measured Resonating Frequency	19.67 MHz
Measured Quality Factor	1030

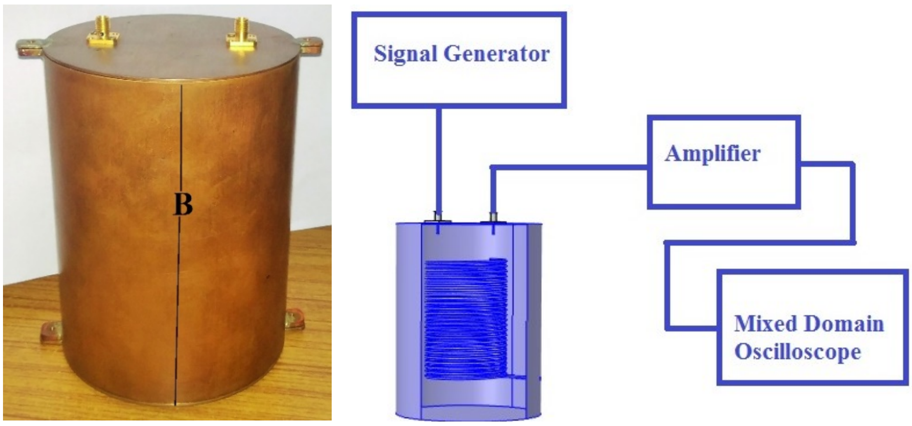
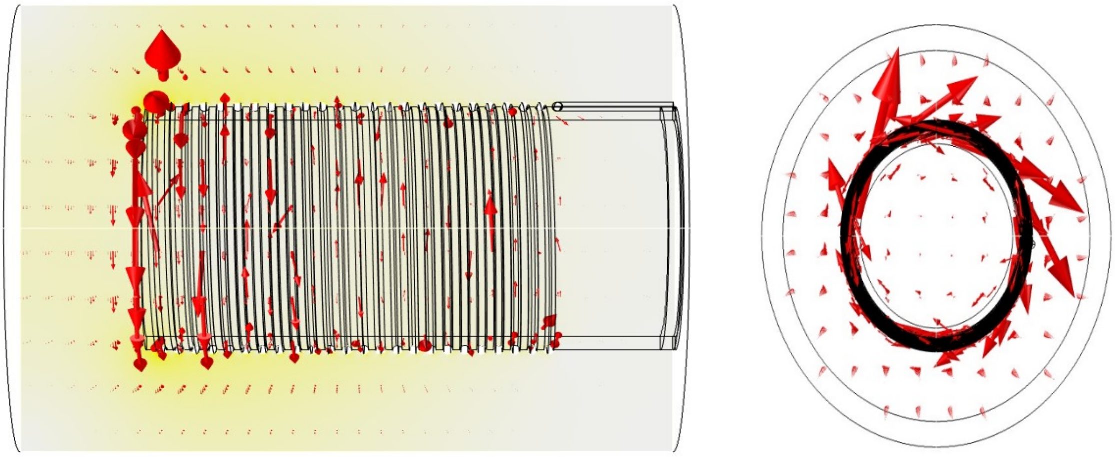


Fig.2: (a) Fabricated 20MHz resonator. (b) Circuit schematic for the measurement of resonator parameter.

3.Simulation Study

Simulation was done using COMSOL Multiphysics incorporating the changes in the design parameter with the parameters of the fabricated helical resonator and we found the resonating frequency as 20.468 MHz and quality factor as 1041. We have found the average power flow within the volume as shown in Fig.3.



(a) (b)

Fig. 3: Time average of power flow (a) side view (b) Top View

There is a negligible effect of dielectric material on the resonator parameter for this resonator has been studied [12]. Hence, we have not considered the effect of dielectric material in the frequency domain analysis. For the different frequency, total electric energy and magnetic energy has been calculated for the 5V peak to peak excitation (as shown in Fig.4) through lumped port boundary conditionswhich is applied in between two conducting boundaries. These ports are acting as a receiver terminal and excitation terminal. Plot shown in Fig.4 is also representing the electromagnetic energy density within the volume at resonant frequency is very high and it is well expected.

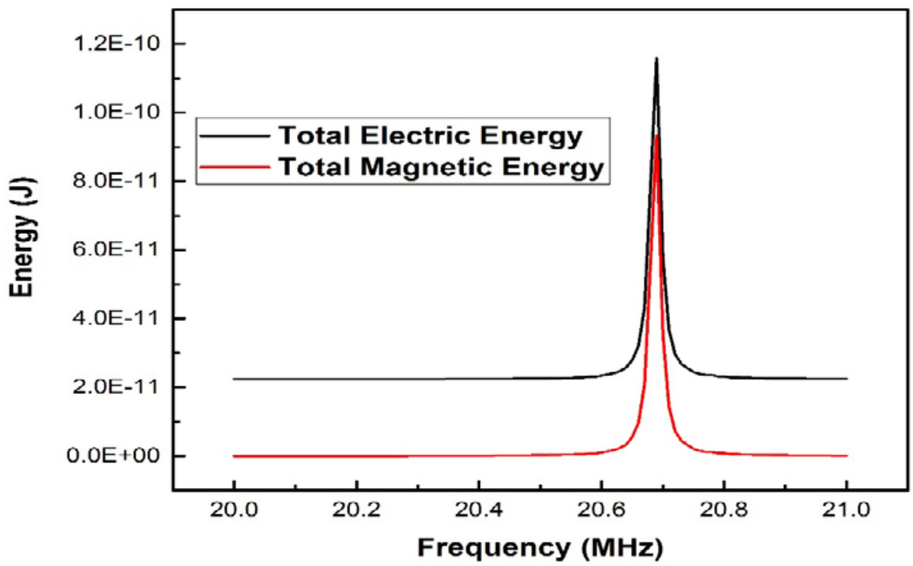


Fig. 4: Total electric and magnetic energy at different frequency of excitation.

To achieve good quality factor electrical conductivity of the helix and shield plays important role. As conductivity of the material decrease, frequency dependent resistive losses will increase.A simulation study on the geometry (without core) for different material has been done and the resonating parameter is tabulated in Table 2. In this simulation conductivity of both shield material and coil has been changed.

Table 2. Resonating Parameter for the different material.

Fabricating Material	Resonating Frequency(MHz)	Quality Factor
Copper	20.688	1017.6
Aluminium	20.686	830.89
Silver	20.689	1068.9

A study has also been done by changing the shape of the outer shield. In this case a block shaped outer shield was taken as shown in Fig.5.

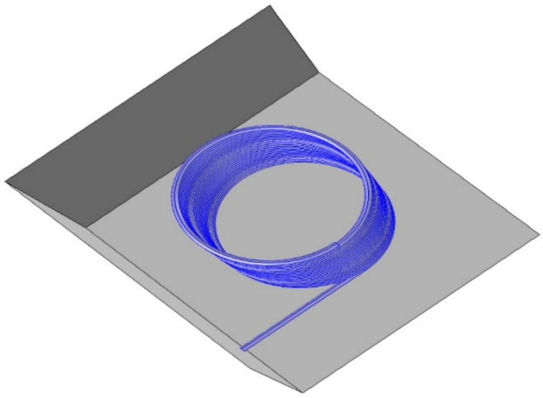


Fig.5: Helical resonator with block shaped shield (three other side are not shown).

Keeping the height of shield same as earlier, Width of the square was taken same as diameter of the cylindrical shield, we found resonating frequency as 20.689 MHz and Q-factor as 1048.2. For the copper material tabulated in Table 2, one can infer that no significant changes found in the resonant frequency. As the volume of block is increased, quality factor increases to 1048.2.

4.Conclusion

In thispaper we had characterized the helical resonator as per simulation design. The measured resonating frequency and quality factor has been found to be in good agreement with the simulation results. Theeffect of electrical conductivity of the fabricating material on the parameter has been studied. The time average flow of the energy within the resonator at the resonating frequency is depicted pictorially.

Acknowledgement

This resonator has been fabricated in VECC workshop. COMSOL Multiphysics community supported this simulation study.

References

[1] Everard, J.K.A.; Cheng, K.K.M.; Dallas, P.A.; "High-Q helical resonator for oscillators and filters in mobile communications systems," Electronics Letters, Volume: 25, Issue: 24, pp.1648-1650, Nov 1989.

[2] Ming Yu, Van Dokas, "High performance helical resonator filters," Microwave Conference,34th European, vol 2, Nov 2004.

[3] R.J. Deri, "Dielectric measurements with helical resonators," Review of Scientific Instruments vol 57, 1986

[4] K. Blaum, "High-accuracy mass spectrometry with stored ions," Physics Reports, vol.425, pp.1-78, Jan 2006.

[5] H Landa, M Drewsen, B Reznik and A Retzker, "Modes of Oscillation in radiofrequency Paul traps," New J. Phys. Vol 14,pp.1367-2630, sept 2012.

[6] J. D. Siverns, L. R. Simkins, S. Weidt, and W. K. Hensinger, "On the application of radio frequency voltages to ion traps via helical resonators," Appl. Phys. B, vol. 107, pp.921-934, Jan 2012.

[7] K. A. Farrar, "Calculation of the electrostatic potential field for an open end- cap cylindrical penning trap" Nuclear Instruments and Methods in Physics Research A 485, pp.780-796, 2002.

[8] A Reza, A. Misra, S. Sarkar, A. K. Sikdar, P.Das "Development of a Helical Resonator for ion trap application," 2015 IEEE Applied Electromagnetics Conference, Dec. 2015.

[9] A. Reza, K. Banerjee, P. Das, "An in situ trap capacitance measurement and ion-trapping detection scheme for a Penning ion trap facility," Rev. Sci. Instrum, vol. 88, pp.034705, March 2017.

[10] P. Vizmuller, "RF Design Guide: Systems, Circuits, and Equations, Artech house, 2nd Edition,1995.

[11] W. W. Macalpine, and R. O. Schildknecht, "Coaxial resonators with helical inner conductor," Proc. IRE, vol. 47, pp.2099-2105, Dec 1959.

[12] Joydip Nandi, Ashif Reza, Anuraag Misra, and Parnika Das, "Design of Helical Resonator for the Detection of Signal in Penning Ion Trap," Journal of Physics: Conf. Series, Vol 1172, conference-1,2019.