RESEARCH ARTICLE OPEN ACCESS

Reconfigurable Impedance Matching Network using RF MEMS Based Switch for 5G Transceivers

Reka Dharmalingam*, T. Aporva Yogalakshmi**, M.R. Gokul bharathi**, B. Jaswanth Narayanan**

*Assistant Professor & Research Guide, ECE Dept., Dr. Mahalingam College of Engineering and Technology, Coimbatore, Tamilnadu,India(e-mail: rekad@drmcet.ac.in)

**Under Graduate, ECE Dept., Dr. Mahalingam College of Engineering and Technology, Coimbatore, Tamilnadu,India(e-mail: {aporvayogalakshmi,mrgokul1999,jadduonboard}@gmail.com

--************************----------------------------------

Abstract:

The upcoming transition towards 5G technology leads to tremendous growth in the field of Wireless communications and there is need for novel technology which is cost affordable and has higher throughput, better coverage and capacity. The 5G technology needs smart phones to fit more antennas into less space. This increases complexity in the RF Handsets as there is need for redundant Impedance Matching Networks (IMN) corresponding to each antenna to ensure maximum power transfer by reducing mismatch losses. In order to resolve the encountered problem, Microelectromechanical switches (MEMS) incorporated IMN has to be designed as they have better performance, power handling capability, less power consumption and low losses at high frequencies. MEMS based Radio Frequency (RF) switches offers reconfigurable nature to the networks which in turn avoids presence of hardware redundancy consuming much space in chip area. In this paper work, a RF MEMS switch based Reconfigurable IMN is designed for 5G applications operating at sub-6GHz. The matching network is designed using Lumped Element Network method. Electromagnetic modelling of MEMS Switches are done using COMSOL Multiphysics and Simulation results of S-Parameters for the designed reconfigurable IMN are obtained using Advanced Design System that showed maximum response at desired frequencies.

Keywords —**Impedance matching networks, Radio Frequency, Fifth Generation Network, Scattering parameters, RF MEMS Switches, Advance Design Systems, COMSOL Multiphysics.**

--************************----------------------------------

I. INTRODUCTION

Wireless Communication technology has been progressing persistently since the deployment of first generation mobile networks by overcoming a lot new challenges in terms of technology, efficient utilization of spectrum and most importantly how compact the developed complex technologies can be provided to the end users. Due to rapid growth in the number of users and the demand for high speed connectivity, it is necessary to develop and establish networks that will meet out the requirements. The scope of 5G is huge as it will elevate the network to interconnect people and Internet of Things (IOT) by delivering multi-Gbps peak rates, ultra-low latency, massive capacity and more uniform user experience. RF handsets deals with Multiple Input Multiple Output (MIMO) array of antenna in order to cover wideband range of 5G [1]. In case of 5G communication devices as specific application, when Maximum power transfer is of major concern, multiple Impedance Matching Networks(IMN) operating at different frequencies are required to match a particular source and load impedance as the RF passive components that composes IMN are frequency dependent. This increases the space complexity and hardware redundancy. Thus reconfigurable nature of networks can be the optimal solution for reducing such redundant circuits.

The designed reconfigurable IMN with RF MEMS incorporated Switch operates at Bluetooth and Wi-Fi Standards which are the subset frequencies of FR1 Band of 5G technology. The matching network assumes Power Amplifier (PA) with source impedance of 12Ω [2] as per the standard at its input stage and Antenna with load impedance of 50Ω at its output stage. RF MEMS incorporated Switches reconfigure the matching network to ensure the impedance matching at both Bluetooth (2.4 GHz) and Wi-Fi Standards (2.4/5.8 GHz) reducing the need of redundant hardware circuits.

A. Impedance Matching Network

Impedance Matching can be done in three ways based on their application. The Transmission Line Matching technique uses a single or double stub which is open circuited or short circuited connected either in parallel or in series with the transmission feed line at a certain distance from the load whereas a transformer line matching makes one impedance look like another by using the turns ratio. For simple applications,single section transformer can be used and for those requiring more bandwidth multi-section transformers can be used.

As designing matching networks that exhibits characteristics at distinct point results in effective impedance matching, the Lumped Element Matching is adopted in this work. The lumped element network consists of reactive components such as capacitor and inductor instead of resistive element as it is a lossy component by nature. Based on the structure of the network, the lumped element matching has three types of networks: L-Network, T-Network and Pi (Π)-Network [3]. In this work, a T-Matching circuit (see Fig.2) is chosen so that it can be used for both upward and downward impedance matching. It is a dual π match circuit. T-match allows setting impedance transformation ratio and Q-Factor/Matching Bandwidth of circuit independently[4].

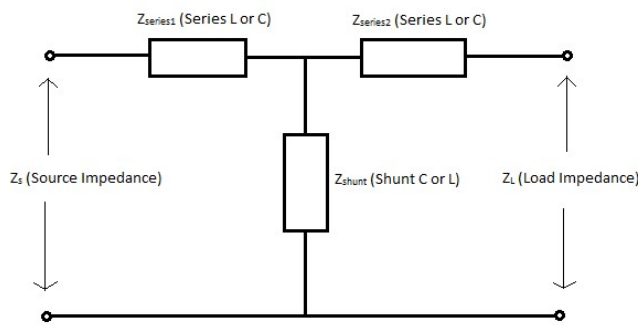

Fig. 1 Matching with Lumped Element using T-Network

B. Introduction to RF MEMS Switches

The Microelectromechanical systems (MEMS) are miniatures scaling about Micro (10^-6) in range. The RF MEMS switch performs RF signal switching by physically blocking or opening the transmission path in microwave devices to achieve transmit/receive operation.This switch consists of two sections: a mechanical and an electrical section. RF-MEMS switches are classified based on Form of contact, Mechanical structure, Actuation mechanism, and Circuit configuration which are listed in the Table I & II.

TABLE I
RF MEMS SWITCH ACTUATION METHODS AND PROPERTIES

Actuation Method	Power Usage	Force Applied	Speed
Thermal	High	Moderate	m sec
Magnetostatic	Medium/High	High	m / μ sec
Electrostatic	Low	Moderate	μ sec
Piezoelectric	Medium/High	Low	m sec

TABLE III
CLASSIFICATION OF RF MEMS SWITCH

Parameters	Type I	Type II
Contact type	Series Configuration	Shunt Configuration
Mechanical structure	Cantilever beam	Fixed-Fixed beam
Form of contact	Ohmic	Capacitive

II. RF MEMS SWITCH SELECTION AND PERFORMANCE

This work makes use of two switches: a Cantilever Beam ohmic type switch in series (see Fig.2) and a Fixed-fixed beam capacitive type switch in shunt configuration (see Fig.3). Electromechanical RF switches are a better option among PIN Diode & FET switches as the former has better performance, power handling capability, less power consumption and low losses at high frequencies [5]. The mechanism for actuation was chosen to be electrostatic as this mechanism uses low power, needs moderate force to be applied in order to bring the beam into contact and switching speed of switch is about microsecond.

The reason for using cantilever beam resistive type switch in series is that it gives direct metal to metal contact when connected in series to the RF signal path [6]. On the other hand Fixed- fixed beam capacitive type switch is used in shunt due to its performance and capacitance offered at high frequencies.For Modelling and design of cantilever beam and Fixed-Fixed beam, the Geometrical, Electrical and Mechanical Parameters are to be analysed.

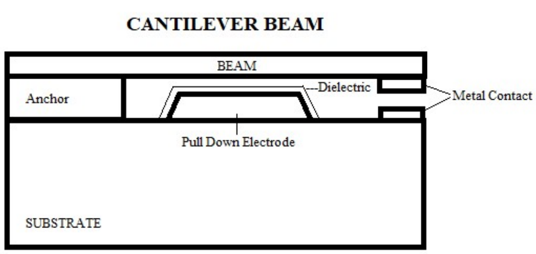

Fig .2Front View of Switch model with Cantilever beam

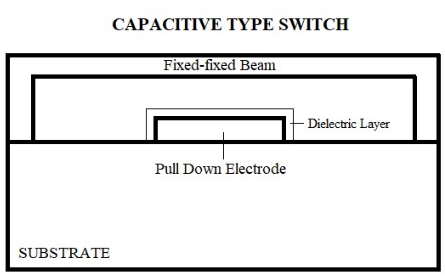

Fig .3Front View of Switch model with Fixed-Fixed beam

C. Mechanical Design and Modelling

The first step in understanding the mechanical operation of RF MEMS switches is to derive the spring constant of the fixed–fixed or cantilever beam. The spring constant of Cantilever beam due to applied force at the center,

$$k_c = \frac{2Ew}{3}\left(\frac{t}{l}\right)^3 \frac{1-(x/l)}{3-4(x/l)^3+(x/l)^4}$$

When the force is applied at the center of a Fixed-Fixed beam, the spring constant is given by,

$$k_c = \frac{2Ew}{3}\left(\frac{t}{l}\right)^3 \frac{1-(x/l)}{8(x/l)^3-20(x/l)^2+14(x/l)-1}$$

Here w & l are the width & length of the electrode between anchor and beam. When a voltage is applied between a fixed–fixed or cantilever beam and the pull-down electrode, an electrostatic force is induced on the beam. It can be calculated by,

$$F_e = \frac{\varepsilon_o A V^2}{2g^2}$$

The necessary voltage required to deform the beam is said to be the Pull-in voltage and it can be calculated by,

$$V_p = \sqrt{\frac{8kg_o^3}{27\varepsilon_o A}}$$

The time required for a mechanical membrane to change from one state to another (either ON or OFF) is called as switching time and it is given by,

$$t_s = 3.67\frac{V_p}{V_s\omega_o}$$

D. Electrical Design and Modelling.

To know the electrical behavior of the switch, the cantilever beam series switch and fixed-fixed beam shunt switch are represented in the circuit model as inFig 4 & 5. The switch impedance (Z_s) of series and shunt configuration are given by,

$$Z_{series} = \frac{2}{j\omega C_s} + \frac{1}{j\omega C_p}$$

$$Z_{shunt} = R_s + j\omega L + \frac{1}{j\omega C}$$

Here R_s is the switch resistance, C_s is the series capacitance and C_p is the Parasitic Capacitance.

In shunt switch, current conducts through bridge to ground during actuation of switch. When R_b is the bridge resistance and R_{cpw} is the coplanar waveguide (CPW) line resistance, the total resistance of switch is given by,

$$R_s = R_b + R_{cpw}$$

The bridge resistance is given by,

$$R_b = \frac{\sigma_b (L/2)}{A_{cr}}$$

Here σ_b is electrical resistivity of bridge material, L is the length of bridge and A_{cr} is the area of the bridge. In order to have low RF power loss during the actuation state of RF MEMS switches, bridge materials with low resistivity are preferred.

When switch is in unactuated state, the up-state capacitance (C_{up}) is due to the air and insulator capacitance in series and it is given by,

$$C_{up} = \frac{\varepsilon_o A}{g + \frac{t_d}{\varepsilon_r}} + C_f$$

Here t_d is the dielectric thickness, ε_r is the relative permittivity and C_f is the fringing field capacitance. When switch is in actuated state, bridge metal-dielectric-signal line conductor forms the down state capacitance which sorts the signal line to ground and it is given by,

$$C_{down} = \frac{\varepsilon_o \varepsilon_r A}{t_d}$$

For wide band operating regime required high capacitance ratio is given by,

$$C_{ratio} = \frac{C_{down}}{C_{up}}$$

Here C_{down} is the capacitance offered by switch at ON state while C_{up} is during OFF state.

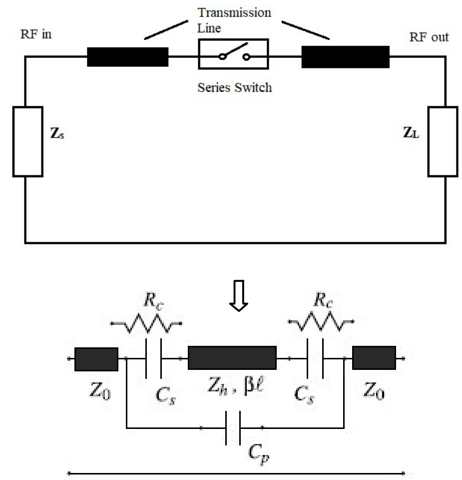

Fig.4 Circuit and Equivalent model of series switch

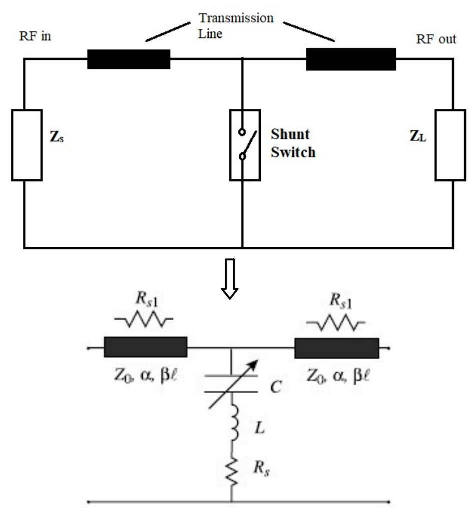

Fig.5 Circuit and Equivalent model of shunt switch

III. DESIGNED RF MEMS SWITCHES AND RECONFIGURABLE IMPEDANCE MATCHING NETWORK

The Cantilever Beam Ohmic type series switch and Fixed-Fixed Beam Capacitive type shunt switch are electromagnetically modelled using COMSOL Multiphysics and the extracted schematic equivalents of switches are implemented with IMN components which make the network reconfigurable by operating at Bluetooth and Wi-Fi frequency. S-Parameter analyses done in ADS are used for Performance analyses of the components over different frequencies.

E. Design of RF MEMS Switch

The Geometrical and material parameter descriptions with calculated values for electrostatically actuated Cantilever beam ohmic type series switch and Fixed-Fixed Beam Capacitive type shunt switch are listed in Table 3 & 4 and the switch structure designs are in Fig 6 & 7 respectively.The achieved capacitances from both the switches are schematically modelled as equivalent series and parasitic capacitance with transmission line characterised with the same width as that of the cantilever beam.The values of equivalent components (capacitor, inductor and resistor) that compose the Schematic series and shunt switches are given in the Table 5 & 6 respectively.

TABLE IIII
GEOMETRICAL, ELECTRICAL AND MATERIAL PARAMETERS OF DESIGNED SERIES SWITCH

Parameters	**Notation**	**Values**
Length of Beam	L	300 μm
Width of Beam	W	$25\mu m$
Thickness of Beam	t	$2\mu m$
Relative Permittivity of air	ε_o	1.006
Bias on the cantilever beam	V_o	5 V
Beam construction material	-	Aluminium
Young's modulus of Al	E	69 GPa
Poisson ratio of Al	ν (nu)	0.334
Density of Al	ρ (rho)	2.7 g/cm^3

TABLE IVV
GEOMETRICAL, ELECTRICAL AND MATERIAL PARAMETERS OF DESIGNED SHUNT SWITCH

Parameters	**Notation**	**Values**
Length of Beam	L	100 μm
Width of Beam	W	$100\mu m$
Thickness of Beam	t	$2\mu m$
Insulator Height	t_d	$0.1\mu m$
Length of Beam Meander	l_m	50 μm
Relative Permittivity of Insulator	ε_r	7.5
Initial Voltage on beam	V_o	1 mV
Step voltage	V_{step}	5V
Beam Material	-	Aluminium
Material used as Insulator	-	Silicon Nitride
Spring stiffness	k	$1^{15}\ N/m^3$
Contact Force	N	$5^5 Pa$

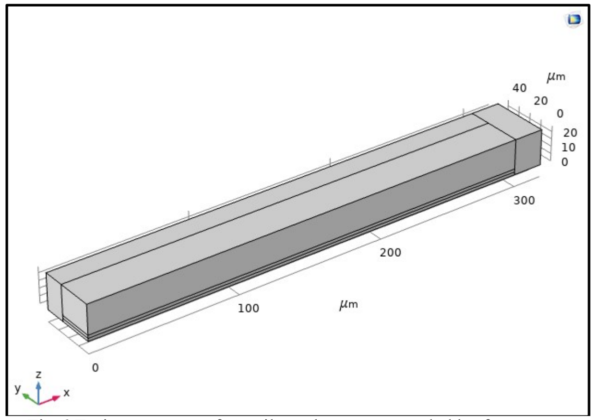

Fig.6 Entire structure of Cantilever beam surrounded by free space

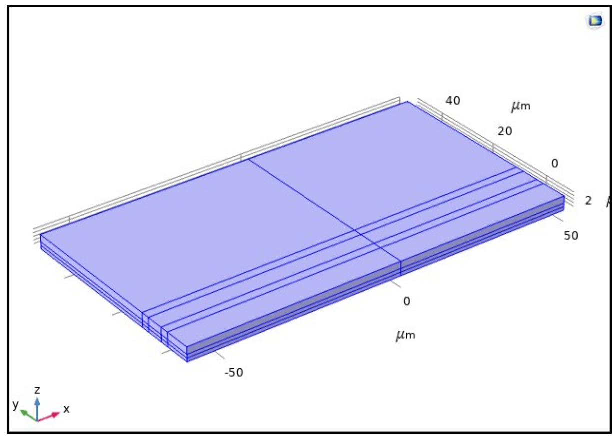

Fig.7Fixed-Fixed beam viewed as $(1/4)^{th}$ of the entire structure

TABLE V
EQUIVALENT ELEMENTAL VALUES OF RF MEMS SERIES SWITCH

Parameter	**Component**	**Value**
Series capacitance 1	C1	1.5fF
Series capacitance 2	C2	1.5fF
Parasitic Capacitance	C3	5.8pF

TABLE VI
EQUIVALENT ELEMENTAL VALUES OF RF MEMS SHUNT SWITCH

Parameter	**Component**	**Value**
Shunt capacitance	C1	1.6pF
Shunt Inductance	L3	4pH
Shunt resistance	R1	0.1Ω

F. Designed Reconfigurable IMN for 5G Applications

Fig 8 is the Schematic design of RF MEMS based switch incorporated Reconfigurable IMN when both the switches are in ON STATE and Fig 9 is the network when switches are in OFF STATE. The Coplanar waveguide used is a Ground-Signal-Ground Configuration for easy calibration with $5/25/5\mu m$ (G/W/G) for both series switch and shunt switch.

IV. RESULTS AND DISCUSSION

The RF MEMS Cantilever beam Ohmic type switch and Fixed-Fixed Beam Capacitive type switch performance are studied using COMSOL Multiphysics software. The Total Displacement of the beam, applied Electric potential, Contact force and Offered Capacitance are the parameters analyzed after the study. The schematic equivalents of both switches were found and the proposed reconfigurable impedance matching network is simulated over a wide range of frequencies in Advanced Design System. The S-Parameter analysis is done to obtain return loss and the same is checked for desired impedance matching between the source and load using Smith chart.

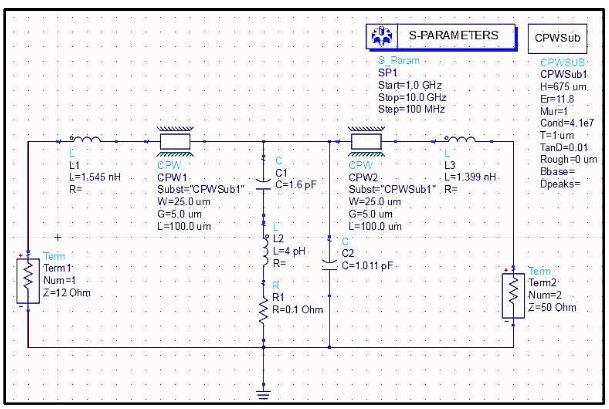

Fig.8Proposed Reconfigurable IMN when switches are in ON state

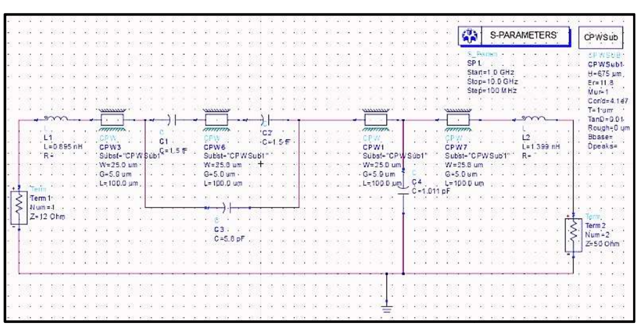

Fig.9Proposed Reconfigurable IMN when switches are in OFF state

G. Results of Designed RF MEMS Switch

The tip of Cantilever beam Ohmic type switch for series configuration has maximum downward displacement of $0.75\mu m$ for the applied voltage of 6.1 V. Fig 10 presents a plot on displacement of the cantilever beam for different applied voltages versus arc length. Fig 11 represents a plot on offered capacitance**Error! Bookmark not defined.** by the cantilever beam. The membrane of Fixed-Fixed beam capacitive type switch for shunt configuration has maximum downward displacement of $0.9\mu m$ for the applied voltage of 4.2 V. Fig. 12 presents a plot on displacement of the Fixed-fixed beam for applied voltage versus simulated time. Fig. 13 represents plot on offered capacitance by the Fixed-fixed beam.

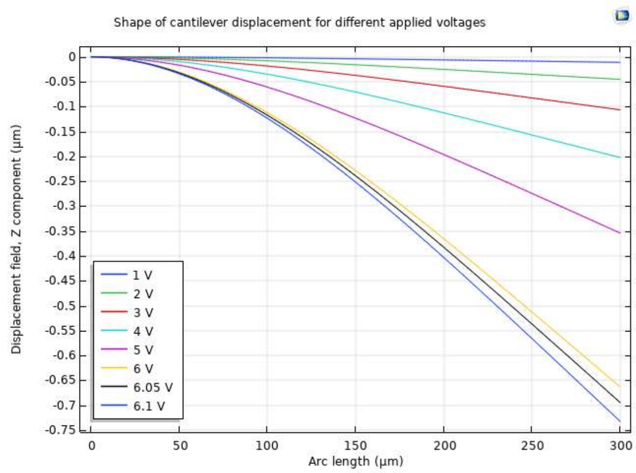

Fig.10 Plot on Displacement vs. Arc length at different applied voltages

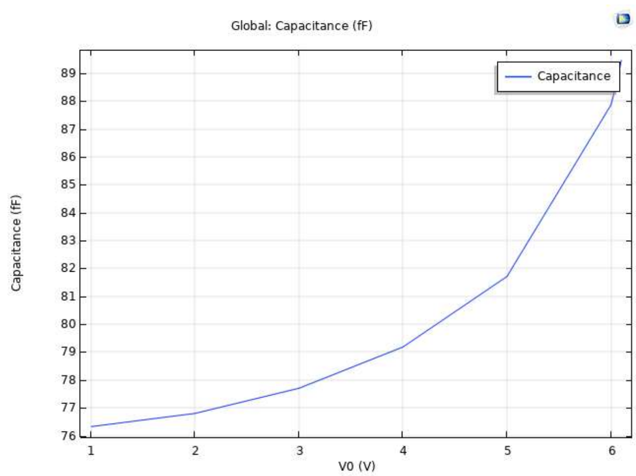

Fig.11Plot on offered capacitance vs. applied voltages

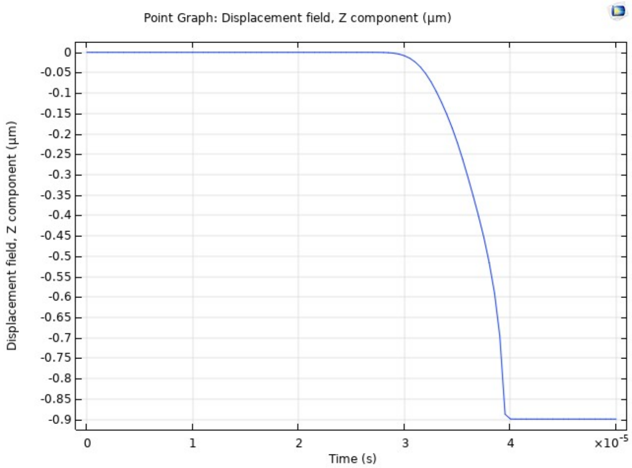

Fig.12Plot on Displacement vs. switching time

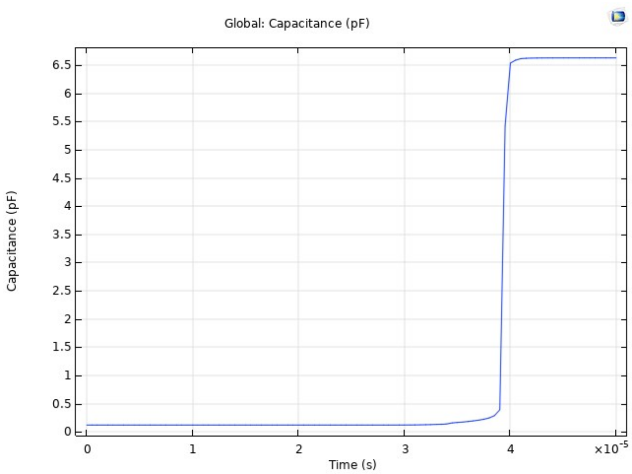

Fig.13Plot on Capacitance vs. switching time

H. Results of Designed RF MEMS Based Reconfigurable IMN for 5G applications

The simulation results of RF MEMS based Switch incorporated Reconfigurable IMN designed for 5G applications are shown in the Fig 14 & 15. The results showed return loss of -31.97 dB & -23.01 dB and matched impedance of $Z_o * (1.047 - j0.021)$ & $Z_o * (0.870 - j0.017)$ at 2.4GHz & 5.8GHz operating frequencies.

V. CONCLUSION

As 5G deals with wide band of frequencies, different frequency of operation requires different IMNs for reducing mismatch losses which leads to hardware redundancy. The RF MEMS incorporated switches offers reconfigurable nature to matching networks and have better performance at high frequencies. In this work, RF MEMS Switch based IMN is designed for FR1 band of 5G communications. At First, RF MEMS series and shunt switches are electromagnetically modelled using COMSOL Multiphysics. Later, the simulated S-Parameter results of proposed RF MEMS based reconfigurable IMN using ADS shows that the network matches the impedance of source and load while operating at Bluetooth and Wi-Fi frequencies and results in better Return Loss. As FR2 Band of 5G provides wider applications, reconfigurability allows such a potential to manifest. The idea of imparting MEMS technology in communication devices, paves the way for future scope of this work.

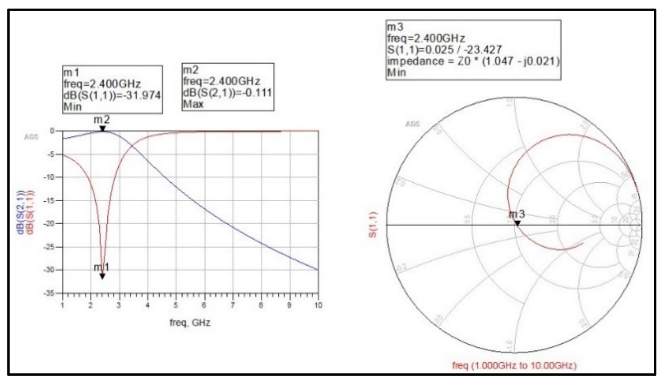

Fig.14Simulation results of reconfigurable IMN (2.4GHz)

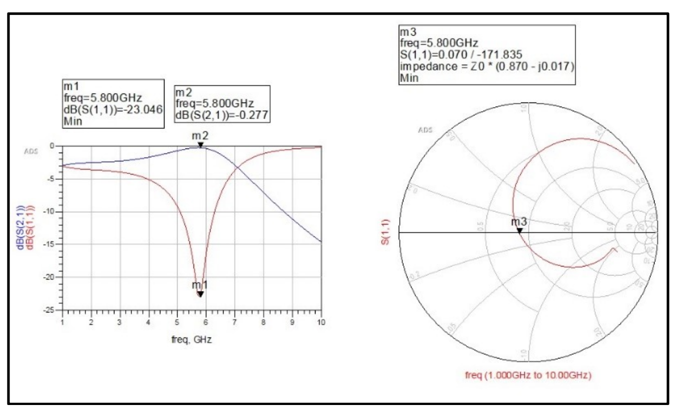

Fig.15Simulation results of reconfigurable IMN (5.8GHz)

REFERENCES

[1] Meenal G Kachhavay, Ajay P Thakare, "5G Technology-Evolution and Revolution", International Journal of Computer Science and Mobile Computing", (IJCSMC), pg.1080-1087, March 2014.

[2] Iannacci J, "Reconfigurable RF-MEMS-based impedance matching networks for a hybrid RF-MEMS/CMOS class-E power amplifier", Microsystem technologies, Springer nature June 2019.

[3] Louis E Frenzel, "Back to Basics: Impedance Matching Part 1-3", Electronic Design, Oct 24, 2011. Available: https://www.electronicdesign.com/technologies/communications/article/21801154/back-to-basics-impedance-matching-part-3.

[4] Abu Bakar Ibrahim, Abdul Rani Othman, Mohd Nor Husain, and Mohammad Syahrir Johal, "The Cascode and Cascaded Techniques LNA at 5.8GHzUsing T-Matching Network for WiMAX Applications", International Journal of Computer Theory and Engineering, Vol. 4, No. 1, January 2012.

[5] Gabriel M Rebeiz, "RF MEMS Theory, Design and technology", John Wiley & Sons, ISBN: 0-471-20169-3, February 2003.

[6] Anesh K Sharma, Ashu Gautam, C G Balaji, Asudeb Dutta & S G Singh, "Ohmic RF MEMS Switch with Low Loss and Low Force on Quartz for Reconfigurable Circuits", International Journal of Electrical and Electronics Engineering Research (IJEEER), ISSN 2250-155X, Vol. 3, Issue 1, March 2013.

[7] Girija Sravani K, Srinivasa Rao K, "Analysis of RF MEMS shunt capacitive switch with uniform and non-uniform meanders", Microsyst Technol, Springer-Verlag GmbH Germany, October 2017.

[8] David M Pozar, "Microwave Engineering", Addison-Wesley Series in Electrical and Engineering, ISBN: 978-0-470-63155-3, November 2011.

[9] Domingue F, Fouladi S, Mansour RR, "A reconfigurable impedance matching network using dual-beam MEMS switches for an extended operating frequency range", Proceedings of IEEE MTT-S international microwave symposium, pp 1552–1555, July 2010.

[10] Elliot R. Brown, "RF-MEMS Switches for reconfigurable integrated circuits", IEEE Transactions on Microwave Theory and Techniques, Volume: 46, pp. 1869-1880, November 1998.

[11] Farzad Yazdani, Raafat R. Mansour, "Realizing reconfigurable stub impedance matching networks using MEMS switches", 47th European Microwave Conference(EuMC), ISBN: 978-1-5386-3964-1, December 2017.

[12] Frederic Domingue, Ammar B. Kouki, Raafat R. Mansour, "Tunable microwave amplifier using a compact MEMS impedance matching network", European Microwave Conference, ISBN: 978-1-4244-4748-0, October 2009.

[13] GajananD Patil, Kolhare N R, Pradip Bhosale, Rokade A I, "Cantilever type switch design", International Journal of Research in Engineering and Technology, pISSN: 2321-7308, Volume: 04 Issue: 01, January 2015.

[14] Haslina Jaafar, Fong Li Nan, Nurul Amziah Md Yunus, "Design and Simulation of High Performance RF MEMS Series Switch", RSM2011 Proc., IEEE, December 2011.

[15] Iannacci J, Gaddi R, Gnudi A, "Experimental validation of mixed electromechanical and electromagnetic modeling of RF-MEMS devices within a standard IC simulation environment", IEEE J MicroelectromechSyst (JMEMS) 19:526–537, May 2010.

[16] Karolinne Brito, Robson Nunes de Lima, "Tunable Impedance Matching Network", SBMO/IEEE MTT-S International Microwave and Optoelectronics,ISBN: 978-1-4244-0660-9, December 2007.

[17] Raji george, Kumar C R S, Gangal S A, "Design and Simulation of low actuation voltage Cantilever RF MEMS switches suitable for Reconfigurable antenna applications", International Journal of Circuits and Electronics, ISSN: 2367-8879, Volume 3, April 2018.

[18] Shveta Jain, Davender Chechi, Paras Chawla, "Performance Study of RF MEMS Ohmic Series Switch", International Journal of Advanced Research in Computer Science and Software Engineering (IJARCSSE), Volume 2, Issue 8, ISSN: 2277 128X, September 2012.

[19] Surendra K Waghmare, Dr. Shah D D, "RF MEMS Capacitive Shunt Switch: A study based practical overview", International Journal of Applied Engineering Research (IJAER), ISSN 0973-4562 Volume 13, Number 15, pp. 11830-11838, September 2018.

[20] M.Unlu, K. Topalli, H.Sagkol, S.Demir, O.A. Civi, S.S. koc, T.Akin, "RF MEMS adjustable impedance matching network and adjustable power divider", IEEE Antennas and Propagation Society International Symposium, ISBN: 0-7803-7330-8, August 2002.

[21] Yi Chen, Dirk Manteuffel, "Miniaturizing of a distributed MEMS impedance matching network", International Workshop on Antenna technology(iWAT), ISBN: 978-1-4673-2830-2, May 2013.

