MOS Loaded Circular Microstrip Antenna with Airgap for Modern Communication

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Abstract: **In this paper a novel structure of circular microstrip antenna with airgap between ground plane and substrate is analyzed. To enhance the agility of antenna a MOS device is loaded on the patch. Various parameters such as input impedance, resonance frequency, bandwidth, frequency agility, VSWR, radiation pattern etc. of antenna are calculated to investigate the structure. The resonant frequency of proposed 10 mm radius patch with 1 mm airgap is 6.60 GHz. By varying bias voltage of MOS, antenna can be tuned down to 1.571 GHz operating frequency, which makes the antenna suitable for modern communication system such as GPS, UMTS, WiMAX and remote sensing. Frequency agility 76.20% is found for a MOS loaded CMSA with airgap.**

***Key words*: Circular patch, airgap, agility, MOS, microstrip antenna.**

I. Introduction

Microstrip patch antennas have been the focus of theoretical and engineering applications oriented research since they came into existence in 1970s. Features like low profile, inexpensive to manufacture and compatible with monolithic microwave integrated circuits (MMIC) design have made microstrip antenna considerably interesting. Due to this microstrip patch antennas are being used for modern communication system such as wireless communication, WLAN, GSM, UMTS, WiMax and remote sensing etc [1][2]. The input impedance of an antenna tends to be sensitive to changes in frequency. While the microstrip antennas have found wide variety of applications, they have narrow bandwidth because of their heavy reactance and impedance mismatch in various applications. Various techniques have been suggested to improve the impedance bandwidth such as shorting posts, variable length transmission lines, varactor diodes and increased thickness of substrate [3][4]. About 20 % frequency agility was achieved using two posts in circular microstrip antenna [5]. Further, using double posts and by adjusting them finely, the maximum tunability was increased to 32.5% [6]. Integration of devices like varactor diode, gunn diode and impedance tuning network in circular microstrip antennas could not provide sufficient impedance bandwidth and frequency agility [7]. Also, impedance bandwidth can be increased by various means such as loading a patch or increasing substrate thickness. Loading can take various forms, such as stub loading, slits, slots, and so forth [8]. Limitations still exists on the ability of these techniques. Analytical models have been presented for calculating the input impedance and resonant frequency of circular microstrip antenna with and without airgap [9][10]. A circular microstrip antenna with an airgap between ground plane and substrate was proposed in [11] and [12].

The authors have proposed a MOS loaded CMSA with airgap between ground plane and substrate to achieve broader band of operation and enhanced frequency agility to make the antenna most suitable for modern communication system such as GPS, UMTS, WiMAX and remote sensing.

II. THEORETICAL ASPECTS

The structure of proposed MOS loaded CMSA with an airgap between the ground plane and substrate is shown in fig. 1. The structure of this antenna is a two layer cavity: the lower layer is an airgap of H_a with relative permittivity 1 and the upper layer is the dielectric substrate of thickness H with relative permittivity ε_r. Using an equivalent single layer structure of total height $H_t = H + H_a$, an equivalent permittivity [9][10]

$$\varepsilon_{re} = \frac{\varepsilon_r (H + H_a)}{(1 + \varepsilon_r H_a)} \tag{1}$$

where ε_r is the permittivity of the substrate, for CMSA without an air gap (H_a=0), $\varepsilon_{re} = \varepsilon_r$.

An improved form of permittivity of transverse magnetic (TM) modes of the medium below the patch in CMSA with airgap, effective permittivity $\varepsilon_{r,eff}$ is defined as [10]

$$\varepsilon_{r,\,eff} = \frac{4\varepsilon_{re}\varepsilon_{r,dyn}}{\left(\sqrt{\varepsilon_{re}} + \sqrt{\varepsilon_{r,dyn}}\right)} \tag{2}$$

The term $\varepsilon_{r,eff}$ is introduced to take into account the effect of the equivalent permittivity (ε_{re}) of the medium below the patch in combination with the dynamic permittivity ($\varepsilon_{r,dyn}$)

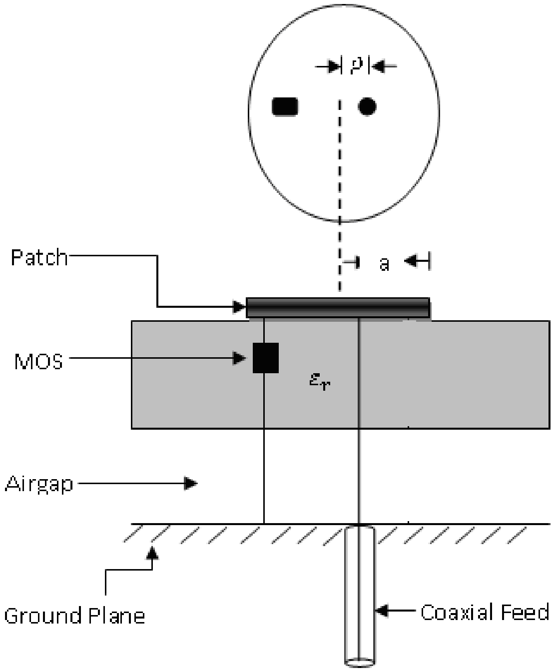

Fig.1 Structure of a MOS loaded circular microstrip antenna with airgap

to improve the model. The resonant frequency and effective radius of the CMSA with airgap are calculated as [13]

resonant frequency

$$f_r = \frac{\alpha_{nm} c}{2\pi a_{eff}\sqrt{\varepsilon_{r,eff}}} \tag{3}$$

where c is velocity of light in free space, α_{nm} is mth zero of first kind Bessel function of order n.

The effective radius

$$a_{eff} = a\sqrt{(1+q)} \tag{4}$$

where the term q arises due to the fringing fields at the edge of the patch [7].

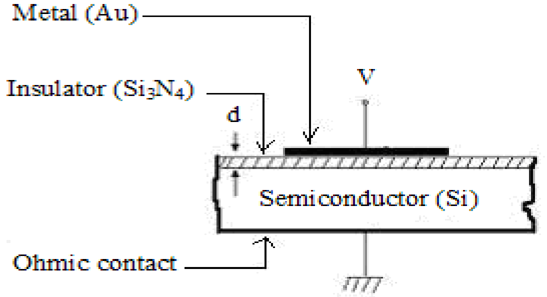

Fig.2 Schematic of MOS capacitor

A. *Metal-Oxide-Semiconductor*

Fig. 2 presents schematic of a typical Metal-Insulator-Semiconductor (MIS). The MIS under consideration is Au-Si_3N_4-Si. Total capacitance of MOS is found as in [14][16]

$$C_{mos} = \frac{C_i}{\left[\sqrt{1+\left(\frac{2V_g C_i^2}{\varepsilon_{rsi}\varepsilon_0 q N_a}\right)}\right]} A \tag{5}$$

where

$$C_i = \frac{\varepsilon_0 \varepsilon_{ro}}{d} \tag{6}$$

V_g is bias voltage, N_a is acceptor concentration of doping material and q is charge of an electron, A is the cross sectional area of MOS device, ε_{ro} is relative permittivity, and d is the thickness of insulation layer,.

B. *MOS loaded Circular Microstrip Antenna with airgap*

The antenna is analyzed in TM_{11} mode. A circular microstrip antenna posses the properties of a parallel combination of resonance resistance R_0, inductance L and capacitance C. These parameters are calculated from the theory of modal expansion and cavity model as in [19]

resonance resistance

$$R_0 = \frac{1}{G_T}\frac{J_n^2(k\rho)}{J_n^2(ka)} \tag{7}$$

where J_n is the first kind of Bessel function of order n, ρ is probe position, G_T is total conductance associated with dielectric loss, radiation loss, and conduction loss.

capacitance associated with antenna

$$C = \frac{Q_T}{2\pi f_r R_0} \tag{8}$$

and inductance

$$L = \frac{R_0}{2\pi f_r Q_T} \tag{9}$$

where Q_T is total quality factor [9], which includes radiation loss, dielectric loss and conductance loss.

The equivalent circuit of a MOS loaded circular microstrip antenna with airgap is presented in fig. 3. Total capacitance of patch can be calculated as

$$C_{total} = C + C_{mos} \tag{10}$$

Hence, total input impedance of a MOS loaded CMSA with airgap is calculated as

$$Z_{in} = \frac{1}{\left\{\left(\frac{1}{R_0}\right) + (j\omega C_{total}) + \left(\frac{1}{j\omega L}\right)\right\}} \tag{11}$$

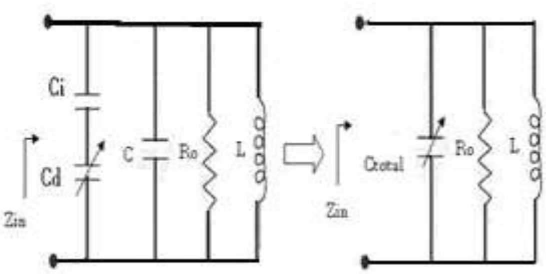

Fig 3 Equivalent circuit of MOS loaded circular microstrip antenna

The reflection coefficient of circular patch is given by

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{12}$$

where, Z_0 is impedance (50 Ω) of coaxial feed.

Voltage standing wave ratio of patch is given as

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{13}$$

The return loss of the antenna is given by

$$RL = 20\log(|\Gamma|) \tag{14}$$

III. Design specifications

The design specifications of MOS device are given in table I and that of the MOS loaded circular microstrip antenna are given in table II. Same specifications are considered for the theoretical analysis and simulation of proposed antenna.

TABLE I. SPECIFICATIONS OF MOS

Parameter	Value
MOS capacitor structure	Au-Si_3N_4-Si (n+0.0005 Ω cm)
Cross section area of device (*A*)	1.6×10^{-8} m^2
Relative permittivity of oxide layer (ε_{ro})	7.5
Relative permittivity of Semiconductor (ε_{rsi})	11.9
Acceptor concentration (N_a)	$1.45\times10^{22} m^{-3}$
Bias voltage range (V_g)	0-5volts
Thickness of oxide layer(*d*)	100, 200, 300, 400, 500 A^o
Peak values of C_{mos}	106.2, 53.1, 35.4, 26.5, 21.2 pf

TABLE II. SPECIFICATIONS OF PROPOSED ANTENNA

Parameter	Value
Substrate material	Beeswax
Radius of circular patch (a)	10 mm
Substrate thickness (H)	1.5748 mm
Airgap (H_a)	1.00 mm
Relative dielectric constant of substrate (ε_r)	2.35
Loss tangent (tan δ)	0.005
Probe position (ρ)	3.1 mm

IV. Radiation pattern

The radiation pattern of antenna is given by Bhartia and Bahl [19] for TM_{11} mode

$$E_\theta = -\frac{jVak}{2}\frac{e^{-jkr}}{r}\cos(\phi)J_1^{'}(ka\sin(\theta)) \tag{15}$$

$$E_\phi = \frac{jVak}{2}\frac{e^{-jkr}}{r}\frac{J_1(ka\sin(\theta))}{ka\sin(\theta)} \tag{16}$$

Radiation pattern is calculated as

$$R = |E_\theta|^2 + |E_\phi|^2 \tag{17}$$

For E-plane pattern $ø=0^o$, and for H-plane pattern $ø=90^o$

TABLE III. FREQUENCY AGILITY OF A MOS LOADED CIRCULAR MICROSTRIP ANTENNA WITH AIRGAP FOR DIFFERENT THICKNESS OF OXIDE LAYER

Sr. No.	Oxide thickness (A^o)	Minimum achievable frequency (GHz)	Total frequency agility(GHz)	Percentage agility (%)
1	100	1.571	5.032	76.20
2	200	2.161	4.442	67.27
3	300	2.579	4.024	60.94
4	400	2.905	3.698	56.00
5	500	3.172	3.431	51.96

V. Results and discussion

The fig. 4 shows the variation of input impedance with the frequency of antenna for different airgap. It is found that the resonance frequency of the antenna increases with increasing the airgap, due to the fact that the effective value of permittivity decreases. It is further found that peak value of real part of input impedance decreases with increasing airgap between the ground plane and substrate. The resonant frequency of antenna with airgap has upward shift up to 6.60 Ghz as compared to 4.99 Ghz for circular microstrip antenna without airgap. This upward shift of frequency due to airgap between ground plane and substrate has broadened the bandwidth of antenna. Fig. 5 shows variation of capacitance with bias voltage for a typical MOS. It is found that there is sharp variation in capacitance near zero bias voltage. Capacitance is almost constant for all values of thicknesses for the bias voltage above 1volt. The peak values of capacitances are 106.2pf, 53.1pf, 35.4pf, 26.5pf, and 21.2pf for oxide layers of 100A^o, 200A^o, 300A^o, 400A^o and 500A^o respectively.

The variation of resonant frequency with bias voltage for a MOS loaded circular microstrip antenna with airgap is shown in fig. 6. The variation of resonance frequency is higher at lower bias voltage comparatively to higher bias

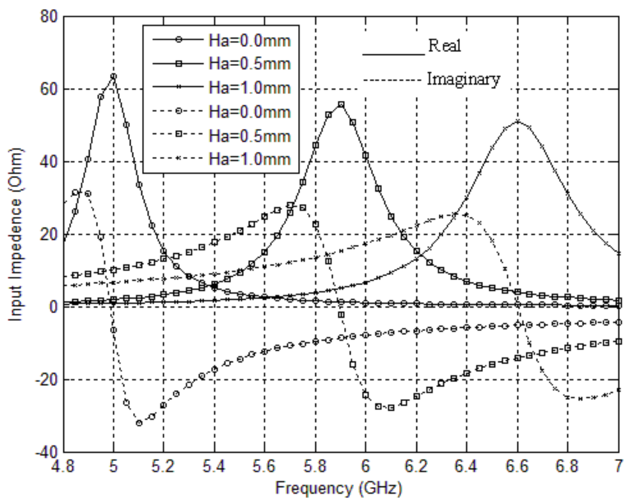

Fig. 4 Variation of Input Impedance with frequency of circular microstrip antenna with different airgap

voltage. It is also found that variation of resonance frequency is negligible for all oxide layers for higher bias voltage. Table III shows percentage agility for a MOS loaded antenna for different oxide layer thickness. Maximum agility for a MOS loaded patch is 76.20% (for 100A^o oxide layer). It is evident from table III that frequency agility decreases as oxide thickness increases.

The variation of frequency agility with radius of patch is shown in fig. 7. It is found that frequency agility decreases with a increase in the radius of patch, due to the fact that capacitance of patch increases. It is evident that antenna has better frequency agility for low patch radius, frequency agility of antenna with 10 mm radius of patch is 76.20%.

Fig. 8 shows variation of real parts of input impedance with frequency for different bias voltage for proposed antenna. The resonant frequency of antenna shows interesting downward shift for different values of thickness of oxide layers. It is found that for 0 volt bias voltage and 100 A^o oxide layer, the resonant frequency of antenna is downward shifted to 1.571 Ghz from 6.60 Ghz design frequency. Hence, the resonant frequency of proposed antenna can be tuned by varying the bias voltage. It is found that the frequency of operation of antenna is shifted upward to 6.60 GHz from 4.99 Ghz due to 1 mm airgap. However operating frequency of the antenna is downward shifted to 1.571 GHz due to the integration of a MOS device.

Fig. 9 shows theoretical and simulated on IE3D [20] results for VSWR of antenna with and without MOS as a function of frequency at Vg = 0.25 volt. It is found that theoretically calculated VSWR give a close match with simulated result. The E-plane and H-plane radiation patterns

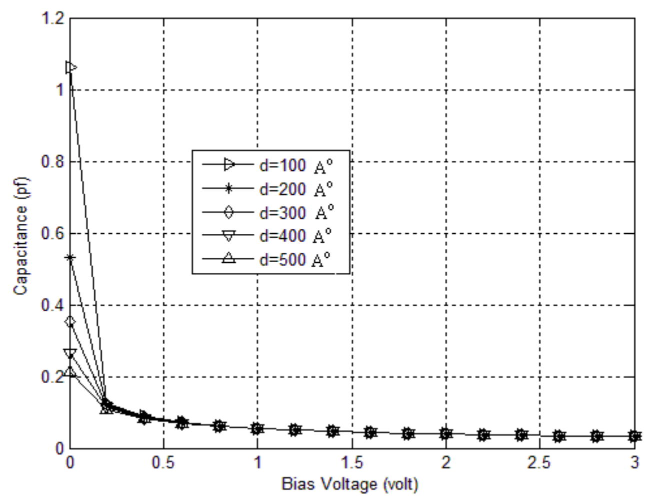

Fig.5 Variation of capacitance of a MOS with bias voltage

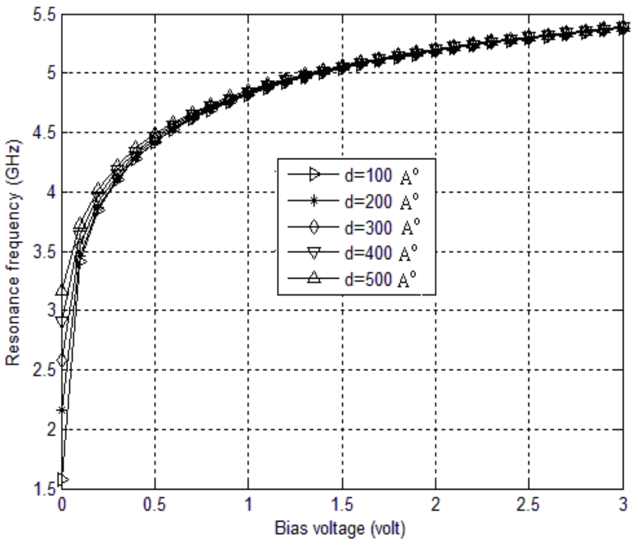

Fig.6 Variation of resonant frequency with bias voltage of MOS loaded CMSA with airgap

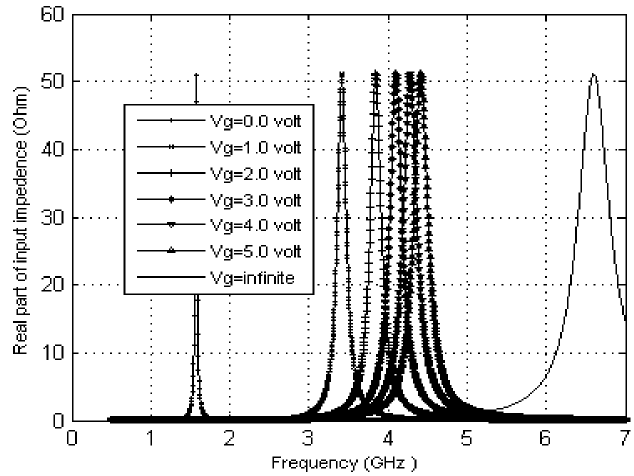

Fig.8 Variation of input impedance with frequency with different bias voltage (V_g) of MOS loaded circular microstrip antenna with airgap (H_a = 1.0 mm)

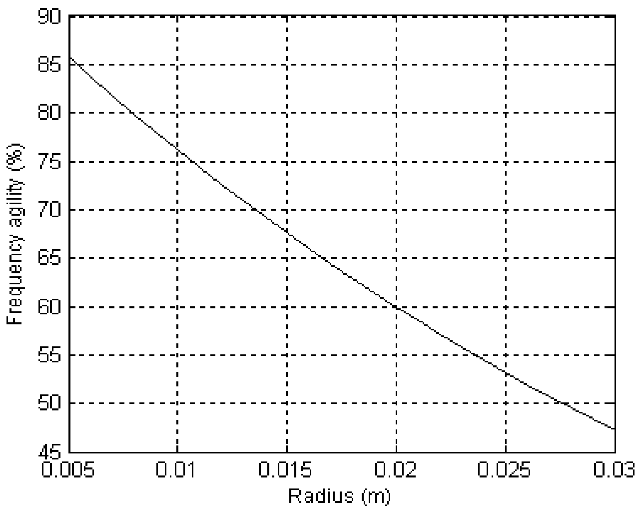

Fig.7 Variation of frequency agility with radius of patch of MOS loaded circular microstrip antenna with airgap (H_a=1.0 mm)

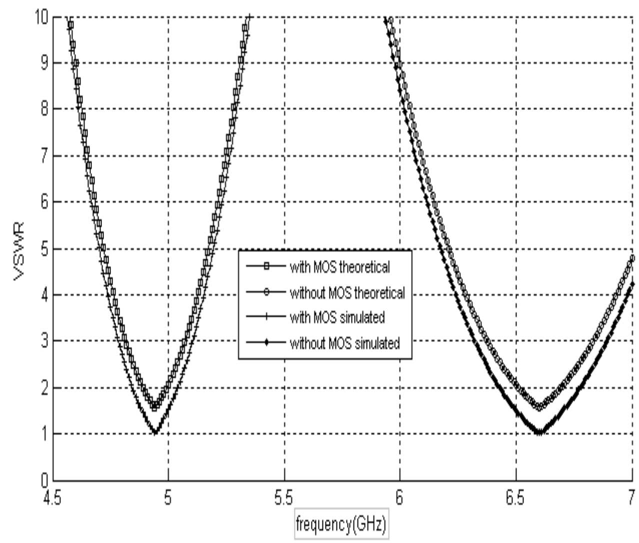

Fig. 9 Variation of VSWR with and without MOS circular microstrip antenna with airgap (H_a = 1.0 mm)

for a MOS loaded CMSA are shown in fig. 10 and 11 respectively. Also, simulated radiation patterns for Vg = 5.0 volt for both plane are shown in these figures. Which are close to the respective calculated results.

VI. Conclusion

A new model of a MOS loaded circular microstrip antenna with airgap between the ground plane and substrate is presented. The minimum operating frequency achieved for a MOS loaded CMSA with 10 mm radius of patch and 1 mm airgap is 1.571 GHz and it can be tuned to any frequency up to design frequency 6.60 GHz, which makes the antenna useful for modern communication system such as GPS, UMTS, WiMAX and remote sensing applications. Percentage agility of 76.20% has been achieved for a MOS loaded CMSA with airgap.

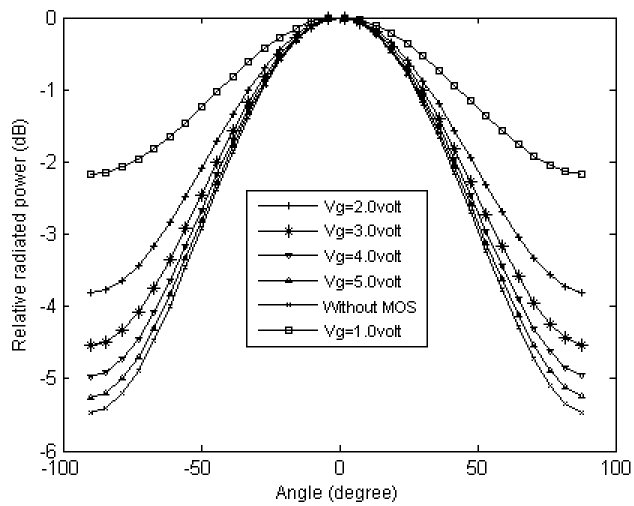

Fig. 10 E-plane radiation pattern of MOS loaded circular microstrip antenna with airgap (H_a = 1.0 mm)

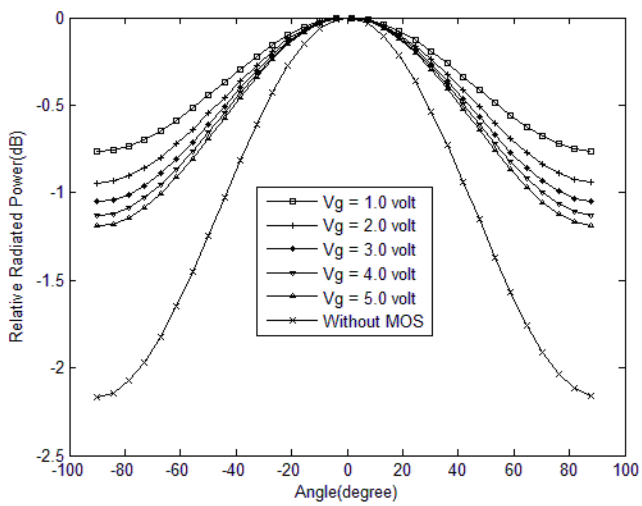

Figure 11: H-plane radiation pattern of MOS loaded circular microstrip antenna with airgap (H_a = 1.0 mm)

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