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# MAGNETO-HYDRODYNAMIC ANTENNA WITH ROTATING FLUID

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## ABSTRACT

Dielectric Resonator Antennas (DRAs) have received lots of attention in the last two decades due to several attractive characteristics such as high radiation efficiency, light weight, and low profile. There is also increasing challenges for the design of high bandwidth and multi-bands antennas which can be achieved using MHD Antennas for high speed and reconfigurable applications in wireless communication. In this work the objective is to design and develop a cylindrical MHD antenna with circular patch and two annular rings. Magneto-hydrodynamics (MHD) Antenna is a Fluid based Antenna in which the fluid resonator provides excellent coupling of RF energy into fluid. Fluid resonator volume, chemical properties, electric field and magnetic fields are the factors of resonant frequency, gain and return loss. The proposed antenna shall be tuned in the wide band of frequency range between 7.9 – 27 GHz. Simulations using HFSS and measurements have been carried out in respect of design prototype for ‘Air’ and BSTO (Barium Strontium Titanate Oxide) microwave fluid. The findings in this work that the Fluid Resonator based hybrid approach for antenna enhances the bandwidth by a large factor and annular rings with circular patch in proper geometry provides multiband operation. Variation in the volume of the fluid shifts the resonant frequency of the solid structure in the wideband. When magnetic field is applied, significant improvement has been noticed in return loss of the proposed antenna.

**KEYWORDS**: Frequency agility, DRA, reconfigurability, MHD, radiation pattern, saline water.

## I. INTRODUCTION

The word magneto hydrodynamics (MHD) is derived from magneto – meaning magnetic field, hydro – meaning liquid, and dynamics meaning movement. The field of MHD was initiated by Hannes Alfvén in 1942 and later in 1970, Ting and King determined that the conducting fluid can oscillates under the influence of electromagnetic field conditions. This conducting fluid can be used as one of the element of antenna at microwave frequencies. An antenna based on the MHD principle using hybrid approach in which a Dielectric Fluid Resonator in combination with circular patch and annular rings is presented. The feed given to this antenna is a microstrip feed. The fluid resonator was filled with ‘Air’ and ‘BSTO (Barium Strontium Titanate Oxide) microwave fluid’. The molecules of the fluid oscillate and impact ionization takes place due to which electromagnetic field changes. The circular patch helps the fluid to resonate in the cylindrical shaped fluid resonator. The annular rings used around Fluid resonator provide multi-band operation. Measurement for Resonant frequency, Return Loss and impedance matching using 40GHz Agilent VNA (Vector Network Analyzer) 5230A has been performed. In addition to above parameters simulations using HFSS have been carried out for S11, Radiation Pattern and Gain. Taking benefit from the advantages of DRAs and the antenna symmetry using hybrid approach, the results shows wideband (7.9-27 GHz) with multiband features and shift of resonant frequencies by changing fluid volume for the proposed Antenna Prototype.

## II. FORMULATIONS

### Navier–Stokes equations

The Navier–Stokes equations dictate not position but rather velocity. A solution of the Navier–Stokes equations is called a velocity field or flow field, which is a description of the velocity of the fluid at a given point in space and time. Once the velocity field is solved for, other quantities of interest (such as flow rate or drag force) may be found. This is different from what one normally sees in classical mechanics, where solutions are typically trajectories of position of a particle or deflection of a continuum. Studying velocity instead of position makes more sense for a fluid; however for visualization purposes one can compute various trajectories

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Navier Stokes equation is given as

$$\rho\left(v.\nabla v+\frac{dv}{dt}\right)=-\nabla.p+\eta\nabla^2 v+J\times B \qquad (3.3)$$

Where $\rho=$ mass density
J= Current density
$v=$ velocity of fluid
p=pressre
$\eta=$ fluid viscosity
B=Magnetic field

By solving equation 3.3, The equation of motion of a fluid in a uniformly rotating frame with angular velocity *w* is given by

$$v.\nabla v+\frac{dv}{dt}+2\omega\times v+\omega\times(\omega\times r)=-\frac{\nabla p}{\rho}+v\nabla^2 v \qquad (3.4)$$

Where $v=$ kinetic viscosity $=\frac{\eta}{\rho}$

$$v_x=\frac{\partial\psi}{\partial y}(x,y,z)=-\frac{\partial\psi}{\partial x}(x,y,z) \qquad (3.5)$$

Assuming the flow to be two dimensional and fluid to be incompressible, obtain an equation for the stream function. Velocity of fluid is given below

$$v=v_x(t,x,y)\hat{x}+v_x(t,x,y)\hat{y} \qquad (3.6)$$

Where $\psi$is a stream function telling trajectory of fluid particle

$$v=v_x(t,x,y)\hat{x}+v_x(t,x,y)\hat{y} \qquad (3.6)$$

$$\omega=\omega_0\hat{z} \qquad (3.7)$$

$$v_x=\frac{\partial\psi}{\partial y}=-\frac{\partial\psi}{\partial x} \qquad (3.8)$$

$$\psi=\psi(t,x,y) \qquad (3.9)$$

Varticity $\Omega$ is defined as

$$\Omega=\nabla\times v=\nabla\times(v_x\hat{x}+v_x\hat{y}) \qquad (3.10)$$

$$\Omega=(\frac{\partial}{\partial x}\hat{x}+\frac{\partial}{\partial y}\hat{y}+\frac{\partial}{\partial z}\hat{z})\times(v_x\hat{x}+v_x\hat{y}) \qquad (3.11)$$

Where $\nabla=\frac{\partial}{\partial x}\hat{x}+\frac{\partial}{\partial y}\hat{y}+\frac{\partial}{\partial z}\hat{z} \qquad (3.12)$

$$\Omega=\frac{\partial v_x}{\partial x}\hat{z}-\frac{\partial v_x}{\partial y}\hat{z}-\frac{\partial v_x}{\partial z}\hat{y}-\frac{\partial v_x}{\partial z}\hat{x} \qquad (3.13)$$

$$-\frac{\partial v_x}{\partial z}\hat{y}-\frac{\partial v_x}{\partial z}\hat{x}=0 \text{ because no moment of fluid in z direction}$$

By using equation 3.8

$$\Omega=\frac{\partial}{\partial x}\left(-\frac{\partial\psi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial\psi}{\partial y}\right) \qquad (3.14)$$

$$\Omega=-\frac{\partial^2\psi}{\partial x^2}-\frac{\partial^2\psi}{\partial y^2}=-\nabla^2\psi \qquad (3.15)$$

Varticity is known as spinning motion of fluid.

Taking the curl on navier stock equation is given by:-

$$\nabla\times(v.\nabla v)+\nabla\times\left(\frac{dv}{dt}\right)+\nabla\times(2\omega\times v)+\nabla\times\big(\omega\times(\omega\times r)\big)=\nabla\times\left(-\frac{\nabla p}{\rho}\right)+\nabla\times(v\nabla^2 v)$$

(3.16)

By using equation3.10 in equation 3.16

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$\nabla\times(\Omega\times v)+\left(\frac{d\Omega}{dt}\right)+2\nabla\times(\omega\times v)+\nabla\times\left(\omega\times(\omega\times r)\right)=\nu\nabla^2\Omega$ (3.17)

here $\nabla\times\left(-\frac{\nabla p}{\rho}\right)=0$ (curl of gradient is zero)

$\left(\omega\times(\omega\times r)\right)=0$ (Assume ω is constant)

So equation comes out to be

$\nabla\times(\Omega\times v)+\left(\frac{d\Omega}{dt}\right)+2\nabla\times(\omega\times v)=\nu\nabla^2\Omega$ (3.18)

The field E, B, ν can be obtained on solving coupled Maxwell and Navier's stock equation

$$\nabla\times E=-\mu\frac{\partial H}{\partial t}$$

$\nabla\times H=\sigma(E+\nu\times B)+\epsilon\frac{\partial E}{\partial t}$ (3.19)

$$\Omega=\nabla\times\nu$$

B=μH (3.20)

$\nabla.\nu=0$ (3.21)

There exist a vector field ψ such that $\nu=\nabla\times\psi$ and ψ can be chosen such that

$\nabla.\psi=0$ (3.22)

The magnetic vector potential produced by fluid can't be taken as

$A(t,r)=\frac{\mu}{4\pi r}\int J(t-\frac{r}{c}+\frac{\hat{r}r'}{c},r')d^3r'$ (3.23)

Where volume integral define region of conducting fluid. Taking Inverse Fourier Transformation of ν and B gives

$\nu(t,r)=\int_r \nu(\omega,r)e^{j\omega t}\,d\omega$ (3.24)

$B(t,r)=\int_r B(\omega,r)e^{j\omega t}\,d\omega$ (3.25)

$\nu\times B=\int e^{j(\omega_1,\omega_2)t}(\hat{\nu}(\omega_1,r)\times\widehat{B}(\omega_2,r))dw_1d\omega_2$ (3.26)

$A(\omega,r)=\frac{\mu e^{-jkr}}{4\pi r}\int J(\omega,r)e^{jk(r-r')}d^3r'$(3.27)

Where $k=\frac{\omega}{c}$and k.r>>1 since $\phi(\omega,r)$ is scaler

div. A= -jμtωϕ (3.28)

$\phi=\frac{1}{\mu\epsilon\omega}\text{div}.A$ (3.29)

$E=-\nabla\phi-j\omega A$ (3.30)

**Fluid Frame Description**

$E=E_x\hat{x}$ Electric field in X direction (3.31)

$B=B_y\hat{y}$ Magnetic field in Y direction (3.32)

$\nu=\nu_x\hat{x}+\nu_y\hat{y}+\nu_z\hat{z}$ (3.33)

We know that

$F=ma=Q(E_x+\nu\times B)$ (3.34)

Acceleration in x direction

$\nu_x'=\frac{\partial\nu_x}{\partial t}=\frac{Q}{m}\left(E_x-\nu_zB_y\right)$ (3.35)

No Acceleration in y-direction

$\nu_y'=\frac{\partial\nu_y}{\partial t}=0$ (3.36)

$\nu_z'=\frac{\partial\nu_z}{\partial t}=\frac{Q}{m}\nu_xB_y$ (3.37)

$\frac{d}{dt}\begin{bmatrix}\nu_x\\ \nu_z\end{bmatrix}=\frac{Q}{m}B_y\begin{bmatrix}0&-1\\1&0\end{bmatrix}\begin{bmatrix}\nu_x\\ \nu_z\end{bmatrix}+\frac{Q}{m}E_x\begin{bmatrix}1\\0\end{bmatrix}$ (3.38)

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Let $\frac{Q}{m} = \alpha$

$\frac{v_z'}{\alpha B_y} = v_x$ (3.39)

Diffentiation above equation we get

$\frac{v_z''}{\alpha B_y} = v'_x$ (3.40)

$\frac{Q}{m}\left(E_x - v_z B_y\right) = \frac{v_z''}{\alpha B_y}$ (3.41)

We know that

$v'_x = \alpha\left(E_x - v_z B_y\right)$ (3.42)

Diffentiation above equation we get

$$v_x'' = \alpha\left(0 - v'_z B_y\right)$$

$v_x'' = -\alpha v'_z B_y$ (3.43)

$$v_z' = \alpha v_x B_y$$

$v_x'' = -(\alpha B_y)^2 v_x$ (3.44)

General solution of this equation is given as

$v_x(t) = A\cos(\alpha B_y t + \phi)$ (3.45)

Let $\alpha B_y = \omega$

Hence, fluid frame velocity shall be

$v_x(t) = A\cos(wt + \phi)$ (3.46)

We know that

$v_x(0) = 0$ at t=0

$$A\cos\phi = 0$$

$$\cos\phi = \cos\left(\frac{n\pi}{2}\right) \quad (3.47)$$

where n=1,2,3,………..

Put n=1

$$\phi = \frac{\pi}{2}$$

$$v_x(t) = A\cos\left(wt + \frac{\pi}{2}\right)$$

$v_x(t) = A\sin wt = A\sin(\alpha B_y t)$ (3.48)

$$v_z(0) = 0$$

$v_x'(t) = \alpha\left(E_x - v_z B_y\right)$ (3.49)

$v_x'(0) = \alpha E_x$ (3.50)

$v_x'(t) = A\omega\cos(\omega t)$ (3.51)

$$v_x'(0) = A\omega \quad (3.52)$$

From equation 3.50 and 3.52 we get

$A\omega = \alpha E_x$ (3.53)

$A = \frac{\alpha E_x}{\omega} = \frac{\alpha E_x}{\alpha B_y} = \frac{E_x}{B_y}$ (3.54)

$$A = \frac{E_x}{B_y}$$

$v_x(t) = \frac{E_x}{B_y}\sin(\omega t)$ (3.55)

We know that

$v_x' = \frac{Q}{m}\left(E_x - v_z B_y\right) = A\omega\cos(\omega t)$ (3.56)

$$\alpha\left(E_x - v_z B_y\right) = \frac{E_x}{B_y}\alpha B_y\cos(\omega t)$$

$$(\mathrm{E_x} - \mathrm{v_z B_y}) = \mathrm{E_x}\cos(\omega t)$$
$$-\mathrm{v_z B_y} = \mathrm{E_x}\cos(\omega t) - \mathrm{E_x}$$
$$\mathrm{v_z B_y} = \mathrm{E_x}(1 - \cos(\alpha \mathrm{B_y} t))$$

$\mathrm{v_z} = \frac{\mathrm{E_x}}{\mathrm{B_y}}(1 - \cos(\alpha \mathrm{B_y} t))$ (3.57)

The fluid velocity can be defined as
Put $\mathrm{E_x} = \mathrm{E_0}$ and $\mathrm{B_y} = \mathrm{B_0}$ we get the following expression
$\mathrm{v} = \frac{\mathrm{E_0}}{\mathrm{B_0}}(\sin \mathrm{w_0 t}\,\hat{\mathrm{x}} + (1 - \cos \mathrm{w_0 t})\hat{\mathrm{z}})$ (3.58)

Current density in this case shall be
$J = neAv$ and $J = \sigma E$

$$J = \sigma(E_0\hat{x} + E_1\cos(wt)\hat{y} + \frac{E_0}{B_0}(\cos(\omega_0 t)\,\hat{x} + (1 - cos(w_0 t))\hat{z} \times B_0\hat{y})$$

Radiation Intensity pattern

$$F_0(\theta,\phi) = \int e^{-i\frac{w_0}{c}}(x\cos\phi\sin\theta + y\sin\phi\cos\theta + z\cos\theta)dx'dy'dz'$$
$$dx'dy'dz' = \rho' d\rho' d\phi' dz'$$

When input is applied at the center, Radiation field pattern

$$f(\theta,\phi) = \int_a^b \int_0^{2\pi} \int_{-\frac{1}{2}}^{\frac{1}{2}} e^{-(j\frac{\omega_0}{c}(\rho' \sin\theta\cos\phi\cos\phi' + \rho' \sin\theta) + z'(\cos\theta))} \rho' d\rho' d\phi' dz'$$

Radiation Pattern can be written as

$$\int_0^{\pi}\int_0^{2\pi}\left[\left(\frac{\mu\omega_0}{4\pi c}\right)^2 |\rho x J_0|^2 |F_0(\theta,\phi)|^2 + \left(\frac{\mu\omega_1}{4\pi c}\right)^2 |\rho x J_1|^2 |F_1(\theta,\phi)|^2\right]\sin\theta d\theta d\phi$$

Only real part if we consider

$$R_e[J_0 e^{-j\omega_0 t} + J_1 e^{-j\omega_1 t}]$$

Here, we get multiple harmonics in the results. These harmonics can be filtered out. For any particular frequency application, unwanted frequency can be rejected by making use of proper filtering techniques.

**Input Impedance Of The Antenna**

$$Z_{in} = \int (E.J/|I|\tilde{}2)dV$$
$$Z_{in} = \frac{\int_0^6 \int_0^{2\pi} \int_6^{11} \sigma E_1(E_0 + vB)\rho d\rho d\phi dz}{\sigma^2(E^2 + vB^2)}$$

Where J is current density, E is electric field applied , I is load current, v velocity of the fluid and V represents volume integral.

**Far field radiation Pattern**

Space here r-radius, $\theta$-Angle of elevation, $\phi$- azimuth angle, are first and second components of the frequency and r, $\theta, \phi$ are spherical co-ordinates.

$$0 \le \theta \le 180\ (\pi\, rad)$$
$$0 \le \phi \le 360\ (2\pi\, rad)$$
$$r = \sqrt{x^2 + y^2 + z^2}$$
$$\theta = \cos^{-1}\frac{z}{r}$$

$$\phi = \tan^{-1}\frac{y}{x}$$
$$x = r\sin\theta\cos\phi$$
$$y = r\sin\theta\sin\phi$$

Z=rcos $\theta$

v x B shall provide pointing vector in case of fluid. E x H gives pointing vector , here H vector to embed v effect due to conducting fluid $E_\theta, H_\theta, E_\phi, H_\phi$ are electric and magnetic fields of MHD antenna and the pointing vector shall have the effect of conducting fluid velocity generated due to E, Radiation pattern shall depend on average radiated power. Any spherical coordinate triplet (r, $\varphi$), specify single point of three space coordinates in radiation field.

$$E_\theta = -\frac{\delta A_\theta}{\delta t} - \frac{\delta\phi}{\delta\theta}$$

$E_\phi = -\frac{\delta A_\phi}{\delta t} - \frac{1}{r\sin\theta}\frac{\delta\phi}{\delta\theta}$ and

$$E_\theta = -\frac{\delta A_\theta}{\delta t}$$
$$E_\phi = -\frac{\delta A_\phi}{\delta t}$$

Also $H_\theta = \frac{1}{\mu}\vec{\nabla}\times\vec{A} = \begin{vmatrix} \frac{\hat{r}}{r^2\sin\theta} & \frac{\hat{\theta}}{r\,sin\,\theta} & \frac{\hat{\phi}}{r} \\ \frac{\delta}{\delta r} & \frac{\delta}{\delta\theta} & \frac{\delta}{\delta\phi} \\ A_r & rA_\theta & \text{rsin}\,\theta\, A_\phi \end{vmatrix}$

Solution of above matrix shall provide us

$$\frac{\hat{\theta}}{\text{rsin}\,\theta}\left(\frac{\delta}{\delta\phi}A_r - \frac{\delta}{\delta r}\sin\theta\, A_\phi\right) + \frac{\hat{\phi}}{r}\left(\frac{\delta r}{\delta r}A_\theta - \frac{\delta}{\delta\theta}A_r\right)$$

Hence

$$H_\theta = -\frac{1}{rsin\,\theta}\frac{\delta}{\delta r}(r\,sin\,\theta\, A_\phi) = -\frac{\delta}{\delta r}A_\phi$$

And

$$H_\phi = \frac{1}{r}\frac{d}{dr}(rA_\theta) = \frac{\delta}{\delta r}A_\theta$$
$$(E\times H).\sigma = E_\theta H_\phi - H_\theta E_\phi$$

(Resulting Pointing Vector) On substitution
Pointing vector $= -\frac{\delta}{\delta t}A_\theta\frac{\delta}{\delta r}A_\theta - \frac{\delta}{\delta t}A_\phi\frac{\delta}{\delta r}\phi$

$$A_\theta = \frac{\psi(r,\phi,t)}{r} - \frac{\psi,t}{r}$$

And

$\int_0^\pi\int_0^{2\pi}(E\times H).\sigma\, r^2\sin\theta\, d\theta d\phi$Shall provide pointing vector of radiator.
And J= (E + v x B) shall be the resultant of MHD antenna system, we need to calculate E at a given frequency. Here, first and second component of vector potentials are.

$$A_1 = \frac{\mu}{4\pi}\sigma\frac{\int\vec{E}(\vec{r'},\omega)e^{-\frac{j\omega|\vec{r}-\vec{r'}|}{c}}}{|\vec{r}-\vec{r'}|}d^3r'$$

or

$$A_1 = \frac{\mu}{4\pi r}\sigma\int\vec{E}(\vec{r'},\omega)e^{-\frac{j\omega|\vec{r}-\vec{r'}|}{c}}d^3r'$$

And second component

$$A_2 = \frac{\mu}{4\pi}\sigma\frac{\int\vec{v}(\vec{r'},\omega)\times\vec{B}(\vec{r'},\omega-\omega_1)e^{-\frac{j\omega|\vec{r}-\vec{r'}|}{c}}}{|\vec{r}-\vec{r'}|}d^3r'd\omega_1$$
$$A_2 = \frac{\mu}{4\pi r}\sigma e^{-\frac{j\omega}{c}r}\int\vec{v}(\vec{r'},\omega_1)$$

$X\,\vec{B}(\vec{r'},\omega-\omega_1)d\omega_1 e^{\frac{j\omega}{c}\hat{r}r'}d^{3r'}$, with the help of A1 and A2 we can evaluate total magnitude of radiated energy per unit frequency per unit volume. This spectral density can be evaluated by applying Parseval's theorem (mathematics of DFT). As electric field

$$E_\theta = -j\omega(A_{1\theta}+A_{2\theta})$$
$$E = -j\omega A_{1\theta}\hat{\theta} - j\omega A_{1\phi}\hat{\phi}$$
$$H_\phi = -\frac{j\omega}{r}(A_{1\phi}+A_{2\phi})$$

Here $H_\phi$embeds the velocity component of fluid at a given frequency. Now we shall evaluate to compute energy spectral density. On integration we can evaluate $A_{1\theta}$ $and$ $A_{2\theta}$total radiated energy. Also, we shall work to find x, y, z component of pointing vector.

Where r' denotes source and r denotes far field distance. at a large distance shall contribute for η=μ/Ɛ for plane wave propagation.

$A_{1\theta}$ $and$ $A_{2\theta}$ should be function of $(\theta,\phi,\omega)$ also $\hat{\theta}=\hat{\phi}X\hat{r}$ from spherical coordinates $E_\theta X H_\phi$shall provide us the pointing vector of the radiated field. Here 1/r component reside in $\phi$, we need to calculate Component $\theta$ to enable us far field component at large distance, also η=μ/Ɛ for plane wave. We can thus evaluate total energy radiated.

We have$\hat{r}=\,'\hat{\theta}$ and after normalization Sin $\theta$ term gets cancelled.
(E x B) pointing vector for x, y, z components and taking$e^{-j\omega t}$ as common, we can evaluate$E_x, E_y, E_z$.

$$E = -j\omega A_{1\theta}\hat{\theta} - j\omega A_{1\phi}\hat{\phi}$$

Our objective is to evaluate total energy radiated per unit frequency per unit volume.

$$E_\theta = -j\omega(A_{1\theta}+A_{2\theta})$$
$$H_\phi = -\frac{j\omega}{\eta}(A_{1\phi}+A_{2\phi})$$

here effect fluid velocity v have been embedded in H field

$$\frac{1}{2}Re[E_\theta H_\phi] = \int \frac{\omega^2}{\eta} Re(A_\theta A_\phi)\,d\omega r^2 \sin\theta\, d\theta d\phi$$

assuming real part will effectively contribute.

$$\hat{r} = \hat{x}\cos\phi\sin\theta + \hat{y}\sin\phi\sin\theta + \hat{z}\cos\theta$$
$$\hat{\theta} = \frac{\delta\hat{r}}{\delta\theta} = \hat{x}\cos\phi\cos\theta + \hat{y}\sin\phi\cos\theta - \hat{z}\sin\theta$$
$$\hat{\phi} = \frac{\delta\hat{r}}{\delta\phi} = -\hat{x}\sin\phi\sin\theta + \hat{y}\cos\phi\cos\theta$$

Hence

$$A_{1\theta} = \frac{e^{-j\frac{\omega}{c}r}}{r}\left[\frac{\mu\sigma}{4\pi}\int (E_x(\vec{r'},\omega)\cos\phi\cos\theta + E_y(\vec{r'},\omega)\sin\theta\sin\phi) + E_z(\vec{r'},\omega)\cos\theta e^{-j\frac{\omega}{c}(x'\cos\theta\cos\phi + y'\sin\theta\sin\phi + z'\cos\theta)}\right]dx'dy'dz'$$

$$A_{2\theta} = \frac{e^{-j\frac{\omega}{c}r}}{r}\left[\frac{\mu\sigma}{4\pi}\int v_\phi(\vec{r'},\omega) + B_r(\vec{r'},\omega-\omega_1) + B_\phi(\vec{r'},\omega-\omega_1) \quad e^{-j\frac{\omega}{c}\hat{r}\vec{r}}\right]d^3r'$$

Hence, pointing vector can be defined as

$$E_\theta = -j\omega\frac{e^{-j\frac{\omega}{c}r}}{r}(A_{1\theta}(\theta,\phi,\omega) + A_{2\theta}(\theta,\phi,\omega))$$

And

$$H_\phi = -j\omega\frac{e^{-j\frac{\omega}{c}r}}{r}(A_{1\phi}(\theta,\phi,\omega) + A_{2\phi}(\theta,\phi,\omega))$$

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Hence energy spectral density

$$D = -j\omega \int \omega^2 \, Re(A_{1\theta} + A_{2\theta})(\overrightarrow{A_{1\phi}} + \overrightarrow{A_{2\phi}}) \sin\theta \, d\theta \, d\phi$$

Energy Spectral Density be evaluated by applying Parseval's Theorem

$$\int f(t)g(t)dt = \frac{1}{2\pi}\int \hat{f}(\omega), \hat{g}(\omega)d\omega$$

Or

$$\int \vec{E}(\vec{r},\omega) \times \int \vec{H}(\vec{r},\omega)\, \hat{x} ds \, d\omega$$

This shall provide us total energy radiated by the MHD antenna system.

$$D = \frac{1}{2\pi}\int \vec{E}(\vec{r},\omega) \times \int \vec{H}(\vec{r},\omega)\, \hat{x} ds \, d\omega$$

## III. DESCRIPTION OF MHD ANTENNA

Two cylindrical tubes of Propylene Random Copolymer Pipes (PPR) of diameters of 10.5cm and 6.2cm of height 6.5cm respectively mounted on copper ground plane of 35cm diameter. Standard SMA is mounted at the center of y axis for RF excitation. Two tin electrodes for biasing plasma are mounted in such a way that filed is orthogonal to RF input and magnetic field making direct contact with the conducting fluid. Bias voltage to the electrodes of tin 1.2 cm x 4.1 cm mounted on the inner wall of the tube, making physical contact with the conducting fluid, is given through variable DC source in the range 5-25 volts with BIAS TEE arrangement safety of VNA . SMA connector male part (protruded) acts as probe inserted into plasma. The probe dimensions are 0.08 cm in diameter and 0.75cm long. This probe is inserted in such a way that it makes direct contact with the conducting fluid in dielectric resonator. Two permanent bar magnets having dimensions 15cm x4cm x2cm are placed perpendicular to the electric field, so as to produce Lorentz force, resulting into fluid flow. Here, DRA (Dielectric Resonator Antenna) is filled with saline water having TDS (total dissolved salt) between 4000 to 12000. Adding common salt to water will provide variable TDS. Volume of saline water decides geometrical dimensions of DRA to produce desired resonant frequency. The resonator column effects resonant frequency. Radiating resistance and resonant frequency depends on largely on shape and geometrical dimensions of fluid inside the tube and nano particles of the fluid. 40 GHz Network Analyser VNA-L5230 have been used to measure return loss and resonant frequency. The Radiation patterns and Gain measurements were carried out at near field test facility of Bharat Electronics an Ministry of Defence, for resonant frequency 4.59 GHz to get E , H and Cross fields patterns. Measured results of prototype antenna are Return loss = -27.1dB, Gain = 9.2 dBi and Resonant frequency = 4.59 GHz. We have formulated various equations based on fluid frame of our prototype design. Here, we first describe beam formation, radiating patterns and resonance frequency. Here, we see radiation parameters of our antenna depends not only on electromagnetic fields, but also on fluid velocity field. From analytical results it is observed that it generates harmonics of resonant frequency. Comparison between prototype result and numerical results has been made. Here it observed that varying fluid volume can result into tunable resonant frequency. The adaptable permeability and permeability is described in section three. This can result into possible tuning of polarization. As results have shown generation of harmonics with fundamental frequency, hence with proper filtering, this antenna can made to operate at any desired frequency from the harmonics. The effects of magnetic bias on antenna have been investigated. The principle of this class of antenna is dielectric resonator, where salt (in solution) and electric field modifies the dielectric properties. We have varied fluid salinity, magnitude electric field and magnetic field, fluid height for all possible combinations. Here, we see chemical properties of fluid, shape of tube, effective biasing voltage and magnetic field conditions changes antenna parameters. Here ionized currents contribute to radiate energy in conducting fluid. The tube was applied external magnetic field which interacts with electric field to produce Lorentz forces, resulting in fluid flow with velocity v. Now there are three main fields i.e. electric field, magnetic field and velocity fields, which are responsible for the possible radiations. The radiated energy and its pattern are function of RF input excitation, fields applied, fluid shape and nano particle of fluid. Hence an adaptive mechanism can be built in antenna to produce versatility in radiation pattern, due to dynamic fluid perturbations. We shall consider the fluid in coordinates rotating with it and mechanical equations of motion must include effects of centrifugal and Coriolis forces. Wave are also due to Coriolis forces (2v x Ω), which occur in rotation. Here we first describe beam formation, radiating patterns and resonance frequency. Radiation patterns in the far fields depend not only on electromagnetic field but also on fluid velocity. Gain measurements with and without electric and magnetic fields were carried out . It got increased from 6.22 dBi to 9.10 dBi on applying electric fields at a value of 5.2 V, DC to 7.5 V. Also considerable change in Return loss were seen i.e. S11 measured -18.7 dB without Electric and Magnetic fields and increased to -21.7dB DC bias. Return loss further improved to -27.7 dB when both electric and magnetic fields were applied 40 dB isolation was seen in cross polarization results. The above quoted results are not optimized. No corrosion takes place in this type of antenna. Obtained results indicated, reconfigurability, frequency agility and tuning of Gain possibility. Sea water and mercury results

In this antenna, only ionized currents contribute to radiateenergy in conducting fluid. Radiating resistance and resonantfrequency shall depend on shape of fluid inside the tube andnano particles of the fluid. The tube was applied to externalmagnetic field which interacts with electric field to produceLorentz forces, resulting in fluid flow with velocity v. Nowthere are three main fields i.e. electric field, magnetic field andvelocity fields, which are responsible for the possibleradiations. The radiated energy and its pattern are function ofRF input excitation, fields applied, fluid shape and nanoparticle of fluid. Hence an adaptive mechanism can be built inantenna to produce versatility in radiation pattern and broadband effects, due to dynamic material perturbations.We have formulated to focus onphysics of the design analysis of an MHD antenna. Here wedescribe complete mechanism for beam formation, radiatingpatterns and resonance. Radiation pattern in the far fieldsdepends not only on electromagnetic field but also on fluidvelocity field. We have described mathematical relations ofpermeability as the function of E, H and v, when conductivityand permittivity are kept constant. With proper filteringtechniques, MHD antenna can made to operate at one singlefrequency. Fluid shape with fields decides resonant frequency.The effective permeability can be controlled by applying astatic magnetic field. This leads to the possibility of magnetically tuning of polarization of the antenna.Polarization tuning of antenna was measured as a function ofstrength for magnetization parallel to the x- and y-directions.The effects of magnetic bias on antenna have been investigated.The principle of this class of antenna is essentially that of adielectric resonator, where salt (in solution) and electric fieldmodifies the dielectric properties. The resonator column shapedetermined the operating frequency, allowing impedance matchand frequency of operation to be fully tunable. We have varied fluid salinity, electric field,magnetic field and fluid height for all possible radiationmeasurement in experimentations.

## IV. IMPORTANT RESULT

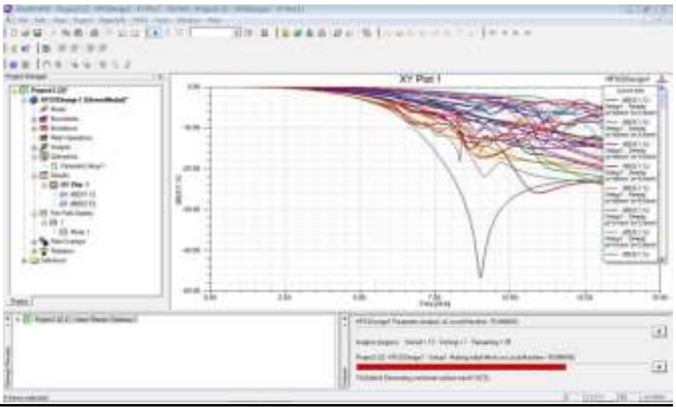

***Figure 1. Return loss when both electric and magnetic field applied.***

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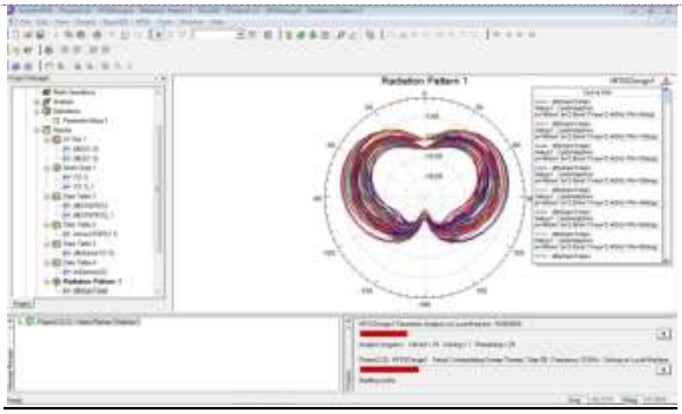


***Figure 2. HFSS Radiation Pattern***

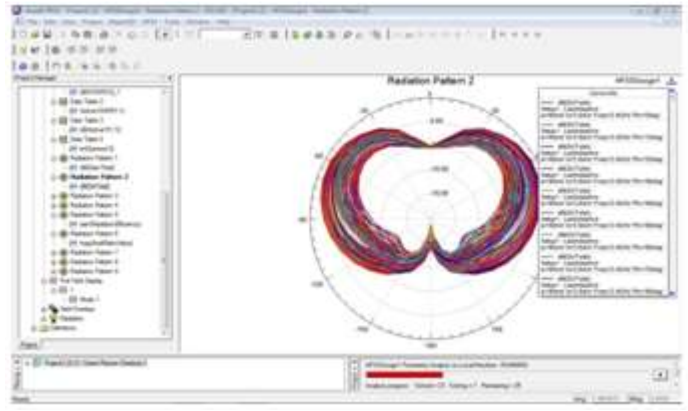


***Figure 3. Directivity***

## V. CONCLUSION

It was observed from the measured results that there is significant improvement in return loss when salinity of fluid is enhanced. Also return loss improved due electric and magnetic fields intensity. We have observed that electric field have significant impact on return loss, these measured results are placed. Bias TEE was used to feed mixed signal from the same port .Return loss was significantly high at 17V, DC. Height of fluid tube (fluid shape), nano particles of fluid contribute to form resonant frequency of fluid antenna. When height of fluid was 3.5 cm, our antenna resonated at 4.59 GHz and when height of fluid increased to 6.0 cm , same antenna resonated at 8.59 GHz. We have also simulated taking saline water as dielectric in HFSS antenna software for resonant frequency evaluation as per. We could thus achieved reconfigurability and frequency agility in this antenna. It has stealth property, as reflector is voltage dependent, hence can be most suitable for Military applications. We can also use this antenna as MIMO (multiple input outputs). More work towards micro-fluidic frequency reconfiguration, fluidic tuning of matching networks for bandwidth enhancement need to be explored. As a Future work, we will investigate radiation patterns as a special case to this cylindrical antenna with detailed physics involved.

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