

# Dual-Polarized Radiating Elements Based on Electromagnetic Dipole Concept

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**Abstract**—Dual Polarized radiating element is a critical component in the Multi-function Phased Array Radar (MPAR) System. This paper shows study of dual polarized radiating element based on EM dipole concept. Various geometries for loop as a magnetic dipole and E dipole are discussed which can be used as potential elements to build an array. Several techniques are used to address the challenge; these include probe and differential feed structures, stacked layers, as well as capacitive loading techniques. Radiation patterns are shown based on Ansoft HFSS simulation software. Element designs for low cross pol and omni-directional pattern are investigated. Future work and scope to align the antennas and test plan are discussed.

**Keywords**—MPAR; dual-polarized elements; cross-pol; EM dipole array; probe feed; differential feed; capacitive loading techniques

## I. INTRODUCTION

Antenna elements having characteristics such as low cross polarization and omnidirectional pattern capable of functioning over a wideband are important for many applications. One such application is Multi-function Phase Array Radars (MPAR) which aims to perform aircraft tracking, wind profiling, and weather surveillance.

Theoretically, an ideal radiating element consists of co-linear electric and magnetic dipoles, which ensures the orthogonality of co- and cross-pol E-fields in all spatial directions [1]. Initial implementation of such dipole elements has been made by the industry, but much more work remains to be done to achieve a realistic, low-cost and well-performing engineering designs.

This paper shows the study of different antenna geometries such as loop and planar dipoles. Several techniques are used to address the challenge; these include probe and differential feed structures, stacked layers, as well as capacitive loading techniques. For example, one of the candidate designs consists of circular ring fed with a parallel strip feed line, which acts as an impedance transformer. The second example has circular ring fed by coax feed. The third one is a stacked circular ring structure which also uses coax feed. The design process is based on cavity theory model and for initial validations, spectral domain moment method is used. The characteristics of these radiating element designs have been studied with HFSS simulations. The simulations show that these structures result in uni-direction circular current distribution and

improvement at all aspects of the antenna characteristics including radiation pattern, return loss and cross-polarization isolations at single element level are shown.

## II. MAGNETIC DIPOLE MODELS AND GEOMETRIES

### A. Single Layer Loop with Probe Feed.

Among various forms of micro strip antennas, the loop or ring antennas have received considerable attention. This is because when ring is operated in fundamental  $TM_{11}$  mode, it's size is smaller as compared to its rectangular counterparts and have broadband characteristics with high input impedance[2].

The first candidate design is a coax fed single layer loop antenna operating on  $TM_{11}$  dominant mode. This antenna design is based on cavity theory model [2]. The resonant frequency is obtained as

$$f_{mn} = \frac{X_{nm}c}{2\pi a\sqrt{\epsilon_{re}}} \quad (1)$$

where  $c$ = velocity of light in free space

$a$ = inner radii of the ring

$b$ = Outer radii of the ring

$\epsilon_r$ = dielectric constant of the substrate

$$\epsilon_{re} = \frac{1}{2}(\epsilon_r + 1) + \frac{1}{2}(\epsilon_r - 1)\sqrt{1 + \frac{10h}{W}};$$

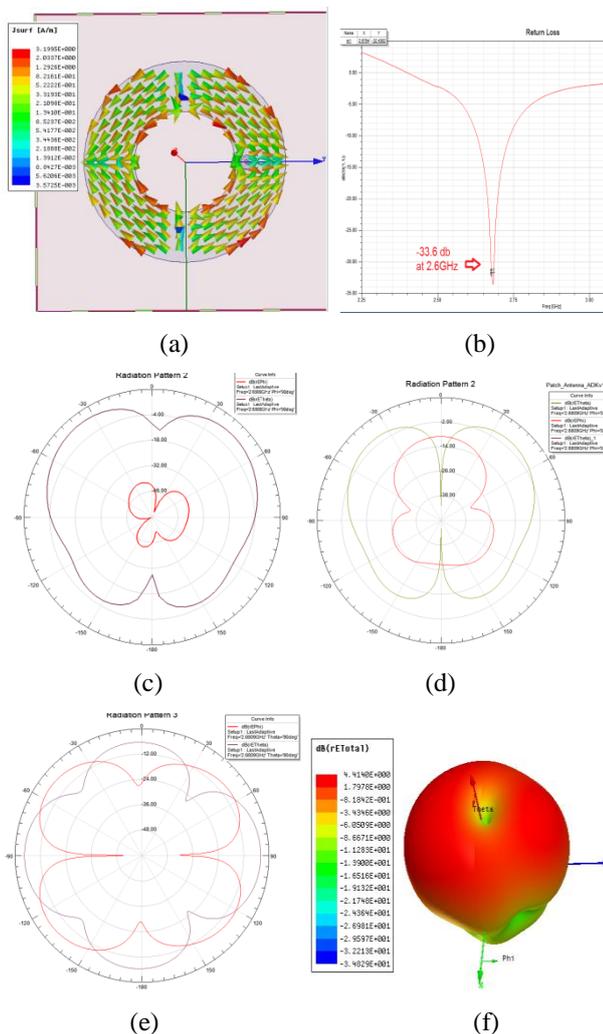
$$W = b - a$$

$$X_{nm} = k_{mn}a \quad ; \quad h = \text{thickness of dielectric}$$

$k_{mn}$  are the roots for the resonant  $TM_{nm}$  modes and are not discussed for the sake of brevity.

The probe feed is located at a distance from the center based on trial and error method to get the best matching results. For different location of the feed point, the return loss is compared and the position where S11 is most negative is selected. Ansoft HFSS (High Frequency Structural Simulator) is used as simulation tool. The loop has the following specifications: Inner Radius  $a=16.902\text{mm}$ , Outer Radius  $b=33.804\text{mm}$ , Rogers 5880 substrate material with  $\epsilon_r = 2.33$  and substrate thickness  $h=6.096\text{mm}$ .

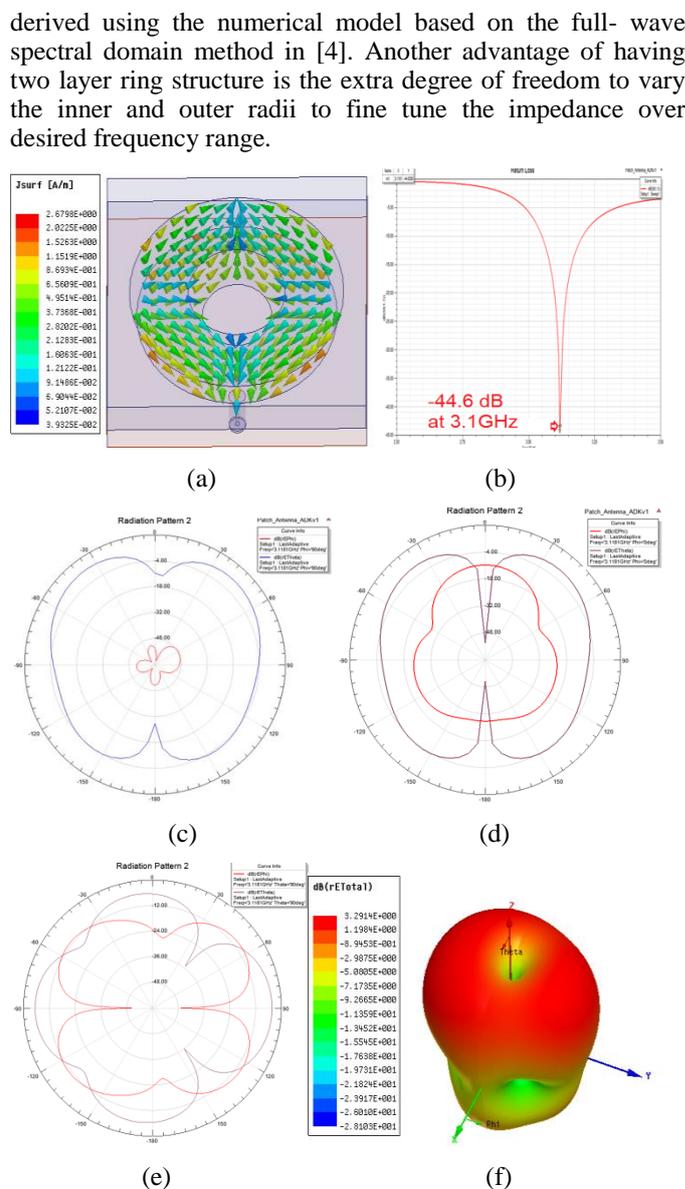
The geometry of the loop and surface current distribution can be seen in figure 1 (a). The recorded return loss is -38.49 dB at 2.68 GHz and about 100MHz bandwidth.



**Figure 1: (a) Proposed Single Layer Loop with Coax Feed (b) Return Loss (dB) (c) Radiation Pattern YZ Plane (d) Radiation Pattern XZ Plane (e) Radiation Pattern XY plane (f) Total 3D Radiation Pattern.**

*B. Multi Layer Stacked Loop with Probe Feed.*

The second candidate design is stacked probe fed microstrip loop antenna which has two different dielectric substrates. This design is based on full wave spectral domain analysis [3] and for the sake of brevity will not be discussed. The advantage of using this method with approximate models such as cavity theory model is that this analysis gives a good insight to design an antenna when using an electrically thick substrate to enhance the bandwidth. As mentioned earlier, when a probe fed ring is operated in its fundamental mode ( $TM_{11}$ ) mode, it has high input impedance at resonance. This high input impedance is advantageous when using stacked configurations. The lower resonator is over coupled and the top layer is effectively used to match the entire configuration [4]. The lower resonator is derived from cavity model analysis and the top layer commonly called as an attachment mode is



**Figure 2: (a) Proposed Stacked Loop with Coax Feed (b) Return Loss (dB) (c) Radiation Pattern YZ Plane (d) Radiation Pattern XZ Plane (e) Radiation Pattern XY plane (f) Total 3D Radiation Pattern.**

As seen in figure 2 (a), there are two dielectrics with  $\epsilon_{r1}=2.2$ ,  $\epsilon_{r2}=1.07$ ,  $\tan\delta_1=0.001$ ,  $\tan\delta_2=0.001$ . The lower layer loop dimensions are Inner radius  $a_1=10\text{mm}$ , Outer radius  $b_1=29\text{mm}$ . The top layer loop dimensions are Inner radius  $a_2=14\text{mm}$ , Outer radius  $b_2=31\text{mm}$ . The probe location is based on trial and error to get the best matching results. The simulation results show that the loop resonates at 3.1GHz with -44.6 dB of return loss. The observed bandwidth is about 200 MHz.

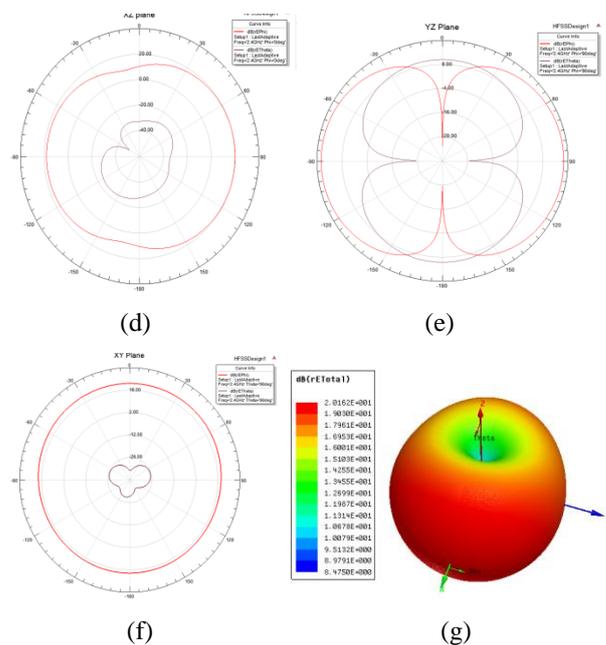
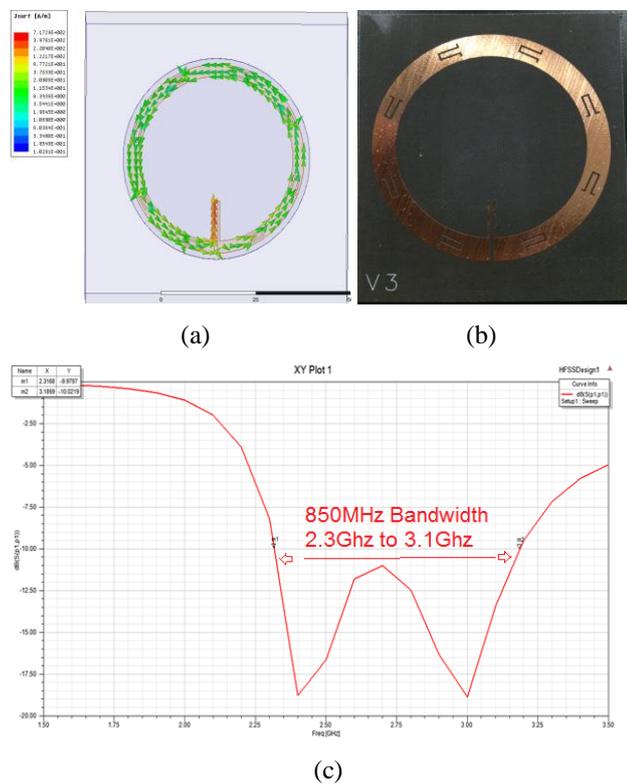
As a comparison with single layer loop, we observe that this stacked loop has better matching and almost twice the bandwidth. The surface current distribution however seems not

uniform which led us to further investigate next candidate design.

### C. Capacitively Loaded Loop

The next design shown is a direct implementation of antenna proposed by Wei et al [5]. The design is re-dimensioned to operate over 2.3GHz to 3.1GHz. As seen in figure 3 (a) and (b), the structure has periodic capacitive loading which helps the surface current to remain uniform and in phase. The two strip lines are used as an impedance transformer for proper matching.

The loop is printed on Rogers RO4725/ Teflon substrate with  $\epsilon_r=2.65$ ,  $\tan \delta=0.0002$  and thickness of 0.787mm. The loop has Inner radius =20.5mm, Outer Radius=23.5mm. The arc lines which constitutes for periodic capacitive loading are place at angle of 45 degree each. The length of strip line is 13mm and width is 0.5mm similar to one used in [5].



**Figure 3: (a) Loop with uni-directional surface current (b) Fabricated Prototype (c) Return Loss (dB) (d) Radiation Pattern XZ Plane (e) Radiation Pattern YZ Plane (f) Radiation Pattern XY plane (g) Total 3D Radiation Pattern.**

As seen in figure 3(c), the antenna has about 850MHz bandwidth. The uni-directional uniform current distribution allows achieving a horizontally polarized radiation pattern. The radiation pattern in azimuth plane (xy-plane) shows that an omnidirectional radiation is achieved while the radiation patterns in elevation plane (xz and yz plane) shows quasi eight shape, thereby making it very close to ideal magnetic dipole. As observed from the radiation patterns the cross-polarization of this antenna element is about -45 dB lower which makes it very good candidate for MPAR applications.

### III. ELECTRIC DIPOLE MODELS AND GEOMETRIES

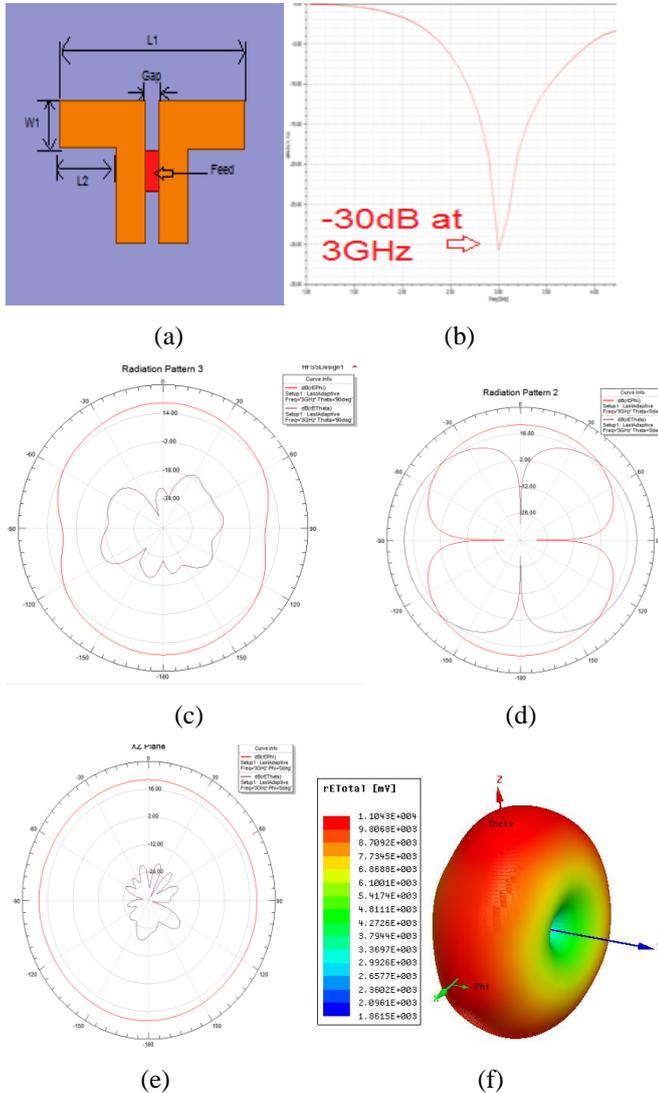
The investigation of E dipole led to implementations of various dipoles. Among all we chose the planar dipole which allows us to avoid 3-D geometries and ease the fabrication process when make a larger array. A common drawback of printed dipoles is that they suffer with narrow bandwidths and often many applications require wide band characteristics. The designs discussed below show printed dipole antenna with low cross-polarization and with sufficient wideband characteristics.

#### A. Printed Dipole I

The geometry of the proposed dipole antenna is shown. The dipole is composed of two dipole arms. The length of each dipole arm is  $l = \lambda_0/4$  and width  $w \approx l/3$ . The substrate used is Rogers 5880 with  $\epsilon_r=2.2$ ,  $\tan \delta=0.0009$  and thickness of 0.787mm. The design parameters were optimized using HFSS

simulation. The design parameters are as follows:  $L_1=41\text{mm}$ ,  $L_2=12.5\text{mm}$ ,  $W_1=9\text{mm}$  and  $\text{Gap}=3\text{mm}$ .

It can be seen in figure 4 that the proposed dipole has a omnidirectional pattern and has a bandwidth of 850 MHz. A differential feed is used when simulating the antenna however, a balun is needed to excite the antenna for proper matching. The cross polarization observed is about 30 lower.

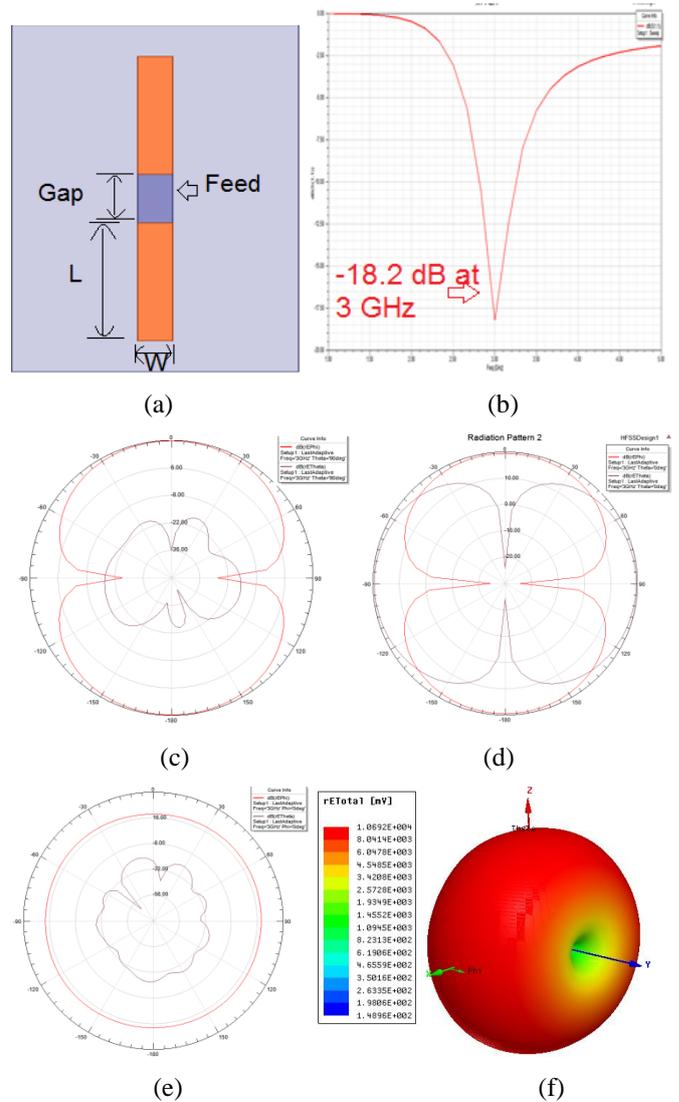


**Figure 4: (a) Printed Dipole Geometry (b) Return Loss (dB) (c) Radiation Pattern E Plane (d) Radiation Pattern H Plane (e) Radiation Pattern XZ plane (f) Total 3D Radiation Pattern.**

*B. Printed Dipole II*

The proposed geometry has a simple design with two identical arms each of length  $L=17\text{mm}$ ,  $W=3\text{mm}$  and  $\text{Gap}=7\text{mm}$ . Rogers 5880 substrate with  $\epsilon_r=2.2$ ,  $\tan \delta=0.0009$  and thickness of  $0.787\text{mm}$  is used. A balun can be used to feed the dipole. As the width of the ground plane affects

the Omni-directional pattern, a smaller ground plane can be selected if very good omni-directional antenna is to be preferred. The antenna has a bandwidth of about 440 MHz and cross polarization levels are about 40 dB lower.



**Figure 5: (a) Printed Dipole Geometry (b) Return Loss (dB) (c) Radiation Pattern E Plane (d) Radiation Pattern H Plane (e) Radiation Pattern XZ plane (f) Total 3D Radiation Pattern**

IV. DUAL POLARIZED EM DIPOLE ELEMENT

The loop and E dipole radiating elements can be united into a single environment to estimate the effect of mutual coupling and interference. Theoretically, an ideal radiating element consists of co-linear electric and magnetic dipoles, which ensures the orthogonality of co- and cross-pol E-fields in all spatial directions [1]. The loop antenna which is designed is electrically large, but a far field distance, it can be treated as

small circular loop, which is a dual antenna to an electrically small electric dipole antenna. That means the far-field electric field of a small loop antenna is identical to the far-field magnetic field of the short dipole antenna and vice versa as shown in figure 6. [6].

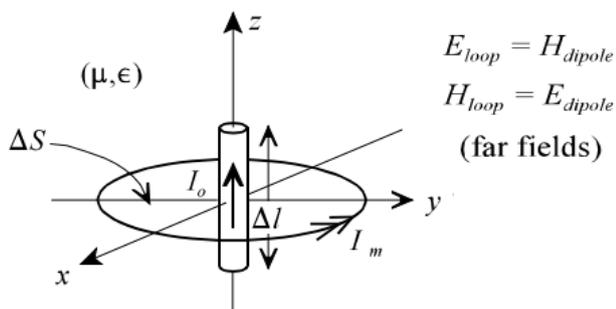


Figure 6: Duality Principle applied to Loop and E dipole

If the radiated fields of the dipole antenna and loop antenna are same, then the radiation patterns are almost matched and the plane of maximum radiation is in the plane of the loop. The following two conditions are to be satisfied [1,6]

$$I_m \Delta l = j \eta k I_0 \Delta S = j \omega \mu I_0 \Delta S \quad (2)$$

$$I_0 \Delta l = j \eta k I_m \Delta S = j \omega \mu I_m \Delta S \quad (3)$$

where  $I_m$  = the magnetic spatial current

$I_0$  = the electric spatial current

$\Delta S$  = Area of loop

$\Delta l$  = Length of dipole.

Applying the same theory to simulate both loop and E dipole in a single environment we get the following results as shown in Figure 7.

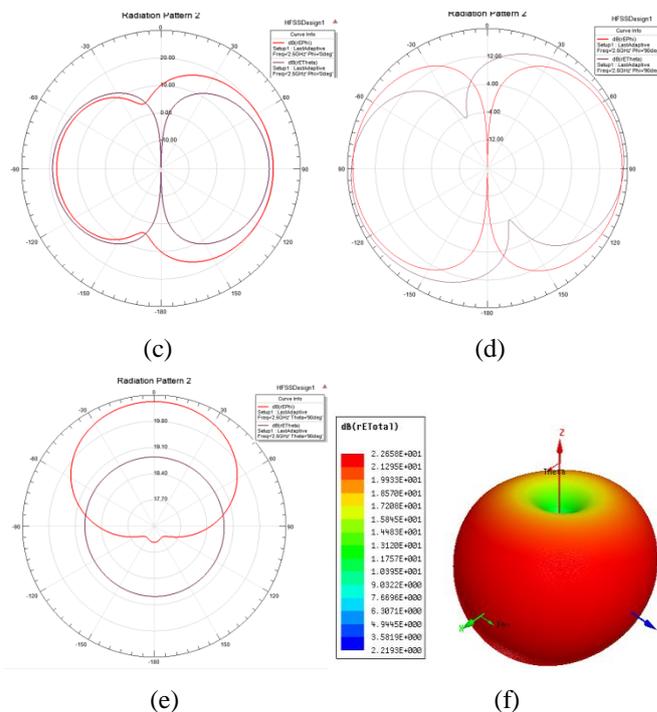
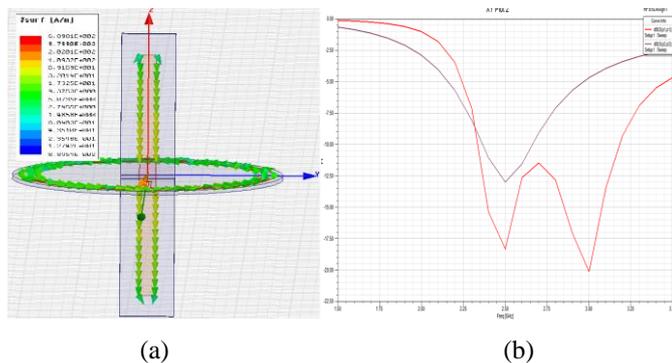


Figure 7: (a) EM dipole simulated together (b) Return Loss (dB) (Red- Loop, Voilet-E Dipole) (c) Radiation Pattern XZPlane (d) Radiation Pattern YZ Plane (e) Radiation Pattern XY plane (f) Total 3D Radiation Pattern

Both Loop and E dipole resonates at 2.5GHz and overall realized bandwidth is about 350MHz. Several simulations based on different ways of aligning the two antenna and different excitations were run and for the sake of conciseness only the best among all is shown in figure 7. In figure 7, both the antennas are excited simultaneously. We can observe that  $\theta$  and  $\phi$  for both antenna almost match each other, thereby giving an omni-directional radiation pattern as verified in figure 7(e).

## V. FUTURE WORK AND CONCLUSION

The main challenge of combined EM dipole is the magnetic dipole performance and controlled interaction between E and H dipoles. The current goal is to achieve a realistic, low-cost and well performing engineering designs. The research team at OU is working towards testing the initial designs in the anechoic chambers as a part of a larger array test bed called Configurable Phased Array Demonstrator (CPAD) at the Radar Innovations Laboratory (RIL).

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