Metamaterial Microwave Absorber (MMA) for Electromagnetic Interference (EMI) Shielding in X-Band

Rakesh Mishra, Ravi Gupta, and Suwarna Datar*

Abstract The present paper is aimed at investigating application of planar Metamaterial (MM) structures for effective EMI Shielding and Stealth applications in X-Band. Various MM structures using FR4 substrate and Copper conductors were conceived and designed followed by simulations carried out using CST MWS Suite software. As a first step, the designs were aimed at achieving extremely high absorption for normal incidence, polarisation independence and maintaining high absorption in wide angle performance while keeping the requirement of light weight, flexibility and environmental ruggedness in mind for deployability on platforms to achieve effective stealth against Radars and for other EMI shielding applications. Circularly symmetric, single layer Metamaterial Microwave Absorber (MMA) design over thin FR4 substrate in spokes and wheel structural arrangement provided these desired features. The thin FR4 substrate of 0.6 mm provides the light weight and flexibility while absorbing the EM waves. Rotational symmetry of the spoke and cut-wheel design gives it polarisation independence and 4 ring planar array concept with rings scaled to different sizes in the same plane in the unit cell provided the increase in bandwidth. Reduction in received signal level of the echo is depicted by the S-Parameter at the input port. Getting values of this S-Parameter less than -60dB at resonant frequency for MMAs is highly encouraging and is not reported much in literature. Enhancement of nearly 3-8 times in operating bandwidth was achieved by changing size of rings in each quadrant in the co-planar
array having four resonant rings in each unit cell.

**Keywords:** Metamaterial, Rotational symmetry, Microwave Absorber, EMI shielding.

### 1 Introduction

The concept of negative refractive index was introduced by Veselago in his seminal article ([1](#)) which was realized by using metallic wires and split-ring resonators to separately demonstrate negative permittivity and negative permeability materials respectively in the 1990s by Pendry et al. ([2](#)) Later, Smith et al. experimentally realized these structures in the microwave regime by using both the structures simultaneously in specific ways to produce Left Handed Materials (LHMs). ([3](#)) Such materials have unique properties which depend on the “meta atomic structure”, rather than the materials they are made up of. Since the introduction of concept of LHMs many applications of metamaterials like invisibility cloaks, super-lens, antennas, Electromagnetic (EM) wave absorbers and so on have been investigated.

With development and use of electronics in every area of life, there is always a need for Radar Absorbing Material (RAM) for applications such as Electromagnetic Interference (EMI) shielding, Electromagnetic Compatibility (EMC), communication antennas, stealth etc. Researchers are working on RAM to improve their performance in absorption, the absorption bandwidth, polarization and angle of incidence independence etc. ([7](#), [8](#)) Extensive research has been done in the area of carbon-based polymer composites like Carbon Fiber Reinforced Polymer (CFRP) Composites, Carbon Nanotubes (CNT) decorated by magnetic nanoparticles and graphene composites for stealth applications. They have been found to be flexible, strong and have shown very encouraging results. ([9](#), [10](#), [11](#)) However, control over operating bandwidth, homogeneity of inclusions and predictability of material properties poses some challenge. Also, production cost and difficulty in large scale production and high weight penalty are few other challenges causing limitation of their applications for stealth against radars. Accordingly, thin, low weight, flexible metamaterials, designed as resonant structures, is a good alternative to these technologies. The objective of the present work is to study new designs of MMA suitable for application to the platform surfaces for stealth and EMI shielding applications in the X-band.

The first microwave absorbers using metamaterials was proposed and realized in 2008 by Landy et al. ([6](#)) Many researchers have proposed different topologies and methodologies to produce high absorption of EM energy using them. This has been possible by reducing the reflection at the surface and by realizing absorption of the waves in the intervening dielectric substrate by engineering the electrical and magnetic resonances to coincide at the same frequency.

EM wave absorbers have been engineered to operate at specific frequency spectrum ranging from microwave to ultraviolet with different features. They can be single-band, multi-band, broad band, polarization insensitive, wide angle etc. ([12](#), [13](#), [14](#), [15](#)) Metamaterial absorbers with switchable frequency([16](#)) and wide band absorbers using Lumped components have also been reported.([17](#), [18](#)) Amongst these, wide angle metamaterial absorbers are most difficult to realize, particularly for the thin structures and they have been generally found to have maximum absorption for orthogonal incidence. ([19](#)) Increasing the angle of incidence has been seen to reduce the absorption characteristics considerably in most designs.([20](#), [21](#), [22](#), [23](#), [24](#), [20](#), [25](#)) The flexibility in realizing metamaterial absorbers for various range of frequencies/wavelength, in the microwave region, in which most of the radars operate, make them suitable candidate for designing and fabricating them to provide stealth
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to military targets against radars or in general as EMI shields. Such metamaterial absorbers in the microwave frequency domain shall be addressed as Metamaterial Microwave Absorber (MMA) in this paper.

2 Design of basic resonant MMA with metal back plane

In the present work MMA structure with resonant design on a substrate having a metal back plane was chosen for investigation as shown in figure 1. The MMA design was conceived as a wheel with four spokes in a unit cell to provide inductive reactance loops in each quadrant and with cuts on the wheel in each quadrant to provide the capacitive element for the resonance. Annealed copper has been chosen for resonant ring and the back plane and lossy FR-4 as the substrate. The thickness of the substrate is chosen as 0.6 mm which is sandwiched between Annealed Copper coatings of 0.035 mm on both sides. The resonant structure design can be screen printed and etched on one side and the other side is left as it is to provide the conducting back plane. The orthographic front view of the Unit Cell of proposed MMA is shown in Figure 1 along with important design parameters where ‘a’ is cell size, ‘oc’ is outer clearance, ‘r1’ is outer radius of annular ring, ‘r2’ is inner radius, ‘rt’ is the ring width, ‘g’ is the capacitive gap, ‘spw_1’ is width of spoke 1, ‘spw_2’ is width of spoke 2. The schematic arrangement of resonant structure, substrate, and the back plane is shown in Figure 2, with thickness represented as ‘st’ and conductor thickness ‘ct’ for resonant structure and the back plane (The ct and st dimensions are exaggerated for visual understanding).

Simulations were carried out on this MMA design in Frequency Domain using Computer Simulation Technologies Micro-Wave Studios (CST MWS) simulation software. Only Zmax Port on the front side of design was used for excitation as shown in Figure 3. The Zmin port on the opposite side was not used as no EM wave is expected to cross the continuous metallic back plane. This was done by putting electric field Et = 0 for the Zmin Port in the boundary conditions.

The structure, being circularly symmetric, was expected to provide polarisation independence. [20] The small thickness of the substrate was expected to provide for the wide
angle performance. The structure being highly symmetric and resonant, when optimised, was expected to provide high absorption hence low reflection and low value of S-parameter at Zmax Port ($S_{Zmax}$).

Further, to improve the bandwidth of absorption, 4-Ring Array structure was designed as shown in Figure 4. The perspective view of unit cell of the array is shown in Figure 5. This structure has four resonant rings in each Unit Cell. The rings are scaled to different sizes in x-y domain to provide closely spaced peaks, thus increasing the operational Bandwidth.
Fig. 4 The orthographic front view of the unit Cell of 4-Ring Array type Spoke and Cut-Wheel MMA having each ring structure scaled in size using a scaling factor in X-Y plane.

Fig. 5 The perspective view of the front side of unit Cell of 4-Ring Array type MMA.

3 Simulation Results

MMA structures with plane annular rings without any cuts or a ring with a single cut were initially designed, simulated and optimised. It was found that the absorption increased when the spoke & cut-wheel structure was introduced (> 60 dB). It was also observed that, single cut structures or complementary ring structures are not symmetric with respect to rotation of Electric Field vector and hence do not exhibit good polarisation independence. In view of these preliminary observations during design and simulation steps, the spoke & cut-wheel structure was conceptualized and studied extensively.

The spoke and wheel MMA design were optimised using parametric sweeps during simulation and the results with this MMA design showed very encouraging peak absorption. After optimisation, it gave \( \sim 100\% \) absorption at the resonant frequency of 9.828 GHz with Scattering Parameter \( S_{Z\text{max}} \) (depicting reflection back to the excitation port) as low as
-65.97dB for normal incidence. Accordingly, it can be treated as perfect MMA for stealth applications at the design frequency.

From the Radar Range Equation, we know that the maximum range of Radar is inversely proportional to the fourth root of minimum detectable Received Signal Level (RSL). [26] As the RSL will be reduced by \(\sim 66 \text{ dB} \) at resonant frequency due to the MMA, the effective Radar Range will be reduced by a factor of approximately 40 times for the Radar transmit frequency. This implies that, if MMA is designed for the radar transmit frequency, a monostatic/bistatic radar with a Maximum Detection Range of 400 km will be able to detect the target platform only when it has reached at a distance of approximately 10 km from the radar. This is very effective stealth. The attendant challenges here are the bandwidth, for different polarisation and direction of incidence of waves with respect to the MMA structure.

The Simulation was done using Frequency Domain Solver of CST MWS simulation software, with smallest mesh size less than the smallest dimensions of the MMA. Option was chosen to get 10001 result data samples for a smooth graph and accuracy of simulation results. Other options were also chosen in a manner to present highest accuracy and correctness of simulation.

The simulation result for \( S_{Z\text{max}} \) vs frequency for the optimised MMA is shown in Figure 6. The total scattered EM energy from the structure, reaching back the excitation port (Radar) is represented by \( S_{Z\text{max}} \) and it has minima of -65.97 dB at the resonant frequency of 9.828 GHz and 10 dB bandwidth of approximately 154 MHz around it.

![Figure 6](image)

Fig. 6 Reflection Parameter \( S_{Z\text{max}} \) of -67.11 dB at normal incidence depicts 100% absorbance of scattered energy at the metasurface at resonant frequency.

The FR-4 substrate thickness and conducting surface thickness were chosen as per specifications of commercially available standard materials in the market. The parameters like outer clearance (oc), ring width (rt), gap width (g), and spoke widths (spw_1 & spw_2) were used for course and fine optimisation to achieve better than -60dB values of \( S_{Z\text{max}} \) at resonant frequency in the frequency range of 9.5GHz to 10.5 GHz. The parameters of the optimized MMA structure are given in Table 1 below. The design being symmetric to 90° rotation in X-Y plane was expected to exhibit polarisation independence. The dependence of absorbance on the polarisation angle Phi (\( \phi \)) and the incidence angle Theta (\( \theta \)) was studied by using Floquet mode excitation in the Frequency Domain Solver of the CST MWS by
Table 1 The simulation parameters of the optimized Spoke & Cut-Wheel (SCW) MMA

| Sl. No. | Parameter | Optimised Parameter (in mm) | Description                      |
|--------|-----------|----------------------------|----------------------------------|
| 1.     | a         | 12.0                       | Cell size                        |
| 2.     | ct        | 0.035                      | Conductor Thickness              |
| 3.     | st        | 0.6                        | Substrate thickness              |
| 4.     | oc        | 0.175                      | Outer Clearance of Ring          |
| 5.     | rt        | 1.0                        | Ring Width/Thickness             |
| 6.     | r1        | 5.825                      | Outer Radius of Ring             |
| 7.     | r2        | 4.825                      | Inner Radius of Ring             |
| 8.     | g         | 0.77                       | Capacitive Gap Width             |
| 9.     | spw_1     | 0.76                       | Width of Spoke-Pair 1            |
| 10.    | spw_2     | 1.133                      | Width of Spoke Pair 2            |

varying the spherical angle phi and theta in simulation. The orientation of spherical angles \( \phi \) and \( \theta \) are depicted in Figure 7.

Fig. 7 Orientation of polarisation angle phi (\( \phi \)) and incidence angle theta (\( \theta \)). Angle \( \phi \) varies along the blue circle and angle \( \theta \) varies along the green circle.

Simulations were carried out for the three cases that arise as given below:-

3.1 For Changing Polarisation Angle \( \phi \) While Keeping \( \theta = 0^\circ \).

Perfect polarisation independence was observed, as expected, due to 90\(^\circ\) rotation symmetry of this MMA design. It can be seen from Figure 8 that all the curves overlap, almost completely, over complete frequency range of simulation for all angles of polarisation.

3.2 For Changing Incidence Angle \( \theta \) While Keeping \( \phi = 0^\circ \).

It was found that the maximum absorption was obtained at \( \theta = 0^\circ \) at the resonant frequency of 9.828 GHz. However, in this case, the absorption gradually decreases with increasing incidence angle \( \theta \) as shown in Figure 9. \( S_{Z_{max}} \) was still better than -10 dB for incidence angle of 75\(^\circ\) and -30 dB for \( \theta = 45^\circ \). Thus, the acceptance cone angle is greater than 150\(^\circ\) for 10 dB and 90\(^\circ\) for 30 dB of reduction in RSL due to the MMA. There could be anomalous behavior of MMA at very steep angles of incidence.
3.3 Both Polarisation angle ($\phi$) and Incidence angle ($\theta$) Varying (Keeping $\theta = \phi$).

When both polarisation and incidence angles are varied simultaneously, keeping them equal, very little change was observed in $S_{Z_{\text{max}}}$ vs Frequency (Figure 10) as compared to case of only incidence angle variation.

The biggest challenge with this perfect, but narrow band MMA conceived above was of increasing the operating bandwidth. As it is known that the Gain–Bandwidth product of any resonant feedback system is generally constant.[27] Accordingly, it was expected that when the Bandwidth is attempted to be increased, the Gain (absorption in this case) is likely to suffer. The observations were as per expectations.

Many studies have been conducted on MMA structures to enhance the operating bandwidth by using the concept of stacking of multiple MMA layers. Here the resonant frequency-selective surfaces were separated by layers of substrate and were scaled up or down in size to resonate at closely spaced peak frequencies thus increasing resultant bandwidth. However, such multi-layer structures have unacceptable weight penalty and possibility of peeling-off
of the layers from each other under thermal and other environmental stress.[20,21,22,23,24,20,25]

The obvious solution is to keep the structure planar and single layer type, keeping the structure lighter and rugged. Thus, the scaling of resonant structures was to be done in the same plane itself. Accordingly, simulations on various planar-arrays were attempted, having more than one spoke and cut wheel structure, scaled in size, in the same X-Y plane only. The bandwidth enhancement was also attempted by changing the capacitive gaps in each quadrant of the ring. The results were encouraging for 2x2 Array of four rings.

The simulation and optimisation in time domain were carried out and minima of -63.8 dB was achieved for the S-parameter which is equivalent to absorbance of 99.99996% at 9.912 GHz. It showed an enhancement of Bandwidth by 3 to 8 times as compared to the sharply resonant peak of Single-Ring Single-Layer MMA structure as seen in Figure 6 above. The results of 4-Ring Array for Absorption and S-Parameter with increased bandwidth are shown in Figure 11 and Figure 12 respectively. It shows a 30 dB bandwidth of Approximately 96 MHz.

Fig. 10 S.Zmax vs frequency when both polarisation and incidence angle vary (keeping $\theta = \phi$).
4 Fabrication and Testing

A spoke and cut-wheel MMA was fabricated by using FR4 as substrate and copper as conductor by creating a mask using gerber (.gbr) format of design from CST MWS software then using photo-printing and etching technique to remove the remaining copper as shown in Figure 13 below.

The testing of the fabricated MMA was carried out by first subjecting the back plane side of the MMA to RF wave around the resonant frequency in the X-Band. The Microwaves were generated and transmitted by an RF source (Vector Network Analyser) and transmitting antenna and then received at an antenna located adjacent to it. This served as the reference graph representing the echo from a metallic platform of interest without the MMA pasted over it and the random noise reflections from the surroundings as shown in black colour in Figure 11 for the given set up. The frequency sweep was narrowed down around the resonant frequency for better appreciation of BW. Keeping the set-up and the environment
exactly same, the MMA was flipped and the resonant structure was exposed to the incident EM waves. The resulting signal received at the receiving antenna represented the EM wave after absorption by the MMA across the swept frequency range as seen in red colour in Figure 14.

![Fig. 14 Results of testing of Single Ring Spoke and Cut wheel MMA structure](image)

The comparison of S21 curves for the reference plane and from the resonant surface represents the absorption by the MMA. Absorption of 56.1 dB was observed at the Resonant frequency of 10.19 GHz for this fabricated MMA which was higher than the resonant frequency of 9.828 GHz as predicted in the simulations. This is possibly due to material and fabrication tolerances. However, it validated the high absorbance possible with the spoke and cut-wheel design of the MMA. To identify the cause of reduction in absorption properties of structure and the shift in resonant frequency, measurements were carried out on the fabricated MMA using microscope. The measured parameters (as shown in Figure 15 below) were not exactly as per the gerber file given for the designed MMA with the design parameters as mentioned in Table-1.

![Fig. 15 Measurements carried out on the fabricated MMA using microscope.](image)

Simulation was then carried out on the MMA design with the parameters measured on the fabricated MMA. Minor drift in resonant frequency towards the measured resonant frequency was observed indicating fabrication and material tolerance causing the drift. Further,
any changes in the orthogonality of the incident radiation also causes shift in resonant frequency as can be seen from Figure 9. However, it did not explain the large change in resonant frequency of the order of 300 MHz to 400 MHz. The parameters of the material used were suspected and the epsilon value (electric permittivity) of the substrate was varied in simulations. The observations easily explain the drift in resonant frequency for the fabricated MMA. These Simulation results for the fabricated MMA, as per measured parameters and changing epsilon, predicted epsilon ~4.1 for the material used for fabrication instead of 4.3 as available in CST MWS Library of materials.

Results obtained during experiments with fabricated MMA (Absorption 56.1 dB at 10.19 GHz) were closest for simulation carried out with epsilon equals to 4.1 (Absorption ~51.74 dB at 10.10 GHz) as seen in Figure 16. It indicates that the FR-4 material used for fabrication has epsilon value of ~4.1 instead of the value of 4.3 used during optimisation of design.

5 Conclusions

Presented work consists of conceiving and simulating a perfect Metamaterial Microwave Absorber (MMA) with extremely high absorbance over a fairly wide band in the X-Band while exhibiting polarisation independence and wide-angle performance. It was also aimed to keep the structure light and flexible for which it was kept as a single-layer planar-array in a unit cell over a thin FR-4 substrate of 0.6 mm. The optimisation of the conceived Spoke and Cut-Wheel structure of the MMA showed excellent absorption results of 99.99996% absorbance (and S-Parameter of –65.97 dB) at resonance frequency of 9.828 GHz and 10 dB BW of 150 MHz around resonance. Widening of bandwidth was achieved by creating a unit cell having a planar array of 4 rings scaled to different sizes in such a way so as to keep the resonance frequency of each ring close by to each other. This structure when optimised gave a resonant peak absorption of 63.8 dB at 9.912 GHz and Bandwidth enhanced by 3-8 times as compared to bandwidth presented by the structure having single ring per unit cell. The extremely high absorption results of greater than 66 dB achieved in simulation and duly validated by experiments have not been reported earlier while simultaneously exhibit-
ing the other features of light weight, flexibility, polarisation independence and wide-angle performance with reasonable Bandwidth in X-Band.

The features of the presented work and the results obtained have been compared against various parameters, after extensive survey, to other similar works reported in the recent past. These have been brought out in Table 2. It has been found in the survey that even the Narrow-Band MMAs have not reported with absorption peaks greater than 40 dB, while simultaneously achieving perfect polarisation independence and excellent wide angle performance. These features, coupled with light weight and flexibility, make it a suitable candidate for application on aircraft for Stealth against radars. The proposed design of MMA can also be used for excellent EMI shielding of own resources against known frequencies. For example it can be used for shielding receiver against own and other transmitter radiation while maintaining nearly transparent window. The only challenge of increasing the Bandwidth, while maintaining other features, is a subject of further study.
Table 2 Performance comparison between the proposed MM absorber and previously reported MMAs.

| Sl. No. | Features                                                                 | 10 dB BW & Peak Absn | 40 dB BW Polsn | Wide Angle Performance | Thickness & Flexibility | Remarks |
|---------|--------------------------------------------------------------------------|----------------------|----------------|------------------------|-------------------------|---------|
| 1.      | Multilayer structure, Wide band, poln insensitive[28].                   | 2.3 GHz to 18.9 GHz, ~20 dB absn. | Nil            | Not reported.          | 11 mm, Not flexible.    | Thick, multi-layer structure, not suitable for Aircraft. |
| 2.      | Two layered hybrid absorbers with epoxy loaded foam. Good results with 13 mm thickness [29]. | 2 GHz to 18 GHz, and ~20 dB absn. | Nil            | Shift in peak absn freq with changing angle hence reduced absn at fixed freq. | 13 mm, Not flexible.  | 13 mm thick, Double layer structure, not suitable for Stealth aircraft. |
| 3.      | Split circular & Square rings configuration. BW improved by changing section lengths [21]. | 12.8 GHz to 16.6 GHz, and ~20 dB absn. | Nil            | Shift in peak absn freq with changing angle hence reduced absn at fixed freq. | 1.0 mm, Flexible.    | Poln & incidence angle dependence. Absorptivity of only, ~10 dB across BW. |
| 4.      | Single layer, Annular Ring with a split subtending an angle at center [30]. | 5.94 GHz to 16.84 GHz, and ~30 dB absn. | Nil            | Absn drops drastically with changing incidence angle, < 70% at 15°. | 4mm, Not flexible. | Thck, poln & incidence angle sensitivity. Not suitable for stealth. |
| 5.      | Periodic array of metal-dielectric, multilayered frustum pyramids [31]. | 1 GHz to 15 GHz, and ~15 dB absn. | Nil            | Good upto 40° Absorption suffers after 60° and becomes < 80% | 5mm, Not flexible. | 5mm thick pyramidal structures are not suitable for stealth aircraft. |
| 6.      | Multilayered structure using lumped resistors, Multi-band resonance. Large BW [22]. | Appears Nil          | Fair           | Incidence angle changes peak absn freq as well as the absn. | 5mm, Not flexible. | Not suitable for stealth aircraft needs to be thinner and flexible. |
| 7.      | Single layer Two scaled elements per cell for wider BW [23]. [22] | FWHM BW GHz: 4.97-5.55 GHz and ~30 dB absn. | Nil            | Reasonable up to 30°, Drops thereafter. | 1.6 mm, Not enough flexible. | Not suitable for stealth aircraft needs to be thinner and flexible. |
| 8.      | Asymmetric structure at two corners [24]. | 10.45 GHz to 17.64 GHz, and ~26 dB absn. | Nil            | No, Sensitive to incidence angle. | 1.6 mm, Not enough flexible. | Not suitable for stealth aircraft. |
| 9.      | Thin, Single Layer. Three designs, one for each peak of ~30 dB absn [20]. | 4.97 GHz to 17.64 GHz, and ~26 dB absn. | Nil            | Incidence angle changes peak absn freq as well as the absn. | 0.4 mm, hence flexible. | Complicated design. Peak absn could be higher. |
| Sl. No | Features                                                                 | 10 dB BW & Peak Absn | 40 dB BW | Polsn Indep | Wide Angle Performance | Thickness & Flexibility | Remarks                                                                 |
|-------|---------------------------------------------------------------------------|----------------------|----------|-------------|------------------------|-------------------------|-------------------------------------------------------------------------|
| 10    | Detailed comparison of latest Narrow-Band and Wide-Band MMA[19].          | All designs reporting < 30 dB absn. | Nil       | yes         | Wider BW through lumped resistors. Not suitable for aircrafts | discussed structures are flexible. | All structures report < 30 dB. Peak absn.                               |
| 11    | Single layer, Hybrid structure.                                           | 7 GHz to 12.8 GHz and ~30 dB absn. | Nil       | Good        | Good                   | 3.4 mm Thick, not flexible. lumped resistors. Make it not suitable for stealth aircraft. |
| 12    | Single layer, resonant, circularly symmetric, light weight, flexible, polsn indep, wide-angle performance. Extreme Absn ~64 dB not reported in literature. BW increased by scaling in same plane. [This Work] | 350 MHz at resonant freq for scaled co-planar 2X2 array in the unit cell. 99.99996% or ~64 dB absn. | 24 MHz at 9.91 GHz (resonant freq.) | Excellent due to circular symmetry. > 52 dB absn for all angles of polsn. > 90% absn even at 75° of incidence angle for all polsn. | Excellent absn (99.9%) up to 30° angle of incidence. Only challenge is 10dB BW improvement. | Reduction in Max Radar Range is nearly 40 times on at resonant freq. Suitable for Stealth aircraft application due to reported features. reported features. |

Abbreviations Used-
absn: absorption;
polsn: polarization;
indep: independence;
**Declaration**

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**Conflicts of interest**

There are no conflicts to declare.

**Availability of data and material**

The data that support the findings of this study are available from the corresponding author upon request.

**Code availability**

The simulation code that support the findings of this study are available from the corresponding author upon request.

**Author’s Contribution**

R. K. Mishra: Simulation, Validation Formal analysis, Writing - Original Draft  
R. D. Gupta: Simulation  
S. Datar: Conceptualization, Formal analysis, Writing - Review and Editing, Funding acquisition

**Ethics Approval**

Not Applicable

**Consent to participate**

Informed consent was obtained from all authors

**Consent for publication**

The authors confirm that there is informed consent to the publication of the data contained in the article.
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