

Comparative characterization of microstrip patch antenna array with defected ground structure for biomedical application

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ABSTRACT

In this paper, microstrip dual band antenna array with defected ground structure has been proposed for low frequency wearable on-body applications. The array has been simulated with Cotton, Polyimide, Polyester and Teflon (PTFE) flexible materials which are mostly used for biomedical applications. The performance of 2x2 trapezoidal patch array with partial ground, thin slot deflection at center has been studied in terms of return loss, VSWR, power handling capability, radiation pattern and surface current distribution. All substrates exhibits acceptable fractional bandwidth below -10 dB and Cotton proves its superiority than other substrates with -20 dB and -48 dB return loss with 16.12% and 7.73% bandwidth at 1.24 GHz and 1.94 GHz respectively. The proper matching of array has been proved with VSWR value below 1.3 for all substrates. The observation of input port impedance shows that, Cotton array has good impedance matching nearly to 50 Ω and PTFE array has 100 Ω poor impedance matching. The proposed four flexible array exhibit omnidirectional pattern in H plane with 1.43 dBi gain and bidirectional pattern in E plane with 1.4 dBi gain which are support for ideal fitness of proposed flexible material array for medical applications.

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1. INTRODUCTION

Recently the innovation in engineering materials enlarge the flexible electronics for disposable, portable, user friendly and less expensive environment [1]. The need for flexible wireless devices in biomedical applications increases rapidly due to the demand in health monitoring implantable devices [2]. The implantable devices must be conformable and stretchable with human body to integrate for implementation of drug delivery system, intracranial sensors and continuous gait analysis [3]. Several researchers have reported for wearable antenna material, fabrication and application [4]. Some notable literature are related to practical guide for non textile and fully textile wearable antenna design guide [5], flexible printed monopole antenna [6], wearable antenna material from very high frequency (VHF) to mm band [7], ultra wide band (UWB) antennas for wireless body area network (WBAN) [8], survey of wireless local arear network (WLAN) antenna [9] and flexible antenna [10]. Among the different types of printed antennas for biomedical applications, microstrip patch antenna (MPA) is the most advanced antenna due to the following merits: (1) can be used in various parts of human body since available in various shapes, (2) simple, low profile and inexpensive due to printed fabrication circuit, (3) planar and non planar surface compatibility and robust in mechanical [11], (4) small and light weight and compatible for monolithic

microwave integrated circuit (MMIC) design, (5) insensitive to human skin, low profile, no cavity backing [12] and conformal in clothing integration. One of the major disadvantages of MPA is substrate layer surface wave excitation [13] which reduces the operating bandwidth, gain and efficiency of antenna. In antenna array, the surface wave plays a vital role in array element mutual coupling [14]. To avoid mutual coupling arrays, electronic band gap (EBG) and defected ground structure (DGS) have been used to improve antenna performance. Array with EBG needs large area for periodic pattern and defining the unit element is difficult. Hence, DGS is mostly preferred in array to control the input impedance and surface current in the ground plane [13].

Photonic band gap (PBG) based DGS was first proposed by Kim *et al.* for low pass filter and planar circuit application [15]. Different shapes like spiral, dumb bell and circle [16] have reported for DGS in single element microstrip antenna. Recently hexagonal DGS in two element array [17], complementary capacitively loaded loops (CLLs) array [18], DGS with dual frequency patch antenna to reduce mutual coupling [19] are also reported in literature. DGS can also be introduced by slot introduction in resonating patch [20], quarter wave patch [21], truncated corners rectangular patch [22], 2x2 rectangular patch antenna with flexible arm [23], resonant gap or slot in ground plane in 4 x 4 rectangular patch [24].

High gain and minimum return loss microstrip patch antenna and antenna array for biomedical application has been achieved by several authors using different types of substrate. RT duroid DGS antenna with 1.6 mm thickness at 2.45 GHz [25] and 350 MHz bandwidth for ISM applications, 0.8 mm thickness FR4 substrate pentagon patch DGS microstrip antenna with -31 dB return loss for good gain of 5.28 dBi [26], 1.52 mm thickness Taconic substrate square ring resonators patch with U shaped DGS having 70 MHz bandwidth and 1.5 dBi gain [27] and 0.55 mm thick Taconic substrate inset fed antenna [28] for industrial scientific medical (ISM) band application are studied for comparison in this paper. The properties of other substrates like Polyimide [29], Polyester [30], PolyTetraFluoroEthylene (PTFE) [31] and Cotton [32] which are utilized for flexible and wearable biomedical application devices fabrication is also reviewed. Recently, 1 x 4 dumb bell DGS microstrip patch antenna array with has been reported for ISM medical application using FR4 [33] which is not flexible for human body injection.

In this paper, the flexible material analysis for the use of substrate in 2x2 trapezoidal patch microstrip dual-band antenna array has been proposed for the operating frequency for low frequency applications. The most used Cotton, Polyester, Polyimide and PTFE has been used as substrate for the proposed array structure to analyze the return loss, VSWR, impedance matching, power handling capacity, radiation pattern and current distribution. Among the four flexible materials used in this proposal, Cotton substrate array shows suitable properties with low return loss (-19 dB and -48 dB at 1.94 GHz), VSWR (1.2 and 1.02) closer to ideal value, 50 ohm impedance matching, bidirectional - E - plane and omni - directional - H - plane radiation pattern at 1.24 GHz and 1.94 GHz. The presentation of this paper is organized as: in section 2, the design flow of antenna array with four substrate materials has been discussed. The parameter analysis of proposed antenna array has been reported in section 3 followed by conclusion in section 4.

2. ANTENNA DESIGN

The proposed microstrip patch trapezoidal antenna array (MTAA) with DGS is shown in Figure 1. A thin slot at the center and exactly back to fed point (shown in Figure 1(a)) is etched in half of vertical ground having $W/2=1.5$ mm size and indicated by white color in Figure 1(b). 2x2 array is achieved by connecting four trapezoidal radiating element at a space of 6.5 mm from the wall of substrate at four corners as shown in Figure 1(a). The optimized dimensions of array as given in Table 1 is finalized after many trails based on transmission line theory and the final arrived array has the total size of 30x70 mm² on four different substrates.

Table 1. Optimized dimension (in mm) of proposed MTAA with DGS

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
W	30	L	70	W2	6.5	W1	2.5
Wf	2	Lf	20	L2	7	L1	6
Wp	10	Lp	21	G	0.5	G1	14.5

50 ohm microstrip feed line is used to feed input and DGS is achieved by reducing the background by half and inserting the 0.5 mm slot exactly at the back of feed point. Initially the array has been tested with FR4 substrates [34] for its basic performance with -35 dB return loss with -10 dB bandwidth of 120 MHz at 2.8 GHz resonant frequency.

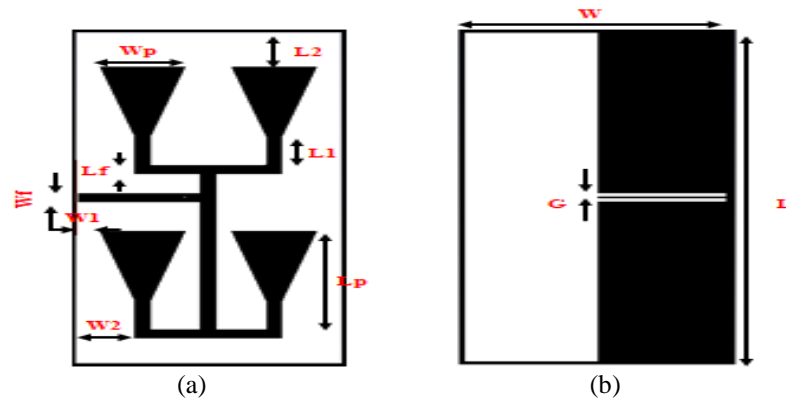


Figure 1. Structure of proposed microstrip antenna array for four substrate comparison (a) front view and (b) back view

The four substrates used in this paper for performance comparison of antenna array have been named as in Table 2. The electrical properties, ability to support for medical applications and applications are listed for four substrates. The properties of substrates used in simulation parameters has been taken from Table 2 to compare the performances in terms of return loss, VSWR, impedance matching, power handling, current distribution and radiation pattern.

Table 2. Proposed flexible array (FA) with DGS in four different substrates with its properties

Antenna Name	Name	Thickness (mm)	Loss tangent	Substrate		
				Dielectric constant (mm)	Ability	Applications
FAPM	Polyimide	0.2	0.005	2.91	Biocompatibility, flexibility, high tensile strength	drug delivery systems
FAPE	Polyester	1.6	0.02	2.8	Minimal risks of toxicity, immunogenicity and infection.	Drug delivery system
FAPT	Teflon (PTFE)	2	0.0028	2.1	Use for internal body fluid & tissue contact without explicit consent.	On body
FACT	Cotton	2.8	0.02	1.6	Soft, absorbent and hypoallergenic	Non-implantable products

3. RESULTS AND DISCUSSION

A trapezoidal patch microstrip feed $30 \times 70 \text{ mm}^2$ antenna array with partial ground slot based DGS is designed with four flexible substrates and simulated using electromagnetic solver from 1 GHz to 3 GHz. The simulated results are summarized for return loss, VSWR, radiation pattern and current distribution.

3.1. Return loss

10 dB return loss which is the percentage of energy emitted from the array shows dual band for all four substrates. From the comparison of S_{11} of array with four substrates as in Figure 2(a), it is noted that FACT has -20 dB and -48 dB with 16.12% and 7.73% impedance bandwidth compared to -17 dB and -18 dB along 13.7% and 6.9% by FAPM, -17 dB and -23 dB along 9.2% and 6.7% by FAPE and -19 dB and -20 dB along 14.5% and 6.5% by FAPT at 1.2 GHz and 1.9 GHz dual band. Comparing among four loss plots, though there is no much difference in return loss at 1.24 GHz first band, the FACT shows vast variations in its loss characteristics at 1.94 GHz compared to others substrates arrays. The Polyester substrates shift towards left in second resonant at 1.75 GHz compared to other substrates which maintain the second resonant at 1.94 GHz. Reflection characteristics analysis conform that, Cotton array shows better performance with lower return loss at 1.24 GHz and 1.94 GHz with better impedance property compared with other substrates arrays. Our proposed array performs in dual band with better impedance bandwidth compared to low cost non flexible FR4 substrate.

3.2. VSWR

Voltage standing wave ratio is the other property of antennas to show its idealness in terms of impedance matching and power handling capability. The proposed array attains VSWR very close to 1 which

is typical and ideal value to prove its effectiveness at both operating frequency. In this property also, Cotton substrate array shows ideal performance with 1.32 and 1.08 values at 1.2 GHz and 1.9 GHz as shown in Figure 2(b) compared to other material arrays. The other substrates VSWR also falls under this region within the values of 2 and proves the idleness for medical applications.

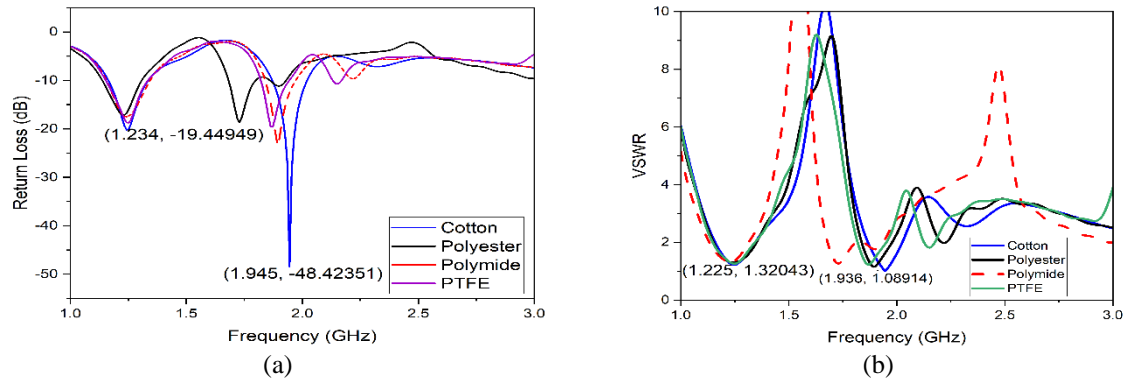


Figure 2. Comparative analysis of proposed array with four substrates (a) return loss and (b) VSWR

3.2. Impedance matching & power handling

Generally, in radio frequency antenna, for maximum power transmission, the input and output impedances are considered as main design parameters to avoid return loss due to mismatching between the two points in contact. The input impedance property of antenna used in medical applications is essential technical parameter to improve the efficiency of devices by reducing the loss due to reflection. To confirm the minimization of loss for the proposed antenna array, the impedance matching at feed point is verified for four materials and the comparison is shown in the Figure 3. The variation in impedance is considerable level in array with Polyester and array with other material shows that the input impedance is very closer to ideal 50 ohm value. As depicted in Figure 3(a), both at 1.24 GHz and 1.94 GHz, the Cotton substrate array matches with 50 ohm impedance and is not achieved in other material array having impedance variation even upto 100 ohm. This confirms the superior performance of Cotton substrate rather than other materials. The impedance matching is verified in terms of power accepted at input port and outgoing power at other output ports. In CST software, the input power spectrum is averaged in time domain for the period at every frequency as shown in Figure 3(b).

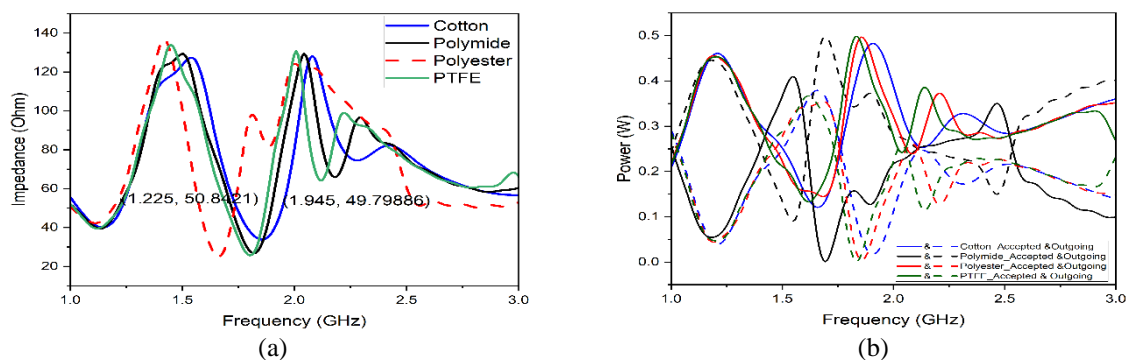


Figure 3. Parametric comparison of array with four substrates (a) input impedance and (b) power accepted at input ports and outgoing at all output ports

This input power is used as the feed point excitation to this dual band antenna and is applied separately with 0.5 watt at each frequency. The Figure 3(b) shows the comparison of net power accepted by the array presented as power accepted and the total power reflected by the array to the feed point as power outgoing. The peak to peak amplitude of input power accepted and output power is same with 180° phase

shift for four flexible materials MTAA. This ensures the minimum insertion and absorption loss in the proposed structure for biomedical applications.

3.3. Radiation pattern

The simulated radiation pattern at dual frequency for E plane and H plane for four substrate materials MTAA has been compared in Figure 4. At 1.24 GHz as in Figure 4(a) for x-z, azimuth or E plane simulated radiation pattern, it is observed that FACT provides a gain of 1.43 dBi in 88° beamwidth with $\phi=90^\circ$. FAPT, FAPE and FAPM array provides 1.31 dBi, 1.24 dBi and 1.22 dBi gain respectively. In x-y, elevation or H plane, the Cotton array provides 1.4 dBi gain with main lobe direction at 174° compared to 1.29 dBi with 176° for FAPT, 1.22 dBi at 179° for FAPE and 1.2 dBi at 175° for FAPH array for $\phi=0^\circ$ as shown in Figure 4(b).

From the radiation pattern figures, it is clear that proposed antenna array with four flexible substrate provides bidirectional pattern in E plane with eight shape in 2D and unidirectional radiation in H plane. These ideal patterns are disturbed in all four cases at 1.94 GHz as in Figure 4(b). The gain is reduced with side lobe of 0.9 dB for Cotton array and Polyimide array provides 1.15 dBi at 178° with 94.3° , 3 dB beam width. Polyester material deliver 1.13 dBi gain at 179° with 87.2° beam width and side lobe level of 1 dB. In H plane, at 1.94 GHz, 1.2 dBi, 1.12 dBi and 1.22 dBi gain values achieved from Polyimide, Polyester and Teflon array respectively as shown in Figure 4(c) and (d).

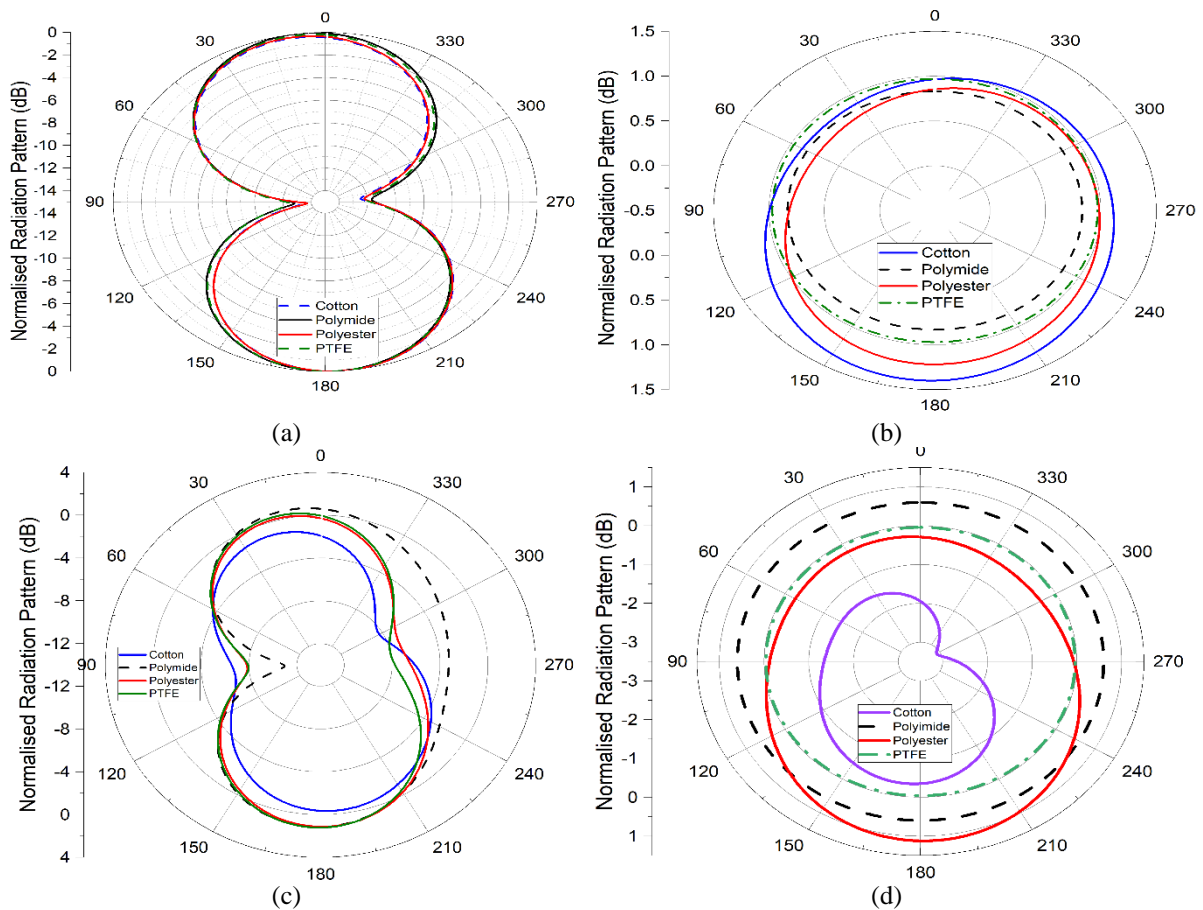


Figure 4. Comparison of far field radiation pattern of MTAA with Cotton, Polyimide, Polyester and Teflon substrate at 1.24 GHz; (a) azimuth or E plane, (b) elevation or H plane and comparison of pattern at 1.94 GHz, (c) azimuth or E plane, and (d) elevation or H plane

3.4. Surface current

The current density of the antenna array is analyzed for four substrates and the current distribution for Cotton array is plotted in Figure 5. At 1.24 GHz, the density is high at 45.3 A/m in Polyester array

compared to 42.3 A/m, 41.4 A/m and 36.7 A/m density for Polyimide, Teflon and Cotton array (Figure 5(a)) respectively. But at 1.94 GHz, this distribution shows higher density for Cotton array with 128 A/m level compared to 98.3 A/m, 86.3 A/m and 7.2 A/m for Polyester, Teflon and Polyimide array respectively.

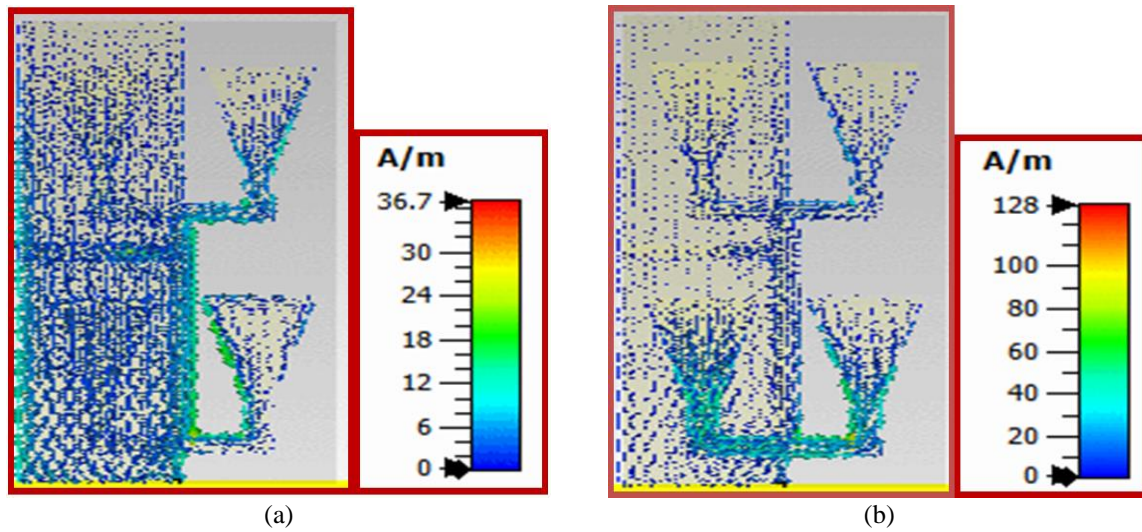


Figure 5. Current distribution in Cotton array at (a) 1.24 GHz and (b) 1.94 GHz

Table 3 shows the performance comparison of proposed array with the similar antenna array reported in references. It is depicted that our proposal attain higher impedance bandwidth at both the resonant compared to other antennas without the compensation in size. The Cotton substrate array proves efficient with 170 MHz and 330 MHz bandwidth at 1.24 GHz and 1.94 GHz which can be used for wide band medical diagnosis applications in L - band at 1-2 GHz.

Table3. Comparison of our flexible array with others in literature (NS: not stated)

Ref.no & year	Array size (mm ²), no element & shape	Substrate	F (GHz)	Impedance bandwidth (MHz)	Return loss(dB)	No of band	Gain (dBi)
[23] & 2021	58 x 86, 1 x 4 & Dumbbell	FR4	2.4	107	-23	01	7.44
[30] & 2020	42.4 x 48.5	Cotton/ Polyester	2.4 2.5	NS	-30 & -35	02	NS
[28] & 2019	1 x 2, 1x 4, 1x8 rectangular, 50 x 38.5	Taconic	2.4	15.9	-13.46	01	4.94
[23] & 2017	120 x 50, 2 x 1, square	FR4	7.64	NS	-23	01	6.7
[24] & 2018	41 x 40, 1 x 4, slot	Rogers	2.4	NS	-39	01	6.8
This paper	30 x 70, 2x 2, partial ground with thin slot	Cotton Polyimide Polyester Teflon (PTFE)	1.24 & 1.94 1.23 & 1.72 1.24 & 1.89 1.24 & 1.89	170 & 330 170 & 120 180 & 120 180 & 120	-20 & -48 -17 & -18 -17 & -23 -19 & -20	02 02 02 02	1.4 1.21 & 1.21 1.22 & 1.12 1.29 & 1.22

4. CONCLUSION

The 2 x 2 trapezoidal microstrip dual band antenna array having DGS with four flexible substrate materials has been designed successfully and electrical parameters in terms of return loss, VSWR, input impedance, power handling capability, radiation pattern and current density are compared. The proposed array has low loss profile up to -48 dB with 1.02 VSWR, no power absorption with 50 Ω input impedance, ideal eight shape bidirectional E plane and omnidirectional H plane radiation pattern. Out of four flexible material array studied, Cotton array proves the better performance in lower loss, impedance matching, better fractional bandwidth, high gain of 1.4 dBi with lower side lobe of 1 dB in E plane eight shape bidirectional and H plane omnidirectional pattern in both 1.24 GHz and 1.94 GHz resonant frequency. The proposed low

frequency dual band flexible material array can be used for study of structural biology and intrinsically disordered proteins, capsule endoscope communications, in body transmitter, noninvasive sensing and imaging techniques and wireless telehealth systems.




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