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Design and Performance Evaluation of Origami Based Incremental Pleat Antenna

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ABSTRACT—

This article focuses on the design and implementation of an origami-based reconfigurable antenna. The antenna is made of paper and can be folded into different shapes to achieve desired radiation properties. The performance of the antenna is validated through simulations and measurements, and the results demonstrate the feasibility of the proposed design approach. Resonant frequencies have been found to be 950MHz for an unfolded state and 830MHz for a folded one. When the gain measurements are plotted on a polar plot, the results show that the antenna has the characteristics of an omnidirectional antenna when it is unfolded and a directed antenna when it is folded.

Keywords— Origami, reconfigurable, incremental pleat antenna.

I. INTRODUCTION

Numerous technical and scientific applications have been influenced by origami, a traditional Japanese paper folding technique. Origami based Reconfigurable antennas are a new and innovative type of antenna design that utilizes principles of origami, to create a versatile and highly reconfigurable device. The art of origami is applied in many different contexts. Numerous antennas are created utilising the origami approach to attain the best results. These antennas change shape to offer ultra-compact stowage, simple deployment, and weight reduction.

The origami-based reconfigurable antenna is a novel approach that combines the principles of origami and antenna engineering to create a compact, low-cost, and lightweight antenna system with reconfigurable capabilities. This type of antenna can be easily reconfigured in the field, enabling it to adapt to different operating conditions and requirements. The design of origami-based reconfigurable antennas typically involves the use of thin, flexible metal sheets or other conductive materials, which are folded into specific patterns to form the antenna structure. The folds in the metal sheets create resonant structures that can be reconfigured to change the antennas frequency, polarization and radiation pattern. The reconfigurable of origami-based antennas allows them to be adapted to different frequency bands, polarization and radiation patterns, making them suitable for a wide range of wireless communication applications. Additionally, their compact size and low profile make them well suited for use in wearable and portable devices as well as in unmanned aerial vehicles and satellite.

A. Related Work

Recent studies have demonstrated the use of Origami for antenna design and analysis.

The author in [1], The antenna was created using the Origami Helix model. The antenna's bandwidth, gain, and polar plot are measured using a network analyzer between 900 and 1300 MHZ.

The author in [2], We exfoliate light on Origami antennas by presenting the elaboration of this unique technology by using design of antennas on thin substrates and designs with flexible, thick and rigid accoutrements.

The author in [3], They proposed a frequence reconfigurable antenna actuated by a three- storey palace kirigram. The proposed antenna was realized on a flat PET film and also stereteched to the three- storey palace configuration. In addition these antenna will also shows further structural variety and stable.

The author in [4], Tetrahedron Origami Antenna To produce a high gain origami antenna, a brand-new design with a tetrahedron figure was presented in. An affordable and compact antenna was made with a triangular-structured monopole antenna, a glass, and two parasitic strips. Utilising mirrors, directors, and a folding procedure, gain was increased.

The author in [5], The authors have investigated numerous use cases and scientific applications for origami.

The author in [6], Both RHCP and LHCP were used by the authors. This antenna's polarisation can be simply changed.

The author in [7], Self-assembling robots and adjustable metamaterials can be created using the esemethods that are used to create origami art, but with unique qualities that may not be present in nature.

The author in [8], The main object of this is the objectification of the fit printing of conductive essay on paper substrate with the art the origami to produce a Reconfigurable antenna by changing its shape.

The author in [9], The practicality of this system is the scalability of the tone- folding distance, both in terms of resolution of the individual rudiments and the number of rudiments that can be effectively combined in a single distance.

The author in [10], To speed up the design and optimisation processes, parameterized models of origami antennas and reflectors were developed in this study based on several origami patterns.

II. METHODOLOGY

The ancient art of origami is applied in a variety of contexts. Many antennas are designed using origami method to accomplish the possible results where such antennas morph their shapes to provide ultra compact stowage, easy deployment and reduce weight.

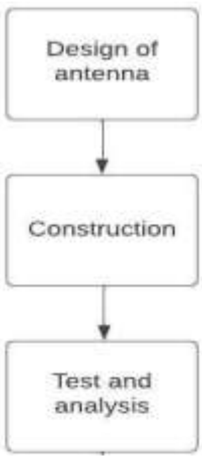

Fig. 1 Block diagram

A. Design of antenna:

The antenna is designed using the solid edge software, to obtain an incremental pleat antenna, a triangular shape of incremental pleats is reflected to create the elaborate layering pattern of the antenna, which is constructed using incremental origami pleats. The antenna design parameters are as shown in Fig. 1 where the antenna design is plotted on a sheet of paper using the solid edge.

The antenna design is constructed in the shape of rhombus. Where the whole rhombus is divided into 16 parts but not equal. The dotted line represents the valley crease and the red line represents the mountain crease and folded accordingly. Once the crease is formed the aluminium foil is attached to it. The crease helps in creating the folded state easily for calculating the gain values.

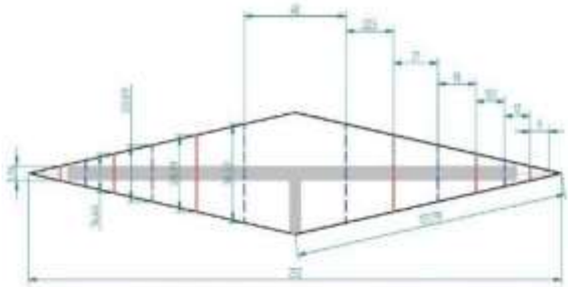

Fig. 1 Antenna design

B. *Construction*:

The bold line in T shape is used to attach Aluminium foil as shown in Fig.2. The horizontal part of T shape aluminium foil has the length 21.2cm and breadth 5mm and the vertical part of T shape aluminium foil has the length 2cm and breadth 5mm.Then the antenna is folded according to the mountain and valley crease along with aluminium foil attached to the paper which creates incremental pleat antenna.

Fig. 2 Incremental pleat antenna

These is the unfolded state of antenna with an aluminium foil attached to it in T shape.

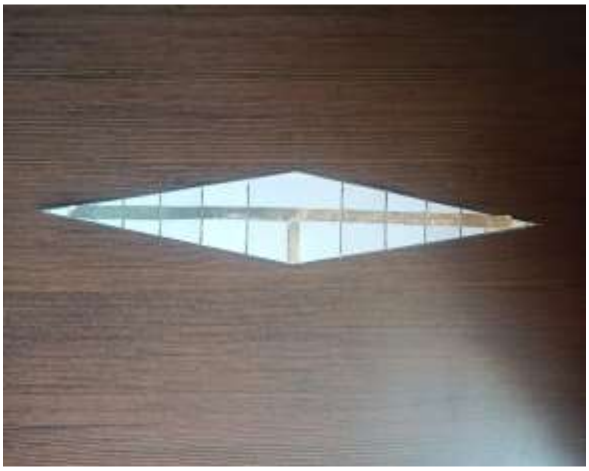

Fig. 3 Unfolded antenna design

Further the antenna is coupled with the Bayonet Neil- Concelman (BNC) to SubMiniature version A(SMA) antenna connector and to the MCT device and the gain value is calculated for both folded and unfolded state by varying the frequency.

C. *Testing:*

The antenna is then tested using a Microstrip component training (MCT) device. The testing is done by varying the frequency from 850 MHz to 1300 MHz and the gain is calculated in decibel-microvolt. The resonant frequency is calculated using the gain values of the unfolded state of the antenna followed by the folded state of the antenna.

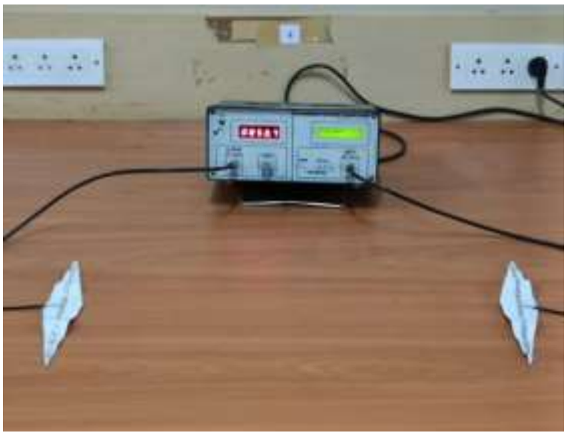

Fig. 4 Unfolded state antenna testing

Antenna is kept both in folded state and unfolded state to measure the gain values and are kept 50cm apart from each other and at the left we have the transmitter antenna and receiver antenna at the right as shown in Fig. 4 and Fig. 5.

Fig. 5 Folded state antenna testing

Using these resonant frequency values one of the main character of the antenna is found by plotting the readings of the gain values by changing the angle from 0 to 360 degrees. Using gain readings in MATLAB tool the polar plot is found.

III. EXPERIMENTAL RESULTS

The unfolded condition of antenna is coupled to MCT, and the gain for frequencies between 850 MHZ and 1300 MHZ is computed. The readings are noted from 830MHz, with a difference of 10MHz, till 970 MHz, and the gain is calculated. These extended readings are noted in view of accuracy and to note that specific frequency which provides the largest gain.

The gain values are first calculated in dBuV and then converted to dBm using the formula

$dB\mu V = dBm + 90 + 20\log(\sqrt{Zo})$

TABLE I. UNFOLDED STATE GAIN READINGS

Freq. (MHz)	**Trail-1**		**Trail-2**		**Trail-3**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***	***Gain-3 (dBuV)***	***Gain-3 (dBm)***
850	67.5	-39.49	67.4	-39.59	67.5	-39.49
900	73.1	-33.89	72	-34.99	73.1	-33.89
950	75.1	-31.89	74.9	-32.09	75.3	-31.69
1000	74.2	-32.79	74.1	-32.89	74.2	-32.79
1050	73.4	-33.59	73.2	-33.79	73.3	-33.69
1100	69.4	-37.59	69.2	-37.79	69.1	-37.89
1150	61.5	-45.49	61.2	-45.79	61.5	-45.49
1200	67.3	-39.69	67.4	-39.59	67.3	-39.69
1250	64.1	-42.89	64.1	-42.89	64.4	-42.59
1300	67.2	-39.79	67.1	-39.89	67.5	-39.49

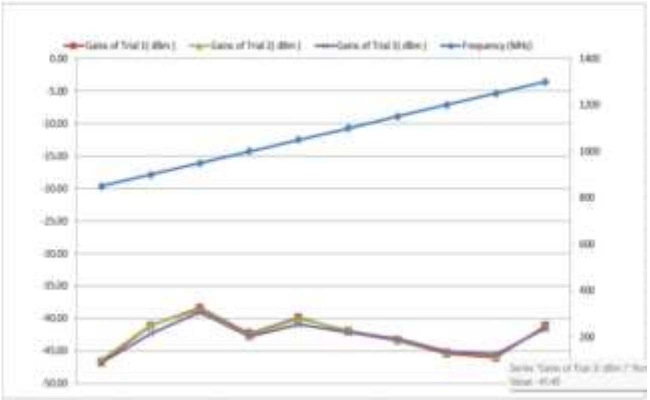

Fig. 7 Unfolded state graph

TABLE II. UNFOLDED STATE EXTENDED READINGS

Freq. (MHz)	**Trail-1**		**Trail-2**		**Trail-3**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***	***Gain-3 (dBuV)***	***Gain-3 (dBm)***
830	76.5	-30.49	76.7	-30.29	76.6	-30.39
840	74.2	-32.79	74	-32.99	74.3	-32.69
850	73.9	-33.09	73.6	-33.39	73.5	-33.49
870	74.5	-32.49	75.2	-31.79	74.2	-33.79
890	72.9	-34.09	72.6	-34.39	72.6	-32.79
900	72.4	-34.59	72.4	-34.59	72	-34.99
910	72.3	-34.69	71.9	-35.09	72	-34.99
930	68.1	-38.89	68.2	-38.79	68.1	-38.59
950	70	-36.99	69.3	-37.69	68.5	-38.49
970	65.1	-41.89	65.1	-41.89	64.2	-42.79

The readings from 830MHz with the difference of the 10MHz up to 970 MHz is varied and the gain is calculated, these extended readings is taken to make it accurate as to which is the frequency with highest gain.

As the gain value is highest for the frequency 950 MHz, to get the accurate resonant frequency the gain value for 945 MHz and 955 MHz is also calculated and it is computed that the resonant frequency for the unfolded state is 950MHz.

TABLE III. RESONANT FREQUENCY OF UNFOLDED STATE

Freq. (MHz)	**Trial-1**		**Trial-2**		**Trial-3**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***	***Gain-3 (dBuV)***	***Gain-3 (dBm)***
945	68.3	-38.69	67.7	-39.29	67.5	-39.49
950	68.3	-38.69	67.7	-39.29	67.8	-39.19
955	68.2	-38.79	67.7	-39.29	67.7	-39.29

The Resonant frequency of the unfolded state antenna is : 950MHz.

A polar plot is a graph that shows the directional gain of an antenna in different directions around the antenna. The polar plot of an antenna can provide valuable information about its performance.

TABLE IV. POLAR PLOT OF UNFOLDED STATE

Angle (degree)	**Trail-1**		**Trail-2**		**Train-3**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***	***Gain-3 (dBuV)***	***Gain-3 (dBm)***
0	69.1	-37.89	68.8	-38.19	70.1	-36.89
30	68.3	-38.69	68.5	-38.49	68.2	-38.79
60	72.9	-34.09	70.4	-36.59	73.3	-33.69
90	68.3	-38.69	68.1	-38.89	66.1	-40.89
120	71.4	-35.59	71.2	-35.79	72.8	-34.19

150	76.6	-30.39	77.2	-29.79	77	-29.99
180	68.9	-38.09	65.2	-41.79	71.9	-35.09
210	74.2	-32.79	74.7	-32.29	76.5	-30.49
240	76.1	-30.89	75.5	-31.49	74.5	-32.49
270	64.1	-42.89	67.9	-39.09	74.1	-32.89
300	73.3	-33.69	74.5	-32.49	74.9	-32.09
330	68.5	-38.49	71.5	-35.49	70.7	-36.29
360	68.7	-38.29	68.8	-38.19	70.7	-36.29

The polar plot values are then put in matlab software to get the polar plot graph. These polar plot graph is specified in two parts known as the major lobe and the minor lobe. From this plot it is proved that the incremental pleat antenna has the characteristics of omnidirectional antenna in unfolded state.

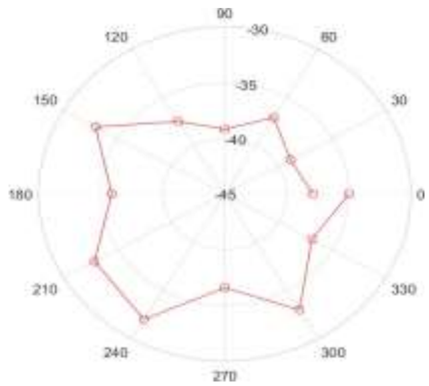

Fig. 11 Polar plot graph of Unfolded state

The folded state of the antenna is coupled to MCT, and the gain for frequencies between 850 MHZ and 1300 MHZ is computed. The readings are noted from 830MHz, with a difference of 10MHz, till 970 MHz, and the gain is calculated. These extended readings are noted in view of accuracy and to note that specific frequency which provides the largest gain

TABLE V.FOLDED STATE GAIN READINGS

Freq. (MHz)	**Trail-1**		**Trail-2**		**Trail-3**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***	***Gain-3 (dBuV)***	***Gain-3 (dBm)***
850	73.2	-33.79	73	-33.99	73.7	-33.29
900	72	-34.99	71.7	-35.29	71.5	-35.49
950	70.2	-36.79	69.2	-37.79	68.6	-38.39
1000	64.2	-42.79	62.6	-44.39	61.2	-45.79
1050	69.2	-37.79	68.9	-38.09	69.4	-37.59
1100	62.1	-44.89	65.4	-41.59	66.2	-40.79
1150	67.1	-39.89	67.6	-39.39	67	-39.99
1200	67.7	-39.29	67.4	-39.59	66.2	-40.79
1250	64.9	-42.09	64.6	-42.39	63.9	-43.09
1300	67.8	-39.19	67.6	-39.39	66.3	-40.69

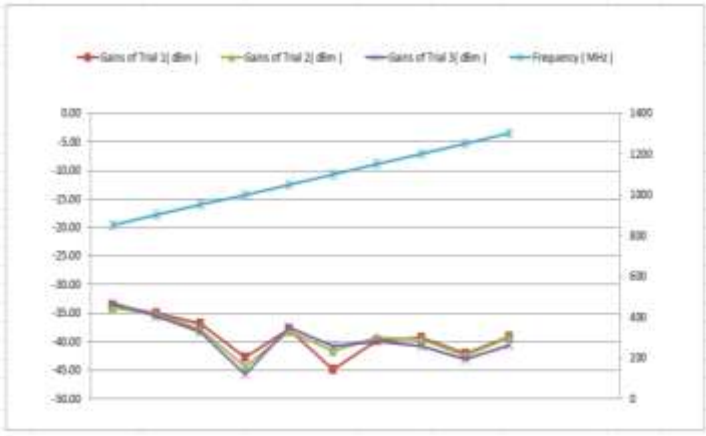

Fig. 13 Folded state graph

The readings from 830MHz with the difference of the 10MHz up to 930 MHz is varied and the gain is calculated, these extended readings is taken to make it accurate as to which is the frequency with highest gain.

TABLE VI. FOLDED STATE EXTENDED READINGS

Freq (MHz)	**Trail-1**		**Trail-2**		**Trail-3**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***	***Gain-3 (dBuV)***	***Gain-3 (dBm)***
830	76.5	-30.49	76.7	-30.29	-30.39	830
840	74.2	-32.79	74	-32.99	-32.69	840
850	73.9	-33.09	73.6	-33.39	-33.49	850
870	74.5	-32.49	75.2	-31.79	-32.79	870
890	72.9	-34.09	72.6	-34.39	-34.39	890
900	72.4	-34.59	72.4	-34.59	-34.99	900
910	72.3	-34.69	71.9	-35.09	-34.99	910
930	68.1	-38.89	68.2	-38.79	-38.89	930
950	70	-36.99	69.3	-37.69	-38.49	950
970	65.1	-41.89	65.1	-41.89	-42.79	970

As the gain value is highest for the frequency 830 MHz, to get the accurate resonant frequency the gain value for 835 MHz and 840 MHz is also calculated and it is computed that the resonant frequency for the unfolded state is 830MHz.

TABLE VII. RESONANT FREQUENCY OF FOLDED STATE

Freq. (MHz)	**Trail-1**		**Trail-2**		**Trail-3**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***	***Gain-3 (dBuV)***	***Gain-3 (dBm)***
830	76.8	-30.19	-30.29	76.8	830	76.8
835	75.3	-31.69	-31.49	75.4	835	75.3
840	74.3	-32.69	-32.59	74.5	840	74.3

The Resonant frequency of the folded state antenna is: 830MHz.

A polar plot is a graph that shows the directional gain of an antenna in different directions around the antenna. The polar plot of an antenna can provide valuable information about its performance.

TABLE VIII. POLAR PLOT OF FOLDED STATE

Angle (degree)	**Trail-1**		**Train-2**	
	Gain-1 (dBuV)	***Gain-1 (dBm)***	***Gain-2 (dBuV)***	***Gain-2 (dBm)***
30	61.2	-45.79	67.2	-39.79
60	71.2	-35.79	70.2	-36.79
90	74.5	-32.49	74.6	-32.39

120	75.6	-31.39	78.5	-28.49
150	73.6	-33.39	81.6	-25.39
180	73.8	-33.19	77.4	-29.59
210	78	-28.99	72.7	-34.29
240	73.4	-33.59	61.2	-45.79
270	76	-30.99	63.5	-43.49
300	64.4	-42.59	71.1	-35.89
330	69.4	-37.59	73.2	-33.79
360	75.4	-31.59	75	-31.99

The polar plot values are then put in MATLAB software to get the polar plot graph using the formula. These polar plot graph is specified in two parts known as the major lobe and the minor lobe. From this plot it is proved that the incremental pleat antenna has the characteristics of directive antenna in folded state.

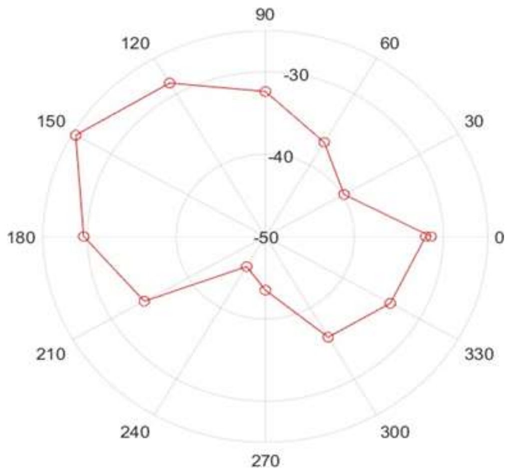

Fig. 17 Polar plot graph of folded state

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