Cloth Based Patch Antenna Array for an Experimental FM-CW Radar

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Abstract: Cloth based radiating element design is the latest approach of fabricating microstrip antennas.This paper focuses on the design and development of a patch antenna array on a low dielectric constant substrate, such as buckram cloth material. Use of lower dielectric constant provides better efficiency, larger bandwidth, loosely bound fields for radiation.When cloth antenna array is constructed, the power divider for this has to be designed separately (using a higher dielectric constant substrate). The patch antenna array is developed at C- band and finds application in an experimental test bed FM-CW radar.The cloth based radiating element can also be used as smart clothes in mobile communications. Simulation results and experimental results of the product are presented. This paper concludes with a discussion on some future directions of research in this area.

Keywords: Smart clothes, mobile communications, FM-CW radar, cloth based substrate, microstrip patch antenna.

1. Introduction

There are many methods on the design of microstrip patch antennas. The patch antenna has many unique and attractive properties, such as low profile, light weight, compact and is conformable to many mounting structures. They are easy to fabricate and integrate with solid state devices. Although patch antennas have narrow bandwidths, recent technology advances such as usage of thicker substrate with aperture slot coupling, external matching circuits, sequential rotational element arrangement, parasitic coupling, U-shaped slot feed,L-shaped probe feed, etc have made them to operate over wider bandwidths. However, the wider bandwidth is achieved at the expense of increased physical volume.When designing a microstrip array,one has to live with a larger ohmic insertion loss than other types of antennas of equivalent aperture size.The ohmic loss occurs in the dielectric substrate and the metal conductor of the microstrip line power dividing circuit. We have used a coax feed method for exciting the cloth based microstrip patch antenna element.As regards different methods available for design,we have used the cavity model approach.The cavity model is chosen because its physical mechanism is more easily understood,such as its resonating and cross-polarisation behaviors. By this method we have designed and developed a microstrip patch antenna element as well as a four element array using a buckram cloth based dielectric substrate.However,one can choose other cloth materials for the antenna design.

The antenna after fabrication has been subjected to tests such as return loss and radiation pattern. This is compared with the simulated results.

2. Element Design and Construction

A. (i)Design

The most commonly used microstrip element consists of a rectangular patch, backed by a ground plane spaced in between by a dielectric substrate.However,the radiating patch may be square,thin strip(dipole),circular,elliptical,triangular, or any other configuration. There are many choices in the selection of dielectric substrate materials,such as PTFE ceramic,Hydrocarbon ceramic,PTFE glass fiber,PTFE ceramic woven glass,liquid crystal polymer,etc. Of late, cloth based materials are finding application as dielectric substrates,as they are inexpensive and can be worn on the body.Out of the various cloth materials,we have chosen buckram cloth as the dielectric substrate.

The length L of the patch is the most critical dimension and is slightly less than $\lambda/2$ in the dielectric substrate.

$$\mathbf{L \approx 0.49\, \lambda_d = 0.49\, (\lambda_o / \varepsilon_r)} \qquad (1)$$

Where,

L= length of the element

ε_r = relative dielectric constant of cloth based material

λ_o= free space wavelength

The effect of dielectric constant on the performance of patch antenna can be described on the basis of Gauss law from electrodynamics.

$$\mathbf{\Delta . E = (\rho / \varepsilon_o \varepsilon_r)} \qquad (2)$$

Where,

E=Electric field (volts/m)

ρ=volume charge density in (coulombs/m^3)

ε_o= permittivity of free space=8.854 x 10^{-12} (farads/m)

ε_r = relative permittivity (dimensionless)

The law states that the divergence of electric field is inversely proportional to the relative dielectric constant and proportional to the volume density of charge. If the relative dielectric constant is higher, the fields are tightly bound and less radiation occurs into the free space. This law helps us in the selection of substrate material with different dielectric constants. Usually the value of dielectric constants chosen for patch antenna design is in the range of 2 to 5. Since the relative dielectric constant of cloth based material is 1.3, it is a good choice for antenna design. Other advantage of cloth based substrate is its lower cost.

A.(ii) Parameter selection

The parameters to be chosen for patch antenna design is the thickness of the cloth based dielectric material. We have selected a Buckram cloth of thickness 3/8 and folded it 8 times to get 3mm. The width W of the patch must be less than a wavelength in the dielectric substrate material so that higher-order modes are not excited. The design of the patch is done at a frequency of 4.1GHz,as the FM-CW radar test bed developed by us is operating at this frequency. The design values obtained from the cavity model approach are : L=2.89 cm and W=3.41 cm. Simulations were carried out using Matlab to arrive at the antenna radiation pattern, beamwidths and directivity. [3].

At this point,we have to decide the excitation method. There are many methods of excitation such as (a) microstrip line feed (b) probe feed (c) aperture coupled feed (d) proximity coupled feed.We have chosen the probe feed method as it is simple to implement.The location of the point x(as indicated in fig1) depends on the edge impedance of the patch. The edge impedance of the patch works out to be 217.9768 Ω. To match this edge impedance to the input impedance of the coaxial connector, the following formula is used(fig1).

$$x = L/\pi \ \text{arc} \sin \sqrt{(R_i / R_e)} \quad (3)$$

Where

'x' is the location of the pin of the coaxial connector from the center of the radiating patch along the length

L=length of the patch

R_i= input impedance of the coax-feed(50 Ω)

R_e=edge impedance of the patch

From equation (3), x = 1.3 cm.

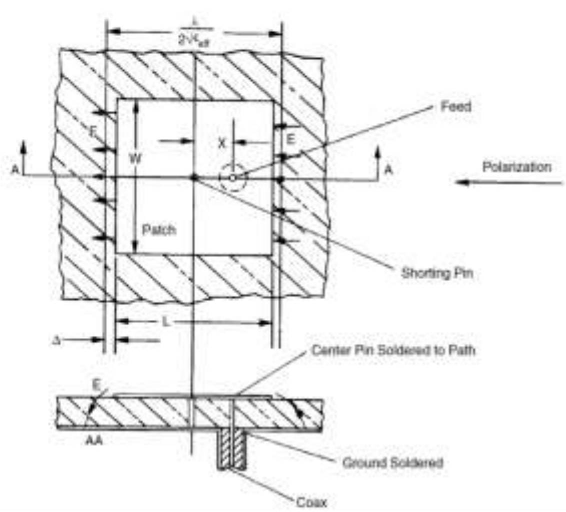

Figure 1: Coax-fed microstrip patch antenna element

B. Construction

A cloth based material sheet of 3mm thick was cut into a size of 6cm x 6cm . One side of the sheet is covered with a sticking copper metal foil to act as a ground plane.On the other side of the sheet,a metal foil of size equal to that of the radiating patch is stuck(L=2.89cm,W=3.41cm).An SMA panel mounting connector is used for probe feeding.The centre pin of the connector is soldered to the patch and the flange of the connector is soldered to the ground plane. It is important that the feed pin be securely soldered to the microstrip element since most failures of microstrip antennas occur at this soldering point.This completes the element fabrication.

3.Array design and construction

A.Design

The number of elements chosen by us for the array is four. Considering the mutual coupling and grating lobe problems, we have chosen a spacing of 0.5 λ_d=35mm between the adjacent patches where λ_d is the wavelength in the dielectric material.

B.Construction

The buckram cloth material sheet of 3mm thick was cut into a size of 20cm x 6cm. One side of this sheet is covered with a sticking copper metal foil to act as a ground plane. On the other side of the cloth sheet, four patches of the copper foil each with a size of 3.4cm x 2.9cm is stuck. The metal patches are symmetrically placed on the cloth based sheet.

For exciting the four patches, four SMA panel mounting connectors are used. The method used for exciting each single patch is the same as that employed for the element design. All the four patches have to be fed from a single RF source. For doing this, we require a power divider. The power divider is configured by using a number of SMA T connectors and SMA bends(fig 3).The four element array fabrication is thus completed.

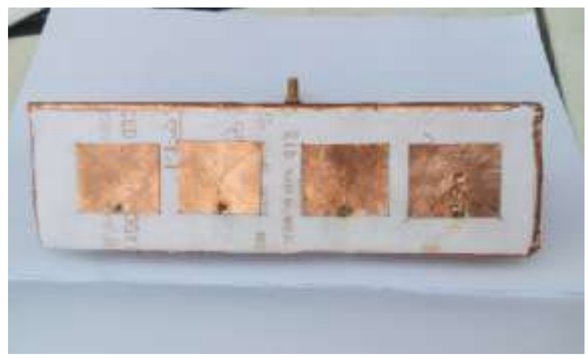

Figure 2: 4 element array @ 4.1GHz

Figure 3: Four element array with Power divider circuit

The photograph of the radiating element ,the antenna array are shown in figures 2 & 3.

4. Simulation

Microstrip antenna radiation patterns can be accurately calculated. Cavity model approach is used for the simulation. The simulated patterns at a frequency of 4.1 GHz are shown in figures 4 and 5.The appearance of sidelobes in the visible region occurs when the number of radiating elements is more than 4. Table 1 provides a summary of the beamwidths and directivity of a single element and four element antenna at a frequency of 4.1 GHz . The gain of the antenna will be lower than the directivity as the efficiency factors comes into picture.

Table 1: The Directivity and Beamwidths of a single element and four element array for cloth antenna

Frequency(GHz)	Beamwidths (degree)		Directivity (dB)
	E	H	
4.1(Single element)	60	70	9.1215
4.1(Four element array)	29	70	15.5

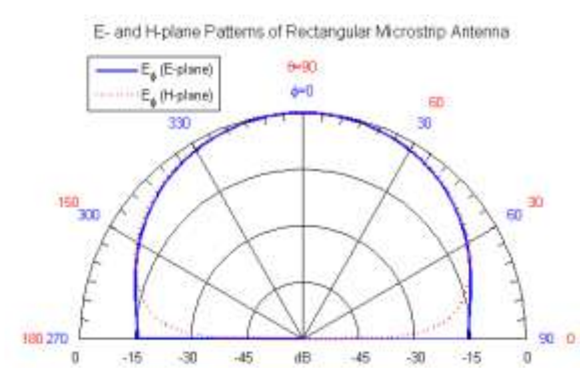

Figure 4: E and H plane patterns of single element cloth antenna at 4.1 GHz

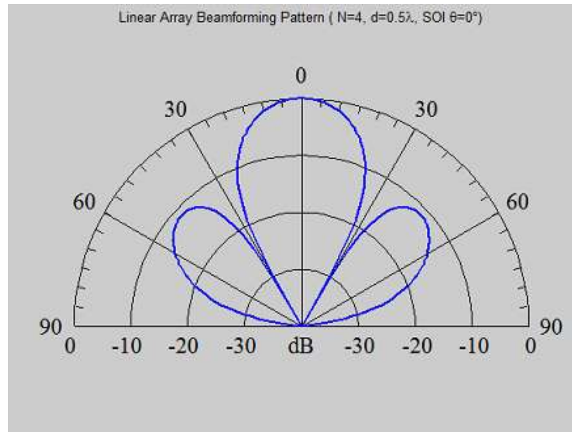

Figure 5: Linear beamforming pattern for four element array of cloth antenna

5. Measurements

Measurements of the Patch antenna with cloth based dielectric material have been carried out at C-band. The measurements carried out are (a) Return loss(reflection coefficient) (b) Radiation pattern (c) Gain and Directivity.

A.Return loss measurement

The return loss measurement was carried using a high directivity dual directional coupler model number 11692D of Hewlett Packard with a frequency range of 2-18 GHz. The device has a nominal coupling of 22 dB for incident and reflected ports. The source used for this is a VCO in the frequency range of 4-6 GHz

Table 2:Summary of reflection coefficient measurements

The photos of the reflection coefficient measurement setup for single element a four element array are shown in fig 6&7.

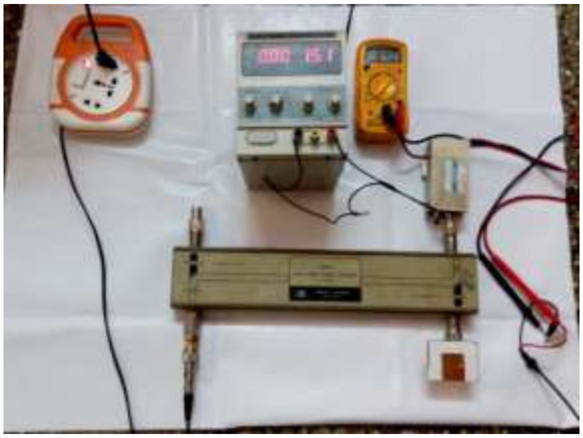

Fig 6:Return loss Measurement setup for single element cloth antenna

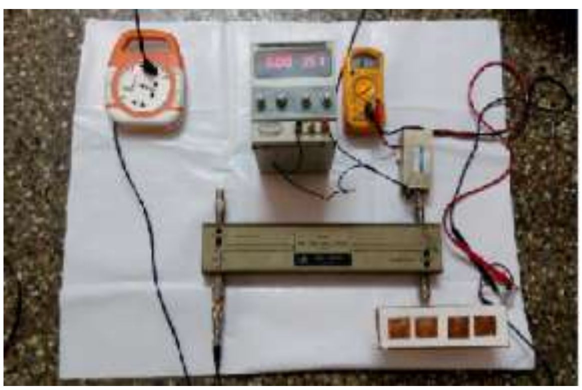

Fig 7: Return loss Measurement setup for four element array cloth antenna

By taking the ratio of reflected voltage with incident voltage, the reflection co-efficient can be calculated. The VSWR can be calculated using the formula

$$VSWR=(1+\Gamma)/(1-\Gamma) \quad (4)$$

The results are tabulated (table2).The VSWR figure ≈ 2 is acceptable for many of the short range radar application. This VSWR figure can be reduced further by experimentally determining the location of the center pin of the SMA flange connector. From the results it can be seen that the Patch antenna bandwidth is around 2%.

Frequency(GHz)	Reflection Coefficient(Γ)	VSWR
4.0	0.375	2.2
4.02	0.354	2.1
4.04	0.358	2.12
4.06	0.354	2.1
4.08	0.365	2.15
4.10	0.354	2.1
4.12	0.352	2.09
4.14	0.344	2.05
4.16	0.339	2.03
4.18	0.337	2.02
4.20	0.333	2

B. Radiation pattern measurement

A wide band horn operating in the frequency range of 4-6 GHz is used as the transmitting antenna.The cloth based element and array are used in receiving mode which were mounted on a turn table.The radiation pattern results are shown in figures 8&9.

The measured results differ considerably from the simulated values as can be seen from figure 8&9. For obtaining accurate results on the antenna radiation pattern, however, it is necessary to use open range test setup or use an anechoic chamber, to simulate free space conditions.

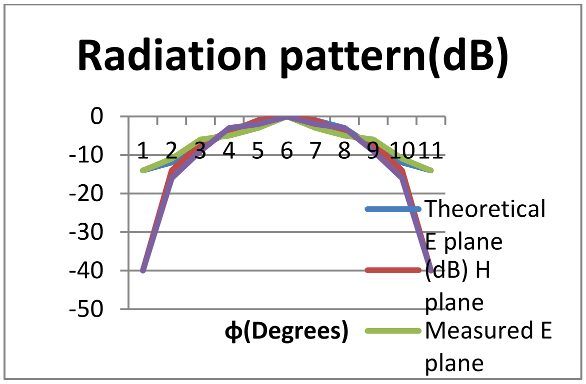

Fig 8 :Theoretical and measured pattern of a single element cloth antenna

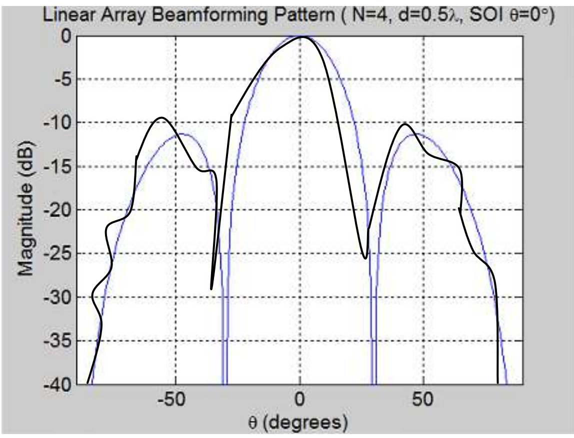

Fig 9 :Theoretical and measured pattern of a four element cloth antenna

6. FM-CW Radar Test Bed

The cloth based four element antenna array is used in the FM-CW Radar test bed setup and is shown in figure 10.

Fig 10:FM-CW test bed with the cloth antenna array visible in the photo

A function generator which has a capability to generate a triangular wave is used to feed the voltage tuning port of the VCO. The modulation frequency is selected at 150Hz and the frequency deviation is around 100MHz.The frequency deviation can be adjusted by using the dc offset knob provided on the function generator. A crystal detector acting as a single ended mixer is used to recover the beat frequency of the signal which is proportional to range.

A digital oscilloscope manufactured by Tektronix is used to display the echo signal of the target and also to analyse the waveform.If there are more than one target,the mixer unit gives a number of different beat frequencies.To resolve the multiple targets,a Fast Fourier Transform(FFT) technique can be used.The Digital oscilloscope of Tektronix has a built in FFT and we propose to use this feature to analyse the echo signals.Work on this is under progress.

7. Conclusion

The design and development details of patch antenna using buckram cloth based material are provided in this paper. Though the cloth based antenna is inexpensive, the loss tangent of the buckram cloth material is high, leading to lower gain figures.Choice of cloth materials with lower loss tangent figures have future applications. Flexibility of the cloth material with higher thickness may find usage in conformable antennas. A higher dielectric constant value for the substrate material greater than 5 is preferred for designing power dividers. For short range Radar applications,the lower gain figures of the cloth antenna due to higher loss tangent may be tolerated.

8. Acknowledgement

The authors wish to thank the management of Dayananda Sagar College Of Engineering for encouraging and supporting this project.

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