Development of Microstrip Patch as HDTV Antenna for Terrestrial Indoor TV Reception

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Abstract: This paper presents design, construction and analysis 4 by 2 corporate fed circular patches as High Definition Television (HDTV) antenna configuration for Ultra High Frequency (UHF) indoor reception. The single element was designed based on transmission line method. The single element radiation pattern is omnidirectional with high beamwidth of about 6dB and low gain of about2dBi which are poor for UHF television reception. As a result, single element patch was optimized to achieve 6 elements which was arranged in 4 by 2 corporate fed circular patches as HDTV antenna configuration. By calculation, the 4 by 2 corporate fed circular patches antenna produced directional radiation pattern of low beamwidth of about 3dB and high gain of about 9dBi. The antenna was then fabricated by depositing resin of relative permittivity of 4.5 and thickness of 0.2cm using wet etching technique on un-galvanized aluminium of radius 2cm. The antenna’s gains in passive and active modes were measured by Gain – Comparison Technique (GCT) with the aid of GSP 810 Spectrum Analyzer. The results obtained show that the peak gain at various frequencies in passive and active modes were 9, 8.83, 9, 8.97dBi, at 487.6, 497.9, 531.4, 549.7, 566.9MHz, and 9.62, 11.23, 9.20, 8.99, 9.09dBi, at 480.3, 499.1, 531.6, 549.7, 566.9, 588.6MHz respectively.

Keywords: High Definition Television, Indoor, UHF Antenna, High gain

I. INTRODUCTION

An antenna is a metallic conductor that is cut into size and shape which radiates and receives electromagnetic waves effectively. The major function of an antenna is to couple radio waves in free space to an electrical current used by a radio receiver or transmitter. In reception, the antenna intercepts some of the power of electromagnetic waves in order to produce a tiny voltage that the radio receiver can amplify. Antennas are of different types based on their frequency of operation, application and characteristics [1] – [5]. Examples of the convectional antennas that are employed for Very High Frequency (VHF) and Ultra High Frequency (UHF) Television (TV) reception are Yagi-Uda, Log Periodic, Folded Dipole and Helix. High definition Television (HDTV) antennas are the antennas that are incorporated to HDTV through card slot port at indoor reception [6] – [8]. In recent years HDTV has been popular due to high pixel level of picture and ability to interface with various memory elements with an inbuilt slot card. The beginning of terrestrial digital TV broadcasting may considerably reduce the need for on-roof, outdoor, remote control, directional antennas and increase the use of indoor antennas. Also, for the storming tropical weather conditions that usually destroy antenna’s mast, high gain indoor antenna will be the best option. Moreover, the conventional outdoor antenna are pure electric field antennas, and hence, their performance is significantly deteriorated in vicinity of conductive objects such as concrete walls [9], [10]. In addition, the convectional Terrestrial antennas for receiving TV signal are quite large in size such that they are not suitable for indoor applications. However, the small and omnidirectional monopole antennas which could have been preferable as indoor antennas also have low gain, and an attempt to increase the gain will make the antenna size large [6] – [11]. This paper therefore presents the characteristics of the 4 by 2 corporate fed circular patch antenna designed and constructed as HDTV antenna for indoor applications at frequency range of 470MHz to 900MHz.
II. MATERIALS AND METHODS

A. Design of the Antenna

From the literature review, the effective radius of circular patch is found by [1], [5], [10], [11]:

\[
 r = \frac{F}{\left(1 + \frac{2h}{\pi\varepsilon_r F} [\ln\left(\frac{\pi F}{2h}\right) + 1.7726] \right)^{\frac{1}{2}}} 
\]  

\[
\text{Where, } F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} 
\]

\[
r = 2\text{cm} 
\]

The radiated field of the E-plane and H-plane for a single element circular patch can be expressed by [6]:

\[
 E_{\theta} = E_0 - jV_o \frac{ak_0e^{-k_0r}}{2r} \cos \theta \left( k_o a \sin \theta \right) 
\]

\[
 H_{\theta} = -jV_o \frac{ak_0e^{-k_0r}}{2r} \cos \theta \left( k_o a \sin^2 \theta \right) 
\]

Where \( V_o \) is the voltage across radiating slot of the patch, which is 0.03934.

\( k_0 = \frac{2\pi}{\lambda} \)  

To determine the gain of a circular patch antenna some parameters need to be determined from [2]:

\[
 G = e_r D 
\]

The directivity of the circular patch antenna is given by [5]

\[
 D = \frac{K r}{120 \text{Grad}} 
\]

Where, \( \text{Grad} = \frac{4r}{\lambda} \)

\( G_{\text{rad}} = 6.09 \times 10^{-1} \)

Therefore, \( D = 1.16\text{dB} \)

\[
 e_r = \frac{R_r}{R_{\text{in}}} 
\]

Where \( R_r \) = Radiation resistance and \( R_{\text{in}} \) = input resistance

\[
 R_{\text{in}} = 9.54\Omega \quad R_r = 16.42\Omega \quad e_r = 1.72 \quad G = 2\text{dB} 
\]

The single element has gain of 2dB and is omnidirectional with broad beamwidth as shown in the Figure 1. This gain is low to receive signal at UHF band. Then the array of the single patch is formed based on the equation [7]:

\[
 N = \frac{\text{BW(desired)}}{\text{BW(sin gle element)}} 
\]

To determine the bandwidth of a single circular patch element, it was discovered that the fractional bandwidth of the circular patch is inversely proportional to the total Quality factor \( Q_t \) [6]. The quality factor is a figure of merit which is
a representative of three antenna losses. Typically radiation, conduction (ohmic) and dielectric, the summation of which gives the total quality factor $Q_t$, which is influenced by all these loses.

\[
Q_t = Q_{\text{rad}} - 1 + Q_{\text{c}} - 1 + Q_{\text{d}} - 1, \quad Q_{\text{c}} = \sqrt{\pi f \mu \varepsilon}, \quad Q_{\text{c}} = 3.16 \times 10^{-3}, \quad Q = \frac{1}{\tan \theta}
\]

$Q_{\text{rad}}^{-1} = 1.10395 \times 10^{-13}$

$Q_t = 3.16 \times 10^{-3}$

Single element bandwidth = 316.46

\[
\text{Desired bandwidth} = 1.2 \left( \frac{h}{\tau} \right)
\]

(9)

Where, $\tau$ = Surface wave losses

$\tau = 9 \times 10^{-5}$

Bandwidth = 2666.66

$N = \frac{2666.66}{316.46}$

$N = 8$ elements

Circular patches with 8 elements are arranged in an array in which each row and column of array consisting of 4 by 2.

- \[ W = \text{Width of the patch} \]
- \[ W = 1.5L, \quad L = 23\text{cm} \]

$D = 5.06\text{dB}$

\[
D = 4 \left( \frac{W}{\lambda_0} \right)
\]

(10)

$G = e_D$

Therefore, $G = 9.0\text{dB}$

\[
Af = A_0 \frac{\sin \left( N \sin \left( \frac{\psi}{2} \right) \right)}{N \sin \left( \frac{\psi}{2} \right)}
\]

(11)

The array factor deduced is then multiplied with E-field and H-field in equation 3 and 4 to generate array radiation pattern as shown in the figure 2.
Fig. 1: showing the E and H radiation pattern of a single element microstrip patch.
B. Construction and Experimental Measurement of the Antenna’s Characteristics

The un-galvanized aluminium plate was cut into circular diameter of 4cm each using lathe machine. Then the edge of the circular patch was smoothened using a metal file. The thickness of the patch was measured using micrometer screw gauge 0.28mm. After this, 2grams of plaster of Paris (POP) was evenly mixed with resin(C19H29COOH) inside a glass slide using capillary rod for stirring. Two drops of accelerator Stanum Chloride (SnCl₂) were added to the mixture followed by 2ml of catalyst. 50Ω coaxial cable was screwed with each of the patch for proper ohmic contact. The mixed chemical was then applied on the surface of each circular patch metal immediately using a tiny brush and was left for five minutes to dry. The etched patch was then arranged on a drilled wood using corporate fed method. The wood was drilled using hand drilling machine of one and half inches bits. Then circular patch was then fixed into each holes made with hand drilling machine on the wood. There after coaxial cable was then connected from one patch to another and then coupled together with couplers to form corporate feed arrangement which was later covered at the back with a fiber glass. The front view of the newly constructed antenna configuration is shown in the Figure 3, and the back view is shown in the Figure 4. After the construction, the new antenna was put on test in the passive mode which was later made active by inclusion of amplifier circuit to increase the power received level.

Experimental measurements were carried out indoor to measure the passive and active modes signal power received by the new antenna under test (AUT), a folded dipole array (Standard Century WA-10000TG) and existing linear dipole as standard antennas (SA) with the aid of GSP-810 spectrum analyzer. The gain, G of the new antenna was determined using Gain-Comparison technique (GCT) given by the formula [12]:

\[
G_{AUT} = G_{SA} + 10 \log_{10} \left( \frac{P_{R(AUT)}}{P_{R(SA)}} \right), \quad \text{dB} \tag{20}
\]
Fig. 3: showing the front view of the active microstrip patch antenna

Fig. 4: Sowing the backview of active microstrip patch antenna

III. RESULTS AND DISCUSSION
High definition television (HDTV) antennas are the antennas that are incorporated to HDTV through card slot port at indoor reception. In recent years HDTV has been popular due to high pixel level of picture and ability to interface with various memory elements with an inbuilt slot card. The antenna was designed, constructed, and analysed for the frequency range of 470MHz to 900MHz. The single element designed was carried out using transmission line method to compute the various parameters. The simulation process was done using matlab 2009 version with single element radiation pattern demonstrated omnidirectional property with high beamwidth (~6dB) as shown in the Figure 1, and low gain of 2dBi.
All the properties exhibited by single element were not enough for ultra high frequency (UHF) Television reception. As a result, single element patch was optimized to achieve 8 elements which was arranged in 4 by 2 corporate fed circular
patch HDTV antenna configuration. Hence, from the computation, the new designed antenna produced directional radiation pattern of low beamwidth (~3dB) as shown in the Figure 2 and high gain of ~9dBi. The antenna was fabricated by depositing resin of relative permittivity, \(\varepsilon_r = 4.5\) and thickness of 0.2cm using wet etching technique on un-galvanized aluminium of radius 2cm. The new 4 by 2 corporate fed circular patch HDTV antenna configuration is shown in the figures 3 and 4.

Experimental measurement was carried out by Gain-Comparison technique (GCT) in passive and active modes to determine the new antenna gain. A standard folded dipole array (Century WA-10000TG) and existing linear dipole were employed as standard antennas. Figures 5 and 6 are the plots of the power received versus frequency under passive and active conditions by the new antenna under test (AUT), and existing standard antennas: folded dipole array and linear dipole for compare and performance evaluation. The results obtained show that the peak gain at various frequencies in passive and active modes were 9, 8.83, 9, 8.99, 8.97dBi, at 487.6, 497.9, 531.4, 549.7, 566.9MHz, and 9.62, 11.23, 9.20, 8.99, 9.09dBi, at 480.3, 499.1, 531.6, 549.7, 566.9,588.6MHz respectively as shown in the Figure 7.

![Graph showing signal power received against frequency](image-url)
Fig. 6: Showing the graph of signal power received against the frequency by AUT (active) linear dipole and folded dipole.

Fig. 7: Showing the graph of gain against frequency for AUT under active and passive modes.

IV. CONCLUSION

A new HDTV microstrip patch antenna has been presented. The antenna has been designed and constructed for terrestrial TV reception. The designed has been done using transmission line method, and matlab 2009 version for calculation. The new antenna has shown good performance in terms of gain and radiation pattern. There is good agreement between design calculation and experimental measurement results, providing validation of the design procedure. The antenna will be useful as HDTV indoor antenna.

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BIOGRAPHY

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