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# Design, simulation and analysis of a Probe Feed Patch Antenna with Benzocyclobutene as the substrate material

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***Abstract*: In this paper a Probe Feed Patch Antenna is designed and simulated using the Ansoft HFSS Environment. Choosing a suitable substrate material is extremely important while designing a patch antenna; because a proper selection of the substrate material is necessary to fulfill the specific antenna requirements. The overview of a Patch Antenna is given in the initial section which is followed by the design procedure. The basic characteristic features of an antenna i.e. Gain, Directivity etc. are discussed in details with relevant formulae. Benzocyclobutene, in this case, is chosen as the substrate material. The properties of Benzocyclobutene are elaborated with molecular images. The different radiation patterns and 'phi-theta' plots are generated and analyzed for studying the behavior of the patch antenna. The various steps involved in this process are substrate creation, coax creation, analysis set up and creation of generalized reports.**

**( *Keywords*: Probe, Feed, Patch, Antenna, HFSS, Substrate, Coax, Benzocyclobutene, Radiation )**

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## I. INTRODUCTION

***A* Patch Antenna** (also known as a rectangular microstrip antenna) is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called a ground plane. The assembly is usually contained inside a plastic radome, which protects the antenna structure from damage. Patch antennas are simple to fabricate and easy to modify and customize. They are the original type of microstrip antenna described by Howell; the two metal sheets together form a resonant piece of microstrip transmission line with a length of approximately one-half wavelength of the radio waves. The radiation mechanism arises from discontinuities at each truncated edge of the microstrip transmission line. The radiation at the edges causes the antenna to act slightly larger electrically than its physical dimensions, so in order for the antenna to be resonant, a length of microstrip transmission line slightly shorter than one-half a wavelength at the frequency is used. A patch antenna is usually constructed on a dielectric substrate, using the same materials and lithography processes used to make printed circuit boards. Fig. 1 shows a Probe Feed Patch Antenna. [1], [2], [3]

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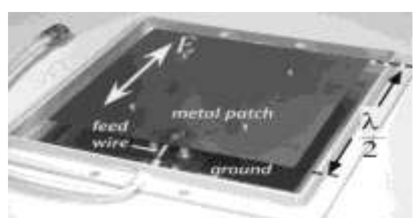


Fig.1 *A probe feed patch antenna*

## II. DESIGN PROCEDURE

A Probe Feed Patch Antenna is designed with the help of *HFSS Antenna Design Software*[25] with Benzocyclobutene as the substrate material.

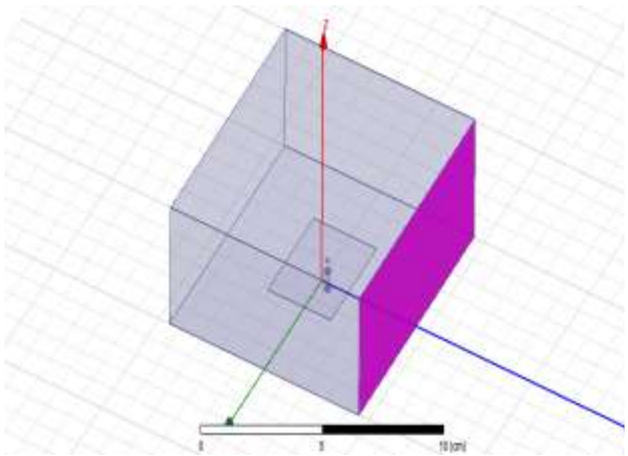

Fig. 2

Fig. 2 shows the snapshot of the Probe Feed Patch Antenna during the design procedure.

## III. SUBSTRATE MATERIAL

**Benzocyclobutene** (**BCB**) is a benzene ring fused to a cyclobutane ring. It has chemical formula$C_8H_8$. BCB is frequently used to create photosensitivepolymers. BCB-based polymer dielectrics may be spun on or applied to various substrates for use in Micro Electro-Mechanical Systems (MEMS) and microelectronics processing. Applications include wafer bonding, optical interconnects, low-K dielectrics, or even intracortical neural implants.[16], [17]

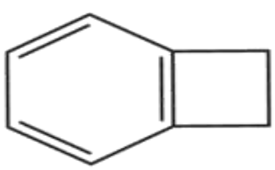

Fig. 3

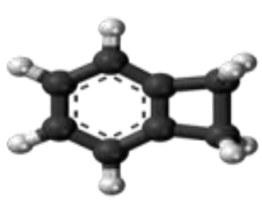

Fig. 4

*Molecular structures of Benzocyclobutene*

| ***Properties*** | |
|---|---|
| *Molecular formula* | $C_8H_8$ |
| *Molar mass* | 104.15g $mol^{-1}$ |
| *Density* | 0.957 g/cm3 |
| *Boiling point* | 150 °C, 423 K, 302 °F |
| *Refractive index* | 1.541 |

[i]. *Benzocyclobutene properties*

## IV. SIMULATION RESULTS

**Antenna Gain:**

The "gain" of an antenna takes account of the antenna efficiency as well as its directivity. The formal definition of gain in any direction (theta, phi) is "power density radiated in direction (theta, phi) divided by the power density which would have been radiated at (theta, phi) by a lossless (perfect) isotropic radiator having the same total accepted input power." If the direction is not specified, the value for gain is taken to mean the maximum value in any direction for that particular antenna, and the direction along which the gain is maximum is called the "antenna boresight". The general dependence of directivity and gain on the angles (theta, phi) is called the "radiation pattern".

**Power gain** (or simply **gain**) is a unitless measure that combines an antenna's efficiency $E_{antenna}$ and directivity D,

$$G = E_{antenna} . D \quad (1)$$

When considering the power gain for a particular direction given by an elevation (or "altitude") $\theta$ and azimuth $\varphi$, then,

$$G(\theta,\varphi) = E_{antenna} . D(\theta,\varphi) \quad (2)$$

$D(\theta,\varphi)$ is known as the directive gain. The directive gain signifies the ratio of radiated power in a given direction relative to that of an isotropic radiator which is radiating the same total power as

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the antenna in question but uniformly in all directions. The power gain, on the other hand, signifies the ratio of radiated power in a given direction relative to that of an isotropic radiator which is radiating the total amount of electrical power received by the antenna in question. This is in contrast to the directive gain which ignores any reduction in efficiency. If only a certain portion of the electrical power received from the transmitter is actually radiated by the antenna (its efficiency) the directive gain compares the power radiated in a given direction to that reduced power, ignoring the inefficiency. By instead comparing the radiated power in a given direction to the actual power that the antenna receives from the transmitter, the power gain takes into account that poorer efficiency, making it a more useful figure of merit for the ability of a transmitter in sending a radio wave toward a receiver.

The radiation intensity $U$ expresses the power radiated per solid angle. In terms of $U$ the power gain in a specified direction can be calculated as,

$$G = \frac{U}{P_{elec}/4\pi} \tag{3}$$

where $P_{elec}$ signifies the electrical power received by the antenna from the transmitter.

Published figures for antenna gain are almost always expressed in decibels (dB), a logarithmic scale. From the gain factor G, one finds the gain in decibels as, [4], [5]

$$G_{dBi} = 10 \log_{10} (G) \tag{4}$$

**Simulation results with Benzocyclobutene:**

If one looks around him/her self horizontally, he/she is looking in various "azimuth" directions. The azimuth angle varies from 0 to 360 degrees, allowing him/her to look in every horizontal direction. If one looks up or down with respect to him/her local horizon, the angle of view up or down is termed the "elevation". The elevation angle varies from -90 degrees (straight down) to +90 degrees (overhead). We shall call the elevation angle "theta" and the azimuth angle "phi". The distance from the antenna is the radius "R". These are commonly termed "spherical polar co-ordinates". The set of angles phi(0 to 360 degrees) and theta(-90 to 90 degrees) allows us to specify any radiation direction uniquely. In the far field region, the electric and magnetic fields fall off proportional to distance R; that is, they go as 1/R. The power therefore falls off as $(1/R)^2$ and the total radiated power over the entire sphere surrounding the antenna is independent of distance R.[18]

The radiation pattern is shown in Fig. 6. The Gain Total is expressed in decibels(dB). The plot in brown represents the radiation pattern for Phi = 90 deg. and the plot in red represents the radiation pattern for Phi = 0 deg. at a frequency of 2.25GHz with Benzocyclobutene as the substrate material.

*Radiation pattern*

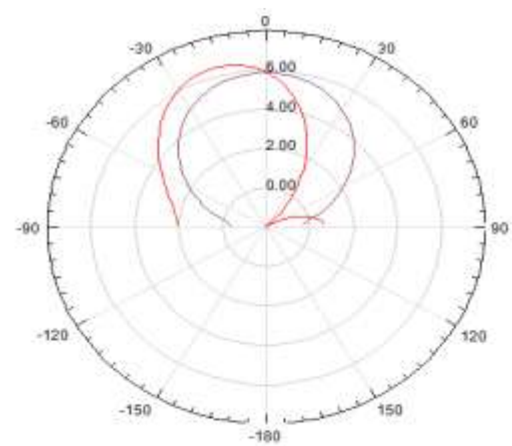



Fig. 6

3D Polar Plot of the patch antenna radiation is shown in Fig. 7; total gain is given in [ii].

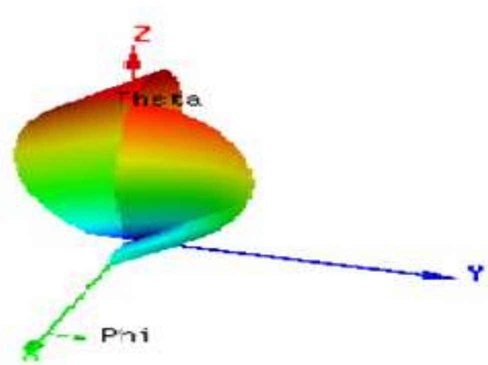
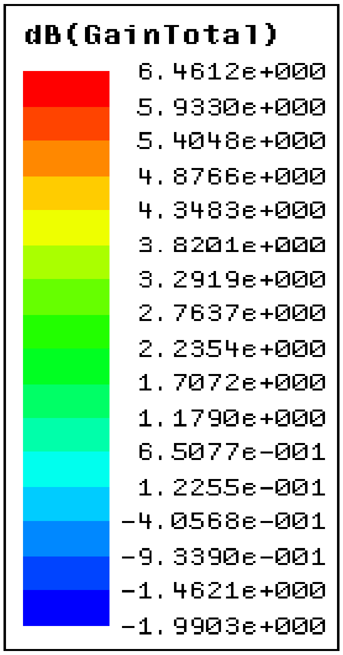



Fig. 7




[ii]. *Total Gain*

[ii] shows the max. and min. values of antenna gain.

3D Polar Plot properties is given in [iii].

| *3D Polar Plot Properties* | |
|---|---|
| *Name* | *dB(GainTotal)* |
| *Primary Sweep* | *Phi* |
| *Secondary Sweep* | *Theta* |
| ***Components*** | |
| *Mag Component* | *dB(GainTotal)* |
| *Theta Component* | *Theta* |
| *Phi Component* | *Phi* |

[iii]. *3D Polar Plot properties and components*

The **Center frequency** of a filter or channel is a measure of a central frequency between the upper and lower cutoff frequencies. It is usually defined as either the arithmetic mean or the geometric mean of the lower cutoff frequency and the upper cutoff frequency of a band-pass system or a band-stop system.[21], [22]

**Return loss** is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line or optical fiber. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB).[24]

**Standing wave ratio** (**SWR**) is the ratio of the amplitude of a partial standing wave at an antinode (maximum) to the amplitude at an adjacent node (minimum), in an electrical transmission line. The SWR is usually defined as a voltage ratio called the **VSWR.**[23]

Fig. 8 shows the terminal S-parameter magnitude(dB) plot with respect to Frequency(GHz).

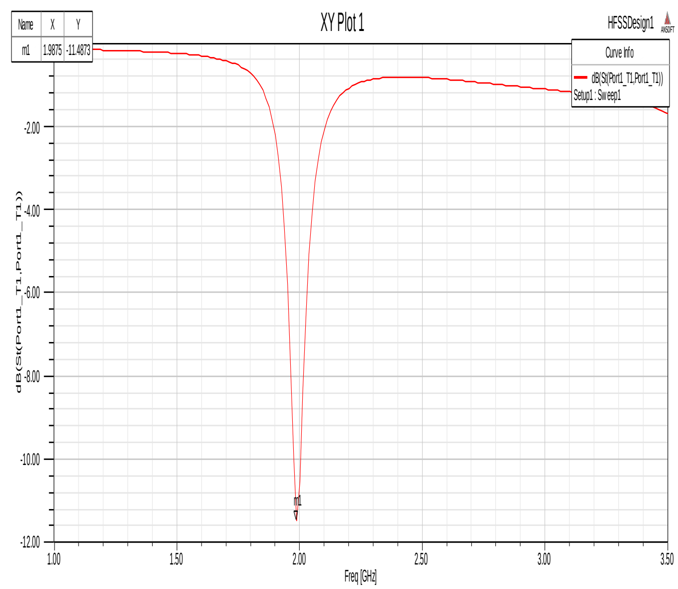
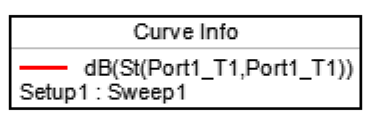



Fig. 8

Fig. 8 reveals the specific co-ordinates and curve information, given in [iii] and [iv] respectively.

| Name | X | Y |
|---|---|---|
| m1 | 1.9875 | -11.4873 |

[iv]. *Minimum co-ordinates*




[v]. *Curve information*

The Return loss of the Patch antenna at the center frequency is -11.4873dB[iv]. This corresponds to a

VSWR of 1.7265. A VSWR < 2 is always acceptable. HFSS could thus provide good impedance characteristics for the antenna under simulation.

**Directivity:**

In electromagnetics, **directivity** is a figure of merit for an antenna. It measures the power density the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal isotropic radiator (which emits uniformly in all directions) radiating the same total power. An antenna's directivity is a component of its gain; the other component is its (electrical) efficiency. Directivity is an important measure because most emissions are intended to go in a particular direction or at least in a particular plane (horizontal or vertical); emissions in other directions or planes are wasteful (or worse).

The directivity, D, of an antenna is the maximum value of its directive gain. Directive gain is represented as $D(\theta,\varphi)$ and compares the radiation intensity (power per unit solid angle) $U(\theta,\varphi)$ that an antenna creates in a particular direction against the average value over all directions,

$$D(\theta,\varphi) = \frac{U(\theta,\varphi)}{Ptot/(4\pi)} \tag{5}$$

Here $\theta$ and $\varphi$ are the standard spherical coordinate angles, $U(\theta,\varphi)$, is the radiation intensity, which is the power density per unit solid angle, and $P_{tot}$ is the total radiated power. The quantities $U(\theta,\varphi)$ and $P_{tot}$ satisfy the relation,

$$P_{\text{tot}} = \int_{\phi=0}^{\phi=2\pi} \int_{\theta=0}^{\theta=\pi} U \sin\theta \, d\theta \, d\phi; \tag{6}$$

i.e. the total radiated power $P_{tot}$ is the power per unit solid angle $U(\theta,\varphi)$ integrated over a spherical surface. Since there are $4\pi$ steradians on the surface of a sphere, the quantity $\frac{Ptot}{4\pi}$ represents the average power per unit solid angle.

In other words, directive gain is the radiation intensity of an antenna at a particular $(\theta,\varphi)$ coordinate combination divided by what the radiation intensity would have been had the antenna been an isotropic antenna radiating the same amount of total power into space.[6]

Directivity, then, is the maximum directive gain value found among all possible solid angles,

$$D = \max\left(\frac{U}{P_{\text{tot}}/(4\pi)}\right) = \frac{U(\theta,\phi)|_{\max}}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta \, d\theta \, d\phi}. \tag{7}$$

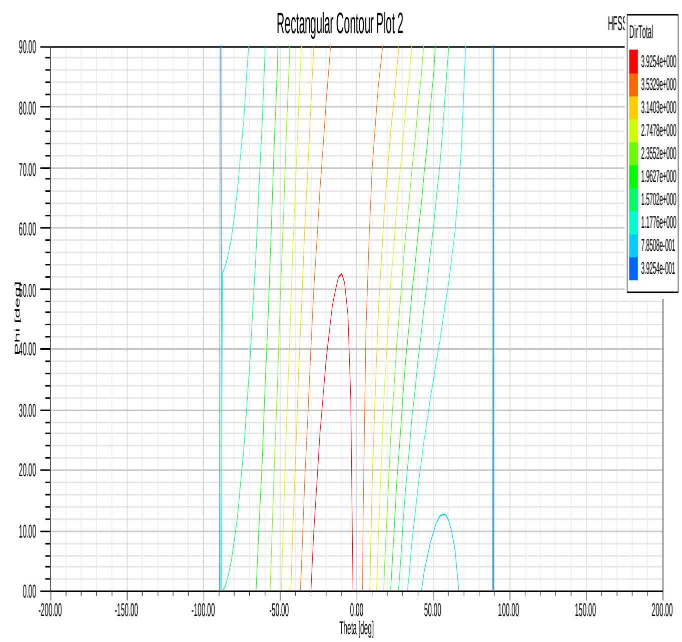
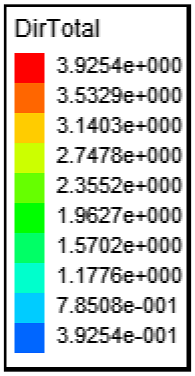



Fig. 9

*Phi[deg] vs Theta[deg] plot.*




[vi]. *Total Directivity*

## V. CONCLUSION

A microstrip or patch antenna is a low profile antenna that has a number of advantages over other antennas it is lightweight, inexpensive, and easy to integrate with accompanying electronics**.** The properties of Probe Feed Patch Antenna using Benzocyclobutene as the substrate material have been analyzed thoroughly with the help of appropriate simulation results. A detailed knowledge of Gain and Directivity is necessary in order to design a Probe Feed Patch Antenna. Choosing a substrate for antenna design also plays an important role. Selecting a suitable substrate, may fulfill the antenna requirements. Among all other substrates, Benzocyclobutene is capable of providing optimum simulation results. In near future, various other substrate materials will be considered and the antenna characteristics will be analyzed with generalized and quantized results.

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