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# Improvement in Accuracy for Design of Multidielectric Layers Microstrip Patch Antenna

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***Abstract*- In this paper multidielectric layer antenna has been designed using conformal mapping techniques with improved accuracy. Formulating an algorithm has eliminated effect of inaccuracies that can have compounding effect from the design stage to fabrication of multidielectric layer microstrip antenna. The algorithm has been successfully tested on both thin and thick dielectric substrates having low permittivity. The antenna designed for the given resonant frequency has been observed to be corresponding to the patch dimension with accuracy exactly to sixth decimal place.**

***Index Terms*-Antenna Parameters, Microstrip Antenna, Permittivity, Resonant Frequency.**

## I. INTRODUCTION

There is a need to accurately design the microstrip patch antenna at a desired frequency of operation and also to follow a proper analysis technique that will accurately predict the behavior of antenna under consideration. The analysis of rectangular patch microstrip antenna employing multidielectric layers is carried out using conformal mapping technique. The design considerations are based on the characteristics of the substrate, the patch geometry and the location of the feed. Design parameters based on empirical formulae for every variable need to be calculated and are interdependent and hence time consuming. An effective and efficient algorithm has been developed and a program using MATLAB7 which gives the result, accurate to 16th decimal place. Configurations of stack patch antennas of different dimensions designed for a given resonant frequency has been analyzed. The accuracy in the physical dimension of the patch calculated is increasing at each step.

## II. DESIGN OF MULTIDIELECTRIC LAYERS MICROSTRIP RECTANGULAR PATCH ANTENNA

### *A. Design Parameters*

A rectangular patch of width ‘W’ and length ‘L’ with three dielectric layers $\varepsilon_{r1}$, $\varepsilon_{r2}$ and $\varepsilon_{r3}$ and height $h_1$, $h_2$ and $h_3$ respectively as shown in fig.1 (a) & fig. 1(b).

Conformal mapping technique involving Wheeler’s Transformation [7] the complex variable plane z= x+jy is mapped to a plane g= u+jv as shown in fig.2 (a), fig.2 (b). The first approximation leaving the areas $S_0$, $S_1$, $S_2$, and $S_3$ is unchanged. Hence the relation for the quasi-static permittivity is as follows:

$$\varepsilon_e = \frac{\varepsilon_{r1} * \varepsilon_{r2} (q_1 + q_2)^2}{\varepsilon_{r1} * q_2 + \varepsilon_{r2} * q_1} + \frac{\varepsilon_{r3}(1 - q_1 - q_2)^2}{\varepsilon_{r3}(1 - q_1 - q_2 - q_3) + q_3} \quad ....(1)$$

Where $q_1$, $q_2$ and $q_3$ are the filling factors, defined respectively, as the ratio of each area of $S_1$, $S_2$ and $S_3$ to the whole area $S_c$, of the cross section in the g-plane [3]. The dispersive behavior $\varepsilon_{eff}$ can be determined as: [5]

$$\varepsilon_{eff} = \varepsilon'_r - \frac{\varepsilon'_r - \varepsilon_e}{1 + P(f)} \quad .......................(2)$$

Where $\varepsilon_e$ is determined by equation (1) and $\varepsilon'_r$ is the permittivity that takes into account the multilayer effect on a microstrip line as all the formulas calculated were for single layer. Hence $\varepsilon'_r$ is given by equation below: [8]

$$\varepsilon'_r = \frac{(\varepsilon_e * 2) - 1 + A}{1 + A} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The parameter A is taken to simplify the above equation, which is expressed as

$$A = (1 + \frac{12 * h_{12}}{W})^{-1/2} \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Since ΔL is the increase in the length due to fringing effect [1], found from the relation in [6] with ($\varepsilon'_r$, u') replacing ($\varepsilon_e$, u) and the height $h_{12}$ replacing h.

$$\Delta L = \frac{h_{12} * \xi_1 * \xi_3 * \xi_5}{\xi_4} \ldots\ldots\ldots\ldots\ldots(5)$$

For $\xi_1$, $\xi_3$, $\xi_4$ and $\xi_5$ refer the relation in [6]. The length L of a patch for a given patch width W and resonant frequency $f_r$ is determined [8].

$$L = \frac{C}{2 * f_r * (\varepsilon_{eff})^{1/2}} - 2\Delta L \ldots\ldots\ldots\ldots\ldots(6)$$

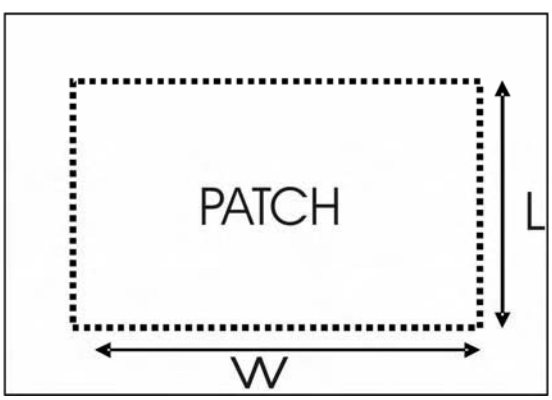


Fig. 1 (a). A multilayer dielectric rectangular microstrip antenna patch [3]

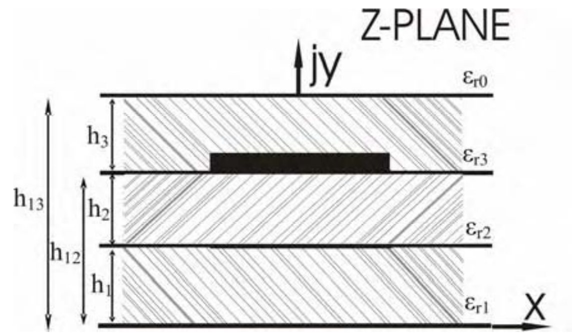


Fig. 1 (b). A multilayer dielectric rectangular microstrip antenna [3]

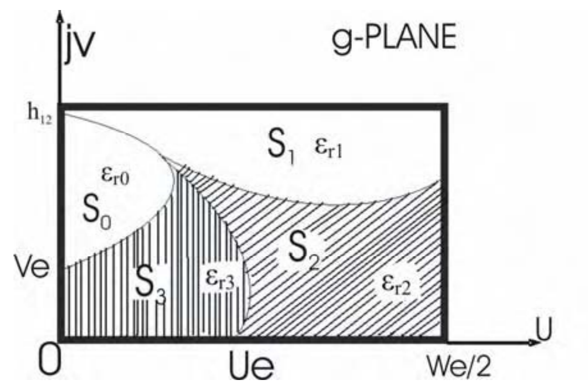


Fig. 2 (a). Conformal mapping of a multilayer dielectric rectangular microstrip antenna [3]

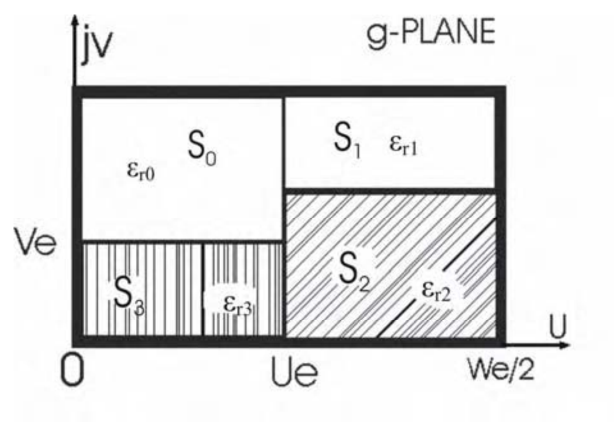


Fig. 2 (b). Conformal mapping of a multilayer dielectric rectangular microstrip antenna approximated [3]

*B. Antenna Parameters- Effect of Inaccuracies*

The analysis of multidielectric layers microstrip antenna is based on empirical relations. Further when the antenna is fabricated certain errors results due to the manufacturing processes. The errors need be minimized to a large extent because the anomalies can have a compounding effect. An illustration shows the effect on the resonant frequency due to change in length of the patch. With increase in the length of patch by 0.0001mm (from 0.0334 to 0.0335 mm) there is a change in resonant frequency of 7.4MHz (from 2.718 GHz to 2.7106 GHz), which is significant as compared to change in the length. Refer Table1.

*C. Accurate Computation of Antenna Parameters*

Calculation of various parameters of the antenna involves large number of computational steps that are repetitive and prone to calculation errors. Conformal mapping technique involving Wheeler Transformation function [7] to map one complex plane into another complex plane involves equations, which require rigorous calculations. The dimension of the antenna i.e. the substrate and the patch are in millimeters and micrometers respectively. The resonant frequency that has been calculated is in the range of gigahertz. Hence a very small variation in the dimension of the antenna parameters will result into a very significant change in the resonant frequency. It is to be noted that these calculations carried out are repetitive as a result, of which the errors is cumulative at every step thereby resulting in a notable change in the frequency.

To minimize the compounding errors an algorithm has been designed. The algorithm aims towards minimization of errors at each step ultimately providing a result, which is highly accurate. Antenna designer can overcome the manual tedious process of determining patch dimension for a required frequency of operation where criticality can be accounted for different values of substrate permittivity. It is important to understand, in an environment where there are multi emitters operating in the same frequency band, a few MHz deviations in resonant frequency can matter and result in interference. Critical design and result obtained thereof through rigorous simulation not only can ensure accuracy in fabrication, but also can provide the requisite tolerance for minor variation in dielectric properties of the substrate obtained from the manufacturer

*D. Algorithm*

I. START MODULE 1
II. Input the height $h_1$, $h_2$and $h_3$ and the corresponding values of relative permittivity $\varepsilon_{r1}$, $\varepsilon_{r2}$ ,$\varepsilon_{r3}$ refer fig. 1(b) and $\varepsilon_{r0}$=1 (permittivity of free space).
III. Input the resonant frequency $f_r$ for antenna design.
IV. Input the width W (refer fig. 1 (a)) of the patch, criterion $W/h_{12} \geq 1$ for $h_{12}$ refer fig.1 (b).
V. Computation of length L of the patch is carried out in following steps:
   - Step 1: The effective line width $W_e$ and quantity $V_e$ values obtained from the formulae in [3].
   - Step 2: The filling factors $q_1$, $q_2$ and $q_3$ refer fig. 2(a) & fig. 2(b) described in reference [3].
   - Step 3: The quasi-static effective permittivity $\varepsilon_e$, refer equation (1).
   - Step 4: The effective permittivity $\varepsilon'_r$ that takes into account the Multidielectric layers, refer equation (3).
   - Step 5: $U=W/h_{12}$ and $U'=W_e/h_{12}$.
   - Step 6: $K_0$ is free space wave number computed at resonant frequency $f_r$.
   - Step 7: Function P(f), is a frequency dependent term refer[5] notation ($\varepsilon'_r$, u') replaces ($\varepsilon_e$, u) and $f_h=47.713*K_0*h_{12}$ ,referred [1] replaces the approximation $f_h=h/\lambda_0$ referred [5].
   - Step 8: The effective permittivity $\varepsilon_{eff}$ based on the frequency factor, refer equation (2).

Step 9: The $\Delta L$ due to fringing effect referred [6] were ($\varepsilon'_r$, u') replaces ($\varepsilon_e$, u).

Step 10: Length L of the patch computed based on the expression

$$L = \frac{C}{2 * f_r * (\varepsilon_{eff})^{1/2}} - 2\Delta L$$

VI. Pass the values $h_1$, $h_2$, $h_3$, $\varepsilon_{r1}$, $\varepsilon_{r2}$, $\varepsilon_{r3}$, $K_0$, W and L to MODULE 2

VII. START MODULE 2

VIII. Computation of resonant frequency $f_v$ (verification frequency) at the Length L found in MODULE 1.

Step 1: The effective line width $W_e$ and quantity $V_e$ values obtained from the formulae in [3].

Step 2: The filling factors $q_1$, $q_2$ and $q_3$ refer fig. 2(a) & fig. 2(b) described in reference [3].

Step 3: The quasi static effective permittivity $\varepsilon_e$, refer equation (1).

Step 4: The effective permittivity $\varepsilon'_r$, which takes into account, the multidielectric layers refer equation (3).

Step 5: $U=W/h_{12}$ and $U'=W_e/h_{12}$.

Step 6: Function P(f), is a frequency dependent term refer[5] notation ($\varepsilon'_r$, u') replaces ($\varepsilon_e$, u) and $f_h=47.713*K_0*h_{12}$ referred [1] replaces the approximation $f_h=h/\lambda_0$ referred [5].

Step 7: The effective permittivity $\varepsilon_{eff}$ based on the frequency factor refer equation (2).

Step 8: The $\Delta L$ due to fringing effect referred [6] were ($\varepsilon'_r$, u') replaces ($\varepsilon_e$, u).

Step 9: The resonant frequency $f_v$ based on the formulae in [3] where notation $f_v$ replaces $f_r$ and the formula is given as:

$$f_v = \frac{c}{2 * (L + 2\Delta L) * (\varepsilon_{eff})^{1/2}}$$

IX. Return the values of $f_v$ to MODULE 1.

X. STOP MODULE 2.

XI. Compare $f_v$ and $f_r$ if equal than MODULE 1 is validated.

XII. STOP MODULE 1.

## III. ANALYSIS

The algorithm has been converted into a MATLAB7 program and the results obtained are shown in a tabular form. Refer Table1. Significance of accurate length calculation and its effect on the resonant frequency can be observed. It is important to note that changes in the resonant frequency in case there is variation of patch length at 4th, 5th, even at 6th decimal place. e.g. patch resonant frequency of operation at 2.7010 GHz, positive variation in its length at 4th, 5th, at 6th decimal place results at corresponding changes of frequency 8MHz, 0.8MHz and 0.1 MHz respectively. Similarly changes in the negative direction variation in patch length leads to variation in resonant frequency, details shown below.

*Case studies*

Ratio of W to $h_{12}$ should be greater than or equal to 1 and ratio of width W to length L should lay between 1 and 2 [1]. In both the cases the parameters for antenna design are width of the patch 32.25mm, substrate permittivity of layer 1($\varepsilon_{r1}$), 2($\varepsilon_{r2}$) and 3($\varepsilon_{r2}$) as 1, 2.32 and 2.32 respectively, height of substrate1 ($h_1$) taken as 0mm and height of substrate2 ($h_2$) taken as 3.18mm. The height of substrate3 ($h_3$) has been varied [3].

*1. Case I (Thin Substrate)*

For simulation in this case W (width of the patch) is taken as 32.25mm, L (length of the patch) is equal to 33.48mm , length of the microstrip feed line is taken as 52.715mm with edge feeding technique. The substrate permittivity of layers

Table1 Determining the length for a given frequency and determining the accuracy in the frequency by varying the length

| Standard Parameters | Cover Thick-ness $h_3$ (mm) | Resonant Frequency of operation $f_r$ (GHz) | Calculated Length L (m) | Calculated Verified Frequency (GHz) Change in L at 4th Decimal Place | | Calculated Verified Frequency (GHz) Change in L at 5th Decimal Place | | Calculated Verified Frequency (GHz) Change in L at 6th Decimal Place | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $\Delta L=+1*10^{-4}$ | $\Delta L=-1*10^{-4}$ | $\Delta L=+1*10^{-5}$ | $\Delta L=-1*10^{-5}$ | $\Delta L=+1*10^{-6}$ | $\Delta L=-1*10^{-6}$ |
| CASE 1: THIN SUBSTRATE | 3.18 | 2.718 | 0.03348578 | 2.7106 | 2.7254 | 2.7172 | 2.7187 | 2.7179 | **2.7180** |
| | 6.36 | 2.701 | 0.03346891 | 2.693 | 2.708 | 2.7002 | 2.7017 | 2.7009 | **2.7010** |
| CASE 2: THICK SUBSTRATE | 9.54 | 2.688 | 0.03345603 | 2.6806 | 2.6953 | 2.6872 | **2.6887** | --- | --- |
| | 12.72 | 2.678 | 0.03344509 | 2.6707 | 2.68533 | 2.6772 | **2.6787** | --- | --- |
| **W=0.03225 m, $\varepsilon_{r2}=\varepsilon_{r3}=2.32$, $\varepsilon_{r1}=1, h_1=0, h_2=0.00318$ m** | | | | | | | | | |

1($\varepsilon_{r1}$), 2 ($\varepsilon_{r2}$) and 3 ($\varepsilon_{r2}$) are taken as 1, 2.32 and 2.32 respectively, height of substrate1 ($h_1$) taken as 0mm and height of substrate2 ($h_2$) taken as 3.18mm and $h_3$ as 3.18mm refer Fig. 3(a)

Deviation in the frequency is obtained $f_r$=2.719GHz after simulation from the one required i.e. $f_r$=2.718GHz and is about 1Mhz, which is acceptable.

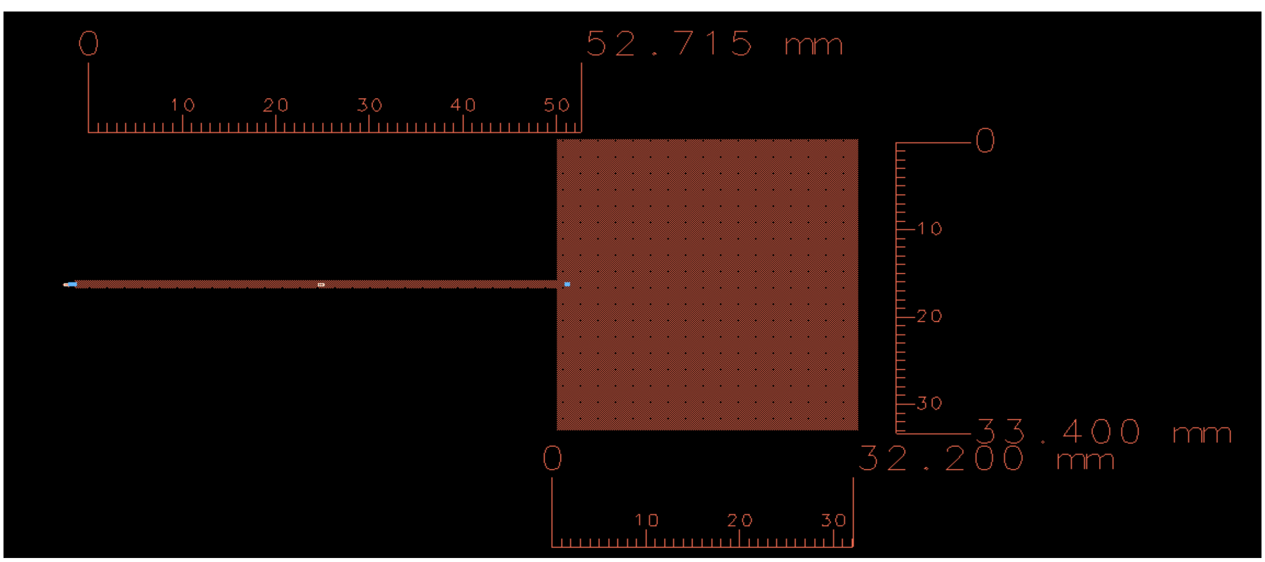


Fig. 3(a). Basic Patch Construction on Momentum

Fig. 3(b) shows the return loss ($S_{11}$) of -17.7db at a resonant frequency of 2.719GHz, which is a good design. Fig. 3(c) shows field plot in Cartesian coordinate.

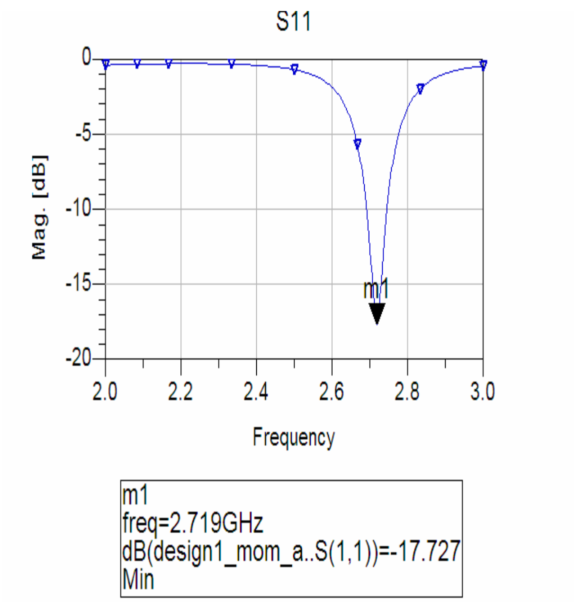


Fig. 3(b). Return loss at the resonant frequency

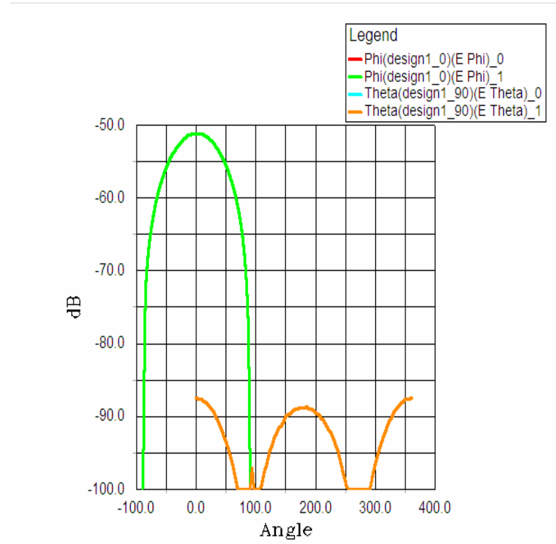


Fig. 3(c). Cartesian plot of Field in theta (orange) and phi (green) plane

*2. Case II (Thick Substrate)*

For simulation in this case W (width of the patch) is taken as 32.25mm, L (length of the patch) is equal to 33.48mm, length of the microstrip feed line is taken as 52.715mm with

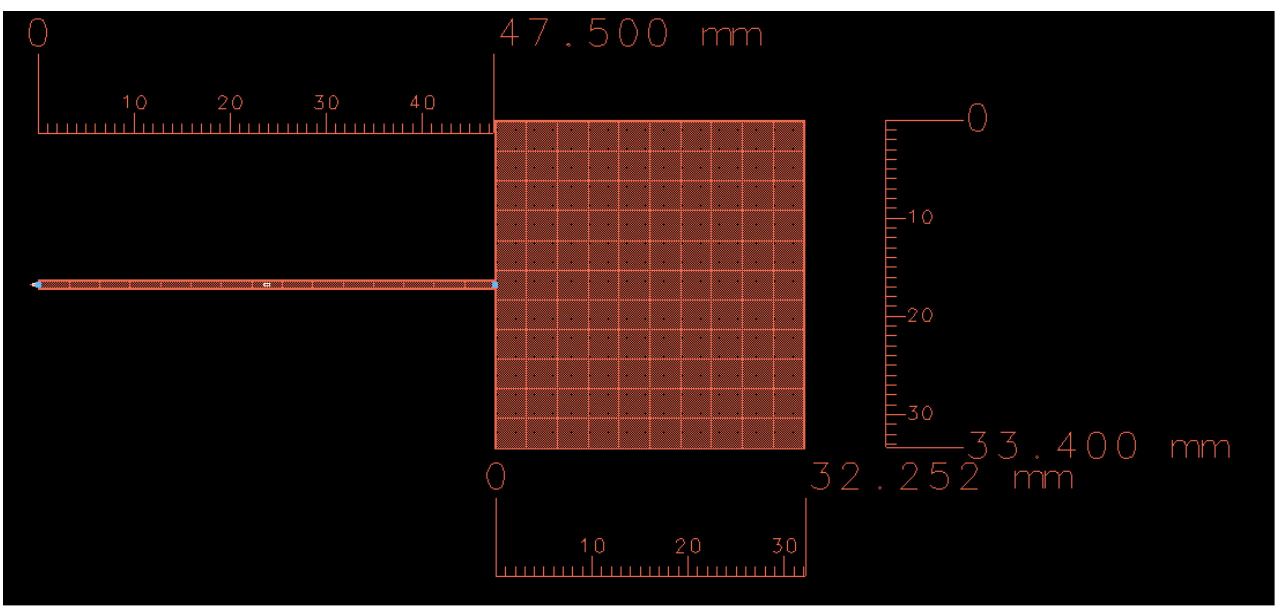


Fig. 4(a). Basic Patch Construction on Momentum

edge feeding technique. The substrate permittivity of layers 1($\varepsilon_{r1}$), 2 ($\varepsilon_{r2}$) and 3 ($\varepsilon_{r2}$) are taken as 1, 2.32 and 2.32 respectively, height of substrate1 ($h_1$) taken as 0mm and height of substrate2 ($h_2$) taken as 3.18mm and $h_3$ as 12.72mm refer Fig. 4(a).

Fig. 4(b) shows the return loss ($S_{11}$) of -11.265db at resonant frequency of 2.677 GHz. $S_{11}$ is low because of the surface wave losses due to the thick substrate. Deviation in the frequency obtained at $f_r$=2.677GHz after simulation from the required i,e $f_r$=2.678GHz and is about 1Mhz, which is acceptable. Fig. 4(c) shows field plot in Cartesian coordinate.

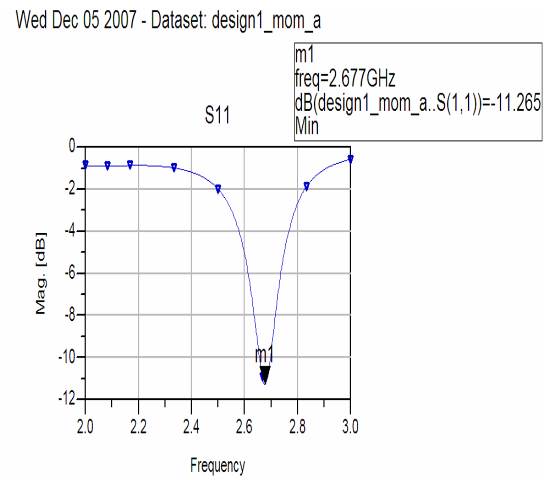


Fig. 4(b). Return loss at the resonant frequency

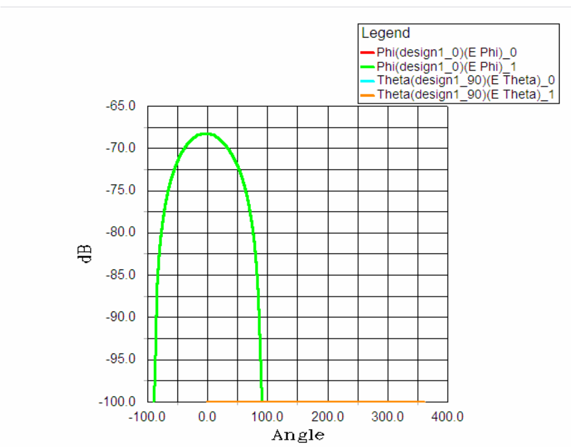


Fig. 4(c). Cartesian plot of Field in theta (orange) and phi (green) plane

The results show that the patch is optimized for the parameters calculated by implementing the algorithm in MATLAB7 program

## V. CONCLUSION

By devising the algorithm the various parameters of the Multidielectric Layer Microstrip Antenna has been calculated with the help of MATLAB7 program. The results have been verified and validated by carrying out the simulation of the antenna using Momentum Advanced Design System Software. Hence an antenna design have been achieved with utmost precision where the errors after $6^{th}$ decimal place are insignificant in case of a thin substrate multidielectric layer and after $5^{th}$ decimal place in case of thick substrate multidielectric layer.

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