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Citation: Lu, Qing, Korolkiewicz, Edward, Danaher, Sean, Ghassemlooy, Zabih and Sambell, Alistair (2009) Optimum design of a probe fed dual frequency patch antenna using genetic algorithm. In: Proceedings of the ARMMS RF and Microwave Society, 20-21 April 2010, Rockingham Forest Hotel, Corby, UK.

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Optimum Design of a Probe Fed Dual Frequency Patch Antenna Using Genetic Algorithm

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Abstract: Recent research has concentrated on different designs in order to increase the bandwidth of patch antennas and thus improve functionality of wireless communication systems. An alternative approach as shown in this paper is to design a matched probe fed rectangular patch antenna which can operate at both dual frequency (1.9 GHz and 2.4 GHz) and dual polarisation. In this design there are four variables, the two dimensions of the rectangular patch, 'a' and 'b', and position of the probe feed, 'X_p' and 'Y_P'. As there is not a unique solution a Genetic Algorithm (GA) was applied using an objective function based on the return loss at each frequency. The antenna was then modelled using AWR software and the predicted and practical results are shown to be in good agreement.

Key Words: Genetic algorithm (GA), dual frequency, dual polarisation, probe fed patch antenna

I. Introduction

Patch antennas are used in many communication systems as they are compact, have low profile and their manufacturing costs are reduced by using printed circuit technology. The main disadvantage of these types of antennas is that they have narrow bandwidth and hence current research has concentrated on different techniques to improve the bandwidth so that they can be used in a variety of communication systems [1-4]. The alternative approach to increasing the bandwidth is to design the antenna so that it can operate in different bands or at least in dual mode with different polarisations so that the same unit can be used in different communication systems [5-7]. Dual band patch antennas can be obtained using slots, stacked patches and shorting pins [8, 9].

In this paper, a single probe fed dual frequency rectangular patch antenna is designed using GA to determine the optimum dimensions of the patch and the position of the probe feed to produce a matching at the two frequencies. The expression for the probe feed impedance has been derived in ref [10] and used as the objective function in the optimisation process.

In the application of the GA optimisation process it is necessary to consider very carefully the upper and lower range of the four variables. The range for the width and length of the patch must be such that each dimension of the patch radiates only the required frequency. Due to the inherent symmetry of the patch there are four possible positions for the probe feed to obtain simultaneous matching at both frequencies. Consequently the feed position range should only be suitable to only one of the four possible solutions.

The electrical and physical parameters of the substrate PCB FR4 used are: dielectric constant is 4.3, the height of substrate is 1.575 mm, the loss tangent is 0.019 and the thickness of the copper patch is 0.035mm.

Π. Genetic Algorithm

The GA [11, 12] is based on the evolution theory where weak species face extinction but strong ones survive and pass their genes to the next generation. However for the strong species to survive there is also a requirement for random injection of genes. As GA mainly manipulates matrices it is normally implemented using Matlab software. The step by step procedure of generating the software program is shown below.

Step 1: Each variable is assigned a number of binary digits so that the required accuracy of this variable is obtained in the final solution.

Step 2: All the variables in their binary form are grouped into a string which is called a chromosome.

Step 3: Matlab is used to select a fixed number of random chromosomes called a population out of all possible number of chromosomes that are present. This is called the current generation.

Step 4: Converting the digital value of each variable in a chromosome to an analogue value, the objective function (F) is evaluated and the relative fitness of each chromosome (Pi) determined. This relative fitness is defined as [13]:

$$F = \sum_{i=1}^{n} eval_i \left[P_i \right] \qquad (1)$$

Step 5: The selective probability is determined by:

$$P_{si} = \frac{eval_i \left[P_i \right]}{F} \qquad (2)$$

The cumulative probability of the chromosomes is given as:

$$q_i = \sum_{j=1}^{n} P_{sj} \qquad (3)$$

Then a random number '*r*' is generated in the range 0 to 1. If $q_{i-1} \leq r \leq q_i$ then select P_{si}.

Step 6: Crossover is applied for random chromosomes between the parent and next generation to produce new off -springs.

Step 7: The population is mutated by changing in a random way the value of the genes with the least significant bit having the highest probability of mutation and the most significant the least.

The next generation now becomes the parent generation and the above process is repeated until the genetic variation in the population is below a certain threshold.

As the number of generations increases both the cross over rate and the mutation rate are gradually reduced.

III. Optimisation of a Dual frequency Dual Polarised Matched Patch Antenna

A rectangular patch antenna is shown in figure 1, where the effective lengths ‘*a*’ (1.9 GHz), ‘*b*’ (2.4 GHz) and the probe feed position (X_p, Y_p) for matching need to be determined.

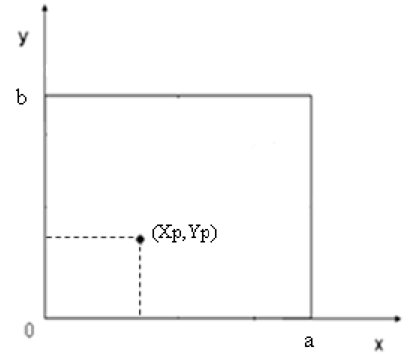


Figure 1: Dimensions and feed position of the patch antenna

The probe feed impedance for the rectangular patch antenna is given by [10]:

$$Z_{pp}(f) = j2\pi f\mu h\left\{-\frac{cosak+cosk(a-2X_p)}{2bksinak} + \frac{b^2}{{W_p}^2\pi^3}\sum_{n=1}^{\infty}\left[\frac{\left[\sin\left[n\frac{\pi}{b}\left(Y_p+\frac{W_p}{2}\right)\right]-\sin\left[n\frac{\pi}{b}\left(Y_p-\frac{W_p}{2}\right)\right]\right]^2}{n^2\sqrt{n^2-\left(\frac{bk}{\pi}\right)^2}\,sinh\left[\frac{a\pi}{b}\sqrt{n^2-\left(\frac{bk}{\pi}\right)^2}\right]}\left[cosh\left[\frac{a\pi}{b}\sqrt{n^2-\left(\frac{bk}{\pi}\right)^2}\right] + cosh\left[\frac{(a-2X_p)\pi}{b}\sqrt{n^2-\left(\frac{bk}{\pi}\right)^2}\right]\right]\right]\right\} \tag{4}$$

where *h* is the thickness of the dielectric substrate, $k^2 = \omega^2\,\mu\,\varepsilon_0\,\varepsilon_{reff}\,(1 - j/Q)$, *Q* is the total quality factor (which is equal to 43.5), ε_0 is free space dielectric constant, ε_{reff} is the mutual effective dielectric constant, ω is the angular velocity.

The return loss at the two frequencies is shown below,

$$S11(1.9\,GHz) = 20\log\left(\left|\frac{Z_{pp}(1.9\,GHz)-50}{Z_{pp}(1.9\,GHz)+50}\right|\right)\text{ dB},$$

and (5)

$$S11(2.4\,GHz) = 20\log\left(\left|\frac{Z_{pp}(2.4\,GHz)-50}{Z_{pp}(2.4\,GHz)+50}\right|\right)\text{ dB}$$

The weighted average objective function (Objval) used in the GA program is,

$$\text{Objval} = S11\ (1.9\text{ GHz}) + S11\ (2.4\text{ GHz}) - |S11\ (1.9\text{ GHz}) - S11\ (2.4\text{ GHz})| \tag{6}$$

The consistent optimised values of the four variables are a = 39.4 mm, b = 30.4 mm, X_p = 14 mm and Y_p = 10 mm.

In applying GA it is necessary to have a good understanding of the relevant theory so that realistic minimum and maximum values for the variables are used. To ensure that only the two required frequencies are radiated at each of the two edges the minimum and maximum values for the dimensions of the antenna are 30 mm $\leq a \leq$ 45 mm and 25 mm $\leq b \leq$ 35 mm. The edge impedances for each mode are high so in order to obtain matching at 50Ω the probe feed must placed away from the edges of the patch. As there are four quadrants of the patch where the probe feed can be placed for matching the range for the probe feed position must only be within one quadrant. In this design the range for the probe feed was limited to 5 mm $\leq X_P \leq$ 20 mm and 5 mm $\leq Y_P \leq$ 15 mm.

IV. Comparison of Predicted and Practical Results

A photograph of the fabricated antenna is shown in figure 2.

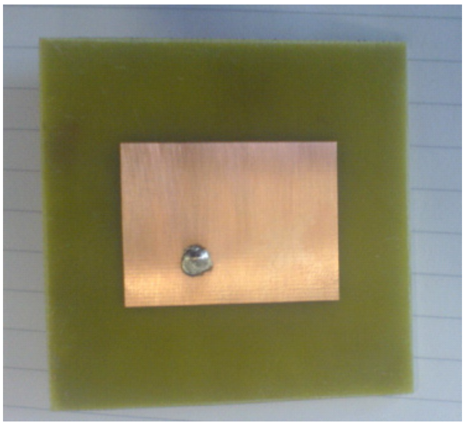


Figure 2: Photograph of the fabricated patch antenna

The frequency responses of the return loss obtained from practical measurements and from the GA are shown in figure 3. The practical measurements were obtained using 'Agilent' network analyser (N5230A) and the predicted results were obtained using the GA program (see the appendix). At 1.9 GHz frequency there is an excellent agreement, while at 2.4 GHz there is about 0.05 GHz or 2% difference between the predicted and the practical results.

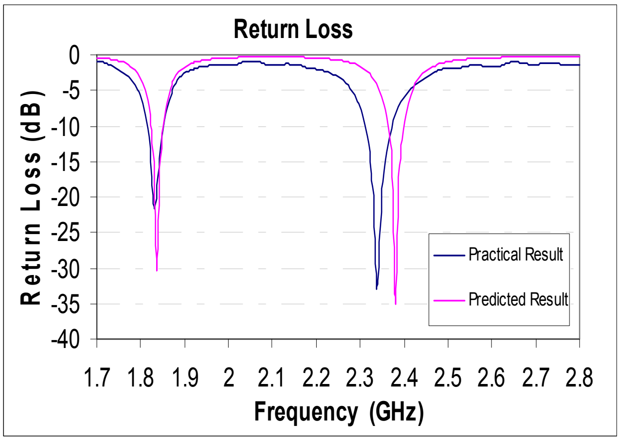
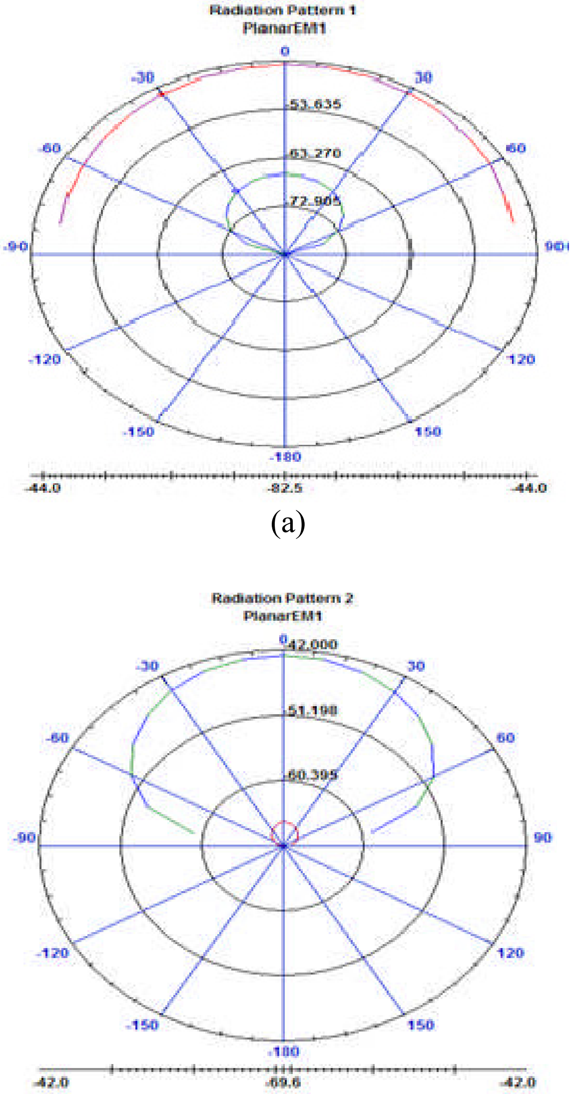


Figure 3: Predicted and practical results for the return Loss

Simulated polar patterns at 1.9 GHz and 2.4 GHz shown in fig. 4 were obtained where the red polar pattern is for 1.9 GHz and the blue polar pattern is for 2.4 GHz. In fig. 4(a) the polar pattern is in the E-plane and in fig. 4(b) it is in the H-plane. As can be seen an excellent isolation of over 64 dB between the two modes has been obtained.



(a)

(b)

Figure 4: Polar patterns at (a) E-plane and (b) H-plane

V. Conclusions

Equal weighted functions for the return loss at each frequency were used in the objective function in the GA program in the design of a matched, dual frequency probe fed rectangular patch operating at 1.9 GHz and 2.4 GHz. An excellent return loss has been obtained at the two frequencies (approx -30 dB). The predicted results for the feed impedance were compared with those obtained from the transmission line model and from practical measurements. A very good agreement has been obtained for all results.

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