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SHORT COMMUNICATION

Genetic Algorithm-based Design Optimisation of Aperture-coupled Rectangular Microstrip Antenna

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ABSTRACT

The technique of feeding a microstrip antenna with a microstrip line through an aperture is gathering a lot of interest in communication and radar systems used for defence applications. This is due to the fact that this feeding technique has many adjustable parameters in the form of aperture length, width, and stub parameters. This paper presents a study on the effect of aperture dimensions and stub length on the voltage-standing wave ratio bandwidth of an aperture-coupled microstrip antenna. Without any additional matching network, optimal impedance matching of the antenna has been achieved using genetic algorithm. In the algorithm, each chromosome consists of three binary encoded genes, one for aperture length, second one for aperture width and the last one for stub length. Finally, the algorithm determines the parameters of the antenna that provides the minimum value of the average reflection coefficient. The investigation is made at different microwave frequency ranges and it extends up to K_u band. The results show that the percentage of fractional bandwidth improves for higher design frequencies and has a maximum of 13.2 per cent for centre frequency of 17.5 GHz. Experimental results are presented for a particular range of frequency and the accuracy of the analysis is briefly discussed.

Keywords: Microstrip antenna, microstrip line, voltage-standing wave ratio, VSWR bandwidth, genetic algorithm, impedance transformer, patch impedance, aperture-coupled antenna

1. INTRODUCTION

An aperture-coupled microstrip antenna is used when a higher-impedance bandwidth is desired[1]. However, it is not capable of offering a very high-impedance bandwidth, owing to the fact that the small-coupling aperture limits the antenna substrate thickness that may be used. By using a thick-antenna substrate, a bandwidth of 20-25 per cent can be achieved[2,3]. But because of the thick-antenna substrate, a larger-slot is needed to obtain the necessary coupling, resulting in a higher level of back radiation. In this paper, the effect of aperture dimensions and stub length on the voltage-standing wave ratio (VSWR) bandwidth of the microstrip antenna is considered without using a thick-antenna substrate. With the help of genetic algorithm, an optimal solution is found.

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2. THEORETICAL PROCEDURE

An aperture-coupled rectangular microstrip antenna is shown in Fig. 1. The transmission-line model and the cavity model are approximate models often used to design and analyse the antenna. These models are chosen to avoid the computational complexities of full-wave analysis which hardly affects the accuracy[4]. The coupling of the patch to the aperture is described by an impedance transformer of turns ratio n_1 roughly equal to the fraction of patch current intercepted by the slot to the total patch current'. The patch impedance is determined at the centre of the slot and its value can be obtained from the simple transmission-line model. The input impedance of the antenna at the centre of the slot is given by

$$Z_{in} = n_2^2/(n_1^2 Y_{patch} + Y_{ap}) - jZ_{om} \cot(\hat{a}_m L_s) \quad (1)$$

where n_2 is the turns ratio of the transformer used to describe the coupling of the patch to the microstrip line and is given by

$$n_2 = (J_0(\hat{a}_s W/2) J_0(\hat{a}_m W_a/2) / (\hat{a}_s^2 + \hat{a}_m^2))$$
$$[(\hat{a}_m^2 k_2 \mathring{a}_{rf}/(k_2 \mathring{a}_{rf} \cos k,h - \sin k_1 h))$$
$$+ (\hat{a}_s^2 k_1/(k_1 \cos k_1 h + k_2 \sin k_1 h))] \quad (2)$$

where $J_0(.)$ is the **zeroth-order** Bessel function and

$$k_1 = k_0 \square |\mathring{a}_{rf} - \mathring{a}_{res} - \mathring{a}_{rem}|, \quad \hat{a}_s = k_0 \square\, \mathring{a}_{res}$$
$$k_2 = k_0 \square |\mathring{a}_{res} + \mathring{a}_{rem} - 1|, \quad \hat{a}_m = k_0 \square\, \mathring{a}_{rem}$$

Here W, ε_{rem}, β_m, Z_{om} are the width, effective permittivity, phase constant, and characteristic impedance of the microstrip line and W_a, ε_{res}, β_s, Z_{os} are the same parameters for the slot line, respectively. Y_{patch} is the patch impedance determined at the centre of the slot with the help of the simple transmission-line model. The aperture susceptance Y_{ap} can again be obtained from the transmission-line model of a shorted slot and is given by

$$Y_{ap} = -2jY_{os} \, c0t(\hat{a}_s L_a/2) \quad (3)$$

where Y_{os} is equal to $1/Z_{os}$.

3. GENETIC ALGORITHM-BASED OPTIMISATION FOR IMPEDANCE BANDWIDTH

Concepts of genetic algorithm are applied to study the effect of aperture dimensions and stub length on the voltage-standing wave ratio bandwidth of a simple microstrip patch antenna[6]. Each chromosome

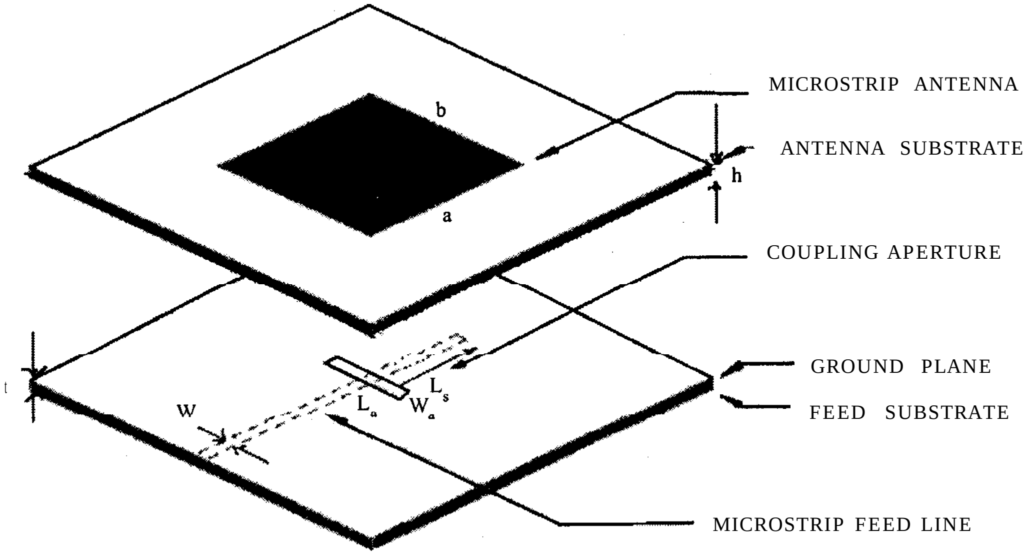

Figure 1. Basic geometry of aperture-coupled antenna

Table 1. Antenna and line substrate parameters

Parameters	Permittivity	Thickness (mm)
Antenna substrate	2.4	1.5
Line substrate	2.4	1.5

consists of three binary encoded genes: One for aperture length, second one for aperture width, and the last one for stub length. For each range of frequency, the patch has been designed using standard design equations[5] which determines its length and width. Hence, aspect ratio of the patch has not been included in the parameter set for genetic algorithm optimisation. Initial process starts with 20 randomly-generated chromosomes to form the initial population. Each gene is binary encoded with 8 bits. Crossover and mutation are performed on the randomly-generated chromosomes based on certain predetermined probabilities to form the next -generation. This procedure is repeated a number of times and the best chromosome evolves through generations, which is chosen based on a fitness function. The fitness function is:

$$\sum_f (Z_{in} - Z_0) / (Z_{in} + Z_0)$$

where summation is taken over the entire frequency range and Z_0 is the characteristics impedance of the line. During decoding of genes, the maximum values chosen for the parameters are:

Maximum value of aperture length = b, maximum value of aperture width = $a/10$, maximum value of stub length = $\lambda_g / 2$, where a is the length of the patch, b is the width of the patch, and λ_g is the guide wavelength. Antenna and line substrate parameters are shown in Table 1.

4. RESULTS & DISCUSSIONS

Table 2 gives the optimised values for aperture dimensions, stub length, and the percentage of fractional VSWR bandwidth for different ranges of frequency obtained theoretically. It is seen from the results that the analysis gives better optimal results for higher frequencies. The 2:1 VSWR bandwidth obtained is maximum (13.2%) for a centre frequency of 17.5 GHz. Figure 2(a) gives the measured reflection coefficient plot for an antenna designed at 9.5 GHz and matched optimally using the results derived in Table 1. The measured result shows that the frequency, at which the reflection coefficient is minimum, is somewhat different from the design frequency of the patch. This shift may be due to fabrication tolerance. Figure 2(b) gives the radiation pattern for the same antenna measured

Table 2. Optimum aperture dimensions, stub length and fractional VSWR bandwidth for different ranges of frequency

Centre frequency (GHz)	Optimum aperture length (normalised to patch width)	Optimum aperture width (normalised to patch length)	Stub length (mm)	VSWR bandwidth (%)
6.5	0.785	0.070	13.200	3.9
7.5	0.784	0.040	11.700	4.6
8.5	0.755	0.170	10.500	5.3
9.5	0.867	0.105	9.460	6.0
10.5	0.995	0.101	8.000	6.8
11.5	0.910	0.075	7.840	7.5
12.5	0.950	0.230	7.200	8.4
13.5	0.940	0.210	6.950	9.3
14.5	0.900	0.010	6.005	10.2
15.5	0.943	0.190	6.000	11.2
16.5	0.991	0.230	6.000	12.1
17.5	0.950	0.250	5.700	13.2

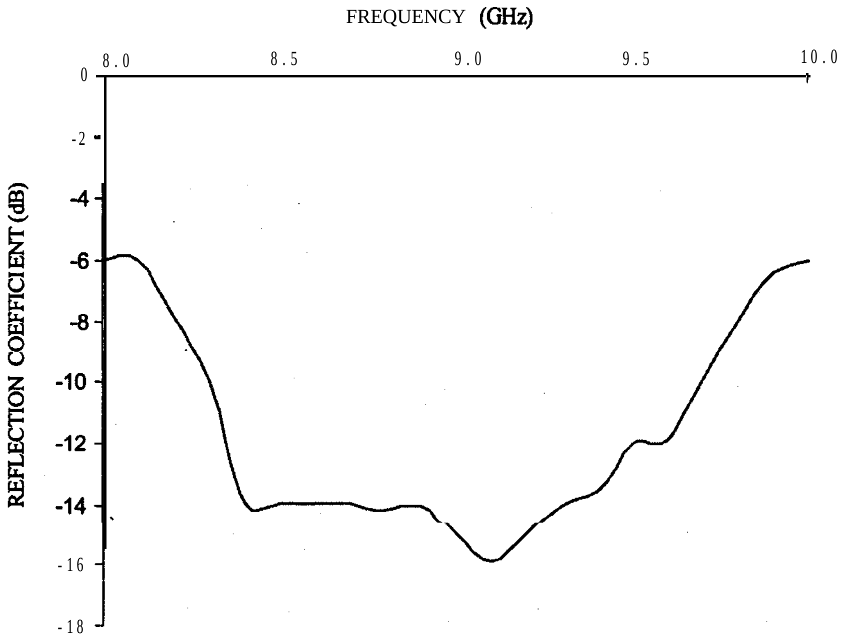

Figure 2(a). Reflection coeffkient versus frequency plot (design frequency of the patch = 9.5 GHz)

at 9.8 GHz. Considering the fact that the radiation pattern has got little variation over the entire band of operation', this has not been repeated at other frequencies. The plots imply that a good amount of matching has been obtained without deteriorating the radiation pattern.

5. CONCLUSIONS

The results obtained show that the application of genetic algorithm for impedance matching of aperture-coupled microstrip antennas is quite promising. From the results obtained for different ranges of frequencies, it can be concluded that with suitable

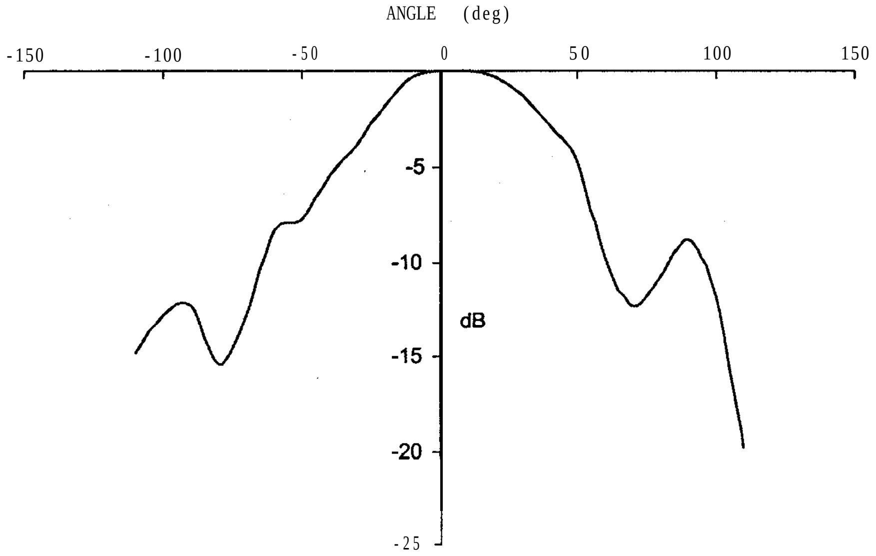

Figure 2(b). Co-polar pattern of the aperture-coupled microstrip antenna measured at 9.8 GHz (cross-polar discrimination = – 20 dB).

aperture dimensions and position, a good matching can be obtained and bandwidth improved considerably without any additional matching network. These results may be advantageous in certain special defence-related applications like MTI radars, weapon guidance systems, mobile-computing links, etc, where a single antenna should operate over a significant range of frequency.

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