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DESIGN AND OPTIMIZATION OF A VIVALDI ANTENNA USING GENETIC ALGORITHM FOR GSM APPLICATIONS

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Abstract

This paper discusses the use of Genetic Algorithm (GA) in designing a Vivaldi antenna optimized for operation at 1.8 GHz, a frequency commonly used in global system for mobile communication (GSM). The proposed antenna was built on a Flame Retardant (FR)-Grade 4 substrate with a dielectric constant (k) of 4.4 and loss tangent is 2 x 10^-3^ at 1.8 GHz. The proposed antenna was optimized for enhanced return loss and gain using a multi-objective function. A hybrid HFSS-MATLAB was used to facilitate iterative GA optimization. Tournament selection, Roulette wheel selection, and Rank-Based selection methods were adopted and compared for efficiency and convergence.

Keywords:

Vivaldi Antenna, GSM, Genetic Algorithm, Tournament Selection, Roulette Wheel Selection, Rank Based Selection

1. INTRODUCTION

GSM band antennas have played a pivotal role in the evolution of cellular networks and have had a profound impact on the way we connect and communicate in today's digital age. Antennas are designed to operate within the specific frequency bands allocated for GSM cellular networks, which include the 900 MHz and 1800 MHz bands in Europe, Asia, and many other parts of the world, and the 850 MHz and 1900 MHz bands in North America [1,2]. The development of GSM technology and its associated antennas marked a significant turning point in the history of telecommunications. GSM networks paved the way for data services. Initially, this was limited to low-speed data (e.g., GPRS and EDGE), but it laid the groundwork for the evolution of mobile data technologies, including 3G, 4G, and 5G [6-11]. GSM band antennas have played a pivotal role in shaping the modern world of telecommunications.

Vivaldi antennas (or slot antennas) are characterized by their distinctive tapered, horn-like shape. This tapering design plays a crucial role in their operation. When RF signals are fed into the wide end of the antenna, they travel along the tapered section, transitioning from a wider aperture to a narrower one. This gradual change in geometry allows the electromagnetic waves to radiate efficiently, leading to enhanced directivity, gain, and a wide operational bandwidth. Unlike many traditional antennas that operate within a limited frequency range, Vivaldi antennas can cover a broad spectrum of frequencies. This wideband capability makes them unique and suitable for applications where a versatile and agile antenna is required [2,3], ranging from radar systems to medical imaging and astronomy.

Antenna design and performance optimization is a critical aspect of modern wireless communication systems and RF engineering techniques help to achieve maximum spectral efficiency, efficient usage of spectrum, higher coverage area, reliable connectivity and enhancing the signal quality by reducing the interferences and signal losses [12]-[17]. This leads to improved voice calls and better data throughput. Optimized antennas can transmit and receive signals without any degradation in signal quality and information losses with less energy consumption for mobile devices and network infrastructure including IoTs. Antenna optimization techniques cut production cost by eliminating the few components such as signal repeaters and boosters. Optimized antennas can also contribute to a more robust and dependable network, reducing the risk of communication failures during emergencies.

GAs is identified as a suitable tool for optimizing wide area electromagnetics and antennas. In this work, three different selection techniques of GA are employed to achieve better return loss characteristics and gain performance of proposed Vivaldi antenna using multi-objective function through a HFSS-MATLAB interfaces. The antenna design is involved in section III, optimization techniques and their performance analysis are discussed in section IV and conclusion remarks are made available in section V.

2. LITERTURE SURVEY

From [2], the proposed antenna is designed in E-type slot spartula-shaped patch antenna at the frequency range of 800 MHz for GSM application, the return loss was obtained 10 dB and gin is greater than 0.9dB. Similarly [3], they designed high gain stacked microstrip patch antenna in the range of 3.9 GHz to 11.04 GHz which is used for UWB radio systems, the return loss was obtained greater -10 dB and gin is greater than 15.18dB.

3. ANTENNA DESIGN

3.1 ANTENNA STRUCTURE

The structure of the Vivaldi antenna was constructed by making a slot in rectangular patch, in which slot is defined by the exponential function as specified in Eq.(1).

$$b(a) = \pm A e^{pa} \tag{1}$$

where a is the width of the patch and b is the exponential curve with respect to a. Therefore $b(a)$ is used for cutting the slot in a rectangular path. From microstrip line theory, the strip width Ws can be computed from Eq.(2) and Eq.(3).

$$\frac{W_s}{h} = \frac{8\exp(H_e)}{\exp(2H_e) - 2} \tag{2}$$

where

$$H_e = \frac{Z_0\sqrt{2(\varepsilon_r + 1)}}{120} + \frac{1}{2}\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left(\ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}\ln\frac{4}{\pi}\right) \tag{3}$$

The design of the proposed Vivaldi antenna selects FR4 as substrate material with the dimension of length is 60 mm and width is130 mm with its thickness of 1 mm. The dielectric constant (k) of the PCB is 4.4 and loss tangent is 2 x 10^{-3} at 1.8 GHz. Later, the copper radiating tapered slot was made by using the formula provided in [2,3]. The width of the tapered radiating patch is also the same as the width of the PCB width and length b= 58 mm. The proposed antenna's back plane features a stub with radius r that is connected to a tapered patch via a lumped port. The various perspectives of the proposed Vivaldi antenna were presented in Fig.1.

3.2 GA BASED OPTIMIZATION OF VIVALDI ANTENNA

The satisfied values of S_{11} and gain (G) are achieved based on appropriate physical dimensions of patch structure. For our proposed antenna, physical dimensions of a patch such as a, b, t, j, M, and k were considered for optimization. These values were adjusted to get better S_{11} and G. For this, Error value (E) was calculated as per Eq.(4).

If $(s_{11})_c > (s_{11})_d$ and $G_d > G_c$

$$E = \sum_{f=f_l}^{f=f_u} \left[(s_{11})_c - (s_{11})_d - (G)_c + (G)_d \right] \quad (4)$$

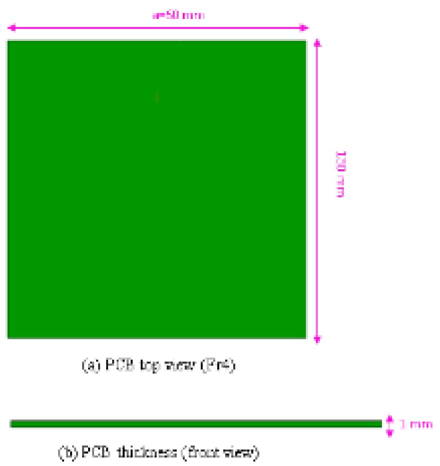
If $(s_{11})_c < (s_{11})_d$ and $G_d < G_c$

$$E = 0 \quad (5)$$

Few parameters such as current return loss $(S_{11})_c$, desired return loss $(S_{11})_d$, current gain (G_c), and desired gain (G_d) were used to calculate E. Additionally lower frequency f_l and upper frequency f_u are also included for E computation. In the proposed design concept, tournament selection, Roulette wheel selection, and Rank-Based selection methods were utilized to pick the best parents' chromosomes from the population set. In our case, desired return loss $(S_{11})_d$ is assumed to be below -10dB and calculated return loss $(S_{11})_c$ is achieved from experimental works.

4. RESULTS AND DISCUSSIONS

After designing the proposed antenna in EM- simulator HFSS (High Frequency Structural Simulation), the HFSS was interfaced with the MATLAB through VB (Visual Basic) script is applied to optimize the impedance matching as per shown in [5].



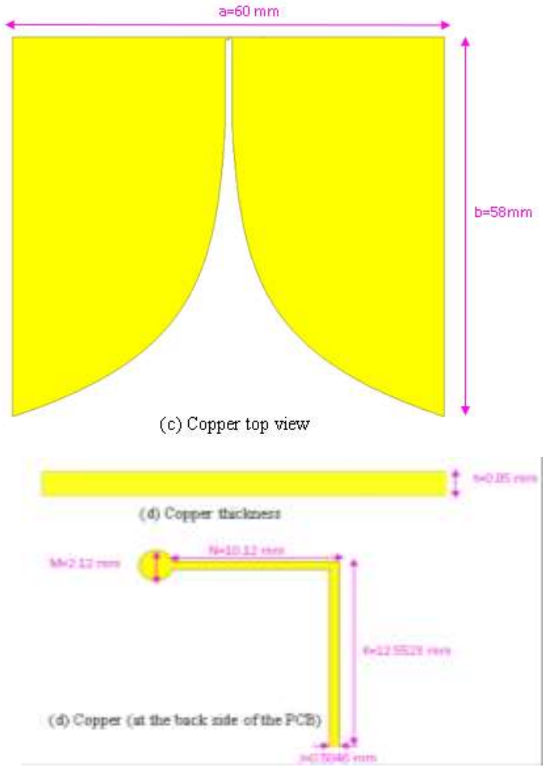


Fig.1. Proposed Vivaldi antenna for GSM applications at 1800 MHz

After successful optimization, the return loss was obtained below -10 dB using tournament selection from 1750 MHz to 1850 MHz presented in Fig.2 (a) and its error is highlighted in Fig.2 (b). From Fig.2(b), shows the error convergence profile where it has been converged to zero at 9th generation. The population size in the proposed design process for tournament selection, roulette wheel selection and rank based selection is fixed to about 30. Hence, the simulation took 9 x 30 = 270 to provide required results and gain is higher than 0.5 dB. Similarly, the return loss was obtained below -10 dB using roulette wheel selection from 1.75 GHz to 1.85 GHz, which is given in Fig.3 (a) and its error in Fig.3 (b). From Fig.3(b), shows the error convergence profile where it has been converged to zero at 9th generation. Hence, the simulation took 15 x 30 =450 to provide the required results with the gain of more than 0.5 dB.

Table.1. Optimized parameter (in mm)

S. No	Variable	P_{min}	P_{max}	GA-1	GA-2	GA-3
1	a	40	70	60	58.76	59.08
2	b	45	65	58	56.98	56.64
3	t	0.01	0.05	0.05	0.0479	0.456
4	j	0.1	1	0.5046	0.3768	0.4987
5	M	1	4	2.12	2.46	2.35
6	k	8	14	12.552	13.08	12.98

Finally, the return loss was obtained below -10 dB using rank-based selection from 1.75 GHz to 1.85 GHz. The return loss and its error are presented in Fig.4 (a) and (b). From Fig.4(b), it shows the error convergence profile where it has been converged to zero at 9th generation. Hence, the simulation took 6 x 30 =180 to provide required results. This part also considered gain to be higher than 0.5 dB. Finally, the gain observed in each selection method was plotted in Fig.5(a), Fig.5(b) and Fig.5(c) respectively. During all the cases of selection method the minimum gain was above 0.5 dB. Finally, the optimized values have been shown in Table.1. In Table. 2, GA-1 corresponds to Tournament selection and Roulette wheel corresponds to GA-2 and GA-3 relates to Rank-Based selection.

Table.2. Performance comparison of GA selection methods

Performance	Tournament Selection	Roulette Wheel Selection	Rank based Selection
Return loss	< -10 dB	< -10 dB	< -10 dB
bandwidth	200 MHZ	200 MHz	200 MHz
gain	> 0.5 dB	>0.5 dB	>0.5 dB
No. of Generation	9	15	6
population size	30	30	30
No. of iterations	270	450	180

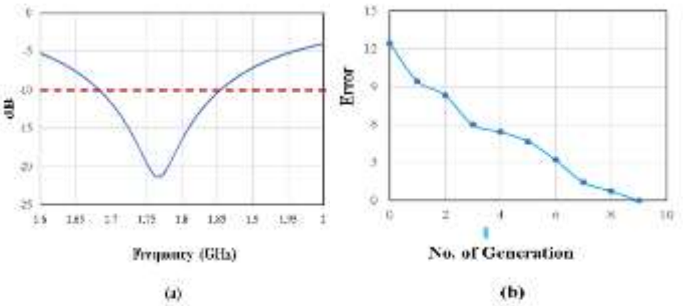


Fig.2. (a) Return loss and (b) error response of the Vivaldi Antenna during tournament selection

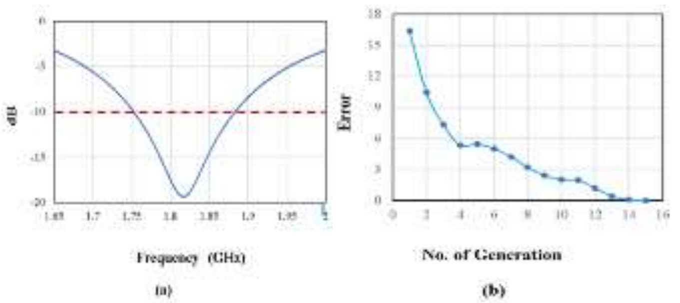


Fig.3 (a) Return loss and (b) error response of the Vivaldi Antenna during roulette wheel selection

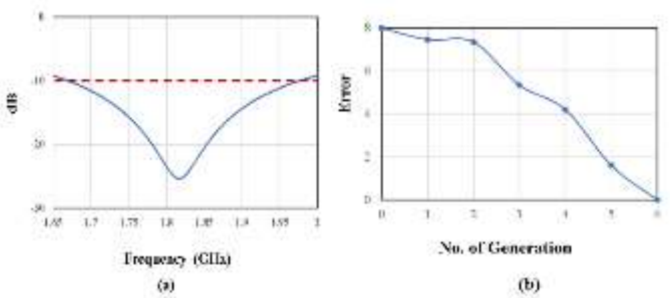


Fig.4. (a) Return loss and (b) error response of the Vivaldi Antenna under rank-based selection

Table.3. Comparison with similar research

	Return Loss (dB)	Bandwidth	Gain (dB)	Loss Tangent	Size (mm)
[2]	10	740 MHz	>0.9	0.02	120 x 120
[3]	< -10	3.06 GHz	15.18	0.008	235.6 x 230 x 9.37
[4]	<-5	2.3 GHz	>1	0.02	38 x 30
[11]	<-5	4.6 GHz	>5	0.025	38.2 x 49 x 0.8
Proposed Work	< -10	1.8 GHz	>0.5	0.002	60 x 130

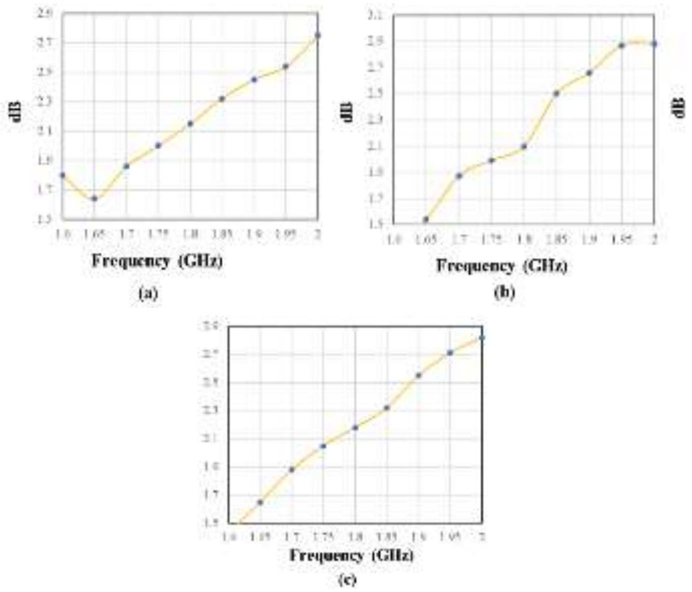


Fig.5. Gain response of the Vivaldi Antenna under (a) Tournament selection (b) Roulette wheel selection and (c) Rank-based selection method

The results achieved based on our experimental works were compared with the existing works and listed in Table.3 [2] [3] [4] [11]. Return loss, Gain and Bandwidth were considered for comparison in Table.3 and it shows that usage of genetic algorithm in our proposed Vivaldi antenna has better performance at 1.8 GHz other than existing antenna.

5. CONCLUSION

This paper demonstrated the usage of GA optimization methods for patch structure in proposed Vivaldi antenna for GSM band applications ranging from 1.75 GHz to 1.85 GHz. Experimental works and analysis show that the Tournament selection method required 270 simulation runs, while the Roulette wheel selection method required 450 iterations. In contrast, the Rank-Based selection method only needed 180 iterations to achieve zero Error function E. In all three selection methods, the objective function and optimization goals remained unchanged. Consequently, the rank-based selection method proved that it is more efficient and required only 180 iterations compared to the other two selection methods. The obtained return loss and gain of designed antenna is below -10 dB and greater than 0.5dB. This finding could potentially serve as a valuable recommendation for future researchers, helping them save time during the optimization of their antenna design.

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