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IMPROVED ADAPTIVE BACTERIA FORAGING ALGORITHM IN OPTIMIZATION OF ANTENNA ARRAY FOR FASTER CONVERGENCE

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Abstract—This paper proposes an improved adaptive approach involving Bacterial Foraging Algorithm (BFA) to optimize both the amplitude and phase of the weights of a linear array of antennas for maximum array factor at any desired direction and nulls in specific directions. The Bacteria Foraging Algorithm is made adaptive using principle of adaptive delta modulation. To show the improvement in making the algorithm adaptive, results for both adaptive and non-adaptive algorithms are given. It is found that Adaptive Bacteria Foraging Algorithm (ABFA) is capable of improving the speed of convergence as well as the precision in the desired result.

1. INTRODUCTION

The placement of radiating elements in space determines the various qualities of radiation such as direction, directivity, beamwidth, energy in main beam etc. These qualities get better and better as we move from single element to linear array to planar array [1]. The radiating system may have its maximum radiation in any direction depending on the relative positions of dipoles (or antenna elements). The requirement is to find suitable excitation weights of antenna elements in space to achieve maximum radiation in any specified direction. The radiated field pattern is very much depended on the excitation to each antenna element. To obtain a desired radiation pattern in a specified direction, it is required the pattern synthesis that determines the parameters of an antenna array. In this age of mobile wireless communication, there are many source of noises to pollute the desired radiation. It is a tremendous challenge to the communication system engineers to provide the radiation beam in the direction of interest nullifying the interference effect thus maximizing signal to noise interference ratio. Null steering is the very common and extensively studied methods for array antenna problem [2–9, 32] controlling either amplitude or phase or both together i.e., complex weights of the antenna excitation.

Soft computing tools like Genetic algorithm (GA) [10–14] and Simulated Annealing [15] have become standard procedures for designing optimized antennas where analytical optimization becomes tough and does not provide satisfactory result. GA ruled several years for antenna optimization problems. But search for new computationally efficient algorithms to handle computationally large and complex problems are continuing. Apart from the modification of GA [16–18, 33], new paradigms have been developed. These are Particle Swarm Optimization (PSO) [19–21, 34, 35], Ant Colony Optimization [22] and Bacteria Foraging Algorithm (BFA) [23–28]. Among them, BFA being the latest trend that is efficient in optimizing parameters of the structures. Nowadays Bacteria Foraging technique is gaining importance in the optimization problems. Because

- Philosophy says, Biology provides highly automated, robust and effective organism
- Search strategy of bacteria is salutary (like common fish) in nature
- Bacteria can sense, decide and act so adopts social foraging (foraging in groups)

Above all Search and optimal foraging decision-making of animals can be used for solving engineering problems. To perform social foraging an animal needs communication capabilities and it gains advantages that can exploit essentially the sensing capabilities of the group, so that the group can gang-up on larger prey, individuals can obtain protection from predators while in a group, and in a certain sense the group can forage a type of collective intelligence.

BFA is based on the foraging behavior of Escherichia Coli (E. Coli) bacteria present in the human intestine [23] and already been in use to many engineering problems including antenna arrays [24–30]. In paper [28], authors have shown the BFA is better than Particle Swarm Algorithm in terms of convergence, robustness and precision. In [29], proposed a hybrid approach involving GA and BFA to tune PID controller (proportional-integral-derivative controller) of an automatic voltage regulator and has shown the efficiency of this approach for global optimization problems. Paper [30] has illustrated the faster settling time and higher robustness with BFA-PID controller. The array antenna optimization technique is used in paper [26] using BFA. This paper also discusses the usefulness of BFA and possible implementation strategy.

In this paper, we have developed an improved Adaptive BFA (**ABFA**) that shows the faster convergence compared to normal BFA.

2. BRIEF REVIEW OF BACTERIA FORAGING OPTIMIZATION TECHNIQUE

The details of BFA are given in [26, 27]. We follow the foraging technique of a group of bacteria as given in [25]. A group of bacteria move in search of food and away from noxious elements — A biological method known as foraging. All bacteria try to move upward the food concentration gradient individually. At the initial location they measure the food concentration and then tumble to take a random direction and swim for a fixed distance and measure the concentration there. This tumble and swim make one chemotactic step. If the concentration is greater at next location then they take another step in that direction. When concentration at next location is lesser that of previous location they tumble to find another direction and swim in this new direction. This process is carried out up to a certain number of steps, which is limited by the lifetime of the bacteria. At the end of its lifetime the bacteria that have gathered good health that are in better concentration region divide into two cells. Thus in the next reproductive step the next generation of bacteria start from a healthy position. The better half reproduces to generate next generation where as the worse half dies. This reproduction step is also carried out a fixed number of times. In the optimization technique we can take the variable we want to optimize as the location of bacteria in the search plane (the plane where the bacteria can move). The specifications such as number of reproductive steps, number chemotactic steps which are consisted of run (or swim) and tumble, swim length, maximum allowable swims in a particular direction are given for a particular problem then the variable can be optimized using this Bacteria Foraging Optimization technique.

The *E. coli* bacteria that are present in our intestines have a foraging strategy governed by four processes, namely, chemotaxis, swarming, reproduction, and elimination and dispersal [25].

Chemotaxis: This process is achieved through swimming and tumbling. Depending upon the rotation of the flagella in each bacterium, it decides whether it should move in a predefined direction (swimming) or an altogether different direction (tumbling), in the entire lifetime of the bacterium. To represent a tumble, a unit length random direction, $\phi(j)$ say, is generated; this will be used to define the direction of movement after a tumble. In particular,

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\phi(j) \tag{1}$$

where $\theta^i(j,k,l)$ represents the ith bacterium at jth chemotactic kth reproductive, and lth elimination and dispersal step. $C(i)$ is the size of the step taken in the random direction specified by the tumble. "C" is termed as the "run length unit".

Swarming: It is always desired that the bacterium that has searched the optimum path of food should try to attract other bacteria so that they reach the desired place more rapidly. Swarming makes the bacteria congregate into groups and hence move as concentric patterns of groups with high bacterial density. Mathematically, swarming can be represented by

$$\begin{aligned} J_{CC} &= \sum_{i=1}^{S} J_{CC}^{i}\left(\theta, \theta^i(j,k,l)\right) \\ &= \sum_{i=1}^{S}\left[-d_{attract}\exp\left(-\omega_{attract}\sum_{m=1}^{p}\left(\theta_m-\theta_m^i\right)^2\right)\right] + \\ &\quad \sum_{i=1}^{S}\left[h_{repellent}\exp\left(-\omega_{repellent}\sum_{m=1}^{p}\left(\theta_m-\theta_m^i\right)^2\right)\right] \end{aligned} \tag{2}$$

where J_{cc} $(\theta,\ P(j,k,l))$ is the cost function value to be added to the actual cost function to be minimized to present a time varying cost function. "S" is the total number of bacteria. "p" is the number of parameters to be optimized that are present in each bacterium. $d_{attract}$, $\omega_{attract}$, $h_{repelent}$, and $\omega_{repelent}$ are different coefficients that are to be chosen judiciously.

Reproduction: The least healthy bacteria die, and the other healthiest bacteria each split into two bacteria, which are placed in the same location. This makes the population of bacteria constant.

Elimination and Dispersal: It is possible that in the local environment, the life of a population of bacteria changes either gradually by consumption of nutrients or suddenly due to some other influence. Events can kill or disperse all the bacteria in a region. They have the effect of possibly destroying the chemotactic progress, but in contrast, they also assist it, since dispersal may place bacteria near good food sources. Elimination and dispersal helps in reducing the behavior of *stagnation* (i.e., being trapped in a premature solution point or local optima).

3. ADAPTIVE BACTERIA FORAGING ALGORITHM: OUR CONTRIBUTION

Bacteria foraging with fixed step size $C(i)$ suffers from two main problems.

i. If step size is very high then the precision gets low although the bacterium reaches the vicinity of optimum point quickly. It moves around the maxima for the remaining chemotactic steps.
ii. If the step size is very small then it takes many chemotactic steps to reach the optimum point. So the rate of convergence decreases. For small number of iterations it may not reach optimum position.

Hence the step size of each bacterium is the main determining factor for both the speed of convergence and error in final output. So it is desired to control the step size depending on how far the bacteria is from the optimum point. If deviation is very high then the step size must be increased and if the deviation is small in which case the bacterium is close to the optimum point the step size is to be reduced.

Here, we have used the principle of adaptive delta modulation [31] to control the step size. In adaptive delta modulation the error or the deviation between the actual signal and the modulated signal is integrated and the output of the integrator is fed in a voltage controller that controls the step size. The algorithm we have used in the BFA is shown in the following block diagram (Figure 1).

Here, X is the parameter to be optimized to obtain the desired value D. $F(X(i,j))$ denote the cost function of X of ith bacterium in jth chemotactic step. $E(j)$ denotes the deviation from the desired value. $S(i,j)$ is the step size which is modified in each chemotactic step depending on the deviations in the previous steps. The multiplier increases or reduces the step size accordingly. Parameter X for next step is obtained by adding the step size with the previous value.

The proportional adder can be replaced by individual gains in the paths of errors. Here we have taken the deviations in last three chemotactic steps and their sum is multiplied with the previous step size.

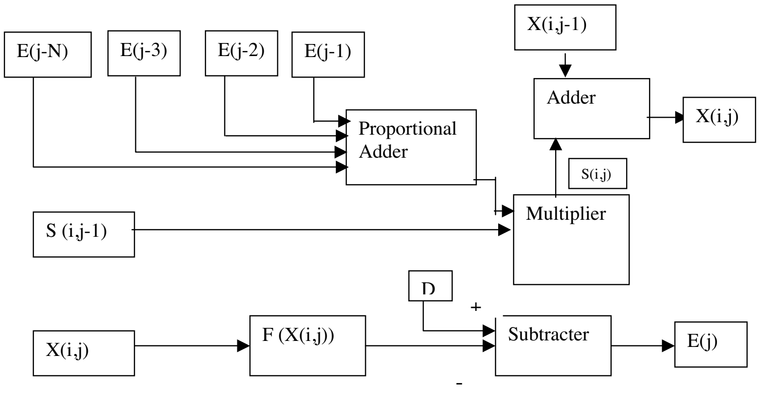

Figure 1. Block diagram for adaptive bacteria foraging algorithm.

We have applied this ABFA in optimizing the antenna array for its maximum value in desired direction and nulls in the directions of undesired signals. For comparison, results for both BFA and ABFA have been provided.

4. PROBLEM STATEMENT

The problem is to optimize the weights of receiving antennas placed 0.5λ apart to obtain array factor maxima in desired direction and placing nulls in the directions of undesired signals as depicted in Figure 2.

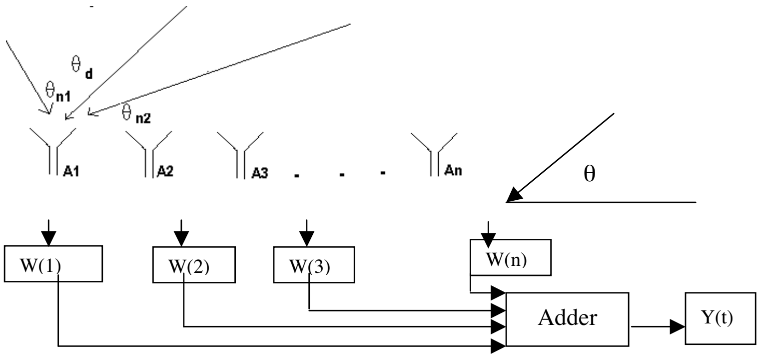

Figure 2. Receiving antenna system in noisy environment.

The weights $W(i)$ are to be controlled to get desired array factor. The angle θ_d is the angle of arrival of the desired signal. θ_{n1} and θ_{n2}

are the two directions from where interfering signals are arriving. In our desired normalized array factor at θ_d is 1 and at θ_{n1} and θ_{n2} is 0. So,

$$AF(\theta_d) - AF(\theta_{n1}) - AF(\theta_{n2}) = 1 \tag{3}$$

We take $AF(\theta_d) - AF(\theta_{n1}) - AF(\theta_{n2})$ as our cost function which is to be maximized to 1 (as the maximum value for normalized array factor need to be 1 in the desired direction and zero value for the undesired direction) in which case we can completely eliminate interfering signal. Here both amplitude and phase of weights are optimized to maximize cost function. Table 1 shows the equivalent terms mapped into BF and Array Antenna and Table 2 is the parameter value for simulation.

Table 1. Equivalent terms used in the bacteria foraging and space antenna array.

Number	Terms in case of bacteria foraging	Equivalent term used in this application
1	Search plane	For each weight complex plane
2	Placement of bacteria in search plane	W(i) for i=1(1)N
3	Food concentration and scarcity of noxious elements (the greater the better)	Array factor for the given weights (the closer to desired the better)
4	Tumble	choosing of random complex number for each weight
5	Swim	Addition of previous weight with step size
6	Chemotactic step	Change in weights of antennas

Table 2. Numerical values for simulation.

Number	Different parameters	Their values
1	Number of bacteria	10
2	Number of allowed chemotactic steps	100
3	Swim length	A+jB where A and B are both random numbers in the range (-S, S) where S is the step size for each weight
4	Number of reproductive steps	2
5	Number of elimination and dispersal steps	2

5. NUMERICAL RESULTS

We have considered a 6 element array antenna. The desired angle of arrival is 120 degree. We consider two interfering signals arriving from

45 degree and 30 degree angle. The array factor is controlled by the weights (both amplitude and phase) to have a maxima in 120 degree and nulls in 30 and 45 degrees using the BFA. Results are presented in this section. Our objective is to get maximum cost function according to Equation (1). The chemotactic steps required to reach the goal is plotted in Figure 3(a) and the array factor after optimization is given in Figure 3(b) when considering the normal BFA [27] having fixed step size = 0.5. Figure 4 is the same representation for step size = 0.1.

A. Using normal Bacteria Foraging algorithm with fixed step size = 0.5.

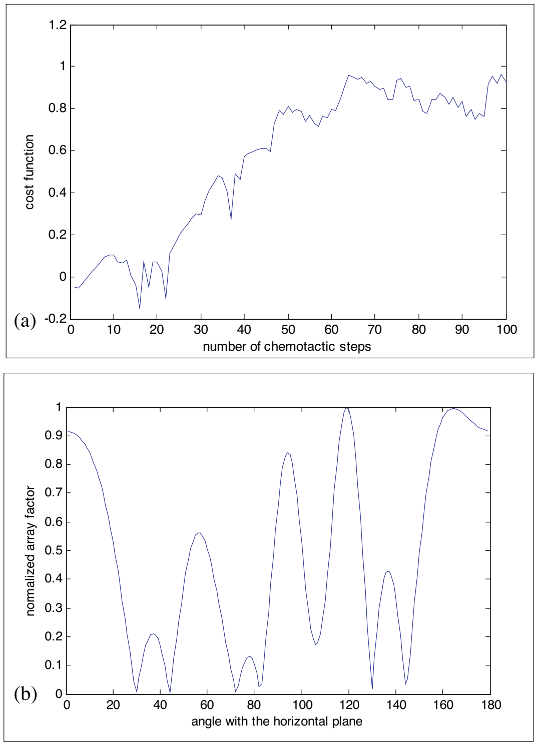

Figure 3. (a) Change in cost function with number of chemotactic steps, (b) normalized array factor with step size 0.5. Obtained cost function = 0.9656.

B. Using normal Bacteria Foraging algorithm with fixed step size = 0.1

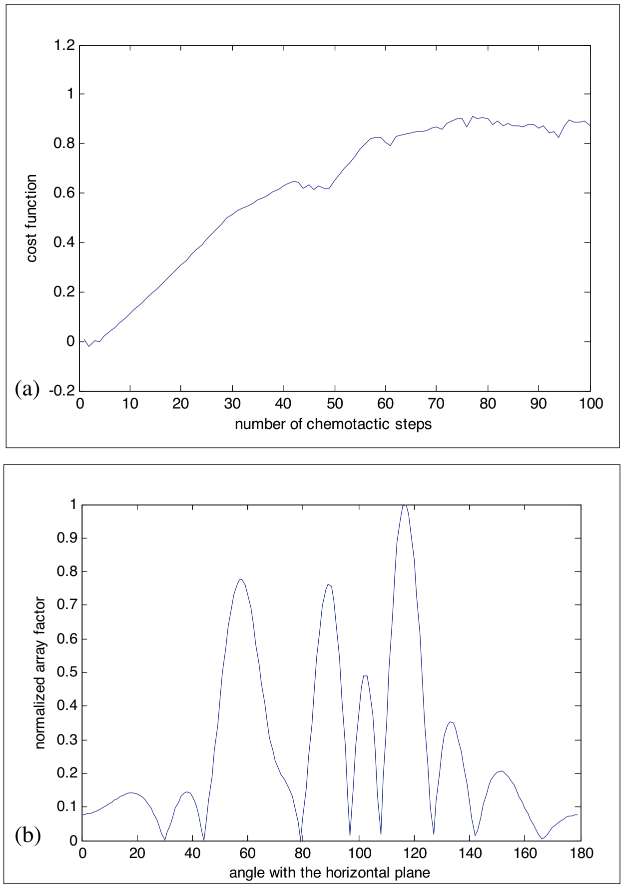

Figure 4. (a) Change in cost function with number of chemotactic steps, (b) normalized array factor with step size 0.1. Obtained cost function = 0.8724.

C. Using proposed adaptive Bacteria Foraging algorithm with varying step size

From Figure 5, it is clearly observed that ABFA shows faster convergence compared to normal BFA. In this particular case, ABFA is almost 5 times faster. Also it can efficiently provide desired result.

D. Adaptive BFA with 3 interfering signals coming from 30 degree, 45 degree and 150 degree with desired signal from 120 degree

Figure 6 is the plot for desired array factor in normalized and logs scale in dB using adaptive BFA. It is clearly observed that apart from

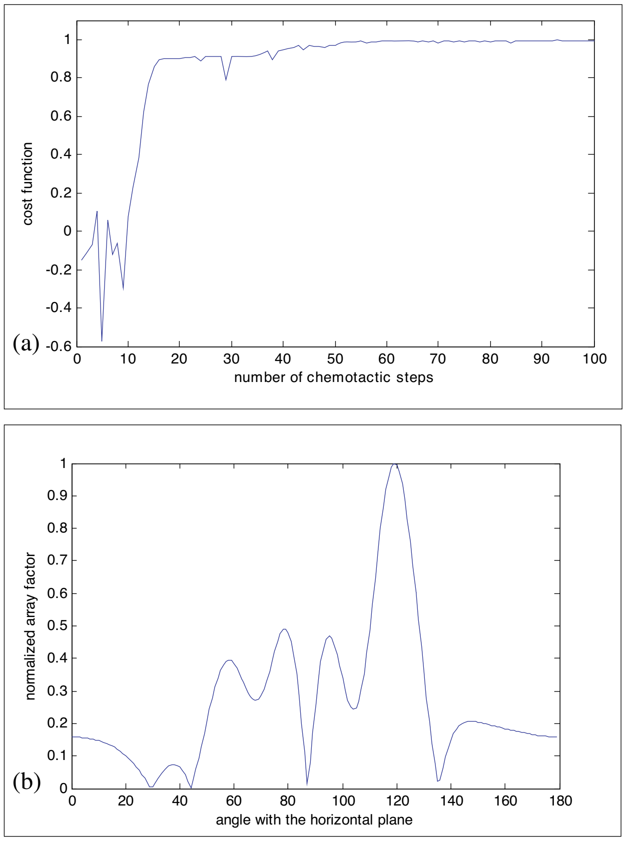

Figure 5. (a) Change in cost function with number of chemotactic steps, (b) normalized array factor with variable step size. Obtained cost function = 0.9954.

the nulls at 30 and 45 degrees, one additional null at 150-degree occurs.

E. Adaptive BFA with four interfering signals at 30, 45, 150 and 60 degrees

Figure 7 is the plot for array factor in dB. The presence of additional null at 60 degree proves that adaptive BFA is efficient enough to nullify nulls in the undesired nulls.

From Figures (3)–(7), it can be observed that adaptive BFA can efficiently provide the desired array patterns whatever may be the direction of noise. With increase number of noise sources, the value of cost function decrease from 0.9954 to 0.9008 using ABFA, which is only 9% error. But, the Array Factor in the desired direction is around

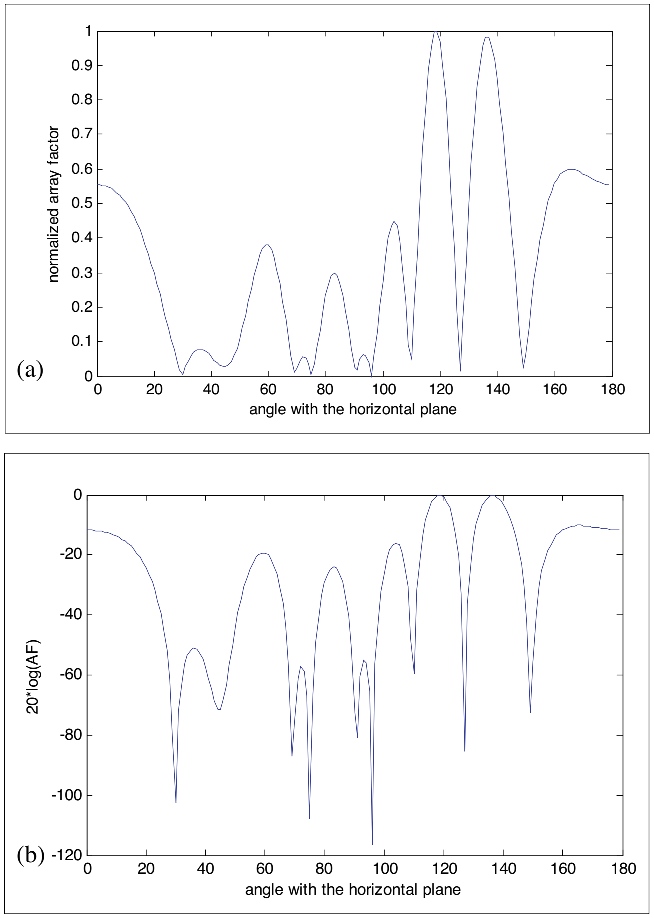

Figure 6. (a) Normalized array factor, (b) array factor expressed in dB for 3 interfering noise signal obtained cost function = 0.9268.

40 dB higher than undesired signal direction. So significant elimination of interfering signals can be achieved even in a very noisy situation. In this optimization we have not considered the condition for side lobe suppression in other direction. That is why in Figure 6 the presence of side lobe near 140° is observed. This could be eliminated by imposing extra constraints on the side lobe suppression.

The simulation time for all of these cases takes less than 1 minute in a simple P4 processor with 512 MB RAM and 1.6 GHz machine under MATLAB 7.0. In the adaptive bacteria foraging algorithm the rate of convergence as well as the precision is better than normal BFA.

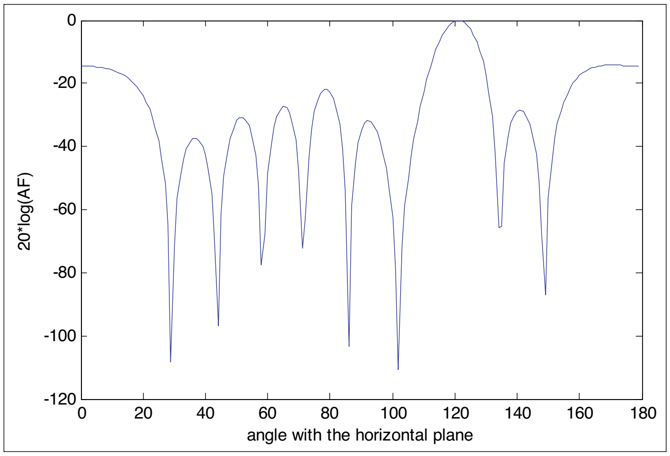

Figure 7. Normalized array factor expressed in dB for four interfering noise signals. Obtained cost function = 0.9008.

So this algorithm can be used less number of chemotactic steps that makes it faster.

6. CONCLUSION

In this paper, null steering in radiation pattern is done using improved Bacteria Foraging Algorithm by controlling both the amplitude and phase of weights. The BFA is made adaptive using the principle of adaptive delta modulation. The results are obtained for 6 element linear array. Results show that the weights are successfully optimized to obtain desired array factor. The proposed ABFA also capable of synthesizing patterns with multiple nulls at any desired direction. This method is very simple and thus can be used in other optimizing problems also. The proposed adaptive BFA may provide faster solution when problem space is large.

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