Design of Ternary Codes for Various Lengths using MSAA

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ABSTRACT
Pulse Compression Sequence is wide utilized inthe field of radar, communication to extend the range resolution. Sequences with good discriminating and merit factor are useful for channel estimation, radar and spread spectrum communication application. Binary sequence has the limitation that the compression ratio is small. Ternary alphabets are suggested as an alternative. The design of ternary codes with good merit factor and discriminating factor can be considered as a nonlinear multivariable mathematical problem which is difficult find a optimal solution. To get the solution for the this problem many global optimization algorithms like Simulated Annealing Algorithm(SA), Genetic Algorithm (GA), Tunneling algorithm (TA) and particle swarm optimization algorithm (PSO) could be used.Further a set of pulse compression sequence are required for spread spectrum and CDMA application such that the individual autocorrelation function of each sequence is like an impulse and the cross correlation between any two sequences in the set must be zero for all lags unfortunately.In this paper, it is proposed to use a new method of algorithm for the design of best ternary codes sets for various lengths by using Modified Simulated Annealing Algorithm. The general features such as global convergence and robustness of the statistical algorithm are revealed.

Keywords
Ternary codes, Pulse Compression Sequence (PCS), Discriminating Factor (DF), Autocorrelation Function, Multivariable Optimization and Modified Simulated Annealing Algorithm (MSAA).

1. INTRODUCTION
The basic purpose of radar is to detect the presence of an object of interest and provide information concerning the object's location, motion, size and other parameters. The first task is called the problem of target detection and the second one is referred to as parameter estimation.

As radar development progressed, and emphasis changed from merely getting things to work, to getting things work in an optimum or near optimum manner, new concepts came into being that laid the foundations of waveform design as an integral part of the radar system development [3].Both the analog and digital pulse compression technologies have been successfully exploited for achieving best results. Range resolution with low probability of intercept can be achieved by employing greater length having good auto correlation and cross correlation properties, synthesis of which is a nonlinear multivariable optimization problem [1]. Various optimization techniques which could be used for this purpose are discussed in this project and a "Modified Simulated Annealing Algorithm" is presented along with the results. The results that are obtained through this algorithm are better. The significance of the project comes from the fact that the algorithm "Modified Simulated Annealing Algorithm" (that converges to global minima without sacrificing the convergence rate) which is used to overcome the problems of the HAS and SA algorithms. This algorithm that synthesizes ternary codes having good auto-correlation properties that can be used in Pulse compression radars to achieve good range resolution. In modern days, military radars are being more and more threatened by electronic counter measure (ECM) and anti-radiation missiles (ARM)[5]. This can be used as a powerful tool to find optimal or near optimal solutions for complex multivariable non linear function. Pulse compression can be defined as a technique that allows radar to utilize a long pulse to achieve large radiated energy but simultaneously obtaining range resolution of short pulse. Theoretically, in pulse compression, the code is modulated on to the pulsed waveform during the transmission. At the receiver, the code is used to combine the signal to achieve a high range resolution [9]. Pulse compression can be clearly understood by this explanation. It is the method of breaking the unwanted constraint between range and resolution. Pulse compression radar transmits a modulated pulse, which is both long having good range characteristics and wideband having good range resolution criterion. The pulse compression becomes attractive when peak power required of short pulse radar can't be achieved with practical transmitter. Since the spectral band width of a pulse is inversely proportional to its width. The bandwidth of short pulse is large .A long pulse can have the same spectral characteristics as a short pulse if the long pulse is modulated in frequency or phase. The received echo signals is processed in a matched filter that compresses long pulse to a width of 1/B where `B' is spectral bandwidth. Thus we achieve a long pulse with large bandwidth. This process is called pulse compression [11].

The applications like radars, communications and system identification square measure in generating the sequences with sensible autocorrelation properties. Polyphase sequence has been suggested by Levanon N [3] which uses in applications like signal processing of sonar and also radar significantly. A very important criterion within the field of signal processing of sonar, system identification and radar has been given by Barker [5]. A problem of optimization for designing of signals for the application of radar sequences like binary, ternary, polyphase and quaternary has viewed and suggested as optimization problem by Griep Karl R John et al [7]. For obtaining good discriminating factor as well as merit factor values work has been carried out extensively. By using shift registers Ipatov [1-2] has designed a large scale of ternary sequences. Ternary sequences of length 2n-1 have been constructed by Shedd and D Sarwatte [4] and Moharir [10] has perfectly given some conditions for the existence of ternary sequences. For generation of ternary codes with good discriminating factor has been given in architecture of VLSI by N Balaji et al [6]. Hoholdt, Tom et al in [8] constructed ternary sequence with periodic autocorrelation.

J.J Blakley, 1998 [9] implemented programmable hardware architecture ternary de Brujin which generates ternary sequences. By considering Hamming scan algorithm Pasha I.A, P. S. Moharir and N. Sudarshan Rao [11] has view that the generation of ternary sequences as a problem of optimization. The technique for the generation of two different lengths of ternary preamble sequences has been proposed by Yuen-Sam [12]. Naga Jyothi.A et al [18] have proposed an efficient VLSI architecture for generation and implementation of the ternary sequences using Finite State Machines (FSM). K Subba Rao and S P Singh [15, 16] combined Hamming scan algorithm with Simulated Annealing algorithm and proposed Modified Simulated. Annealing Algorithm (MSAA) to design binary and thirty – two phase sequences .In this paper, MSAA is used for generating ternary codes with good discriminating factor values.

2. TERNARY SEQUENCE

The ternary sequences are also known as non binary sequences and have the elements of unequal magnitude. Hence they do not have the ideal energy efficiency i.e. their energy efficiency is less than unity. The alphabet of a ternary sequence is [-1, 0, +1]. The ternary alphabet has zero as an element, which implies no transmission during some time slots. It is considered difficult to have on ±off switching at high power in comparison to phase shifting. Binary sequence has a disadvantage that they do not have high merit factor.

Ternary sequence (TSs) eliminates the drawbacks of the binary and polyphase sequences. Generally TSs has good merit factors at all length. Ternary alphabet shares common property of binary and poly phase sequence of peakiness.

$$p = \frac{r(0)}{2\sum_{k=1}^{N-1} |r(k)|} \quad (1)$$

For a sequence of length N=20, the number of search would be only 3^20 as against M^20 where M is generally greater than 4. Hence, the search of ternary sequence is relatively easier than polyphase sequence. The major demerit of TSs is due to inclusion of zero in the alphabet, which is corresponds to a pause in transmission.

The main criteria of goodness of pulse compression sequences or codes are the discriminating factor (DF) and merit factor (MF).The factors DF and MF must be as large as possible for a good sequence or code.

Let S= [x_0, x_1, x_2…x_{N-1}] be a real sequence of length N. Its aperiodic auto correlation is then defined as

$$\gamma(k) = \sum_{i=0}^{N-1-k} x_i x_{i+k} \quad (2)$$

where k=0, 1, 2…N-1. Ideally, the range resolution radar signal should have large auto-correlation for zero shift and zero auto-correlation for non zero shift.

3. DISCRIMINATING FACTOR

The main criteria of goodness of pulse compression sequences or codes are the discrimination factor (DF) and merit factor (MF).The factors DF and MF must be as large as possible for a good sequence or code.

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Where k=0, 1, 2…N-1.

Ideally, the range resolution radar signal should have large auto-correlation for zero shift and zero auto-correlation for non zero shift.The discrimination (DF) is defined as ratio of main peak in autocorrelation to the absolute maximum amplitude among the side lobes.

$$DF = \frac{\gamma(0)}{\underset{k\neq 0}{Max} |\gamma(k)|}. \quad (4)$$

With advent of pulse compression technology the radar system and their application in military and non- military field have undergone a sea change. The trade off between signal transmitted and range resolution was solved and that too without encountering excessively high peak powers; which could cause electrical breakdowns. Both the analog and digital technologies have been successfully exploited for achieving best results. Range resolution with low probability of intercept can be achieved by employing digital phase codes of greater length having good auto correlation and cross correlation properties, synthesis of which is a nonlinear multivariable optimization problem.

4. PROPOSED METHODOLOGY

4.1 Simulated Annealing Algorithm

Simulated annealing (SA) is a generic probabilistic meta-algorithm for the global optimization problem, namely locating a good approximation to the global minimum of a given function in a large search space. It is often used when the search space is discrete (e.g., all tours that visit a given set of cities). For certain problems, simulated annealing may be more effective than exhaustive enumeration — provided that the goal is merely to find an acceptably good solution in a fixed amount of time, rather than the best possible solution.The name and inspiration come from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. The heat causes the atoms to become unstuck from their initial positions (a local minimum of the internal energy) and wander randomly through states of higher energy; the slow cooling gives them more chances of finding configurations with lower internal energy than the initial one.By analogy with this physical process, each step of the SA algorithm replaces the current solution by a random "nearby" solution, chosen with a probability that depends on the difference between the corresponding function values and on a global parameter *T* (called the *temperature*), that is gradually decreased during the process. The dependency is such that the current solution changes almost randomly when *T* is large, but increasingly "downhill" as *T* goes to zero. The allowance for "uphill" moves saves the method from becoming stuck at local minima—which are the bane of greedier methods.The method was independently described by S. Kirkpatrick, C. D. Gelatt and M. P. Vecchi in 1983, and by V. Černý in 1985. The method is an adaptation of the Metropolis-Hastings algorithm, a Monte Carlo method to generate sample states of a thermodynamic system, invented by N. Metropolis et al in 1953.

4.2 Simulated Annealing Algorithm for Design of Ternary Sequences with Good Autocorrelation Properties

The implementation procedure is as follows:

1. An arbitrary code matrix X (0) is chosen as initial sequence set for optimization.

$$X(0)=\begin{bmatrix} x_{0,0} & x_{0,1} & . & . & x_{0,N-1} \\ x_{1,0} & x_{1,1} & . & . & x_{1,N-1} \\ . & . & . & . & . \\ . & . & . & . & . \\ x_{K-1,0} & x_{K-1,1} & . & . & x_{K-1,N-1} \end{bmatrix} \quad (5)$$

Where $X_{(i,j)} \in (-1,0,1) 0 \le i \le K-1$ and $0 \le j \le N-1$

2. T(0) is chosen as initial temperature for annealing. Set the value of i, iterations to be performed at each temperature and the value of ε, lowest possible temperature..
3. In addition the initial energy function value is calculated and designated as E(0).
4. Make a perturbation to the code matrix X(0) by randomly selecting an element X(i , j) from X(0) and changing it to - X(i , j) hence a new code matrix X(1) is generated and the new energy function value is designated as E(1).
5. If the energy is decreased i.e., E(1)<E(0) the new code matrix is accepted.
6. If the energy is increased i.e., E(1)>E(0) the new code matrix is accepted with Probability exp (-ΔE/T).
7. In the same way code matrix perturbation is repeated until the required iterations are Performed at each temperature.
8. Then the temperature is reduced and new equilibrium is setup.
9. Repeat this cooling process until energy function reaches global minimum or the System is frozen (temperature is reduced to the lowest possible temperature.)

4.3 Hamming Scan Algorithm

Hamming scan is a traditional greedy optimization algorithm, which searches in the neighbourhood of the point in all direction to reduce the cost function and has fast convergence rate. The basic difference between GA and HSA is that GA uses random but possibly multiple mutations. The Mutation is a term metaphorically used for a change in an element in the sequence. HAS mutates all the elements in a given sequence one by one and looks at all the first order hamming neighbour of the given sequence .Thus, HAS performs recursively local search among all the hamming -1 neighbours of the sequence and select the one whose objective function is minimum. The concept of HAS has been employed for obtaining the pulse compression sequence of large length with good a periodic autocorrelation properties.

The search time required for HAS increases very fast with length of the sequence as the algorithm performs recursive search among the hamming neighbour of the elements in the sequence.

4.4 Working of Hamming Scan Algorithm

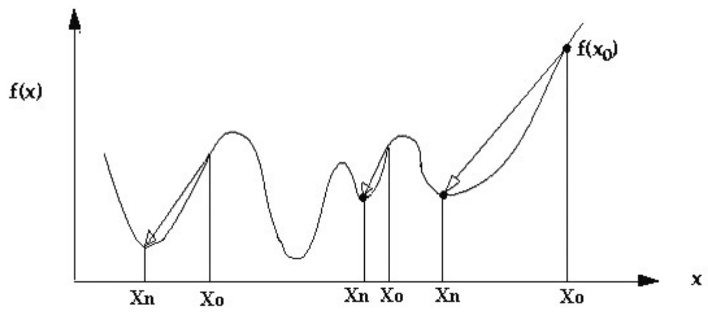

Fig 2. Shows the working of Hamming Scan

Initially the value of the variable X is chosen randomly. Let it be Xo. The cost function value f (Xo) is calculated. A small value Δ is added to Xo to get Xn for which cost function f (Xn) is calculated. If f (Xn) < f (Xo) we replace Xo by Xn and continue this till we reach a point which has the value of the cost function less than its neighbours. If f (Xn)>f (Xo) then we subtract Δ from Xo to get Xn and this procedure is continued until we reach a point which has the value of the cost function less than its neighbours. Thus the Hamming scan finds the minimum which is near to the randomly chosen initial point which is demonstrated in figure 2. In figure 2 it is demonstrated that the value of Xn depends on the value of Xo that is generated initially.As all the minima's are not global minima, the Hamming scan can get stuck in local minima as it makes the comparison only with its nearest neighbors. Therefore the choice of initial point in Hamming scan algorithm is critical.

4.5 Hamming Scan Algorithm to get Ternary Pulse Compression Codes

The Hamming scan is employed for obtaining the pulse compression sequences of larger length with good autocorrelation and cross correlation properties. The basic difference between Genetic algorithm and Hamming scan algorithm is that Genetic algorithm uses random but possibly multiple mutations.

Mutation is a term metaphorically used for a change in an element in the sequence. For example, in the case of binary sequence, a mutation of ternary element implies -1→ +1, -1

→ 0, +1→ 0, +1→ -1, 0 → -1, and 0→ 1. Thus, a single mutation in a sequence results in hamming distance of one from the original sequence. The Hamming scan algorithm mutates all the elements in a given sequence one by one and looks at all the first order hamming neighbors of the given sequence. Thus, Hamming scan performs recursively local search among all the Hamming-1 neighbours of the sequence and selects the one whose objective function value is minimum.

If, it is better than the original sequence, the value of the objective function is increased, the algorithm is recursively continued thereafter, as long as the improvement is possible. Thus, an entirely probabilistic mechanism of mutation is replaced by a locally complete search.The search time required for Hamming scan algorithm increases very fast with the length of the sequence as the algorithm performs recursive search among the Hamming neighbors of the entire elements in the sequence. Thus, the Hamming scan also became unaffordable at larger lengths.The Hamming scan is expedited and hence made applicable at larger lengths, by not calculating the aperiodic autocorrelation of Hamming neighbors initially, recognizing the fact that as only one element is mutated in the sequence, only its different contributions need to be taken into account. Let, the element s_j be changed to c_j in a sequence of N elements. Then, it can be shown that

$\rho^{'}(0) = \rho(0) + (c_j^2 - s_j^2)$And

$$\rho^{'}(k) = \rho(k) + (c_j - s_j)s_{j+k} + (c_j - s_j)s_{j-k}, \quad (6)$$

where k = 1, 2…N-1

j = 0, 1, 2, .N-1

Where ρ (k) and $\rho^{'}(k)$ are autocorrelation before and after mutation, where k is the lag.

In Equation (6) there are two correlation terms. They have to be implemented with care. One way is to assume that s_p is equal to zero if p is outside (0, 1 ………N-1). Alternatively, the correlation term s_{j-k} $(c_j–s_j)$ is included only for k = 1, 2….N-j-1 and the correlation term s_{j+k} $(c_j–s_j)$ is included only for k = j+1, j+2 ….N-1. This idea is certainly trivial, but it has let to significantly increased efficiency, and hence, to search at larger lengths than would otherwise have been possible.

4.6 Modified Simulated Annealing Algorithm

Modified Simulated Annealing Algorithm is a combination of both Simulated Annealing and Hamming scan algorithm. It excerpts the good methodologies of these algorithms like fast convergence rate of Hamming scan algorithm and Global minima trapping capability of Simulated annealing algorithm to increase the probability of converging to the global minimum point. In this process of combining the properties, the modified Simulated Annealing algorithm overcomes the drawbacks of these algorithms. The loophole in Hamming scan algorithm is that it gets stuck in the local minimum point because it has no way to distinguish between local minimum point and a global minimum point. Hence it is sub-optimal [16]. The drawback in Simulated Annealing is that it has a slow convergence rate because even though it may get closer to the global minimum point it may skip it because of the methodology it employs, generating the sequences randomly and accepting them with probability based on annealing schedule (consisting of initial temperature, the temperature decrement and the stopping criteria) [11].The new modified simulated annealing algorithm overcomes these drawbacks as it makes use of simulated annealing to randomly generate a sequence and then it invokes the Hamming scan to converge to the local minima corresponding to that point. Thus the selection of Simulated Annealing and mutations of Hamming scan work well for this algorithm.

4.7 Working of Modified Simulated Annealing Algorithm

The figure 4 gives us a complete picture about working of the New Modified Simulated Annealing algorithm. The X-axis contains all the possible sequences and the Y-axisrepresents the Cost function.Let us consider that weinitially startfrom a point say ‘A’. Now at this point we invoke the Simulated Annealing for selectionprocedure that is we randomlyselect apoint.

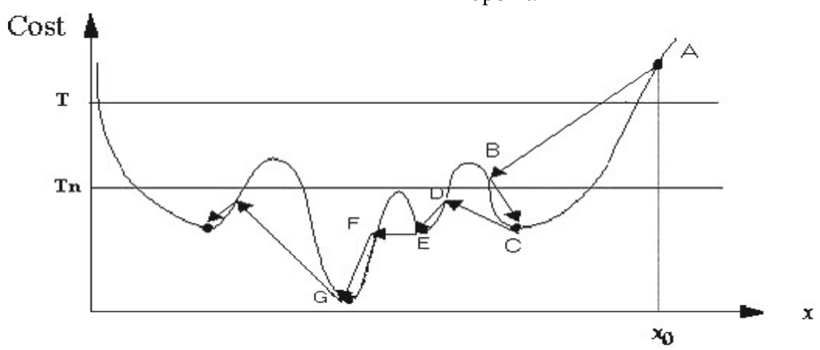

Fig 4. Working of Modified simulated annealing algorithm

Let the new point chosen by this Algorithm be ‘B’. As the selection process is complete it is now time to invoke Hamming scan. Hamming scan ensures that the local minimum is reached which is at point C in the figure 4.This local minimum point is stored. Then again

Simulated Annealing is invoked to get the point ‘D’ even though it is of higher cost because simulated annealing algorithm is a stochastic algorithm which accepts the higher cost function if it lies within certain range of the present cost in the hope that the selected point is in the valley of global minima then the Hamming scan algorithm is invoked for optimization to reach another Local minimum point say ‘E’ which might be global minima because one can find the global minima only after viewing the results of simulation.At each temperature ‘T ’of simulated annealing algorithm, we continue the above process to find out all the local minimum points since the global minimum point is also one of the local minimum points.Thus this algorithm proves to be much more efficient in converging to a global minimum point. Presently the most popular global optimization methods are simulated annealing algorithm, genetic algorithm S-K-H algorithm and

Eugenic algorithm. In this paper algorithm known as "MODIFIED SIMULATED ANNEALING ALGORITHM (MSAA)" is presented .The MSAA is the combination of both SA and HAS .It combines the global methodology of the two algorithms like the global minimum converging property of the SA and fast converging ratio of HSA.MSAA algorithm itself seems to be robust with respect to modifications of choice of energy function, perturbation pattern and annealing schedule as long as they stay stable. This algorithm is relatively simple to implement and efficiently applicable to the synthesis of pulse compression codes.

5. RESULTS AND DISCUSSION

Various pairs of ternary sequences of different lengths having good autocorrelation properties which have been obtained using optimization techniques are given in this section.Ternary sequences are designed using the MSAA. The length of the sequence, N,is varied from 5 to 250. The cost function for the optimization is based on

$$DF = \frac{\gamma(0)}{\underset{k\neq 0}{\mathrm{Max}} |\gamma(k)|} \qquad (7)$$

Below Table 1 shows the synthesized results in Matlab. In column 2 and 5 show sequence length, N, column 3 and 6 show Discrimination factor (DF). From sequences of length from 5 to 250, the correlation properties are good. It may be observed that as the length, N, increases, the DF also increases, which is the conformity with other findings.

Table 1

S.No	Sequence	DF	S.No	Sequence	DF
(1)	**Length N (2)**	**(3)**	**(4)**	**Length N (5)**	**(6)**
1	5	5	37	105	15.8571
2	10	9	38	110	13.8333
3	12	12	39	120	13.8571
4	13	13.0000	40	130	15.8571
5	15	14.0000	41	140	14.3333
6	16	16.0000	42	150	16.8571
7	19	15.0000	43	160	15.8000
8	20	16.0000	44	175	15.8571
9	22	18.0000	45	180	16.5714
10	25	14.0000	46	190	16.1667
11	30	14.5000	47	195	17.0000
12	33	15.0000	48	200	18.3000
13	35	14.6667	49	210	18.0000
14	41	14.7500	50	215	19.6667
15	45	14.0000	51	220	21.0000
16	50	14.3333	52	225	19.8571
17	53	14.3333	53	230	21.5000
18	55	15.8571	54	235	22.0000
19	57	14.6667	55	240	20.5000
20	59	16.1667	56	245	23.5000
36	100	14.1665	57	250	26.0000

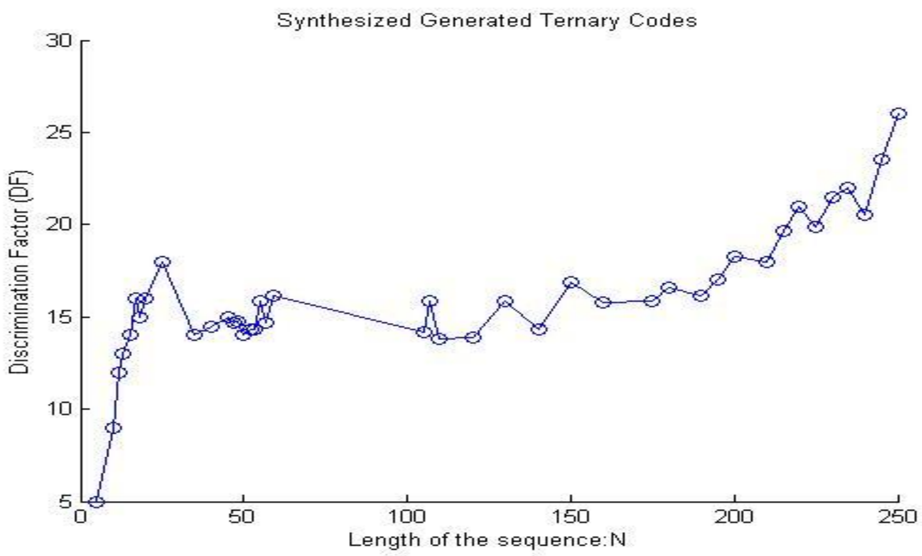

Fig 5 Shows the Synthesized generated ternary codes

6. CONCLUSION

A novel methodology based on Modified simulated annealing algorithm was proposed in this paper to generate ternary codes for various lengths with good discriminating factor value. Hamming scan has a fast convergence rate but it suffers from the disadvantage that it gets stuck in a local minimum.Simulated Annealing is a statistical computational technique which is an effective tool in the design of ternary sequences of specific characteristics. The general features of this statistical optimization algorithm such as global convergence and robustness are revealed in sequence set design. The disadvantage of Simulated Annealing algorithm is a large consumption of CPU time and also formulation of effective annealing schedule. By observing the results we conclude that the full potential of this algorithm is not explored in this design and better results may be obtained through critical choice of control parameters.The New Modified simulated annealing algorithm overcomes these disadvantages and proved to be more effective in synthesizing ternary codes having good auto correlation and cross correlation properties. Results obtained by using this algorithm are better than the results existing in the literature**.** This algorithm may also be employed to synthesize polyphase radar pulse compression codes also. In the future, this algorithm can also be designed such that it makes use of the selection procedure of Hamming scan and mutations of Simulated Annealing. The usage of the algorithm towards the synthesis of good ternary codes for pulse compression radar but it can also be used in different fields to find out a solution to many optimization problems like Traveling sales man problem, placement and layout problems in VLSI design and in image processing techniques.

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