Automatic Impedance Matching and Antenna Tuning Using Particle Swarm Optimization

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Abstract

LC π-network is used as impedance matching network between transceiver and antenna in order to transmit the maximum power to the antenna to achieve maximum transmission efficiency. Particle Swarm Optimization (PSO) is implemented for automatic impedance matching and antenna tuning. PSO works by having a population (swarm) of candidate solutions (particles) and find a global best value by using an appropriate fitness function. It improves the performance of the impedance matching network, to reduce a transmission loss between the transceiver and antenna and achieve fast convergence.

Key words: matching network, Particle Swarm Optimization (PSO), fitness function.

I.INTRODUCTION

Antenna is a metallic device used for radiating or receiving radio waves. It is regarded as a transition between the free space and a system used for launching electromagnetic waves. It is a matching device between free space and wave launching system. Important parameters of antenna include efficiency, radiation pattern and feed-point impedance. In most of the wireless communication systems, same antenna can be used for both transmission as well as reception. From the transceiver designer's point of view, feed-point impedance is the most important antenna parameter.

Nowadays, antennas used in wireless communication operate in the ultra high frequency range and sizes of these antennas are small. Although these antennas can be designed with achievable performance, which results in feed-point impedance varies from the values that is optimum for good power amplifier efficiency or low noise amplifier performance. So, passive impedance matching network is introduced between the antenna and transceiver. Impedance of the antennas varies with frequency and environmental effects. As a result, this matching network is not suitable for matching. Tunable impedance matching network between transceiver and the antenna is used for perfect matching, which is capable of adjusting the changes in antenna impedance over frequency or environmental effects. A low pass LC networks with antenna tuners are used to achieve larger capacitance and inductance at low frequencies. In 4G wireless communication, integrated on-chip matching networks have been used to produce the smaller components required in integrated form.

To deliver power to an antenna from transceiver, the impedance of the radio and transmission line must be well matched to the antenna's impedance. By the use of discrete tuning, impedance characteristics of the matching network is complex and problem of tuning will occur. To overcome this, continuous tuning is used to tune the antenna.

Quantum genetic algorithm (QGA) generates solution to optimization problems by means of mutation, selection and crossover. It also has some limits, such as it takes longer running time on the computer, it needs large storage space, there is no absolute assurance that to find a global optimum and Control in real times are limited.

The proposed system of this paper is Particle swarm optimization (PSO) is a population based stochastic optimization technique and it provides a population-based search procedure.PSO optimizes a problem by having particles. Then moving these particles around search space according to mathematical formulae over the particles position and velocity. Each particle movement is influenced by its local best known positions and guided toward the best known position in search space, which are updated as better positions by other particles. It has no assumption about the problem being optimized and search very large spaces of candidate solutions.

In PSO algorithm, selection of parameters gives good performance such as capacitances and inductance. The system is initialized with a population of random solutions and searches for optima by updating generation.

II.RELATED WORKS

Sun,Y, et al. [1], they have discussed the impedance matching and antenna tuning in wireless communication systems. They proposed the automatic antenna tuning for modern and future generation mobile communications. They have also discussed the fast tuning algorithm and programmable matching systems. Tuning algorithm is designed to achieve perfect impedance matching, while requiring simple impedance sensors and minimizing the number of iterations needed to complete the tuning process.

Ida,I, et al. [3], they have proposed an adaptive antenna impedance matching system for mobile communication terminals. The system controls the pi-network matching circuit detecting the change in the refection coefficient between the antennas combined with the matching circuit. They have discussed the performance of the adaptive impedance matching system. They were able to increase the input power to the antenna for transmission can be about 2 – 3dB per second.

De Jongh, M.A., et al. [9], they have proposed a technique for adaptive control of impedance-matching *L* networks. This technique provides an automatic compensation of antenna mismatch. They have also proposed a cascade of two control loops for independent control of the real and imaginary parts of impedance. They have discussed about control of the real part of impedance and the secondary feedback path. They were able to realize the capacitor tuning ranges with RF-MEMS switched-capacitor arrays.

James Kennedy and Russell Eberhart,. [10], they have proposed a concept for the optimization of nonlinear functions using particle swarm methodology. They have discussed about the evolution of several paradigms and an implementation of one of the paradigms. They were able to prove that the pbest and gbest is similar to the crossover operation.

Qinghai Bai, [11], they have discussed the principle of PSO and their advantages and disadvantages. Particle swarm optimization is a heuristic global optimization method and also an optimization algorithm. They have also discussed about the improved version of PSO and future research issues.

Tim Hendtlass [14], they have discussed about the fitness estimation method and estimate the reliability of the fitness function. They were able to reduce the number of iterations required for the calculation of fitness function without degrading the pso performance.

III.AUTOMATIC ANTENNA TUNING SYSTEM

In the operating frequency range, the transformation of possible range of antenna impedance values to the closed values of transmitter impedance is done by automatic antenna tuning unit. The AATU has a transmitter, a tunable matching network, an impedance sensor, control system and receiving antenna.

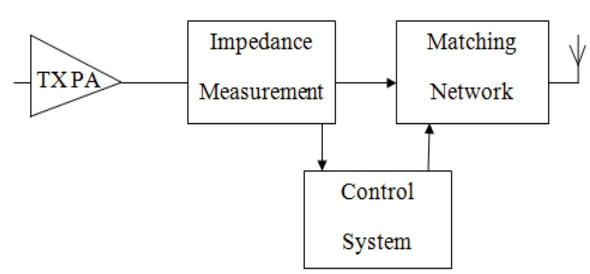


Fig.1 Block Diagram of Antenna Tuning System

Transmitter is a device, which is used to transmit a power to the antenna via transmission line. An impedance sensor is used to measure the impedance of both matching network and control system using tuning algorithm. The function of this system is to adjust the matching network components. Through this optimization of transformed impedance can be achieved. The system responds to antenna impedance variations, due to the changes in operating frequency and with environmental changes.

In 4G wireless communication, research about impedance matching and antenna tuning has been under the process from HF/VHF (3G) to UHF and GHz frequencies. In HF/VHF, electo mechanical tuning and discrete components are used where in UHF, integrated devices are used for impedance matching and antenna tuning.

In wireless system, On-chip antenna tuning is not widely used for continuous tuning. While designing the low pass matching network, fabrication of high-Q inductive and capacitive components and achievement of adequate power handling are difficult. The main objective of the tuning algorithm is to achieve best impedance matching by using the components of Automatic Antenna Tuning system. Tuning process is done by minimizing the number of needed iterations.

IV.IMPEDANCE MATCHING NETWORK

In antenna tuning, impedance matching network is implemented for a radio antenna transmission system in order to achieve maximum transmission efficiency it transmit maximum power to the antenna. Antenna impedance is the complex function of the frequency of operation and environmental factors. Since the impedance matching network should be adjustable with perfect matching capacity. The matching process can be achieved by controlling the matching network process frequently.

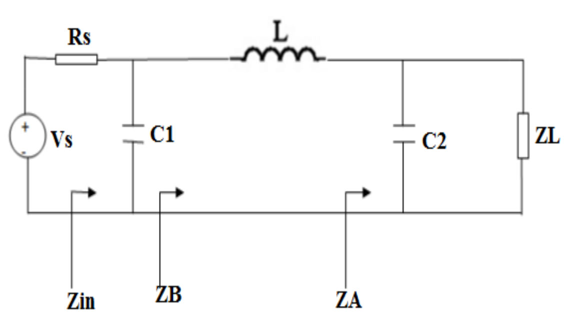


Fig.2 π Impedance Matching Network

This diagram shows the π impedance matching network between the antenna and transceiver. This is the important matching network because it has simple structure, wide range of allowable load impedances and harmonic rejection capabilities.

Where, R_S is the transmitter's source impedance, Z_L is the complex load impedance, Z_{in} is the source input impedance and Z_A, Z_B and Z_C are the impedances of the matching network.

Impedances Z_A, Z_B can be written as,

$$Z_A=Z_L/1+jwC_2Z_L \qquad (1)$$

$$Z_B=Z_A+j\ (X_A+WL) \qquad (2)$$

Input impedance can be written as,

$$Z_{in}=Z_A/1+jwC_1Z_B \qquad (3)$$

Reflection coefficient at source,

$$\Gamma_S=Z_{in}-R_S/Z_{in}+R_S \qquad (4)$$

Voltage standing wave ratio is,

$$VSWR=(1+|\Gamma_S|)/(1-|\Gamma_S|) \qquad (5)$$

In order to achieve perfect impedance matching, Input impedance should be equal to the source resistance, Reflection coefficient must be equal to zero and VSWR should be equal to one.

V.PSO ALGORITHM:

In any mobile communication, it is necessary to achieve fast tuning for its changing loads and environmental reasons. When a large number of matching network combination exists or restrictions applied over the time available for tuning, the tuning algorithms are used to minimize the number of matching network combinations that need to be tested.

PSO is an algorithm which is capable of optimizing a non linear and multidimensional problem while requiring minimal optimization it reaches good solutions efficiently. The basic concept of the algorithm is to create a swarm of particles, which moves around the search space searching for their goal, the place which best suits their needs given by a fitness function. In nature, a bird flock flies in its environment looking for the best place to rest. The best place is a combination of characteristics like space for all the flock, food access, water access or any other relevant characteristics.

5.1 Global Best:

In GBest, all the particles are connected and share the information between them, any particle knows what is the best position ever visited by any other particle in the swarm. Regarding position, all the particles in the swarm are positioned in the n-dimensional space by distributing them within the problem domain, two common ways to do it such as random or uniform position. The velocity is usually set to a random value but lower ones are more adequate to avoid large initial offsets. Since the social and cognitive component values are constant throughout the optimization process, they are determined at the initialization time. It has some advantages such as; it finds the solution more quickly and more susceptible to local minima and also it have some draw backs such as, it is best when fitness close to best solution and has worse search space convergence.

5.2 Local Best:

In LBest, variation reduces the sharing of information between particles to a smaller neighborhood. Instead of each particle knowing the global best value, the swarm is divided into neighborhoods where the particles only share their best value with their neighbors. These neighborhoods are overlap to enable convergence to the global best. It has some advantages such as, it has higher probability that the best solution to be found and has better coverage of the search space. It also has some limitations such as; it needs more iteration to converge, slower to converge on a solution and less susceptible to local minima.

5.3 Fitness Function and Its Evaluation:

In order to evaluate the performance of the PSO algorithm fitness function is used. The fitness function used in this algorithm is a Rosenbrock fitness function.

The function is defined as,

$$f(x) = \sum_{i}^{n-1} 100(x_{i+1} - x_i^2)^2 + (1 - x_i)^2 \quad (6)$$

The value of the global minimum of the function is 0. Searched area is -2 up to +2. Since this function has gradual descent, the gradient method with suitable gain coefficient will easily find the global minimum. In this function, the momentum accelerates moving speed and plural particles will be able to find the global minimum efficiently.

Let the fitness of the current and the best chromosome be $f(x_i)$ and f(xbest), where xbest is the ith bit of the chromosome. Xbest is obtained by,

$$f(xbest) = \max[f(x_1), f(x_2), , , , f(x_n)] \quad (7)$$

The π network population is calculated by,

$$f(C1,C2,L) = \left| Z_{in} - R_s \right|^2 + \left| \Gamma_s \right| \quad (8)$$

where, Z_{in} is the input impedance of the population and Γ_s is the reflection coefficient at source. The purpose of tuning is to find a set of C1, C2 and L values to meet the ideal matching conditions.

5.4 Algorithm steps:

STEP 1: Initialization

The velocity and position of all particles are randomly set to within pre-defined ranges.

STEP 2: Velocity Updation

At each iteration, the velocities of all particles are updated according to,

$$v = v + c_1 * rand * (pBest - p) + c_2 * rand * (gBest - p) \quad (9)$$

where,

p: particle's position
v: particle's velocity
c_1: capacitor-1
c_2: capacitor-2
pBest: best position of the particle
gBest: best position of the swarm
rand: random variable

In the above equation, first term indicates the inertia which makes the particle move in the same direction and with the same velocity. Second term indicates personal influence ,which improves the individualand makes the particle return to a previous position better than the current, and its also conservative. Third term indicates social influence, makes the particle follow the best neighbors direction. Intensification explores the previous solutions, finds the best solution of a given region and diversification searches new solutions, finds the regions with potentially the best solutions.

STEP 3:Position Updation

Assuming a unit time interval between successive iterations, the positions of all particles are updated according to,

$$p_i = p + v \qquad (10)$$

After updating, p should be checked and limited to the allowed range.

STEP 4:Memory Updation

Update pBest and gBest, when condition is met.

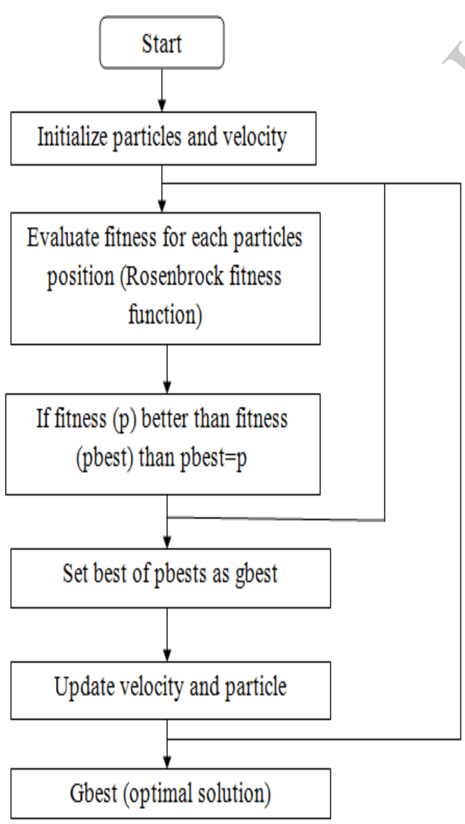
$$pBest=p \quad \text{if } f(p)>f(pBest) \qquad (11)$$
$$gBest=g \quad \text{if } f(g)>f(gBest) \qquad (12)$$

where, f(x) is the objective function subject to maximization.

STEP 5:Termination Checking

The algorithm repeats steps 2 to 4 until certain termination conditions are met, such as a pre-defined number of iterations or a failure to make progress for a certain number of iterations. Once terminated, the algorithm reports the values of gBest and f(gBest) as its solution.

5.5 Flow Chart:



VI.RESULTS AND DISCUSSION:

Proposed design of automatic impedance matching and tuning of antenna using Particle Swarm Optimization (PSO) has been simulated using MATLAB version 7.8.0 (R2009a). It shows results for reducing the transmission loss between transceiver and antenna, and also minimizing the number of iterations needed to complete the tuning process.

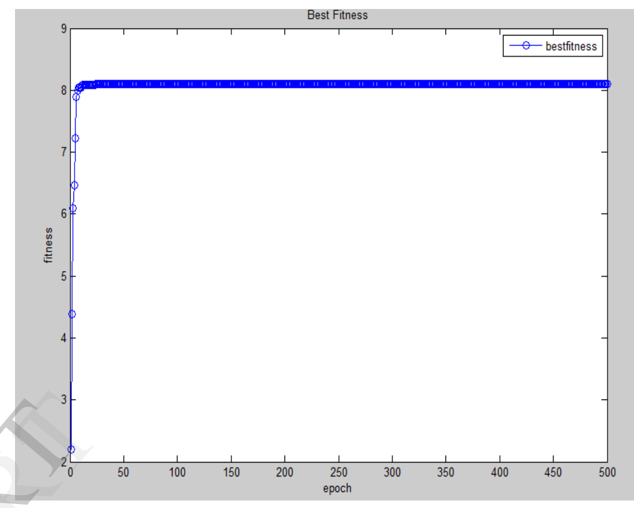


Fig.3 Best Fitness of the PSO for 2.4 GHz

This curve is for a source resistance of 50 ohm, load impedance of 20+j30 ohm, signal frequency of 2.4 GHz and signal amplitude of 1V.

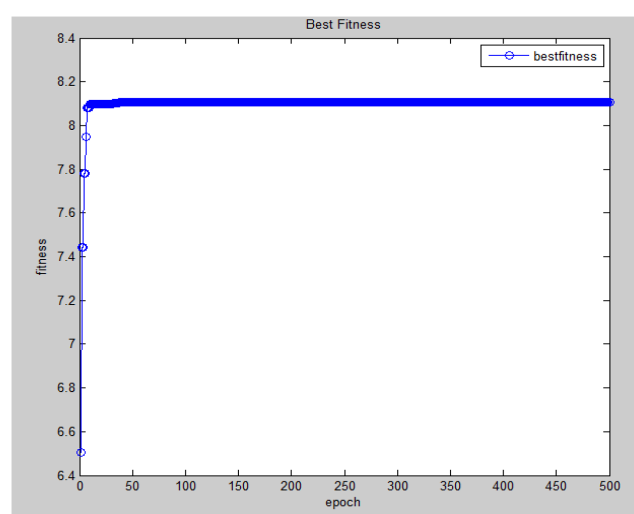


Fig.4 Best Fitness of the PSO for 1.8 GHz

This curve is for a source resistance of 50 ohm, load impedance of 20+j30 ohm, signal frequency of 1.8 GHz and signal amplitude of 1V.

Frequency	Z_L (ohm)	Train epochs	VSWR
2.4 GHz	20+j30 200 50-j75 50+j75	28 78 45 118	1.0142 1.0023 1.0142 1.0142
1.8 GHz	20+j30 200 50-j75 50+j75	68 76 89 122	1.0332 1.0049 1.0173 1.0173

Table.1 Simulation Results of PSO Tuning Method

This table shows the accuracy of the matching network and is obtained from PSO implementation. The results from the proposed algorithm converge to its balance points in a short time. Accuracy varies with the predefined error. For a larger predefined error, the result in a larger VSWR value and it will take shorter time to converge. Generally, a match with a VSWR is less than 1.5 is good for mobile radio transmission systems.

CONCLUSION

The PSO tuning method is able to tune the changes of the network in both antenna impedance and operation frequency. For a wide band radio frequency, by using this method, frequencies used in the band are sweep one by one to ensure that the matching is achieved at every radio frequency in the band accuracy. This tuning algorithm can find a set of inductance and capacitances values for each frequency. This tuning method is normally used in HF/VHF antenna tuning system. This algorithm has been simulated using two different frequencies of 2.4 GHz and 1.8 GHz of mobile and wireless communication. This method is a guaranteed scheme for real time antenna adaptive tuning. Fast convergence can also be achieved by using this method.

FUTURE WORK:

Adaptive Quantum Particle Swarm Optimization (AQPSO) can be used as a modification to PSO in the system with automatic impedance matching and antenna tuning. For the system with PSO, works on a population (particles) and find global best using appropriate fitness function. But in case of system with AQPSO, it combines the optimizations of an improved adaptive PSO (APSO) with a quantum Particle Swarm Optimization (QPSO). AQPSO evaluate the fitness for each particle to get values of pbest and gbest and gives the good accuracy of input impedance matching.

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