A Particle Swarm Optimization for Terminal Resistor Matching

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Abstract

The CAN bus is widely used in the industrial field and its terminal resistance has an important influence on the bus signal. In this paper, a particle swarm optimization based on the joint simulation of Saber and MATLAB is proposed to address this problem. First, we transform the terminal resistor matching problem into a minimisation multi-objective optimization problem and formulate the objective function by considering three objectives: bus voltage, rise time and overshoot. Then, we establish a network topology model of CAN bus in Saber, and combine saber and MATLAB. Finally, virtual simulation and physical verification are conducted and the results demonstrate that the optimized terminating resistor has a significant improvement on the signal quality of the bus, and algorithm has engineering applicability.

Keywords: CAN bus; terminal resistor; the joint simulation; particle swarm optimization algorithm;

1. Introduction

The CAN bus, also known as the Controller Area Network, is a serial communication bus. The CAN bus has the advantages of advanced technology, high reliability, strong immunity to electromagnetic interference, complete functions, and reasonable cost, and is recognized as one of the most promising types of buses [1]. In the signal transmission process, the signal reflection phenomenon and the presence of parasitic capacitance of the wire seriously affect the signal quality of each node of the CAN bus. Therefore, each CAN bus network must match the terminal resistor [2]. The terminal resistor has two roles. One is to make the impedance of the bus continuous, which can reduce the impact of signal reflection on the signal quality; the second is to provide a discharge loop for the parasitic capacitance, which can reduce the influence of parasitic capacitance on the bus signal [3]. Due to the differences in the number of nodes, communication rates, bus cable lengths, transceiver types, and network topology of each CAN network, the optimal terminating resistance of different CAN bus networks varies with different application scenarios. Therefore, in order to ensure the success of communication, a suitable set of matching resistors must be re-selected for each industrial application.

At present, the following methods were adopted in the industrial site. The first method is to use empirical values. This method is the simplest, but the bus has the worst signal quality. In many situations, communication can be reluctant, but the anti-interference ability is poor [4]. When using empirical value bus communication is unsuccessful, the second method is usually used. The second method is to constantly change the terminating resistor value and make multiple attempts until the communication is successful. This method takes time and effort, even if the communication is successful, it can not guarantee that the selected terminal resistance is the optimal or near-optima, and the anti-interference ability is poor [5]. The third method is to use theoretical calculations. This method requires a relatively high level of professional knowledge. It is necessary to establish the equivalent circuit model of the CAN network and solve the model [6,7,8]. This method is time-consuming and laborious, and the calculation result is affected by the accuracy of the model.

Terminal resistor has a very important influence on the bus signal. Ignoring the complex physical relationship between bus signals and terminating resistors, the problem can be seen as a function optimization problem. The terminal resistance is the optimization parameter. There are series of optimization algorithms that have been put forward to solve this type of optimization problem, such as Genetic algorithm [9,10], Ant Colony Algorithm [11,12], Simulated Annealing Algorithm [13,14], Particle Swarm Optimization [15,16], etc. Particle Swarm Optimization is a spatial search algorithm that solves the optimization problem and is very suitable for solving multidimensional problems. It has the advantages of

less iterative steps, fast search speed, simple structure, etc. It is very easy for engineering implementation. The problem of termination resistance matching on the CAN bus is a multidimensional solution problem. Based on the advantages of the particle swarm algorithm described above, it is very suitable to solve the matching problem of terminating resistors using the particle swarm algorithm. However, how to design a particle swarm algorithm and establish an accurate circuit model in a software is still an intractable problem.

In this paper, we present a particle swarm optimization algorithm based on the joint simulation of Saber and MATLAB for terminal resistor matching problem, which aim to find the optimal or near-optimal terminal resistance of CAN bus network quickly and accurately. The fitness function for the multi-objective optimization problem is obtained by weighted sum and technology. Through simulations and experiments, it is found that, under the same conditions, compared with the use of the original empirical resistance value, the best resistance value obtained by using the matching algorithm can make the bus signal the best.

The remainder of this paper is organized as follows. In the next section, the CAN bus circuit model was established in Saber, and Performance Criterions of Bus Signal were developed. In Section 3, we detailed the termination resistor matching algorithm. Subsequently, the results of simulation and experimental verification are presented and discussed in Section 4. Finally, we draw the conclusion of this paper in the section 5.

2. Matching Problems of CAN Bus Termination Resistor

2.1 Establishment of CAN Bus Circuit Model

This paper establishes CAN bus circuit model, and carries on time domain transient simulation in saber to obtain the CAN bus signal waveform. For convenience of modeling simplification, this paper ignores the impact of board design differences on the CAN bus signal. The circuit model of CAN bus is mainly made up of four parts: Controller, transceiver, interface circuit and topological structure. When building a model, these four parts are built according to the actual circuit conditions.

Firstly, for the controller, the parameters to be set are clock frequency and bit time. At the 250 kbit/s communication rate, the controller sets the clock frequency to 4 MHz/s, the bit time setting is tseg1 = 12, tseg2 = 3, brp = 1, and the synchronization jump width SJW = 2 in this paper. Controller circuit model shown in Figure 1. Secondly, for transceiver, this paper uses the transceiver model of TJA1050, as shown in Figure 2.

Moreover, The design of the interface circuit in this paper is shown in the figure 3. The resistor R3 in the interface circuit is one of the terminating resistors to be optimized.
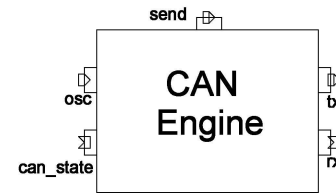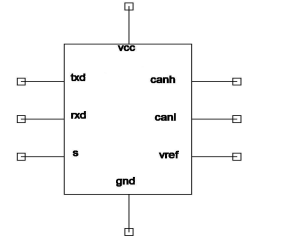

Figure 1 CAN Controller Model
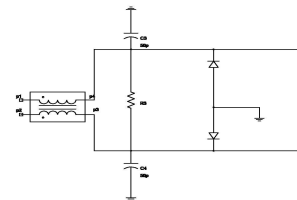

Figure 2 CAN Transceiver Model
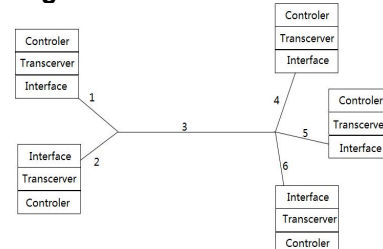

Figure 3 Interface Circuit Model

Figure 4 Bus topology

In addition, the topology used in this paper is a double-star structure often used in automobiles, as shown in the figure 4. Twisted pair is used as cable. In the topology, the lengths of Line 1, Line 2, Line 3, Line 4, Line 5, and Line 6 are: 2 m, 1.7 m, 3 m, 1 m, 2 m, and 5 m.

2.2 Performance Criterions of Bus Signal

The objective of matching terminating resistors is to optimize bus signal quality. This paper pays attention to the dominant/recessive differential voltage, rise time and overshoot for quantifying bus signal quality.

The dominant/recessive differential voltage must comply with the international standards of the CAN bus. That is, the dominant voltage is between 1.5 V and 3 V, ideally 2 V; the recessive voltage is between -0.5 and 0.05, ideally 0 V. Only then can the CAN transceiver recognize the bus signal.

For the dominant stable voltage value, the objective function of this target is defined as

$$f_1 = \frac{|V_h - 2|}{3 - 2} = |V_h - 2| \qquad (1)$$

Where V_h is the dominant stable voltage value. In the case of conforming to international standards, the difference between the actual dominant voltage value and the ideal value does not exceed "3-2 V", ie, 1 V. If the dominant voltage value does not comply with international standards, $f_1 = 1$.

For the recessive stable voltage value, the objective function of this target is defined as

$$f_2 = \frac{|V_l|}{|-0.5 - 0|} = \frac{|V_l|}{0.5} \qquad (2)$$

Where V_l is the recessive stable voltage value. In the case of conforming to international standards, the difference between the actual recessive voltage value and the ideal value does not exceed the absolute value of "-0.5-0 V", ie, 0.5 V. If the recessive voltage value does not comply with international standards, $f_2 = 1$.

The rise time indicates the rapidity of signal response. For the rise time, this paper only cares about the rise time from low voltage to high voltage. The objective function of this target is designed as

$$f_3 = \frac{T_r}{0.3 T_{bit}} \qquad (3)$$

Where T_r is the rise time, T_{bit} is a bit time of CAN bus line. Since the rise time should not be too long, when the rise time is more than 0.3 times the bit time, then make $f_3 = 1$.

Overshoot indicates the stability of signal response. For overshoot, this paper is concerned with both the overshoot of the rising edge and the overshoot of the falling edge, taking the maximum of the two as the objective function. Thus, the objective function of this goal is design as

$$f_4 = \max(\sigma_r, \sigma_d) \qquad (4)$$

Where σ_r is the overshoot of the rising edge and σ_d is the overshoot of the falling edge.

2.3 Objective Function Formulation

There are some contradictions in the performance criterions of bus signal. For example, overshoot and rise time are a pair of contradictions. The reduction in overshoot is often accompanied by an increase in rise time, and the shortening of rise time is often accompanied by an increase in overshoot. Thus, various performance criterions of bus signal should be well balanced to achieve better overall bus signal.

Weighted methods are used in this paper to balance individual various performance criterions of bus signal. First, the various indicators are dimensioned and normalized. The objective function for optimizing bus signal is defined as the weighted combination of various performance criterions, which can be described as

$$f = \lambda_1 f_1 + \lambda_2 f_2 + \lambda_3 f_3 + \lambda_4 f_4 \qquad (5)$$

Where λ_1, λ_2, λ_3, and λ_4 are the weights of the dominant stable voltage, the recessive stable voltage, the rise time, and the overshoot, respectively. After many simulations, these parameters are set to $\lambda_1 = 0.6$, $\lambda_2 = 0.25$, $\lambda_3 = 0.1$, $\lambda_4 = 0.05$.

Accordingly, the Termination resistor matching problem can be formulated as the optimization problem of minimizing the overall objective function f with constraints.

3. Matching algorithm

3.1 The principle of particle swarm optimization

Particle swarm optimization is a global search algorithm based on speed and position. The particles in the population combine their own experience with the experience of other particles in the population. Under the premise of maintaining their own inertia, they appropriately change their speed of movement to conduct a global search to find the optimal solution[17].

The description of the particle swarm optimization algorithm in mathematics is as follows. Assume that the population of particles is composed of m particle individuals. Each particle is searched in a D-dimensional target search space. zi=(zi1, zi2,..., ziD) is the position vector of particle i in D-dimensional space. Where i ranges from 1,2,...,m. Calculate the fitness value of the current position zi according to a preset fitness value function. pi=(pi1, pi2,...,piD) is the optimal position searched for in the D-dimensional search space by particle entity i till now. pg=(pg1, pg2, ..., pgD) is the optimal position for the entire population of particles as of now searched in the D-dimensional search space. vi = (vi1, vi2, ..., viD) is the mid-velocity vector of particle i in D-dimensional space,

representing the flying direction and distance of particle i in D-dimensional space at the moment. Individual particles in the iterative process, through the following formula to update the individual particle speed and position:

$$v_{id}^{k+1} = w * v_{id}^k + c_1 r_1 (p_{id} - z_{id}^k) + c_2 r_2 (p_{gd} - z_{id}^k) \qquad (6)$$

$$z_{id}^{k+1} = z_{id}^k + v_{id}^{k+1} \qquad (7)$$

Where k is the number of iterations, d is the dimension in which w is the inertia weight, which is used to weigh the local optimal ability and global optimal ability. d=1, 2,..., D, c1, and c2 are learning factors, the role of which is to make particle individuals self-summarize and learn from outstanding individuals in the group. r1 and r2 are random numbers in the interval [0,1] to maintain the diversity of particle populations.

In formula (6), the first part is the self-movement state of particle individuals. With time, it uses different weights to adjust the proportion of one's current position. The second part is the particle's own "cognitive" state. Represents the particle's own learning and exploration. The third part is the "society" part, which is the information sharing part of the particle population. It represents the best experience in the individual particle reference particle population to update its speed to find the optimal position as soon as possible. Individual particles will fly to a new location according to formula (7).

3.2 The co-simulation of Saber and MATLAB

Saber and MATLAB have three joint methods: Saber-Simulink co-simulation, simulink model output, and Saberlink simulation result data exchange. The joint method used in this paper is Saberlink simulation result data exchange. Before to co-simulation, it is necessary to configure the Saber software to associate it with MATLAB so that Saber can find relevant paths for MATLAB during co-simulation. In the co-simulation process, the main program is written in Saber and Saber is used to call the functions in MATLAB. To establish co-simulation, two goals must be achieved: Saber's simulation results are passed to MATLAB and optimization results of MATLAB to Saber. In order to achieve these two goals, you need to use Saber's AIM language.

3.3 The implementation steps of the algorithm

The current termination resistance matching method only matches the termination resistance at certain

specific ends of the EUC or certain locations on the bus. The other ECUs directly connect a 1000-ohm resistance or directly float. The method used in this paper can be matched to a reasonable resistance at both ends of each ECU. The number of dimensions of the particle swarm algorithm is equal to the number of terminating resistors that need to be optimized in the actual network topology. Each resistor that needs to be "independently" optimized is a dimension of the particle swarm algorithm. What is meant by a resistor that needs to be "independently" optimized is that its choice of resistance is independent of the resistance of other resistors.

The specific solution process of the algorithm is as follows:

Initialize the algorithm parameters. The learning factor is set to c1=c2=2; the population size is set to 20; the population dimension is set to 5; the upper limit of each dimension is set to 1000; the lower limit is set to 60; the iteration number is set to 1000; and the particle's maximum velocity is 200. In this paper, the variable inertia weight is used, that is, the inertia weight decreases with the number of iterations. Using this kind of linear degressive change weights, in the early stage of the algorithm, there is better global search capability, and in the later stage there is better local search capability, which helps to quickly and accurately find the optimal solution. The formula for calculating inertia weight is designed as:

$$\omega = \omega_{start} - \frac{\omega_{start} - \omega_{end}}{k_{max}} \times k \qquad (8)$$

Where kmax is the maximum number of iterations, k is the current number of iterations, ω_{start} is the starting value of the inertia weight, and ω_{end} is the ending value of the inertia weight.

The position information of each particle was sent from MATLAB to Saber (that is, a set of terminal resistance values was passed to Saber). After Saber modified the resistance value, a simulation was performed to obtain the corresponding waveform data, and the data was passed to MATLAB. MATLAB derives dominant stable voltage values, recessive stable voltage values, rise time and overshoot from these waveform signals. Then, we calculate the fitness value of each particle according to the objective function shown in formula (1) to (4). According to the fitness value, the optimal position and optimal fitness value of the population and particles are updated.

According to the updated information and formula (6) to (7) we update the particle's velocity and position. If velocity or position exceeds the upper and lower limits, the velocity or position is set to the upper or lower limit

value. After the particle gets a new position, MATLAB passes the particle's position information to Saber. Saber gets a new resistance match and then performs a simulation.

Repeat steps 2) ~ 3) above until the maximum number of iterations is reached.

After the optimization is completed, the set of resistance values corresponding to the global optimal particle position is the best termination resistance.

4. Algorithm Simulation and Experimental Verification

4.1 Algorithm Simulation and Experimental Verification

According to the circuit model established in Section 2.1, we perform algorithm simulation. Simulating the CAN network circuit in Saber, and the communication speed is set to 250 kbps, simulation results show that its signal quality is very bad. The simulation waveform is shown as in Figure 5. We match the optimal termination resistance according to the matching algorithm. The result is that the matching resistors of EUC on the No. 1, No. 2, No. 4, No. 5, and No. 6 feeders are 820, 150, 390, 402, and 150 Ohm respectively. According to the optimized terminal resistance value, take the approximate value according to the resistance specification on the market and reconfigure the five-node circuit simulation parameters. The simulated differential signal waveform is shown in Figure 6. Before and after the termination resistance is optimized, the bus signal is compared as shown in the Figure 8.
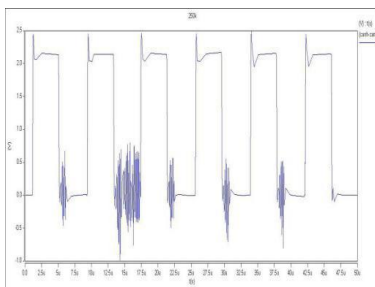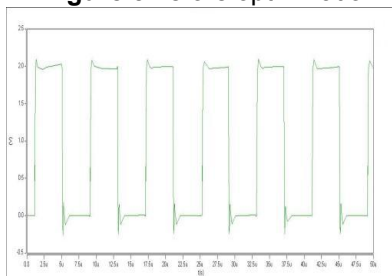

Figure 5 Before optimizatio
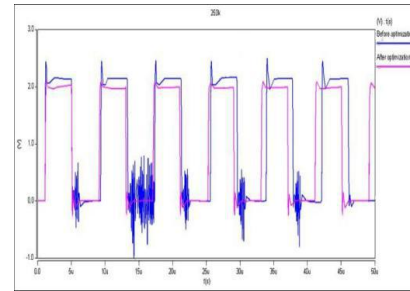

Figure 6 After optimization

Figure 7 Comparison

It can be seen from Figure 7 that the parameters of the signals in the optimized circuit meet the normal communication requirements of the CAN network. The rise time of the bus signal in the optimized circuit is larger than that before the optimization, and the overshoot is reduced. This is because there are some contradictions in the indicators of signal quality evaluation, and the optimization result is obtained through the balance of multiple goals.

4.2 Experimental Verification

In order to verify the validity of the simulation results, we conducted a corresponding experimental verification. Five CAN network communication nodes of the same nature are used in this experiment. The ECU used in the experiment is the ECU of a car air conditioning system with CAN communication function. Transceiver is using TJA1050. The transmission cable in the circuit is shielded twisted pair with a cross-sectional area of 0.5 mm^2. CAN bus interface circuit and topology are consistent with simulation. In the experimental verification process, the signal waveform of the bus under each parameter is read through an oscilloscope. According to the simulation circuit to build a five-node experimental circuit, and the CANH, CANL and differential signals of bus were collected before and after optimization by the oscilloscope. The oscilloscope screenshot of CANH, CANL and differential signals of bus are shown in Figure 8, 9.
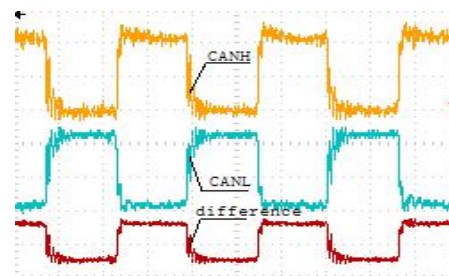

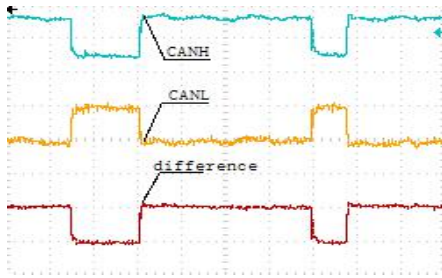**Figure 8** Actual circuit waveform before optimization

Figure 9 Actual circuit waveform after optimization

Comparing the waveforms before and after optimization at 250 kps, the results show that although the waveform signal of the optimized circuit still has some glitches and jitter, the signal quality has been greatly improved. Bus signals meet the relevant requirements in the ISO11898-2 protocol, and The upper computer can correctly read the bus messages.

5. Conclusion

Based on the co-simulation particle swarm algorithm, this paper presents a new CAN bus termination resistor matching method, and carries out a numerical simulation and a physical verification of this method. In order to ensure the accuracy of the model, we use the method of MATLAB and saber joint simulation. The results show that the optimal terminal resistance value solved by the matching algorithm can effectively optimize the bus signal.This method can be applied not only to optimize the termination resistance of the CAN bus, but also to solve the problem of optimizing the circuit structure. This method can avoid the establishment and solution of the mathematical model of the CAN network, and does not require a lot of time to use the enumeration method to determine the terminating resistance. In engineering practice, this method is highly feasible.

Acknowledgement

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