Design of Power Amplifier of Rail Transit Wireless Communication System Based on ADS

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ABSTRACT

The wireless communication system of rail transit has many functions, which plays a very important role in train operation. In order to improve the output power of wireless communication system of rail transit, this paper implemented the design and simulation of power amplifier based on advanced design system (ADS) by using Freescale Semiconductor's amplifier chip MW6S004. The transistor is laterally diffused metal oxide semiconductor. The key to design the power amplifier lies in the matching network, which can find out the best external load impedance ZL at the maximum output power of the power amplifier by using the principle of load-pull. The results show output power>24 dBm, power gain>18 dB, power out at 1 dB compression point>20 dBm in the 1.80 GHz to 2.00 GHz frequency range by experimental simulation.

INTRODUCTION

RF power amplifier plays a crucial role in the wireless communication system of rail transit. Its design affects the operation of whole system. Its output power determines the length of communication distance, and its efficiency greatly increases the battery consumption and service time. Therefore, wireless communication system needs to be designed power amplifier with good performance (Xu, 2013). With the development of rail transit wireless communication system, the development of power amplifier is also put forward higher or even new requirements, so that it has high output power, gain, efficiency and linearity under higher bandwidth.

This paper implemented the design and simulation of power amplifier based on Advanced Design System (ADS) by using Freescale's MWS004. The transistor is MOSFET. In 2013, Wenyuan Li's research group of southeast university designed and produced a class AB broadband power amplifier working in 0.8GHz-2GHz by using the 0.13nm Site HBT process. The power of 1dB compression point is 25.9dBm, the maximum output power is 28.4dBm, and the power additional efficiency reaches 31% (Li et al., 2014). Chinese academy of sciences institute of microelectronics You et al in 2014 for domestic 0.18um SiGe BiCMOS process under the device breakdown voltage, under the optimal load impedance value and frequency of stability were studied, such as the final success for a job at 2.4GHz frequency fully integrated class A power amplifier, the output 1 dB compression point 10.97dBm, saturated output power is 16.7dBm (Sun, 2015).

In this paper, Agilent's Advanced Design System (ADS) software is used for the simulation and designed of power amplifier. After years of development, ADS has gradually improved its simulation functions and methods, and its biggest feature is the integration of simulation modules from chip level to system level. Next, we introduce the chapter arrangement of this paper. The first part of this paper mainly introduces the importance of power amplifier in rail transit wireless communication system, and the development of COMS. The second part mainly introduces the design and simulation process of power amplifier. The third part summarizes and analyzes the simulation performance indexes, including power out at 1dB compression point, power gain, efficiency, and inter modulation distortion (IMD). The fourth part of the power amplifier index completion and future prospects.

DESIGN OF POWER AMPLIFIER BASED ON ADS

Design specifications and chip selection

Power amplifier is a very important part of rail transit wireless communication system. Design of power amplifier has a series of steps, including power transistor selection, matching design, biasing circuit design and EMC. We set the working indexes of the power amplification area to be designed as follows: working frequency is 1900MHz, output power > 26dBm, output power > 24dBm, power gain> 20dB, power out at 1dB compression point > 20dBm.

Bias circuit analysis

The first step in designing power amplifier is to perform a DC analysis to determine the appropriate static operating point. The selection of static working points will directly affect the performance of PA, so that the best static working point should be selected according to the design requirements. As shown in Figure 1, performance curve is obtained by DC simulation analysis. The I-V curve of the transistor is obtained through the DC scanning simulation, so as to determine the required static working point of the amplifier, and basically determine the working state of the amplifier tube. In the simulation, the DC scanning template FET_ curve_ tracer brought by ADS is used to scan MW6S004. Figure 1 is good at $V_{DS} = 28V, V_{GS} = 2.8V$.

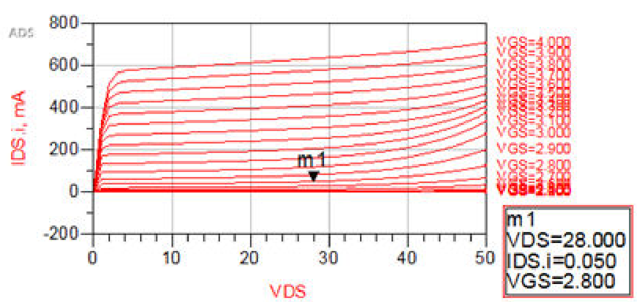

Figure 1. DC simulation result

Stability analysis

In the design of power amplifier, the stability of the system should be carefully considered. Internal feedback of the power amplifier may cause potential instability. If the feedback loop cannot be effectively controlled, the power amplifier may oscillate during operation, leading to functional failure (Wu, 2015). Amplifiers are generally classified into unconditional stability and potential instability. There are defining the stability coefficients K and B. The necessary and sufficient conditions of the absolute stability of the power amplifier need to meet the following conditions (1):

$$\begin{cases} K = \dfrac{1-|S_{11}|^2 - |S_{22}|^2 + |\Delta|2}{2|S_{12}S_{21}|} > 1 \\ |\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \end{cases} \tag{1}$$

Where S11 - reflection coefficient of port 1 when port 2 matches, S22 - reflection coefficient of port 2 when port 1 matches, S12 - reverse transfer coefficient from port 2 to port 1 when port 1 matches, S21 - forward transfer coefficient from port 1 to port 2 when port 2 matches.

Stability analysis can be carried out by analytical method and graphic method. Analytical method is used to calculate stability factors, while graphic method is used to draw stability circles in Smith circle diagram. The analytical method is adopted in this paper. If the stability parameters are not satisfied in the working zone, the method to add resistance is generally adopted to improve the stability (Lin et al., 2013). The simulation result is shown in Figure 2.

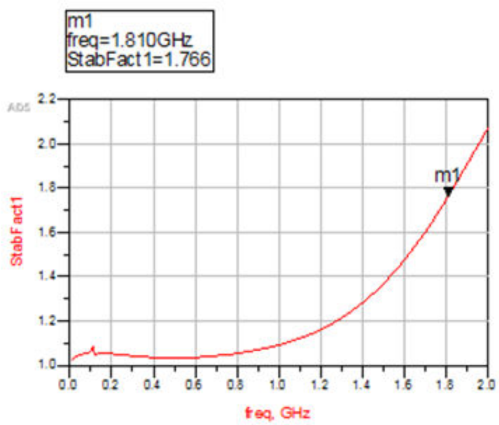

Figure 2. Stability optimization simulation result

Load-Pull and Source-Pull

The optimal load impedance of the power tube will change with the increase of input signal power when the power amplifier works at large signal. In the Smith diagram, equal output power curves at different load impedance are drawn for a given input power to help find the best load impedance at the maximum output power. This method is called load-pull.

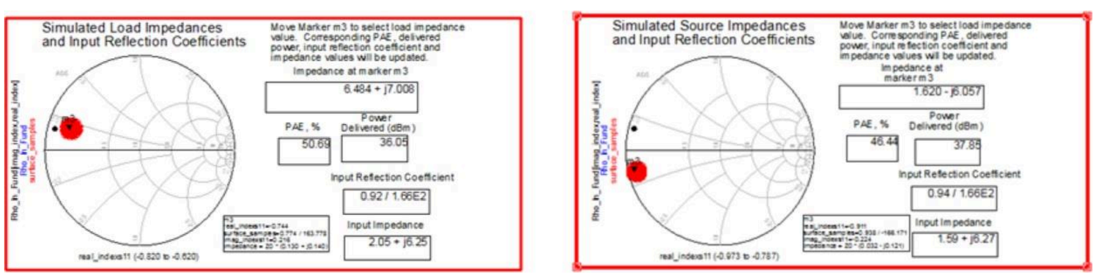

Figure 3. Load-Pull and Source-Pull simulation results

Load-pull is the most accurate method for determining the optimal load impedance, which is used to simulate and measure the characteristics of the power pipe in large signals, including output power, transmission power gain, additional power efficiency, and the linearity of IMD3 and IP3 in the analysis of cross-modulation signals with double tone.

First of the simulation process, the load-pull template is inserted. Next, the scanning parameters need to be determined. The radius and center of the scanning circle need to be constantly modified so that the center of both the power circle and the efficiency circle can be displayed. The principle of source-pull is roughly the same as load-pull. The simulation results are shown in figure 3.

Input and output matching circuit design

Impedance matching in order to maximize the power transmission between the device and the source and load, let the amplifier work in the best mode required, such as maximum power output, maximum efficiency, minimum noise, etc., and reduce the power loss of transmission risks.

To obtain the maximum output power of the power amplifier, 50 ohms should be matched to 6.484+j*7.008 at the output end and 1.620-j*6.057 at the input end through load traction and source traction in the previous step.

The working frequency in this paper is 1900MHz, so the microstrip line uncoupling capacitor is adopted for impedance matching. The circuit design results are shown in Figure 4.

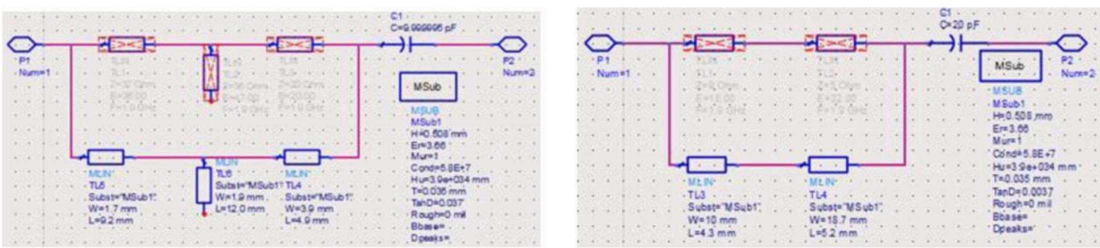

Figure 4. Input and output matching circuit

Bias circuit design

The design of power amplifier bias feed is mainly based on 1/4 wavelength impedance conversion. Since a lot of dampers will be added at the offset pin, the load impedance here is zero for the RF signal. According to the input impedance formula of the transmission line (2):

$$Z_{in}(d) = Z_0 \frac{Z_L + jZ_0 \tan(\beta d)}{Z_0 + jZ_L \tan(\beta d)} \tag{2}$$

When Z_L =0, p=$2\pi/\lambda$, and d=1/4 λ, Z_{in} can be calculated to be equal to infinity. By taking advantage of this, RF signals do not enter the bias power circuit, which is normally supplied by DC power (Hong et al., 2006). The following bias circuit is calculated. As shown in Figure 5.

Harmonic Balance simulation

Harmonic Balance simulation mainly tests the output index of power amplifier, including output power, 1dB compression point, power gain and efficiency. The simulation template of Spectrum, Gain, Harmonic Distortion vs Power (w/PAE) is invoked in ADS (Sun, 2018). The maximum output power of the designed power amplifier is 34.497dBm. HB simulation results are shown in Figure 6.

When the simulation results cannot meet the requirements of the original design, the optimization schematic diagram can be used to complete the adjustment and improvement. The optimized main parameters are used as the capacitance of the input and output to match the circuit. By changing the capacitance value, the parameters of the real-time simulation results can be viewed to complete the circuit optimization and achieve the design goal.

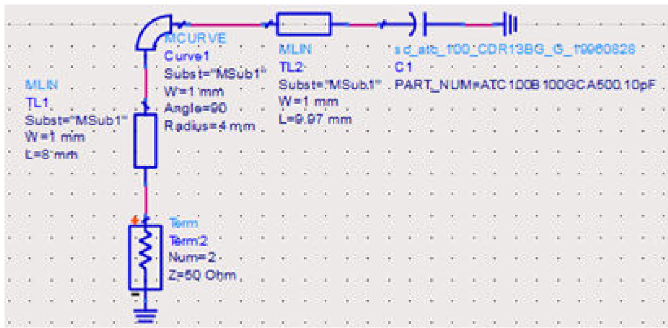

Figure 5. Bias circuit

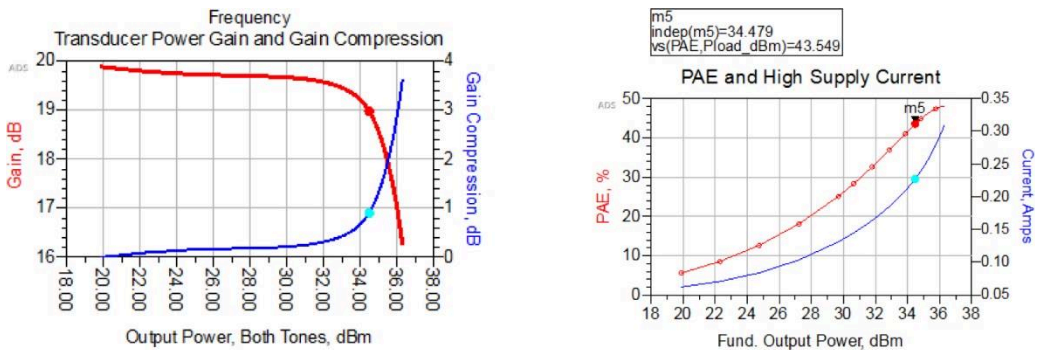

Figure 6. Gain and PAE curves

Simulation results analysis

After optimizing the schematic diagram, the simulation result of the schematic diagram is good in the 1.8GHz to 2.0GHz frequency range. The results as follow: Output power > 24dBm, power gain> 18dB, Power Out at 1dB Compression Point > 34dBm. They meet the requirements at first designing specifications. As shown in Figure 7, the total circuit diagram obtained by optimizing the schematic diagram.

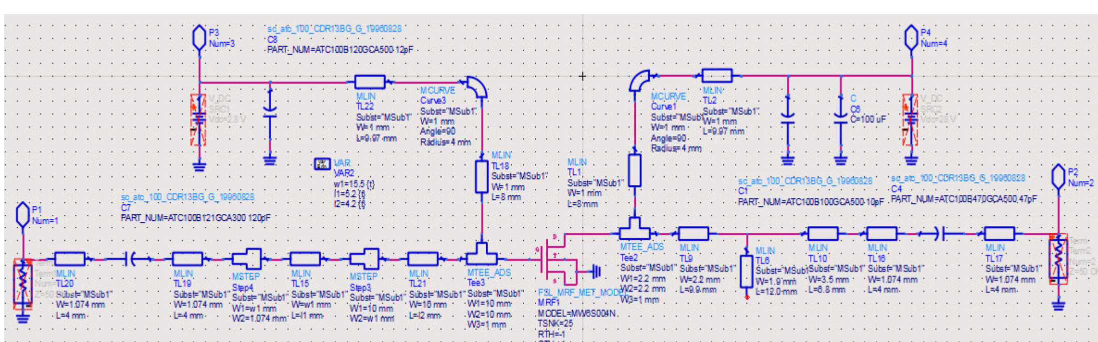

Figure 7. Power amplifier circuit schematic

CONCLUSION

This simulation design is based on the ADS, which reflects the better index parameters in the 1.8GHz to 2.0GHz frequency range, and meet the requirements. Therefore, this paper has a certain reference for the design of related power amplifier. In the design of circuit diagram, balance structure, differential structure and multistage amplifier can be used to get a circuit with larger gain and more accurate precision.

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Research on Non-Parameter Identification of Pantograph of Rail Vehicle

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ABSTRACT

In the traditional study and analysis of coupled vibration of pantograph and catenary, pantograph is generally approximated as linear, and most of the linear parameters are obtained by experimental measurement or derivation. In this paper, the flexibility of pantograph head is added into the quality reduction model of pantograph to establish a two-dimension nonlinear pantograph model which will be more suitable for engineering practice. On the premise of that parts of pantograph system are unknown, the non-parametric identification of two-degree of freedom pantograph is carried out by using the restoring force surface method. The identified parameters are basically consistent with the original model data, which indicates that the recognition effect of this method can be accepted. This method has the potential of engineering application, which can promote the in-depth study of pantograph contact stability and make train operation more safe and reliable.

INTRODUCTION

With the rail transit developing at a rapid speed, vehicle's speed-up is an urgent problem to be solved in China, and pantograph parameters are very critical among many influencing factors. At present, the pantograph put into use in China are mainly imported from abroad or reprocessed with imported parts and components. The loss of parameters seriously affects the research and development of pantograph in China and the process of train's speed raising (Li, 2012).

In the research of parameter calculation, the current researchers can deduce the formula to calculate individual parameters. Xing et al., (2002) simply equivalent the pantographs into two models which are two mass blocks and three mass blocks, combining experimental measurement with formula derivation, to complete the identification of partial equivalent parameters (Xing et al., 2002; Zhou, 2011).

Most researchers are confined to the linear state to measure the equivalent parameters of the pantograph's head and frame respectively, and do not consider the nonlinear state of the pantograph when it runs at high speed. Moreover, most researchers ignore the stiffness of the pantograph frame and the damping of the pantograph head, and do not study or directly approximate them to zero, which affects the results of the establishment of the pantograph equation.

At present, the linear pantograph model cannot meet the needs of research, so it is particularly important to get the performance parameters of pantograph under the premise that the pantograph system is partly unknown.

This paper is based on the widely used 2 of quality reduction model of pantograph, to make the model more fit for the engineering practice and the results of the simulation more representative, considering to apply the compliance of pantograph head mentioned in the literature (Cui, 2018).Then establish a nonlinear mathematical pantograph's model with two degree of freedom whose parameters have been known. Using the restoring force surface method and the software-MATLAB distinguish nonparametric parameters of pantograph with two degrees of freedom. The obtained linear or nonlinear parameters are compared with the model parameters, analyzing and judging, so as to verify the effectiveness of the non-parametric identification method about the two-degree-of-freedom pantograph.

Simulation test of nonlinear parameter's identification

Identification process of pantograph's system

To identify parameters as K, C or nonlinear terms of stiffness and damping of pantograph is equivalent to system identification of pantograph. The definition of identification firstly came from Zadeh's literature in 1962, which is to determine the time-domain characteristic model of the process or system through experiments. In the identification case, the mathematical model needs to be obtained according to the experimental data. In this paper, a nonlinear mathematical model with time domain characteristics of pantograph is firstly given, and the SISO (Single Input Single Output) process is simulated by making the excitation be simulated as the input and the response of numerical solution of the model be simulated as the output (Izeman, 2016) . The simulated pantograph gray box model is shown in Figur1.

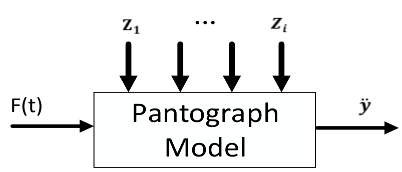

Figure 1. Dynamic process identification of the system

The $F(t)$ simulates pantograph's excitation .The $\ddot{y}$ is the acceleration of the pantograph under forced vibration. Z_1, … Z_i representing interference, in this case, the simulation is ignored, and the interference needs to be separated from the signal during the experimental modeling. $\ddot{y}$, $\dot{y}$, y are obtained from the hypothetical model that will be solving by the function which is Runge-Kutta.

Description of pantograph nonlinear model

Considering the complexity of the frame structure, which is hinged by multiple members, the equivalent parameters corresponding to different heights are not consistent. The nonlinear physical model of pantograph is established as shown in Figure 2. It is assumed that there are no nonlinear terms other than flexibility in the head of pantograph, and there is a nonlinear connection between the frame and the base.

In Figure 2, F_c is the external excitation from Catenary, and F_0 is the static lifting force. M_1 、K_1 and C_1 are equivalent mass of pantograph head, stiffness and damping between pantograph's head and frame respectively. M_2、K_2 and C_2 are respectively equivalent mass of frame, stiffness and damping between frame and base.

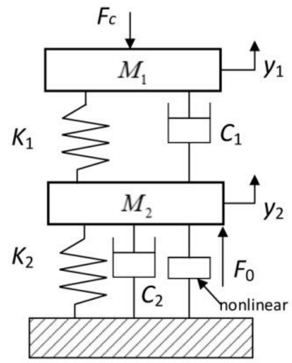

Figure 2. Pantograph Binary Nonlinear Model

The vibration differential equation is:

$$\begin{cases} M_1\ddot{y}_1+\left(C_1+C_{11}\left(\dot{y}_1-\dot{y}_2\right)\right)\left(\dot{y}_1-\dot{y}_2\right)+\left(K_1+K_{11}\left(y_1-y_2\right)\right)\left(y_1-y_2\right)=-F_c \\ M_2\ddot{y}_2+C_2\dot{y}_2+\left(C_1+C_{11}\left(\dot{y}_1-\dot{y}_2\right)\right)\left(\dot{y}_2-\dot{y}_1\right)+C_n\dot{y}_2^2+\left(K_1+K_{11}\left(y_1-y_2\right)\right)\left(y_2-y_1\right)+K_2y_2+K_ny_2^3=F_0 \end{cases} \tag{1}$$

The formula,' $\left(C_1+C_{11}\left(\dot{y}_1-\dot{y}_2\right)\right)\left(\dot{y}_1-\dot{y}_2\right)+\left(K_1+K_{11}\left(y_1-y_2\right)\right)\left(y_1-y_2\right)$ ', simulates the flexible nonlinear force of pantograph's head (Xing et al., 2002), C_{11}, K_{11} are nonlinear parameter ,and $C_n\dot{y}_2^2+K_ny_2^3$ simulates the nonlinear force of frame.

Theory of restoring force surface method

Restoring force surface method is a non - parametric identification method based on time domain. Asri and Caughey proposed in the 1970s (Asri & Caughey, 1979), which is mainly used for the identification on single-degree-of-freedom nonlinear systems. This method is also known as "force-state mapping method" (Chen et al., 2006).

Due to its special mathematical model, the complex nonlinear two-degree-of-freedom system of pantograph can be transformed into studying frame with nonlinear spring-nonlinear damping system. Equation (1) can be translated into:

$$M_1\ddot{y}_1+M_2\ddot{y}_2+C_2\dot{y}_2+C_n\dot{y}_2^2+K_2y_2+K_ny_2^3=-\Delta F_c \tag{2}$$

$$M\ddot{y}+f_{frame}(y_2,\dot{y}_2)=-\Delta F_c \tag{3}$$

The static lift of the pantograph itself is only 70N, $\mathrm{F}_0=70$。 ΔF_c is the difference between the contacting force of the bow net and the static lifting force,

$$M=\begin{bmatrix}M_1 & M_2\end{bmatrix}, \ddot{y}=\begin{bmatrix}\ddot{y}_1 \\ \ddot{y}_2\end{bmatrix} \tag{4}$$

$$f_{frame}(y_2,\dot{y}_2)=f_s(y)+f_d(\dot{y})=K_2y_2+K_ny_2^3+C_2\dot{y}_2+C_n\dot{y}_2^2 \tag{5}$$

$f_s(y)$ and $f_d(\dot{y})$ are functions to be identified, representing the elastic restoring force and damping restoring force respectively.

According to Newton's second law, the motion equation of this system above can be expressed as:

$$f_{frame}(y_2, \dot{y}_2) = -\Delta F_c - M\ddot{y} \tag{6}$$

$f_{frame}(y_2, \dot{y}_2)$ is the restoring internal force, representing the sum of elastic restoring force and damping restoring force, and is also a function of frame's displacement and velocity. M is the mass matrix about head and frame, the only parameter that needs to be known in advance. The expression on the right side of the formula is known, and so is f.

We don't have to assume the exact functional form of the restorative force here. At the same time, displacement and speed correspond to the same restoring force, forming innumerable 3-d numerical point set (y , $\dot{y}$, f) .In practical engineering, the damping and elastic restoring force usually are independent of each other. As long as the displacement and velocity are determined as the phase plane of restoring force surface, and restoring force to the height of the restoring force surface, cross section method can be used to extract the elastic restoring force curve and damping restoring force curve.

Simulation and result analysis

In order to cooperate with the use of the restoring force surface method, the external excitation added should be a simple harmonic excitation whose amplitude increases with time (Yuan, 2019). Here, the excitation equation commonly used in our experiments is taken. Set the external excitation of the pantograph as a simple harmonic excitation whose amplitude increases over time with cubic growth, so given:

$$\Delta F_c = -F_c + F_0 = (150t^3 - 1.3t^2 + 5t + 1.5)\sin(20\pi t) \tag{7}$$

In the initial state of zero, numerical integration method is adopted to solve the response of the system in MATLAB according to the original model data. The velocity displacement vibration response curve is shown in Figure 3 and 4.

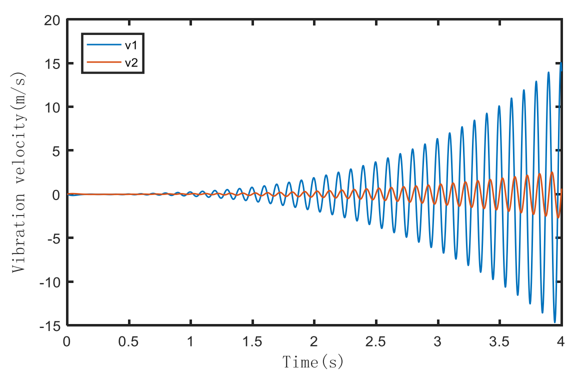

Figure 3. Vibration velocity response of 2-dof model subjected to pantograph

In this model, the expression of nonlinear elastic restoring force of the frame is $f_s(y) = K_2 y_2 + K_n y_2^3$, and the expression of nonlinear damping restoring force of the frame is $f_d(\dot{y}) = C_2 \dot{y}_2 + C_n \dot{y}_2^2$.