Discussion on Teaching Analysis of Multistage Amplifying Circuit

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Abstract. In the course of Analog Electronic Circuit, most textbooks usually directly use the small-signal analysis method (SSAM) to analyze the multi-stage amplification (MSA) circuits without considering the relationship between single-stage and multi-stage. It's difficult for students to analyze the performance of MSA circuits due to the complexity of MSA circuit and its equivalent circuit and the low efficiency of analysis and solution. Based on the teaching idea of "building blocks"，this paper puts forward an effective MSA circuits analysis method based on "relationship of single-stage and multi-stage" and gives the performance index of MSA circuit directly through the relationship between SSA and MSA and the indicators of each basic SSA circuit such as CE, CC and CB. The teaching practice shows that this method can effectively promote the students' understanding of MSA circuits, simplify the analysis process of MSA circuits, and make much sense in teaching.

Keywords: small-signal analysis, single stage amplifying circuit, multistage amplifier circuit

1 Introduction

Multi-stage amplifiers (MSA) in simulation circuit teaching, as an important knowledge point [1-4], constitute an important part of the knowledge system from "Device to single-stage amplification (SSA), to multi-stage amplification (MSA), to integrated amplification". Based on the universality of the small-signal analysis method (SSAM) in analyzing amplification circuits, most textbooks and teaching materials [5-7] mainly introduce SSAM in single-stage amplification circuits (SSA) and discuss the detailed steps, which directly adopt small-signal equivalent analysis in (SSAM) analyzing multi-stage amplification circuits. Due to the complexity of the MSA circuit, the large number of transistors, and the complexity of the equivalent circuit, the efficiency of analysis and solution is highly limited, which leads to difficulties in analyzing the performance indicators of multi-stage amplification circuits for students in the field of electronic and information engineering. Therefore, based on the teaching idea of "building blocks"，this paper puts forward an effective MSA circuits analysis method based on "relationship of single-stage and multi-stage amplifier (RSMA)" and gives the performance index of MSA circuit directly through the relationship between SSA and MSA and the indicators of each basic SSA circuit such as CE, CC and CB. The teaching practice shows that this method can effectively promote the students' understanding of MSA circuits, simplify the analysis process of MSA circuits, and make much sense in teaching.

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2 Analysis of multi-stage amplifier circuit

2.1 Problem Definition

In practical amplifier circuits, Single-stage amplifier circuits have their own advantages and disadvantages in terms of parameters (such as voltage gain, input/output impedance) and cannot simultaneously meet the requirements of various parameters[8-10]. Therefore, multiple single-stage (or single-transistor) amplifier circuits are usually cascaded to form a multi-stage amplifier circuit.

2.2 Principles and Methods of Analysis

Analysis of multi-stage amplifier circuits: From the perspective of the basic requirements for amplifier circuit analysis, the analysis of multi-stage amplifier circuits involves determining the configuration forms of each stage of amplification and conducting an overall analysis of the circuit parameters (such as voltage gain, input/output impedance). The commonly used methods for analysis are the small-signal equivalent analysis method and graphical method.

2.3 Small-Signal Equivalent Analysis Process

According to the superposition theorem, the input total signal source of a circuit is the sum of DC and AC signal sources.When the amplitude variation of the input signal is very small (not exceeding 10 mV), the output signal can be approximated to vary linearly with the input signal. In this case, the linear equivalent model of non-linear devices (such as the transistor) can be used. The general steps for small-signal equivalent analysis are shown in Figure 1.

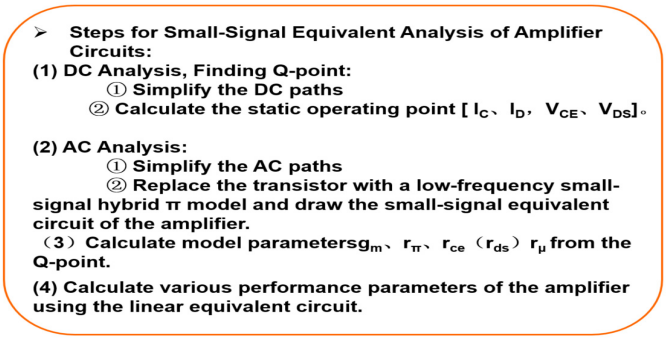


Fig. 1. Steps for small-signal equivalent analysis

The small-signal equivalent analysis method is universal and applicable to non-linear circuits (such as single-stage amplifier circuits, multi-stage amplifier circuits, amplifier circuits composed of BJT or MOSFET) that meet the small-signal condition.

For the analysis of multi-stage amplifier circuits, the small-signal equivalent analysis method can also be used. Most textbooks and teaching materials [5-7] focus on the use of small-signal equivalent analysis method in single-stage amplifier circuits, while the use of small-signal equivalent analysis method in multi-stage amplifier circuits is not well-discussed. Due to the complexity of multi-stage amplifier circuits, the numerous components and the complexity of the equivalent circuit, the efficiency of analysis and solution is low, which results in

difficulties for most students in the field of electronic and information engineering in analyzing the performance indicators of multi-stage amplifier circuits.

3 Analysis Method Based on "Relationship between Single-Stage and Multi-Stage Amplifiers"

To address the above problems, this article introduces a novel teaching approach for the analysis of multi-stage amplifier circuits based on the "relationship between single-stage and multi-stage amplifiers (RSMA)" from the teaching concept of "building blocks". Based on the parameters of the basic single-stage amplifier circuits, the performance indicators of multi-stage amplifier circuits are directly given through the relationship between single-stage and multi-stage amplifiers. Finally, the specific implementation process of this method is demonstrated through examples.

3.1 Method Principles

The knowledge system of "device-single-stage amplifier-multi-stage amplifier-integrated amplifier" in analog circuit teaching is unfolded gradually through a "building blocks" approach. In this approach, prior knowledge is often the foundation and prerequisite for subsequent knowledge. The multi-stage amplifier circuit is composed of single-stage amplifier circuits in cascade. If the analysis of single-stage amplifier circuits that constitute the multi-stage amplifier circuit has been done, the analysis results of the single-stage amplifier circuits can be effectively utilized for the research and analysis of the multi-stage amplifier circuit.

3.2 Performance Indicators of Single-Stage Amplifier Circuits

Firstly, let's review the single-stage amplifier circuits. In the previous course, the three basic configurations (CE, CB and CC) of amplifier circuits were analyzed, and the performance indicators (including voltage gain, input impedance, and output impedance) were calculated using the small-signal equivalent analysis method after DC analysis and AC analysis. Typical applications were also given, as shown in Table 1.

Table 1. Relationship between front and back stages of a multi-stage amplifier circuit

	CE	CB	CC
A_v	$-\frac{\beta R_L'}{r_{be}}$ high	$\frac{\beta R_L'}{r_{be}}$ high	$\frac{(1+\beta_1)R'_L}{r_{be}+(1+\beta_1)R'_L} \approx 1$
R_i'	r_{be} middle	$\frac{r_{be}}{1+\beta}$ low	$r_{be}+(1+\beta_1)R'_L$ high
R_o'	r_{ce} high	$\left(1+\frac{\beta R'_s}{R'_s+r_{be}}\right)r_{ce}$ very high	$\frac{r_{be}+R_S'}{1+\beta_1}$ low
Usage	intermediate stage	high-frequency or broadband circuit current source circuit	input stage/output stage/buffer

3.3 Relationship between Single-Stage and Multi-Stage Amplifiers

Taking a two-stage amplifier circuit as an example, here we give the relationship between single-stage and multi-stage amplifier circuit parameters.

From the perspective of the entire amplifier circuit, the parameters of a multi-stage amplifier circuit refer to the overall amplifier circuit, mainly including voltage gain, input impedance, and output impedance.

Voltage Gain

The voltage gain of a multi-stage amplifier circuit is the product of the voltage gain of each stage:

$$A_v = A_{v1} \cdot A_{v2} \,. \tag{1}$$

Input Impedance

The input impedance of a multi-stage amplifier circuit is the input impedance of the first stage amplifier circuit:

$$R_i = R_{i1} \,. \tag{2}$$

Output Impedance

The output impedance of a multi-stage amplifier circuit is the output impedance of the last stage amplifier circuit

$$R_o = R_{o2} \,. \tag{3}$$

3.4 Relationship between Preceding and Following Stages

When analyzing a multi-stage amplifier circuit based on the "relationship between single-stage and multi-stage amplifiers," it is necessary to consider the relationship between the preceding and following stages, as shown in Figure 2.

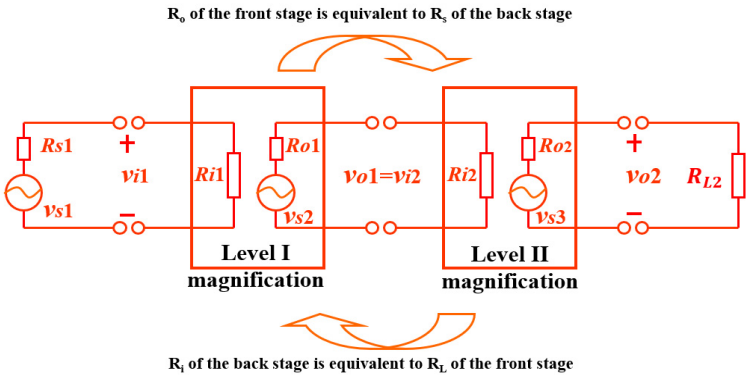


Fig. 2. Relationship between preceding and following stages in a MSA circuit

The following stage can be regarded as the load of the preceding stage. Therefore, the load of the preceding stage circuit is the input impedance of the following stage circuit:

$$R_{L1} = R_{i2} \,. \tag{4}$$

The preceding stage can be regarded as a signal source for the following stage. Therefore, the internal resistance of the signal source in the following stage circuit is the output impedance of the preceding stage circuit:

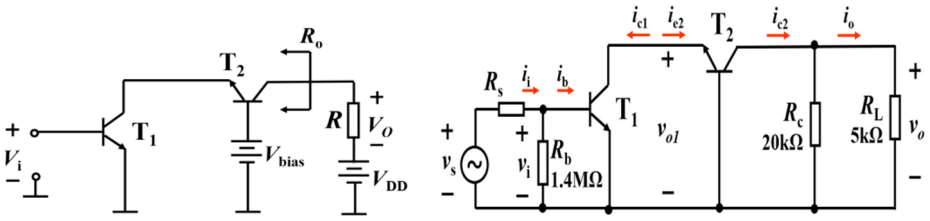
$$R_{s2} = R_{o1}\,. \tag{5}$$

By using this relationship and progressively substituting the parameters of each stage, the performance indicators of the multi-stage amplifier circuit can be obtained.

4 Example Implementation

4.1 Circuit Configuration CE-CB

A two-stage amplifier circuit with a CE-CB series configuration (as shown in the Figure 3(a)) is taken as an example, and the "relationship between single-stage and multi-stage amplifiers" analysis method is used to solve the circuit performance.



(a) Overall circuit configuration (b) AC circuit

Fig. 3. CE-CB series configuration

4.2 Analysis

Firstly, the AC circuit is shown in Figure 3(b). Then we use both small-signal equivalent analysis methods and the "relationship between single-stage and multi-stage amplifiers" analysis method.

Small-signal Equivalent Analysis Method

According to the content of Section 2.3, the two-stage amplifier circuit needs to be simplified to a small-signal equivalent circuit for analysis, and a simplified equivalent circuit for R_o also needs to be derived. The process and solutions are complex and is not discussed in detail for the limitation of space.

"Relationship between Single-Stage and Multi-Stage Amplifier" Analysis Method

This method does not require the drawing of small-signal equivalent circuits and equivalent circuits for R_o, and it can be solved directly. The voltage gain is:

$$A_v = A_{v1} \cdot A_{v2} = -\frac{\beta R_{L1}}{r_{be}} \cdot \frac{\beta R_{L2}}{r_{be}} = -\frac{\beta R_{L2}}{r_{be}}\,. \tag{6}$$

The input impedance is:

$$R_i = R_{i1} = r_{be} // R_b\,. \tag{7}$$

The output impedance is:

$$R_o = R_{o2} = \left(1 + \frac{\beta R_{s2}}{R_{s2} + r_{be}}\right) r_{ce} // R_c = (1+\beta) r_{ce} // R_c\,. \tag{8}$$

Here, it can be concluded from equations (4) and (5) that:

$$R_{L1} = R_{i2} = r_{be}/(1+\beta)\,. \quad (9)$$

$$R_{s2} = R_{o1} = r_{ce}\,. \quad (10)$$

4.3 Comparison and Induction

Through comparison, the similarities and differences between the "directly using small-signal equivalent analysis method" and the "relationship between single-stage and multi-stage amplifier" analysis methods can be found, as shown in Table 2.

Table 2. Comparison between SSAM and RSMA

	"Directly using small-signal equivalent analysis method"	"relationship between single-stage and multi-stage amplifiers analysis method "
AC /DC Decomposition, DC Analysis, AC Circuit	Same	Same
AC Parameters (R_i,R_o, A_v)	SSAM	exp.(1)-(3)
Characteristics	Complex process: SSAM (requires drawing multiple circuit diagrams).	Simplified process: Determine the configuration form and directly solve the circuit using single-stage indices in a cascaded manner.
Prerequisite	None	Proficiency in single-stage is required.
Learning Effect	General method with versatility	High efficiency

(1) Similarities: these include AC /DC Decomposition, DC analysis (which involves DC circuit and working point calculation), and AC analysis (which involves AC circuit). These aspects are the same since they form the basic foundation of amplifier circuit analysis.

(2) Differences: When directly using SSAM, analysis of parameters in AC circuits are more complex. For example, solving the output impedance may require drawing an extra circuit, and sometimes complex equations must be solved (such as when solving the output impedance in CB configuration). By contrast, the latter RSMS only requires the use of the parameter indexes of single-stage circuits and quickly obtain the parameters of the multi-stage circuit.

In summary, the "directly using small-signal equivalent analysis method" is a more tedious process that needs to follow the steps of using small-signal equivalent analysis, but it does not require other prerequisites, while the "relationship between single-stage and multi-stage amplifier (RSMA) " analysis method is simpler but requires familiarization with single-stage.

5 Conclusion

As an important part of the "device-single-stage amplifier-multi-stage amplifier-integrated amplifier" knowledge system, the analysis method of multi-stage amplifier circuits should be effectively mastered by most students in the field of electronic and information engineering. Currently, most textbooks and teaching materials mainly use small-signal equivalent analysis method. Due to the complexity of the multi-stage amplifier circuit, the large number of transistors, and the complexity of the equivalent circuit, the efficiency of analysis and solution is low. In order to reduce the difficulty and improve the teaching effect, this paper puts

forward an effective MSA circuits analysis method based on the "relationship between single-stage and multi-stage amplifiers" for solving the multi-stage amplifier circuits. First, the problem definition, analysis principle, and methods of multi-stage amplifier circuits are discussed. Then, based on the idea of "building blocks," the performance indicators of the multi-stage amplifier circuit are directly given according to the indicators of each basic single-stage amplifier circuit through the relationship between single-stage and multi-stage amplifiers. Finally, a specific implementation process of the method is given through an example. Through actual teaching verification, this method can effectively improve the analysis efficiency of students on multi-stage amplifier circuits and plays a good role in teaching.

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