Preview Report		Experimental Record		Analysis & Discussion		**Total**	

Grade & Major:	2022, Physics	Group number:	A2
Student name:	杨舒云 & 戴鹏辉	Student number:	22344020 & 22344016
Experiment time:	2024/9/25	Teacher's Signature:	

ET2-1 蓝牙音箱的焊接和调试
Welding and Debugging of Bluetooth Speakers

【Precautions】

1. The lab report consists of three parts:

   (1) Prview Report: Carefully study the experimental manual before class to understand the experimental principles; familiarize yourself with the instruments, equipment, and tools needed for the experiment, and their usage; complete the pre-lab thought questions; understand the physical quantities to be measured during the experiment, and prepare the experimental record forms in advance as required (you may refer to the experiment report template and print it if needed).

   (2) Experimental Records: Meticulously and objectively record the experimental conditions, phenomena observed during the experiment, and data collected. Experimental records should be written in ballpoint pen or fountain pen and signed (**Records written in pencil are considered invalid**). **Keep original records, including any errors and deletions; if a correction is necessary due to an error, it must be made according to the standard procedure.** (Records should not be entered into a computer and printed, but handwritten notes can be scanned and printed); before leaving, have the experimental teacher check and sign the records.

   (3) Data Processing and Analysis: Process the raw experimental data (except for experiments that focus on learning the use of instruments), analyze the reliability and reasonableness of the data; present the data and results in a standardized manner (charts and tables), including numbering and referencing the data, charts, and tables sequentially; analyze the physical phenomena (including answering the experimental thought questions, writing out the thought process, and citing data as needed according to standards); finally, draw a conclusion.

The experiment report combines the preparation report, experimental records, and data processing and analysis, along with this cover page.

2. Submit the **experiment report** within one week after completing each experiment (under special circumstances, no later than two weeks).

【Special Note】

Special thanks to **Huanyu Shi**, a senior from the Class of 2019, for providing the LaTeX template for this experiment report.

Due to the absence of an experiment number in the original template, a self-named number has been added for ease of organization on the computer.

Additionally, **this experiment report is being improved towards full English expression, so there may be instances of mixed Chinese and English during this transition period. We appreciate your understanding!**

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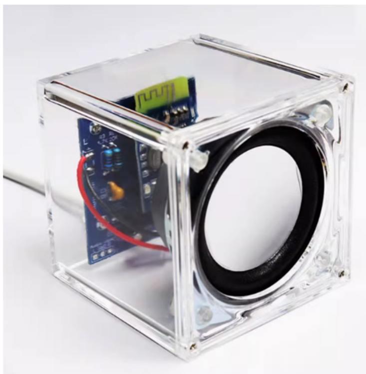
ET2-1 Welding and Debugging of Bluetooth Speakers Preview Report

1.1 Purpose

1. Learn and master basic welding techniques, weld and debug Bluetooth speakers;
2. Review relevant knowledge of electronic technology and analyze the circuits used in the experiment;
3. Learn EDA software and draw relevant PCB boards.

1.2 Instruments & Equipment

Number	Name	Quantity	Main parameters (model, measurement range, measurement accuracy, etc.)
1	Circuit related instruments	1	Provided by the laboratory, as shown in **Figure 1**
2	Analog electronics related instruments	Several	Including but not limited to breadboard, DuPont line, analog electronic technology box, oscilloscope, signal generator and multimeter, etc.
1	Welding related instruments	1	Provided by the laboratory

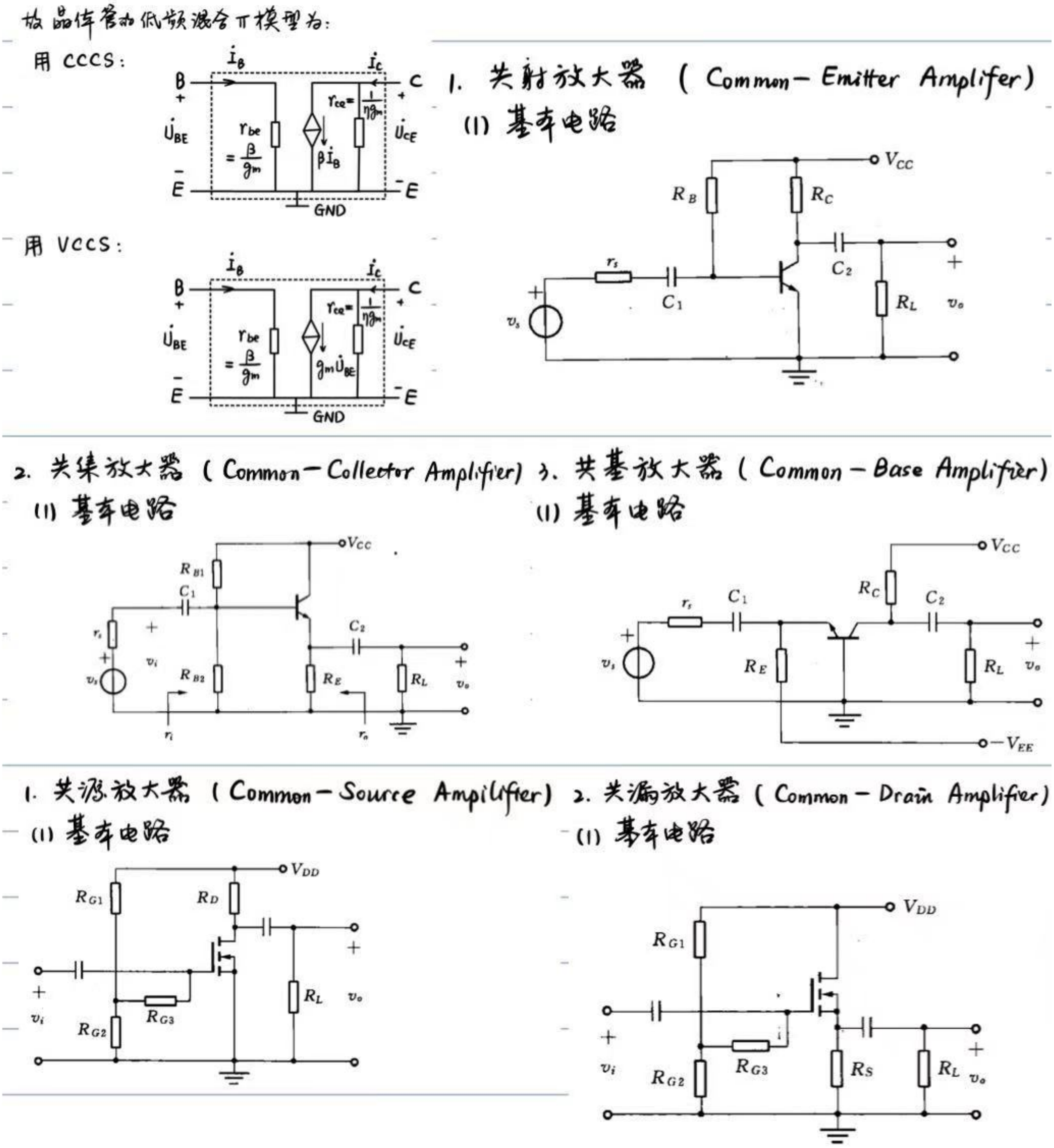


序号	型号	名称	数量	位号	说明
1	4.7KΩ	1/4W电阻器 （黄 紫 黑 棕 棕）	2	R3, R4	
2	20KΩ	1/4W电阻器 （红 黑 黑 红 棕）	3	R0, R1, R2	
3	0.1uF（104）	独石电容器	2	C1, C5	
4	1uF（105）	独石电容器	2	C3, C4	
5	10uF	电解电容器	1	C0	
6	1000uF	电解电容器	1	C2	
7	2302	MOS管	1	Q1	
8	3MM水银开关	水银开关	1	S1	
9	LM4863 DIP16	功放IC	1	U1	
10	16脚管座	IC管座	1	U1	
11	5P排母2.54MM	排母	1	P1	有线版不用
12	MICRO 5P母座	USB座	1	USB	有线版不用
13	10cm导线 红 黑	导线	2		
14	1米白色USB线	USB线	1		有线版不用
15	4Ω 3W 2寸扬声器	扬声器	1		
16	塑料外壳 6*6*6cm	外壳	1		
17	电路板 4*4.4cm	电路板	1		
18	PA1.7*7	自攻螺丝	8		
19	PWA6.0*1.7*5	带帽自攻螺丝	4		
20	6-4*5	尼龙柱	4		
21	蓝牙模块	蓝牙模块	1		
22	USB线		1		有线版的配件
23	音频线		1		有线版的配件
24	尼龙扎带		1		有线版的配件

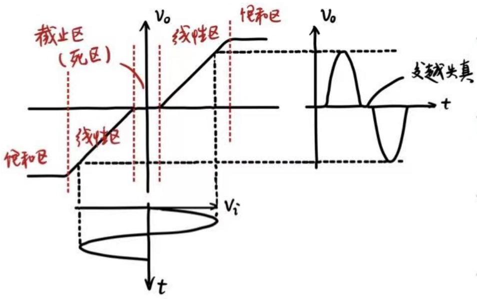
Figure 1: Circuit related instruments

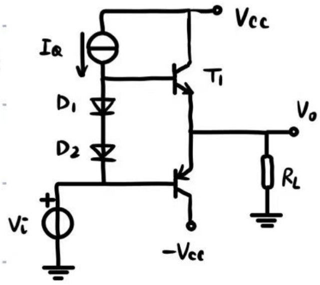
1.3 Principle

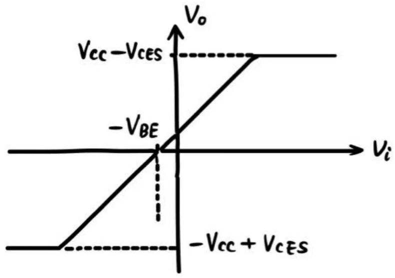
1. Basic amplifier circuit



2. Power amplifier circuit







3. Operational Amplifier

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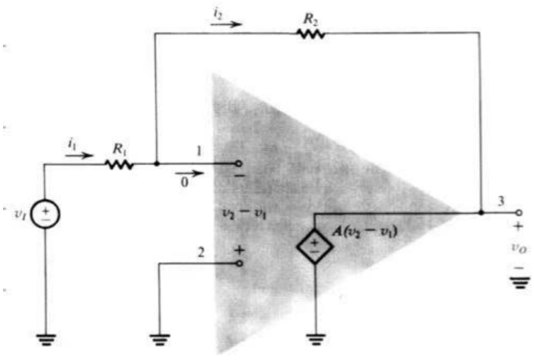
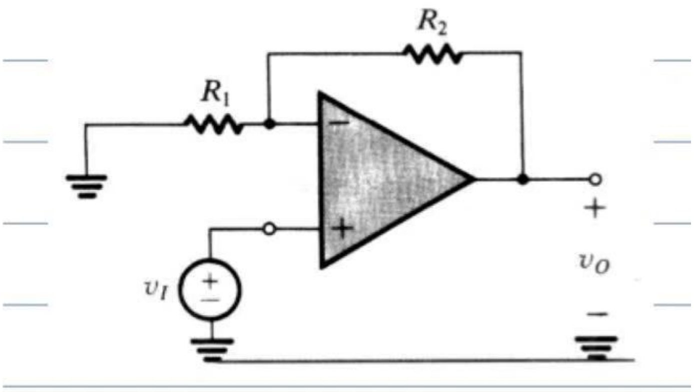
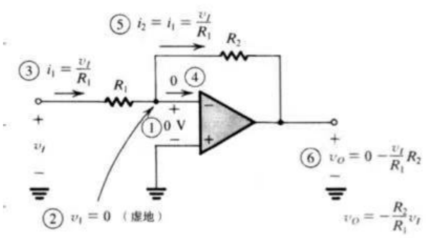
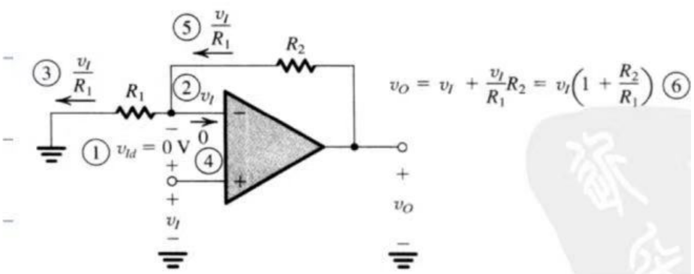


(a)





(b)



Major:	Physics	Grade:	2022
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Room temperature:	30°C	Experimental location:	A522
Student's Signature:	**In Attachment**	Score:	
Experiment time:	2024/9/25	Teacher's Signature:	

ET2-1 Welding and Debugging of Bluetooth Speakers Experimental Record

2.1 Content, Procedures & Results

2.1.1 Operations

1. According to the instructions, complete the welding of the Bluetooth speaker circuit and the assembly of the speaker as a whole. The following is a description of the welding process:
   (1) Solder the components one by one in the order shown in the tutorial.
   (2) It is important to note that some components have positive and negative electrodes, and the direction cannot be wrong. Usually the long foot represents the positive pole.
   (3) During the welding process, make sure to wear appropriate protective equipment, control the temperature and time, clean the solder joint and use the right amount of solder, and check the quality of the solder joint after welding to ensure the safety and quality of the welding.
2. Measure the closed-loop gain of the power amplifier section of the Bluetooth speaker circuit.
3. Finally, we referred to the soldered Bluetooth speaker circuit and PCB, taught ourselves KI-CAD, and copied the PCB.

2.1.2 Display

We measured the output voltage variation with input voltage at a fixed frequency of 1kHz and the output voltage variation with frequency at a fixed input voltage of 50.0Vrms.

The results are shown in Table 1 and Table 2.

As requested by the teacher, we did not measure the power gain, but we conducted a theoretical analysis, see the data **analysis** section for details.

u_{in}/mVrms	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0
u_{out}/mVrms	80.1	159.5	239.1	320.0	400.1	480.5	560.5	640.5	720.7	800.0

Table 1: The output voltage variation with input voltage at a fixed frequency of 1kHz

frequency/Hz	20	35	70	100	200	500	700	1000
u_{out}/Vrms	187.4	271.9	351.9	374.4	393.6	399.9	400.6	400.9

Table 2: The output voltage variation with frequency at a fixed input voltage of 50.0Vrms

PCB:

After class, we used KiCAD and tried to copy the PCB drawing by referring to the datasheet of LM4863 chip and the schematic diagram of Bluetooth speaker, as shown in the Figure 2.

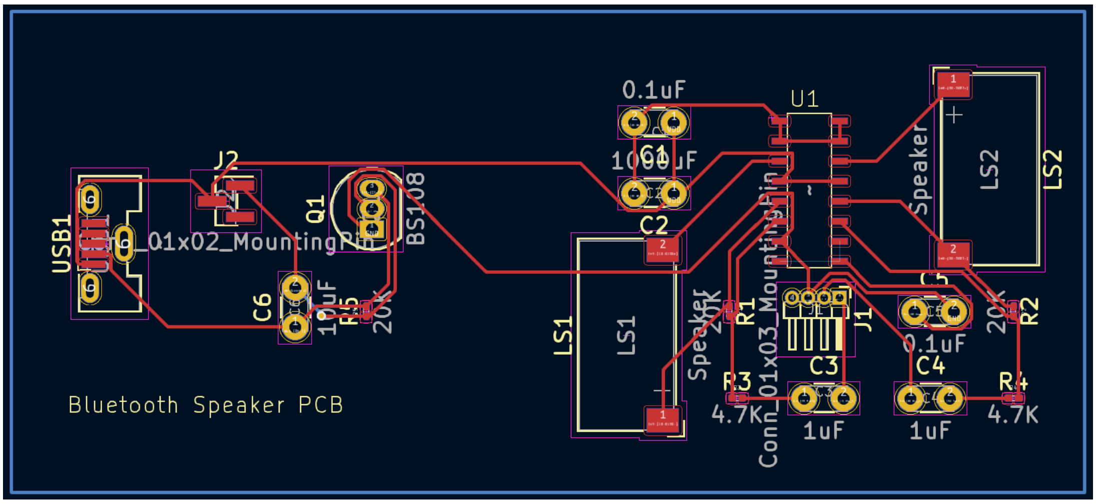

Figure 2: PCB drawing

The welded and assembled Bluetooth speaker is shown in the **Figure 4** and **Figure 5**.

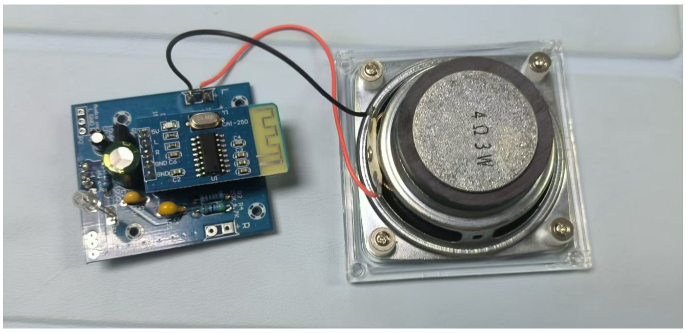

Figure 4: Finished Bluetooth speaker

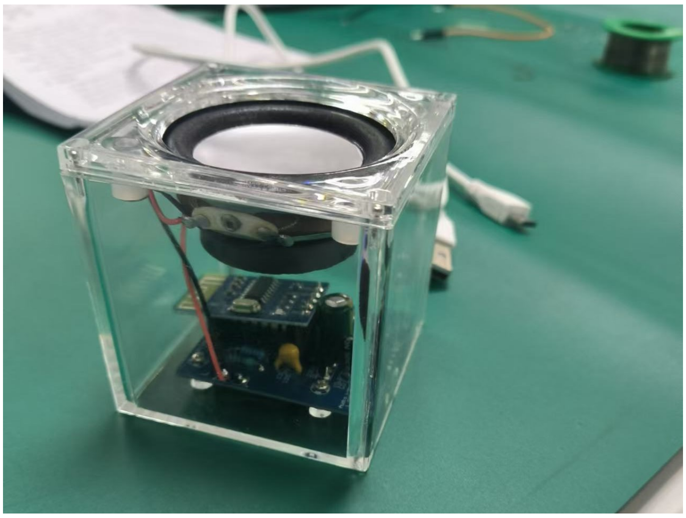

Figure 5: Finished Bluetooth speaker

2.3 Difficulties

1. Because it is the first time to use the soldering iron, the first class spent too much time to get familiar with the use of the soldering iron.

2. When measuring the amplifier of the circuit, pay attention to avoid the signal generator and oscilloscope, which will lead to short circuit of the measured component, so that it can not measure the signal correctly.

3. When measuring the magnification of the circuit, it is necessary to connect the USB power supply to provide the working voltage to the chip.

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Date:	2024/9/25	Score:	

ET2-1 Welding and Debugging of Bluetooth Speakers Analysis & Discussion

3.1 Data Processing

3.1.1 Analysis

In this part, we will solve the requested problems .

1. Analyze the function of the circled circuit in **Figure 6**.

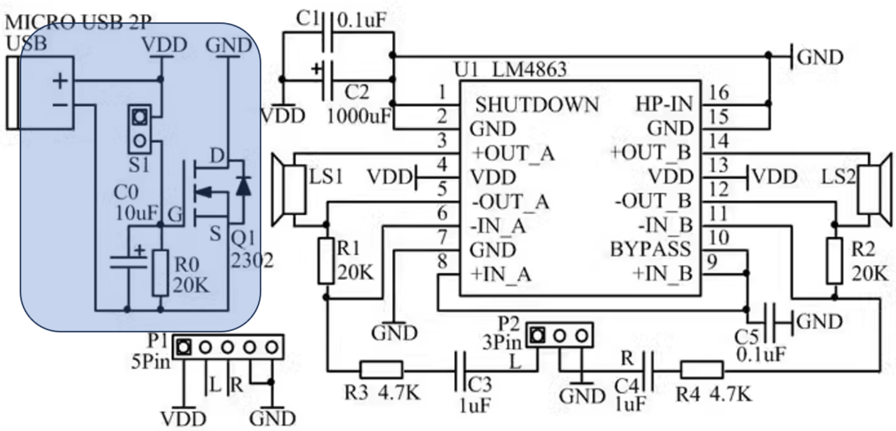

Figure 6: The circled circuit

The circuit is powered through a USB cable, where Q1, R0, S1, and C0 form an electronic switch to replace a common mechanical switch. S1 is a mercury switch, which relies on the flow of mercury to establish or break the connection. When the speaker is placed upright, the mercury switch conducts. If the speaker is tilted, the mercury switch breaks. This principle is used to control the on-off state of the circuit. Q1 is an N-channel MOSFET, which requires a positive voltage at its gate to conduct. When the mercury switch is on, the gate receives positive voltage, and Q1 conducts, providing power to the amplifier circuit. When the mercury switch is off, the gate is grounded through resistor R0, causing Q1 to turn off, thereby cutting off power to the amplifier circuit. Capacitor Co is used for switch debounce. Additionally, the operating current of the mercury switch is small; a 3 mm mercury switch cannot handle more than 300 mA of current. The speaker, however, requires approximately 1 A of operating current, hence a MOSFET is needed for control.

More information:

- MOSFET（Metal-Oxide-Semiconductor Field-Effect Transistor）是一种场效应晶体管，通常用于开关和放大应用。它具有三个主要电极：栅极（Gate, G）、漏极（Drain, D）、源极（Source, S）。本电路中使用的是 P 沟道 MOSFET（型号为 2302），它的工作原理是当栅极电压比源极电压更低时，MOSFET 导通，从源极到漏极的电流被允许通过；而当栅极电压和源极电压相等或栅极电压比源极电压高时，MOSFET 关闭，从而阻止电流流动。
- 在电路中，电源通过 Micro USB 接口输入，并提供 VDD 电压。电容 C0（10 F）作为旁路电容，用于滤波，降低电源电压中的噪声，提供稳定的直流电压给后续电路。PMOS 管 Q1（型号为 2302）是整个电路的核心开关元件，它与机械开关 S1 一起用于控制电源是否为后续电路供电。当 S1 闭合时，栅极通过电阻 R0（20kΩ）接地，形成一个负栅源电压，使 Q1 导通，从而使 VDD 电压能够传递给其他部分的电路；而当 S1 断开时，栅极通过 R0 与源极电压趋于同电位（无负压），使 Q1 截止，切断电源。电阻 R0 的作用是在开关 S1 打开时，将 Q1 的栅极电压拉高至接近源极电压（即 VDD），使得 Q1 能够正确关闭。当 S1 闭合时，R0 限制了从栅极到地的电流，确保栅极电压足够低于源极，使 Q1 导通。另外，PMOS 管 Q1 内部还自带有一个体二极管（图中箭头所示），它用于防止外部电压反向输入。如果电源方向接反，该二极管会阻断反向电流，防止损坏电路的其他元件。
- 这个电路的整体工作流程是：当插入电源时，输入电压经过 C0 滤波以确保其平稳；然后通过 S1 控制是否将电压 VDD 传递到下游电路。当 S1 闭合时，Q1 导通，电源得以供给后续电路；当 S1 断开时，Q1 截止，电源被切断，防止任何电流流动。这样设计的电路在实际应用中非常广泛，例如用于便携式电子设备中，用户可以方便地通过机械开关来控制电路是否供电，同时也具备反向电流保护的功能，防止因误操作造成电路的损坏。

2. Analyze the voltage and power amplification of the LM4863 amplifier circuit.

As we can see in **Figure 7**, it's exactly the same between the left tone and right tone. Thus, we just need to analyze the half.

For Amp 1L, $v_0 = 0$, $v_1 = -\frac{R_1}{Z_i}v_{in}$, and $\frac{v_1 - v_3}{20k\Omega} = \frac{v_3 - v_2}{20k\Omega}$, so that $v_3 = (v_1 + v_2)/2$.

As op amplifier, $v_3 = 0 \Rightarrow v_2 = -v_1 = \frac{R_1}{Z_i}v_{in} \Rightarrow v_{out} = v_2 - v_1 = \frac{2R_1}{Z_i}v_{in}$.

Thus, voltage gain A_v:

$$A_v = \frac{v_{\text{out}}}{v_{\text{in}}} = \frac{2R_1}{Z_i} = \frac{2R_1}{R_3 + \frac{1}{j\omega C_3}} = \frac{2j\omega C_3 R_1}{1 + j\omega C_3 R_3}$$

$$|A_v| = \frac{4\pi f C_3 R_1}{\sqrt{1 + (2\pi f C_3 R_3)^2}}, \quad \arg(A_v) = \frac{\pi}{2} - \arctan(2\pi f C_3 R_3)$$

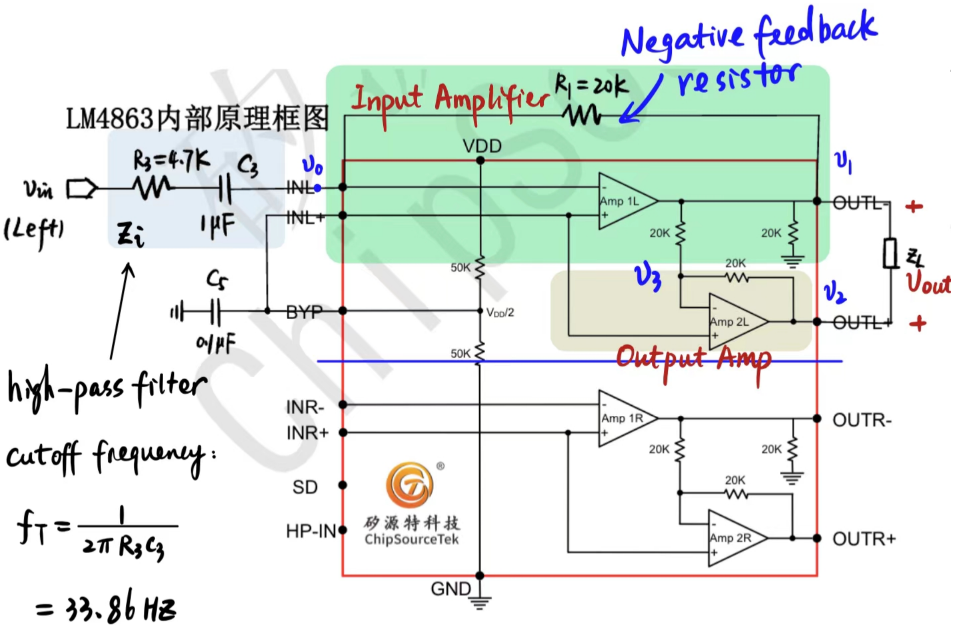

Figure 7: The analysis of circuit

Generally, we can regard C_3 only as a filter capacitor ($C_3 \to \infty$) and calculate:

$$|A_v| = \frac{2R_1}{R_3} = 8.51, \quad |A_v|_{\text{dB}} = 20\log\frac{R_1}{R_3} = 18.6\,\text{dB}$$

System cutoff frequency:

$$\text{Assume } |A_v| = \frac{\sqrt{2}}{2}\cdot\frac{2R_1}{R_3} \Rightarrow f_L = \frac{1}{2\pi C_3 R_3} = 33.86\,\text{Hz}$$

We can see that the cutoff frequency is determined by the input RC filter network. That's because v_0 is equal to zero in small signal circuit and input signal just generate and propagate circuit instead of voltage into the amplifier.

$$P_{\text{out}} = \frac{V_{\text{out}}^2}{R_L}, \quad S_{\text{in}} = \dot{U}\dot{I}^* = v_{\text{in}}\left(v_{\text{in}}^* \cdot \frac{1}{R_3 + j\omega C_3}\right) = \frac{|v_{\text{in}}|^2}{R_3 + j\omega C_3},$$

$$P_{\text{in}} = \text{Re}(S_{\text{in}}) = \frac{(2\pi f C_3)^2 R_3}{1 + (2\pi f C_3 R_3)^2}|v_{\text{in}}|^2$$

$$\Rightarrow G_p = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{1 + (2\pi f C_3 R_3)^2}{(2\pi f C_3)^2 R_3 R_L}\frac{|V_{\text{out}}|^2}{|V_{\text{in}}|^2} \approx 17.0$$

$$(G_p)_{\text{dB}} = 10\log G_p = 12.3\,\text{dB @ } 1\,\text{kHz}$$

The above analysis results can be plotted as shown in the Figure 8 and Figure 9.

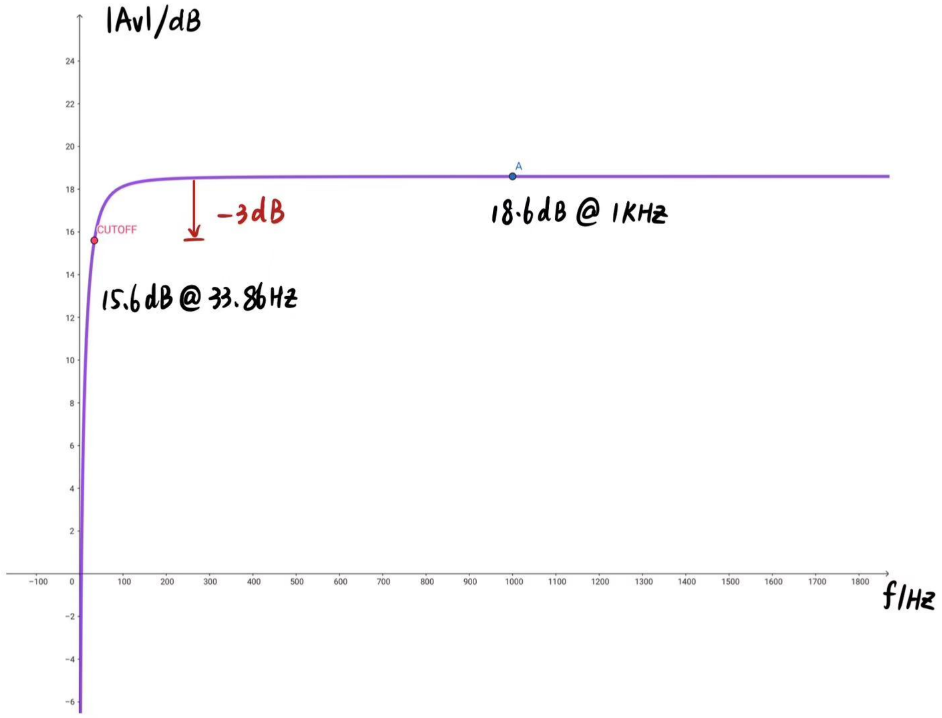

Figure 8: The analysis outcome of circuit (A_v-f)

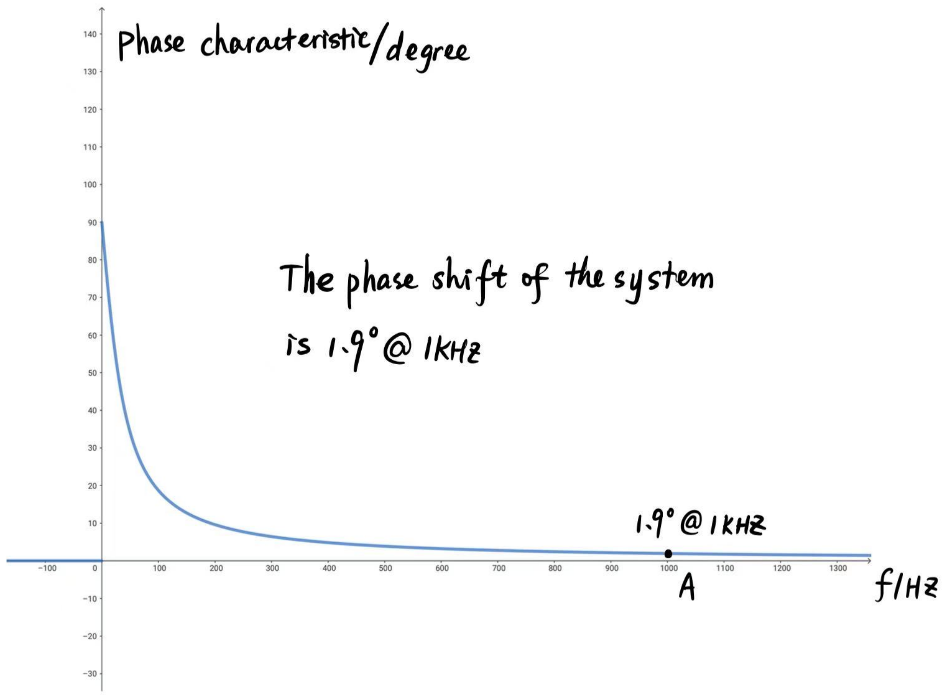

Figure 9: The analysis outcome of circuit (phase)

3.1.2 Discussion

In this part, we will analyze and discuss the data we got in Table 1 and Table 2, according to previous analysis.

1. We visualized the experimental data and the results are shown below.

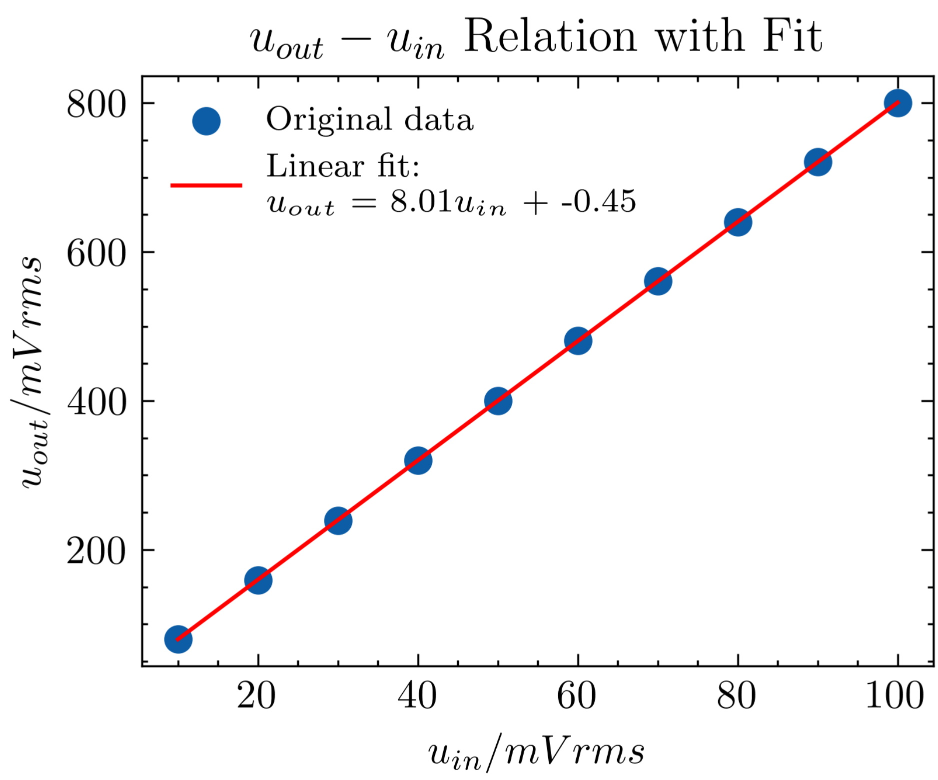

Figure 10: Voltage gain vs. frequency

2. What follows is a discussion of the above results.

   In Figure 10, we performed a linear fit on the experimental data. From the fitting parameters, we can see that the measured value of the voltage gain is 8.01, which is slightly different from the theoretical value of 8.51 we calculated, which is also reflected in Figure 13. On the other hand, we can see from Figure 11 that the voltage gain changes randomly with the output voltage and there is no obvious functional relationship, which shows that our measurement still has a certain degree of reliability.

   In Figure 12, we visualize the relationship between the voltage gain and the frequency. It is worth noting that, as shown in the previous theoretical analysis, -3dB is right around 35Hz. In addition, we performed a fitting, and the figure shows that the values of the components obtained by the fitting are somewhat different from the actual values.

   In Figure 13, we compare our measured results with our calculated theoretical predictions. Overall, the measured results are smaller. Especially in the low-frequency region, the measured

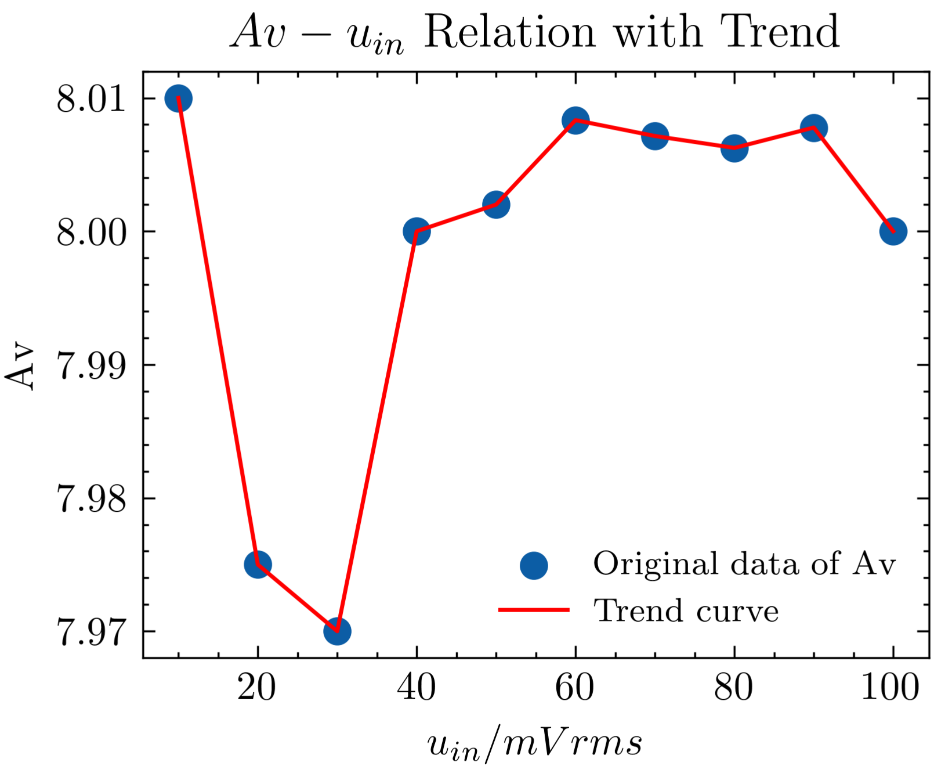

Figure 11: Comparison of the experimentally determined voltage gain versus frequency relationship with the ideal case

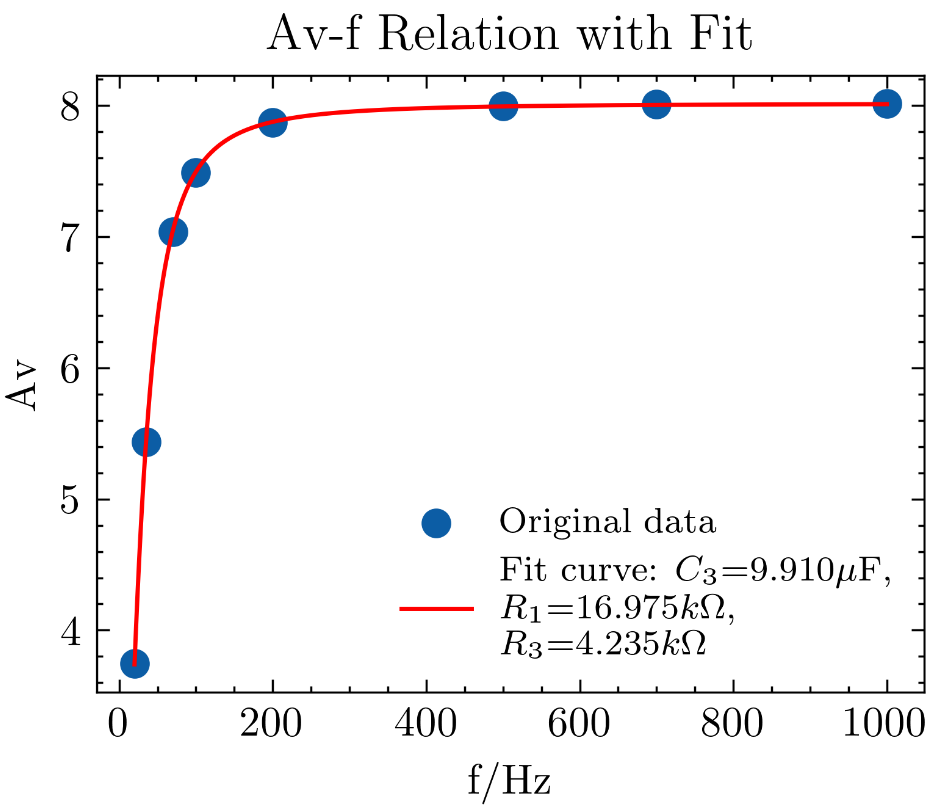

Figure 12: Fitting of amplification factor (the relationship between output voltage and input voltage)

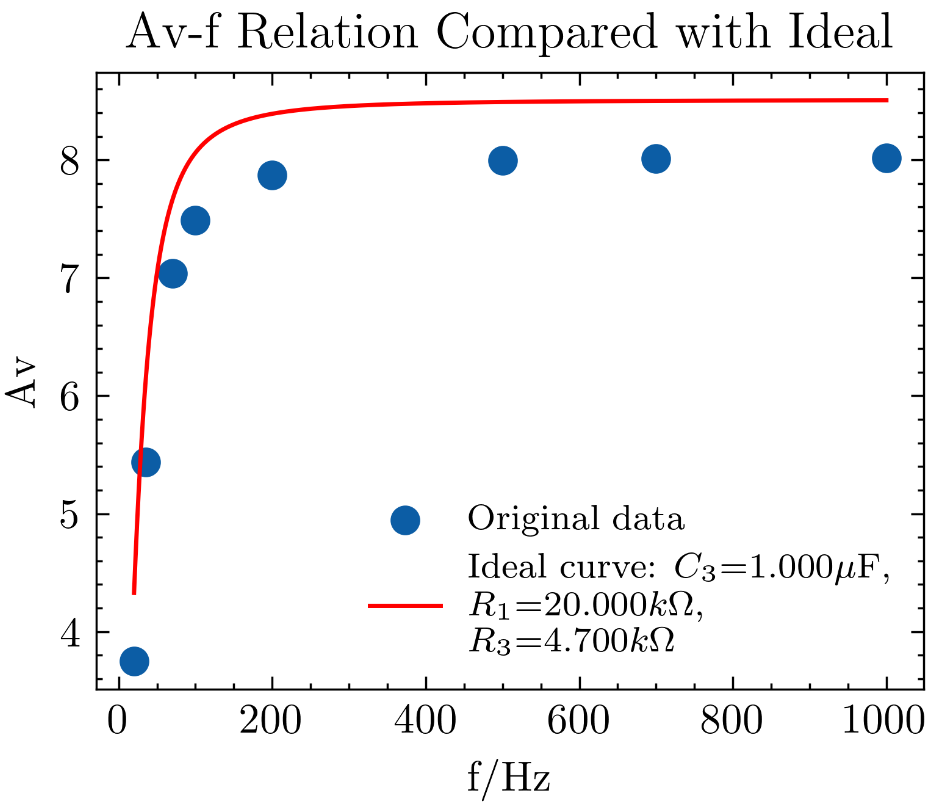

Figure 13: Voltage gain variation trend with input voltage

voltage gain is significantly lower than the theoretically calculated value. The following are possible reasons and analysis for this difference:

- Capacitor deviation and ESR (equivalent series resistance)

  The theoretical curve is calculated based on ideal components, but in reality, capacitors will have manufacturing deviations and additional characteristics. For example, C3 (1.000 μF) in the figure may have a certain deviation and is not exactly 1 μF. In addition, the equivalent series resistance (ESR) of the capacitor will introduce additional losses, especially in the low-frequency band. These factors may affect the efficiency of the signal passing through the capacitor, resulting in reduced gain.

- Low-frequency impact of input coupling capacitor

  Amplifier circuits usually use coupling capacitors to isolate DC bias. These coupling capacitors have limited transmission capabilities for low-frequency signals. When the frequency is low, the impedance of the capacitor is large, which will limit the passage of the signal, resulting in signal attenuation and reduced gain. Therefore, at low frequencies, the actual measured gain may be lower than the theoretical value.

- Gain-bandwidth limitation of amplifier

  The gain-bandwidth product of LM4863 may be limited at low frequencies. Actual operational amplifiers usually have gain-bandwidth limitations in design. When the frequency is low, the gain is affected by the internal circuit characteristics of the amplifier, such as open-loop gain characteristics and frequency compensation. This may cause the gain in the low frequency band to be not as high as ideal.

- The influence of parasitic capacitance and wiring

  In actual circuits, parasitic capacitance and wiring inductance affect the frequency response of the amplifier circuit. Especially at low frequencies, the parasitic capacitance of the wiring may introduce phase shift and signal loss, resulting in low actual gain. In addition, the parasitic impedance present in the PCB wiring may interact with other components, thereby affecting the overall frequency response.

- Component accuracy in negative feedback network

  The theoretical gain in the figure is calculated based on the precise values of R1 and R3. However, in actual circuits, the accuracy of these resistors (usually 5% or 1%) may have some deviation. Any slight deviation in the resistance value will change the proportion of negative feedback, resulting in the actual gain not being completely consistent with the theoretical calculated value, which may be more obvious at low frequencies.

- Temperature and power supply stability

  The performance of the amplifier circuit will also be affected by temperature changes, especially at low frequencies. The internal characteristics of the LM4863 are sensitive to temperature changes, which will affect the internal gain characteristics of the device, resulting in differences between the measured value and the theoretical value. In addition, the instability of the power supply voltage (ripple and noise) may also affect the gain at low frequencies.

- Test instrument and measurement error

  When measuring at low frequencies, the characteristics of the instrument itself may also affect the measurement results. For example, the low-frequency response of the signal source, the probe impedance of the oscilloscope, or the influence of the connecting line will cause certain errors in the measurement accuracy. These errors may not be obvious at high frequencies, but may be more prominent at low frequencies, resulting in deviations between the measured value and the theoretical value.

- Frequency response of coupling and decoupling capacitors

  The coupling capacitors (such as C4, C5) and decoupling capacitors (such as C1, C2) in the figure may also fail to fully function in the low frequency band. For example, the decoupling capacitors cannot fully eliminate low-frequency noise, which may affect the low-frequency gain of the amplifier. If the coupling capacitor is too small, it will have a great impact on the transmission of low-frequency signals, thereby reducing the low-frequency gain.

3.1.3 Conclusion

The performance of the LM4863 amplifier circuit is analyzed by welding the Bluetooth speaker. The actual operation of the circuit is evaluated by measuring the voltage gain and power gain, and the factors affecting the low frequency performance are discussed.

- The experimental results show that the voltage gain of LM4863 amplifier circuit varies with frequency and reaches the -3dB point around 35Hz, which is consistent with the theoretical analysis.
- However, the experimentally measured voltage gain value is usually lower than the theoretically calculated value, especially in the low frequency region. The measured voltage gain is 8.01, slightly lower than the theoretical value of 8.51. The power gain is about 17.0, or 12.3 dB@1kHz.
- These results suggest that the performance of a circuit at low frequencies may be affected by a variety of factors, including capacitor bias, input coupling capacitor influence, amplifier gain-bandwidth limitations, parasitic capacitance and wiring influence, component accuracy in a negative feedback network, temperature and power supply stability, test instruments and measurement errors, and the frequency response of coupling and decoupling capacitors.