HOWARD COLLEGE, UNIVERSITY OF KWAZULU-NATAL, DURBAN

Analogue Electronics – 2 (ENEL3AE-H2)

Year - 3 / Semester- 2 / 2025, Main Examination

Seat.	DO NOT WRITE IN THIS REGION	Student number:

Internal Moderator: Prof Hongjun Xu
Internal Examiner: Dr Bhekisizwe Mthethwa

Date: 5 November 2025 (Wednesday) **Time: 2 hours**
TOTAL MARKS: 70 marks
Instructions:

1. This is a closed-book examination. You can use a Calculator.
2. You are not allowed to use any notes or textbooks to assist you to answer the questions.
3. Write your answers in the space provided on the question paper.
4. Show all calculations on the question paper clear pages.
5. **Untidy work will not be marked**.
6. Please answer **ALL** the questions in the question paper

QUESTION 1 (Amplifier Low Frequency Response) [15 marks]

a) A deep-sea submarine uses SONAR acoustic waves to detect objects and navigate deep in the ocean. The acoustic waves require high amplitudes to propagate over long distances. To generate the high amplitude acoustic waves required for SONAR navigation, the submarines use an amplifier with a transfer function $G(s) = \frac{A_M\, s(s+3000)}{(s+4000)(s+2000)(s+20000)}$ that heavily relies on the amplifier circuit coupling and bypass capacitors. The amplifier output is then connected to an acoustic wave transducer that generates the acoustic waves. The amplifier has a linear midband gain of A_M. Based on this information, what is the **lowest** acoustic signal frequency, in *Hz*, you can supply and feed into the amplifier before the generated acoustic wave amplitude drops to 70.7% of its amplitude at midband frequencies?

[3 marks]

b)

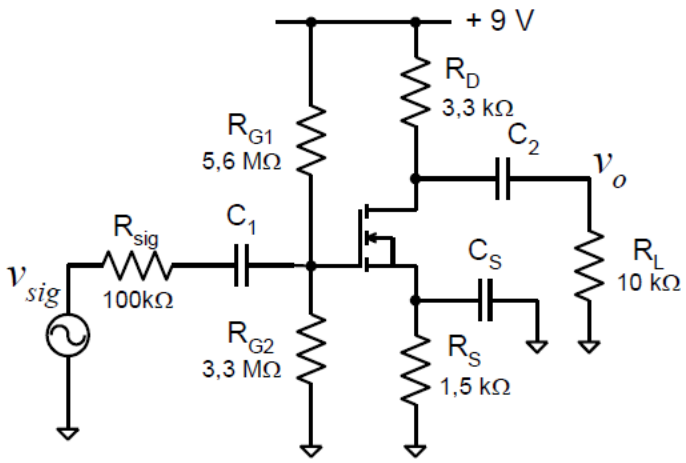


Fig. 1, "Common Source (CS) amplifier"

The CS amplifier in Fig. 1 has an enhancement N-channel type MOSFET with the following transconductance $g_m = 2mA/V$ and the Early effect is neglected. To simplify the **low** frequency response of this amplifier, an engineer proposes a design strategy such that the pole caused by the AC coupling capacitor C_2 cancels the zero produced by the bypass capacitor C_S and to place the remaining two poles at 20 Hz and 1 Hz.

Determine the AC coupling and bypass capacitor values required to meet this design objective such that the total capacitance is **minimized**. [**10 marks**]

c)

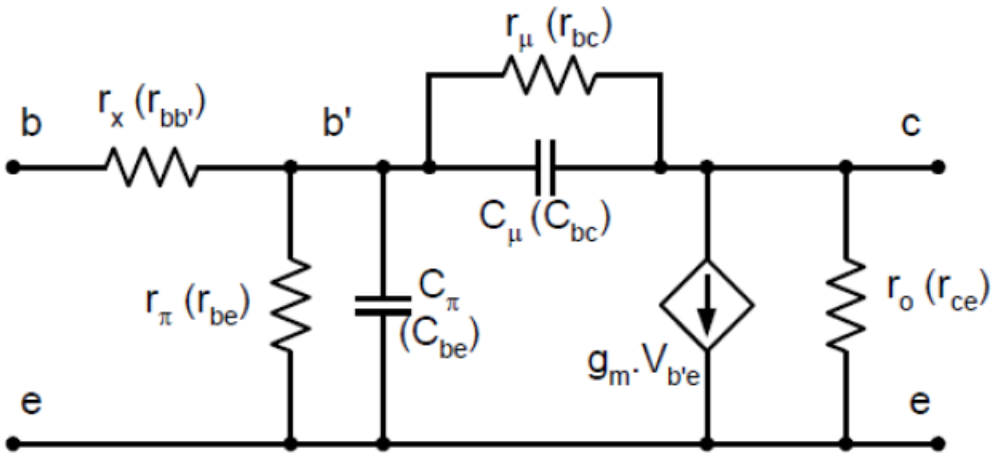


Fig. 2, "BJT high frequency small signal model"

Explain why in the **high** frequency and **low** frequency BJT small signal model the base-collector resistance r_μ, as shown in Fig. 2, is neglected when a BJT is used as part of an amplifier circuit?

[**2 marks**]

QUESTION 2 (Amplifier High Frequency Response) [14 marks]

a) For a 2-port network with an admittance (Y) as a bridge between the input port and output port, show that the admittance (Y) may be split into admittance (Y_1) at the input port and admittance (Y_2) at the output port with both admittances taking the form $Y_1 = f_1(Y, A_v)$ and $Y_2 = f_2(Y, A_v)$, where A_v is an independently determined voltage gain between the input and output voltage of the 2-port network.

[**4 marks**]

b)

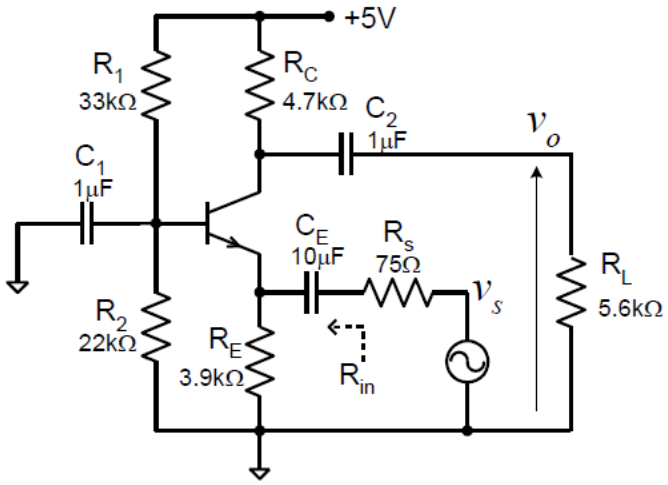


Fig. 3, "Common-Base (CB) Amplifier"

For the CB amplifier circuit shown in Fig. 3, the following BJT data is given:
The unity gain transition frequency is $700MHz;\ C_{ob} = 1pF; I_E = 0.33mA; h_{FE} = 120, \& \ r_x = 0\Omega$

i) Draw an appropriate **high**-frequency small signal equivalent circuit of Fig. 3**.** [**2 marks**]

ii) Find the input resistance R_{in} seen by the source at **high** frequencies. Note that R_{in} is as indicated in Fig. 3. [**2 marks**]

iii) Calculate the internal capacitances of the BJT **high** frequency small signal model of the CB amplifier in Fig. 3. [**2 marks**]

iv) Estimate the linear frequency of the two poles and, hence, the upper −3 dB corner frequency f_H of the CB amplifier in Fig. 3. [**4 marks**]

QUESTION 3 (Amplifier Negative Feedback) [20 marks]

a)

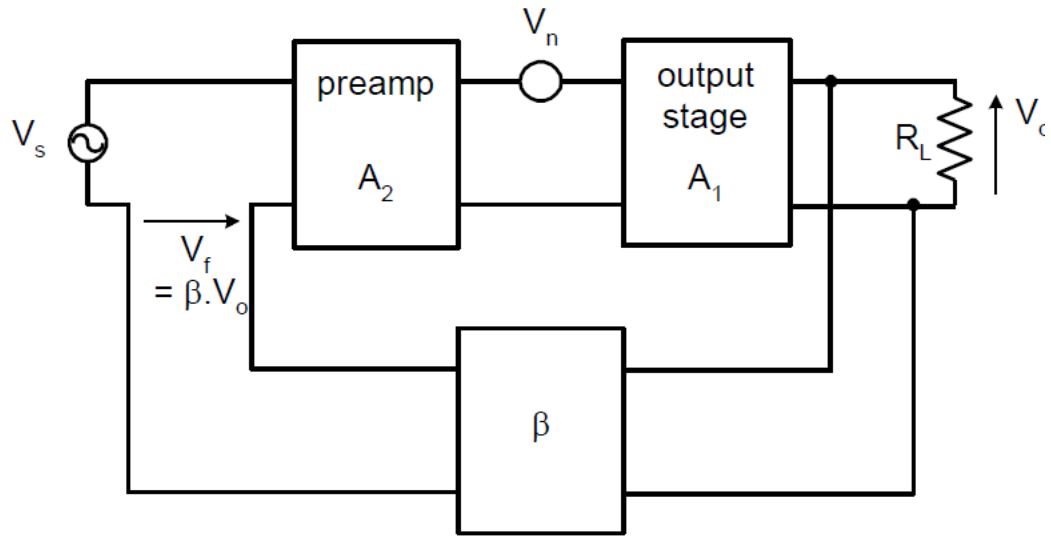


Fig. 4, "Audio Power Amplifier with Hum/Ripple Noise"

An audio power amplifier, as shown in Fig. 4, has an output stage with a gain of $0{,}9\ V/V$ and up to $1\ V_{pk-pk}$ supply voltage ripple/hum. To reduce this ripple/hum, a low ripple/hum preamplifier is used within a negative feedback loop. The closed loop gain required is $10\ V/V$. Determine the gain of the preamplifier and the feedback factor β required if the output ripple/hum is to be reduced to $10\ mV_{pk-pk}$. **[5 marks]**

b)

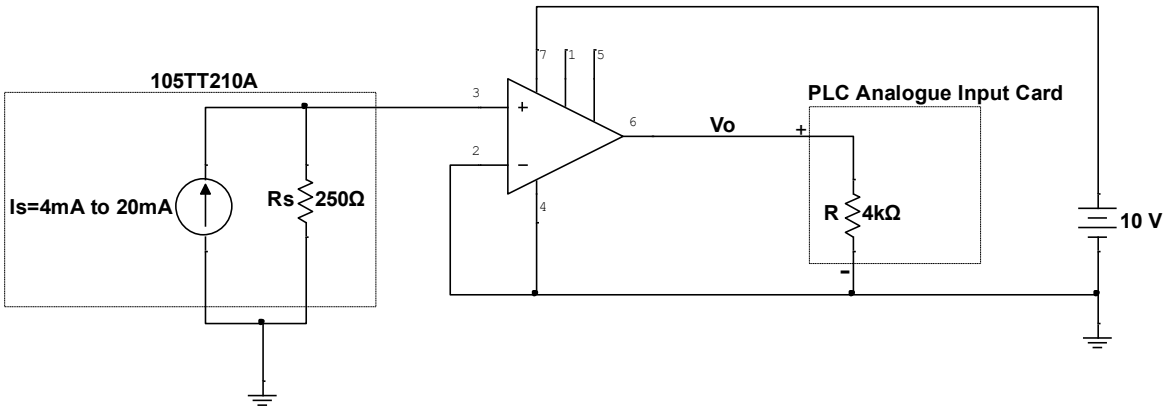


Fig. 5, "Temperature Transmitter Loop Diagram"

Fig. 5 is a modified loop diagram of a 2-wire temperature transmitter (105TT210A) that outputs a linear 4-20mA signal that is directly mapped to a linear scale of temperature with a range $-40°C\ to\ 40°C$. A 4mA signal output corresponds to a sensed temperature of $-40°C$ and 20mA corresponds to $40°C$. For example, a temperature of $0°C$ will have the temperature transmitter sourcing a current of $I_S = 12mA$. The temperature transmitter signal is transmitted to the Programmable Logic Controller (PLC) analogue input card for conversion to a digital value. The temperature transmitter current source has an output resistance $R_s = 250\Omega$. The OP-AMP has an input differential resistance of $R_{id} = 250\Omega$ that converts the OP-AMP input current to a differential voltage V_{id}. The OP-AMP open loop voltage gain is $A_{OL} = 10^4\ V/V$ and its output resistance is $r_o = 4k\Omega$.

i) The objective of the loop diagram in Fig. 5 is to ensure that the temperature transmitter (105TT210A) 4-20mA current is accurately converted to 1V-5V range at the input terminals of the PLC analogue input card. However, the circuit is obviously showing imperfections since if the transmitter outputs $I_S = 12mA$, for example, only 6mA will flow through the OP-AMP R_{id}. To remedy the imperfections, draw the **corrected** modified loop diagram so that the transfer gain of the amplifier is stabilized as follows $A_{vf} \approx 1\ V/V$, assuming the loop gain is very large. Explain how you arrived at your answer. **[3 marks]**

ii) Draw the **loaded** "A network" of the **corrected** modified loop diagram considering the loading effects of the feedback passive network and explain your steps. [**3 marks**]

iii) Using the **loaded** "A network" show that, without making assumptions about the loop gain, the actual stabilized transfer gain is indeed $A_{vf} = \frac{v_o}{v_s} \approx 1\ V/V$. [**5 marks**]

iv) Calculate the input resistance, R_{IN}, as seen by the temperature transmitter when the transfer gain is stabilized i.e $A_{vf} \approx 1\ V/V$. [**2 marks**]

v) Calculate the output resistance, R_{OUT}, as seen by the PLC analogue input card when the transfer gain is stabilized i.e $A_{vf} \approx 1\ V/V$. [**2 marks**]

QUESTION 4 (Positive Feedback and Oscillators) [15 marks]

a)

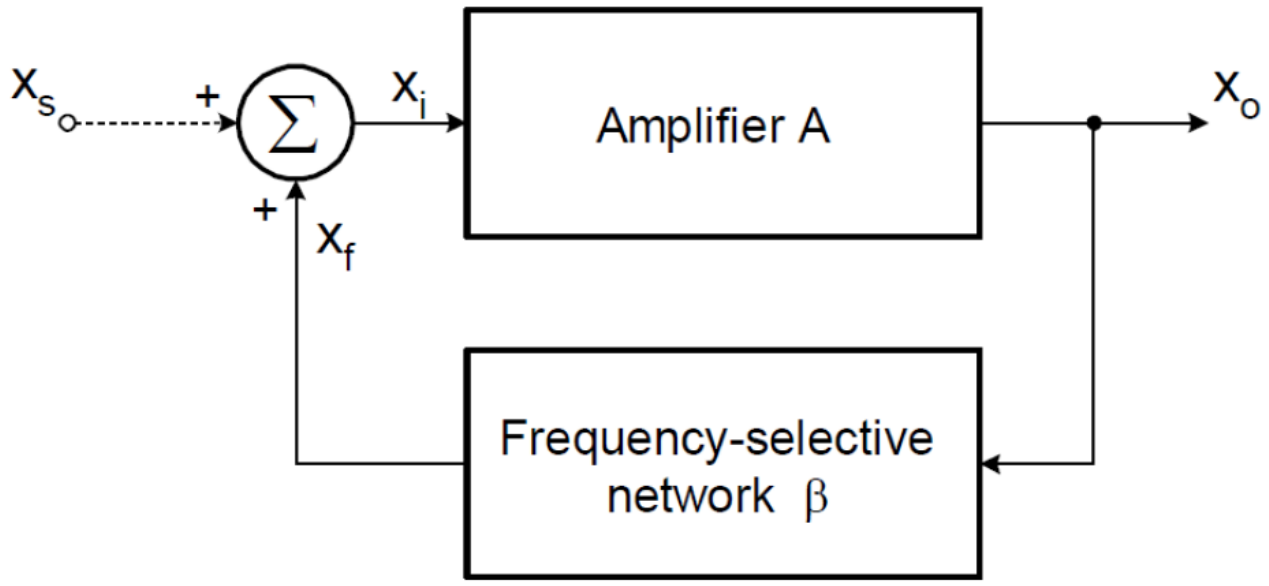


Fig. 6, "A signal flow diagram of an amplifier with positive feedback"

The amplifier, in Fig 6, is setup with **positive** feedback with the intention of creating an oscillator. The amplifier has a frequency dependent voltage gain A and the feedback network has a frequency dependent feedback factor β. The output signal of the amplifier is $X_o = AX_i$ and **positive** mixing, $X_i = X_s + X_f$, is used at the input to produce the input signal, X_i, into the amplifier. The feedback signal is $X_f = \beta X_o$.

Based on the provided information explain, using a **mathematical** technique, why it is necessary for the loop gain $\beta(s)A(s)$>1 for oscillations to start and why eventually setting the loop gain $\beta(s)A(s)$=1 is necessary to sustain oscillations? [**Note:** Assume thermal noise acts as an input signal according to $X_s(t) = n\delta(t) = \begin{cases} n, t = 0 \\ 0, t > 0 \end{cases}$ where $\delta(t)$ is the Dirac-delta function and n is a noise constant.] [**5 marks**]

b)

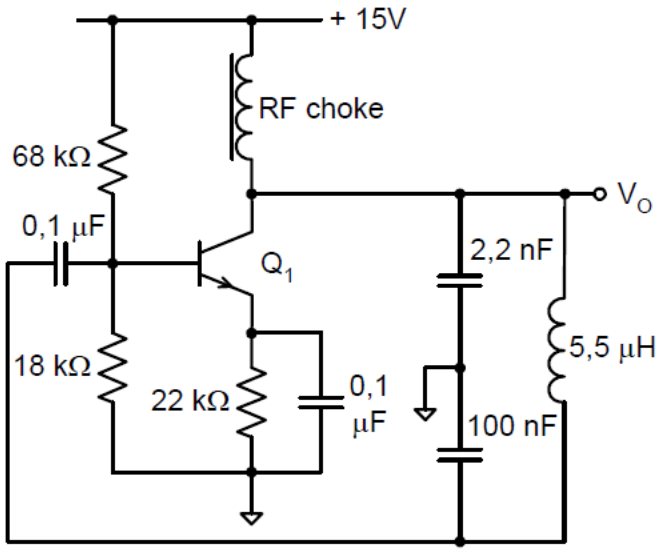


Fig. 7, "An LC-Oscillator circuit"

Fig. 7, exhibits an LC oscillator using a common-emitter (inverting) amplifier circuit.

i) Draw an appropriate **simplified** small signal circuit of an LC oscillator which is of the same type as that shown in Fig. 7. [**1 mark**]

ii) **Hence**, derive a mathematical expression, using nodal analysis, of the LC oscillator output signal frequency f_o. [**7 marks**]

iii) **Hence**, calculate the **linear** frequency of oscillation of the oscillator in Fig. 7. [**2 marks**]

QUESTION 5 (BJT Pairs) [6 marks]

a)

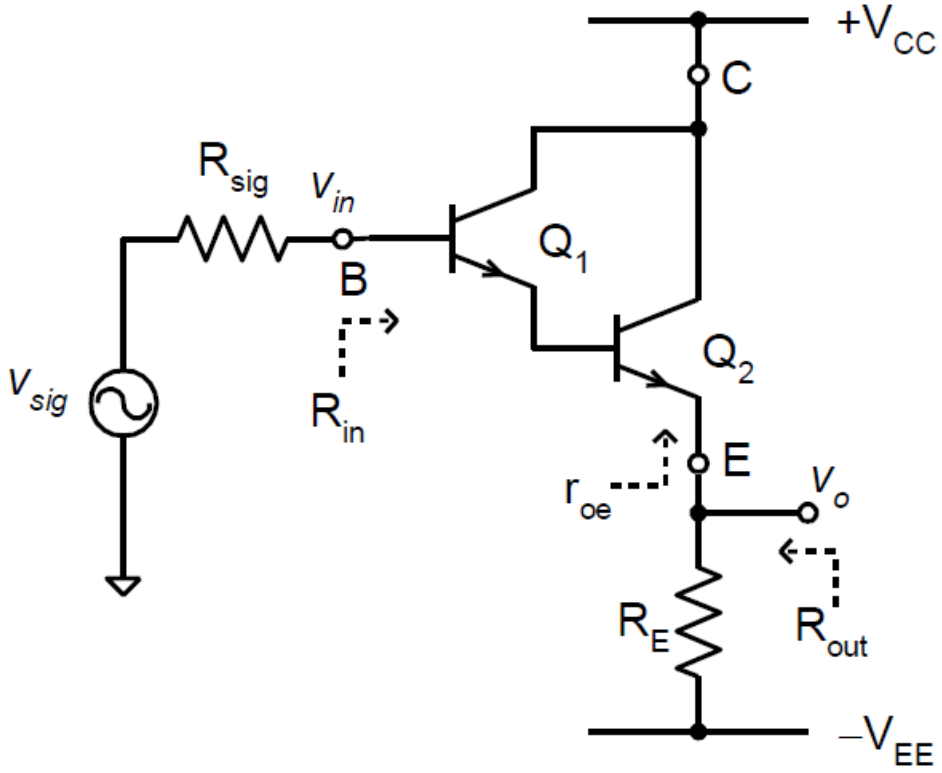


Fig. 8, "NPN Darlington Pair"

In Fig. 8, the first BJT Q_1 has a DC forward current gain $h_{FE1} = 100$ and the BJT Q_2 has a DC forward current gain of $h_{FE2} = 100$. The emitter resistance $R_E = 1k\Omega$ and $R_{sig} = 100k\Omega$. The emitter current flowing through resistor R_E is 5mA. The thermal voltage at room temperature is given as 25mV.

i) Draw a **midband** small signal equivalent circuit, using **ONLY** the **T-model** for the BJTs, of Fig. 8 neglecting the Early effect. [**2 marks**]

ii) Determine the output resistance, R_{out}, as seen from the output stage of the Darlington pair as shown in Fig. 8. [**4 marks**]

END OF QUESTIONS

Analogue Electronics 2 List of Formulae:

-3dB corner frequency approximations:

$$f_L \approx \frac{1}{2\pi}\sqrt{\sum_{i=1}^{n_L}\omega_{Pi}^2 - 2\sum_{i=1}^{n_L}\omega_{Zi}^2}$$

$$f_H \approx \frac{1}{2\pi\sqrt{\sum_{j=1}^{n_H}\frac{1}{\omega_{Pj}^2} - 2\sum_{j=1}^{n_H}\frac{1}{\omega_{Zj}^2}}}$$

SCTC and OCTC:

$$f_L \approx \frac{1}{2\pi}\sum_{i=1}^{n_L}\frac{1}{C_i R_{is}},\ f_H \approx \frac{1}{2\pi\sum_{j=1}^{n_H} C_j R_{jo}}$$

BJT Base-Emitter forward-biased diode dynamic resistance:

$$r_{be} = \frac{h_{FE}V_T}{I_{C(q)}}$$

BJT Transconductance:

$$g_m = \frac{I_{C(q)}}{V_T}$$

BJT Transistor Voltage Controlled Current Source Output Resistance:

$$r_{CE} \approx \frac{V_A + V_{CE(q)}}{I_{C(q)}}$$

BJT Input diffusion Capacitance of Base-Emitter forward-biased diode:

$$C_{be} = \frac{g_m}{2\pi f_T} - C_{bc}$$

MOSFET internal capacitances:

$$C_{gs} = C_{iss} - C_{rss}$$
$$C_{ds} = C_{oss} - C_{rss}$$

High Frequency Response Pole and Zero Frequency Approximations:

$\omega_{P2} \approx \frac{g_m}{C_{gs}}, \omega_Z \approx \frac{g_m}{C_{gd}}$ for Common-Source Amplifier

$\omega_{P2} \approx \frac{g_m}{C_{be}}, \omega_Z \approx \frac{g_m}{C_{bc}}$ for Common-Emitter Amplifier

MOSFET DC drain current (I_D) to Gate-Source (V_{GS}) voltage Relationship in Saturation Mode.

$I_D = \frac{1}{2} k_n'(W/L)(V_{GS} - V_t)^2$ if $V_{DS} \geq (V_{GS} - V_t)$

Feedback Amplifiers' Resistance Formulae:

Current/Series Sampling

$R_{out} = R_{of} - R_L$

Voltage/Shunt Sampling

$$R_{out} = \frac{R_{of} R_L}{R_L - R_{of}}$$

Current/Shunt Mixing

$$R_{in} = \frac{R_{if} R_{sig}}{R_{sig} - R_{if}}$$

Voltage/Series Mixing

$R_{in} = R_{if} - R_{sig}$

Oscillators' Formulae:

Piezoelectric Crystal Oscillators:

$f_s = \frac{1}{2\pi\sqrt{LC_s}}$ and $f_p = f_s\sqrt{1 + \frac{C_s}{C_p}}$

Miller's Theorem:

$$Y_{in} = Y(1 - A_v) \;\&\; Y_{out} = Y\left(1 - \frac{1}{A_v}\right)$$