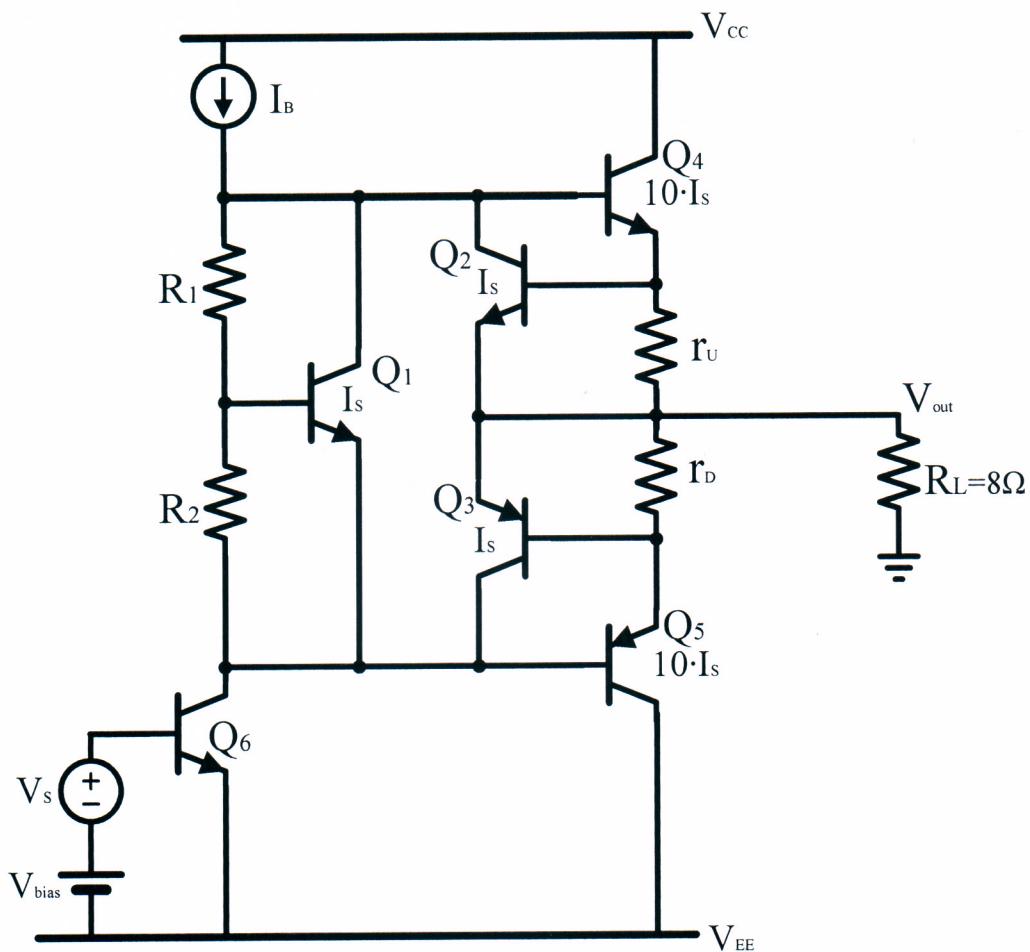


[1] Consider the following output stage circuit. (Assume $V_A = \infty$) [35 points]

$$V_{BE2,active} = V_{BE3,active} = 0.7V, V_T = 26mV, I_s = 1 \times 10^{-13}A$$



- A. What is the minimum $V_{cc} (= -V_{ee})$ to deliver 100W power on 8Ω load with sinusoidal signal? Assume 2V of voltage headroom from the supply. [5 points]

$$V_{out} = V_p \sin \omega t$$

$$P_{out} = \frac{1}{2} \cdot \frac{V_p^2}{R_L} = 100W \Rightarrow V_p = 40V$$

/2

2V의 voltage headroom이 있으므로 하드로우

$$V_{cc} = 42V, \quad V_{ee} = -42V$$

/3

B. To limit output current with 7A, what is r_U and r_D ? [5 points]

7A 이상의 전류가 흐르게 되면 short circuit protection 회로가
active 상태가 되어 output transistors (Q_4, Q_5)의 base 전류를

줄여줘야 하므로

$$\frac{r_U}{2.5} = \frac{r_D}{2.5} = \frac{V_{BE, active}}{7A} = 0.1 \Omega$$

시그널 쓰면 각 17.5 mV

C. To satisfy the result of A, what is minimum bias current, I_B ? Assuming $\beta_{NPN} = 100, \beta_{PNP} = 20$. [7 points]

V_{out} 이 40V 일 때 pull down transistor Q_5 가 input transistor

Q_6 가 깨지게 되므로 I_B 는 모두 Q_4 의 base에 흐르게 된다. /1

$$\therefore (1 + \beta_{NPN}) \cdot I_B \geq \frac{40V}{8\Omega} /2$$

$$\therefore I_B \geq 49.5 \text{ mA.}$$

즉, minimum bias current, $I_B = 49.5 \text{ mA. } /4$

$I_C \approx I_E$ 로 보고 $I_B = 50 \text{ mA}$ 를 풀이로 정답 인정.

(참고: pull up transistor Q_4 가 깨지고 pull down transistor Q_5 가

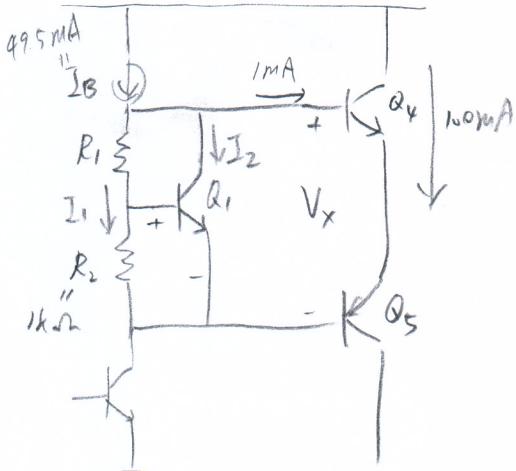
깨진 경우: Q_5 의 base에 $\frac{5A}{21} \approx 238 \text{ mA}$ 가 흐러 나가고

$I_{E, Q_4} + I_D \approx 288 \text{ mA}$ 가 Q_6 를 통해 V_{EE} 에 흐러 나간다.)

D. Using the result of C (bias current, I_B) , to set the Quiescent current at the output to 100mA, what is R_1 ?

Assume $R_2 = 1k\Omega$, and $r_u = r_D = 0\Omega$. (Assume β of Q_1 is big enough, that is, $I_{C1} \approx I_{E1}$.) [10 points]

$$V_U = V_D = 0.2L \Rightarrow Q_2, Q_3 \text{ off}$$



$$V_x = 2.4 \ln \frac{100mA}{10I_s} = 1.5205V$$

$$\begin{aligned} V_{BE,01} &= V_T \ln \frac{I_2}{I_s} = V_T \ln \frac{(48.5mA) - I_1}{I_s} \dots ① \\ &= I_1 R_2 \dots ③ \end{aligned}$$

$$①, ② \text{ 시 } \frac{1}{2} \text{ 편법하면 } I_1 = 800.872 \mu A / 3$$

$$\therefore I_1 \cdot (R_1 + R_2) = V_x / 3$$

$$\therefore R_1 = 898.559 \Omega / 4$$

$$(I_B = 50mA \text{ 은 } \frac{1}{2} \text{ 편법에서 } R_1 = 899.918 \Omega \text{ 를 } \text{ 구해온 정답})$$

E. What is the power efficiency when $V_{out} = 10 \sin \omega t$? Ignore the power dissipation at pre-driver. (Assume that each transistor carries a negligible current around $V_{out} = 0$ and turns off for half of the period.) [8 points]

$$\eta = \frac{P_{out}}{P_{out} + P_{av,n} + P_{av,p} + P_{ru} + P_{rd}} / 1$$

$$P_{out} = \frac{1}{2} \cdot \frac{(10V)^2}{8\Omega} = 6.25W / 1$$

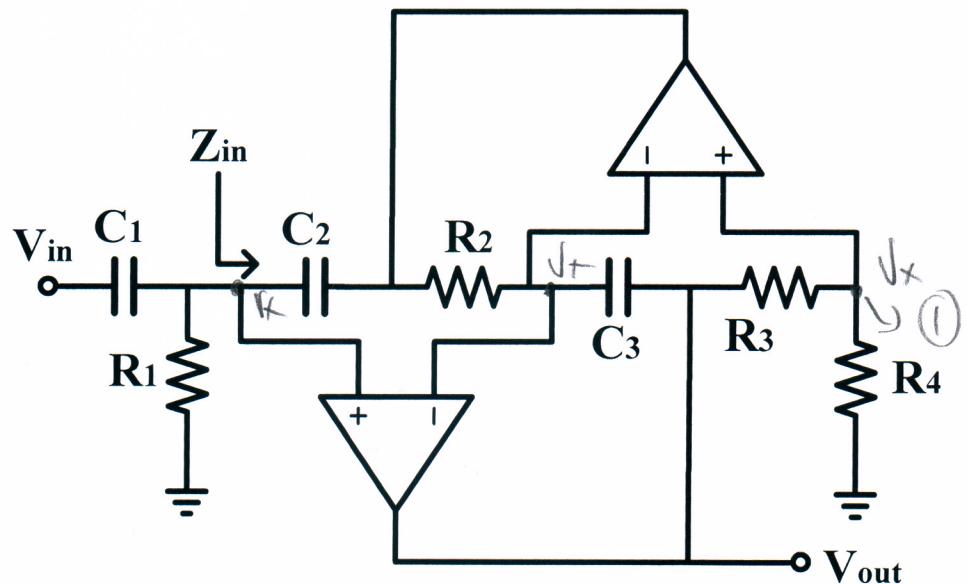
$$P_{ru} = \frac{1}{T} \int_{T/2}^T I^2 \cdot r_u dt = \frac{1}{T} \int_{T/2}^T \left(\frac{10 \sin \omega t}{R_L} \right)^2 \cdot r_u dt = 0.039W = P_{rd} / 1$$

$$P_{av,n} = \frac{1}{T} \int_{T/2}^T \left(V_{cc} - V_{out} - \frac{V_{out} \cdot r_o}{R_L} \right) \cdot \frac{V_{out}}{R_L} dt = \frac{10V_{cc}}{\pi R_L} - \frac{10^2}{4R_L} \left(1 + \frac{r_o}{R_L} \right) = 13.547W = P_{av,p} / 1$$

$$\therefore \eta = 0.187 \quad \therefore 18.7\% / 2$$

(※: $r_u, r_D = 0$ 이라고 풀었을 때와 결과가 같다.)

[2] Consider the circuit below. Assume all OP-Amps are ideal. [20 points]



A. Calculate $Z_{in}(s)$. [6 points]

$$Z_{in}(s) = \frac{R_4}{C_2 s + C_3 s + R_2 \cdot R_3} = \frac{R_4}{R_2 R_3 C_2 C_3 s^2}$$

사소한 틀림은 1점

B. Derive $H(s)$ of this circuit. [6 points]

$$\text{node } ①: V_x \left(\frac{1}{R_3} + \frac{1}{R_4} \right) = \frac{V_{out}}{R_3} \Rightarrow V_x = \frac{R_4}{R_3 + R_4} V_{out}. \dots 2 \text{ points}$$

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{V_x}{V_{in}} \cdot \frac{V_{out}}{V_x} = \frac{R_1 \| Z_{in}}{\frac{1}{C_1 s} + R_1 \| Z_{in}} \cdot \frac{R_3 + R_4}{R_4} \dots 2 \text{ points}$$

$$= \frac{R_3 + R_4}{R_4} \cdot \frac{C_1 s}{\frac{R_2 R_3 C_2 C_3}{R_4} s^2 + C_1 s + \frac{1}{R_1}} : \text{Band-pass filter.} \dots 2 \text{ points.}$$

~~여기서 2개의 미분항은 0이다.~~

C. Determine $S_{C_1}^Q$, the sensitivity of Q to a change in C_1 . [8 points]

$$\frac{W_n}{Q} = \frac{R_4 C_1}{R_2 R_3 C_2 C_3}, \quad W_n = \sqrt{\frac{R_4}{R_1 R_2 R_3 C_2 C_3}}$$

$$Q = \frac{1}{C_1} \sqrt{\frac{R_2 R_3 C_2 C_3}{R_1 R_4}} \rightarrow \frac{k}{C_1} \text{ 2 points.} \dots 2 \text{ points.}$$

$$\underline{S_{C_1}^Q = \frac{\partial Q / \partial}{\partial C_1 / C_1} = \frac{\partial Q}{\partial C_1} \cdot \frac{C_1}{Q} = -\frac{k}{C_1^2} \cdot \frac{C_1}{k/C_1} = -1.}$$

↳ 2 points.

↳ 4 points.

[1] Answer the following questions about Butterworth Response and Chebyshev Response.

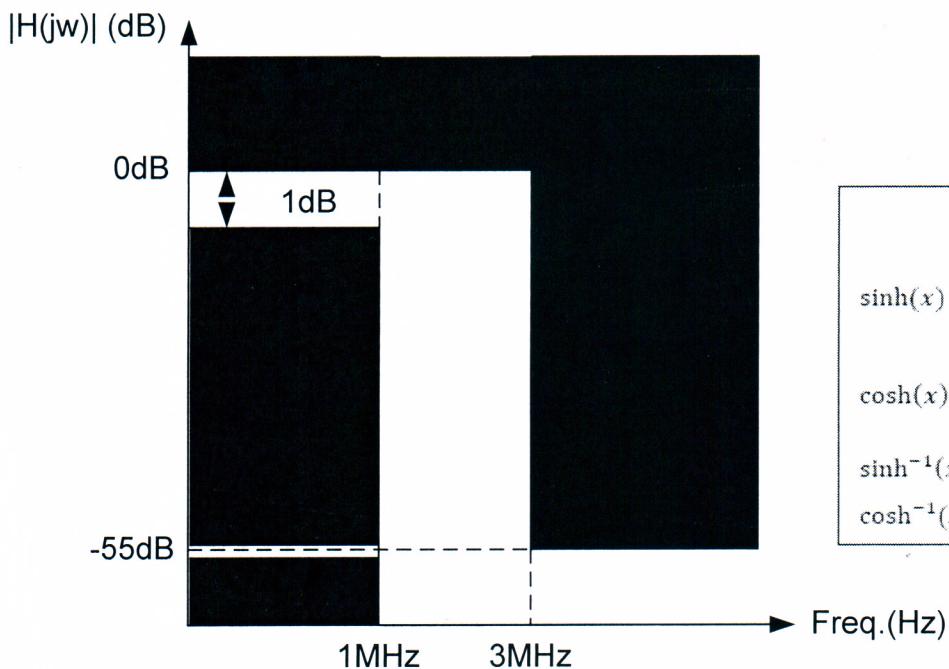
$$|H(jw)| = \frac{1}{\sqrt{1 + \left(\frac{w}{w_0}\right)^{2n}}} , p_k = w_0 \exp \frac{j\pi}{2} \exp \left(j \frac{2k-1}{2n} \pi \right) (k = 1, 2, \dots, n)$$

<Transfer function & Poles of the Butterworth Response>

$$|H_{PB}(jw)| = \frac{1}{\sqrt{1 + \epsilon^2 \cos^2 \left(n \cos^{-1} \frac{w}{w_0} \right)}}, \quad |H_{SB}(jw)| = \frac{1}{\sqrt{1 + \epsilon^2 \cosh^2 \left(n \cosh^{-1} \frac{w}{w_0} \right)}}$$

$$p_k = -w_0 \sin \frac{(2k-1)\pi}{2n} \sinh \left(\frac{1}{n} \sinh^{-1} \frac{1}{\epsilon} \right) + j w_0 \cos \frac{(2k-1)\pi}{2n} \cosh \left(\frac{1}{n} \sinh^{-1} \frac{1}{\epsilon} \right) (k = 1, 2, \dots, n)$$

<Transfer function & Poles of the Chebyshev Response>



Useful Equations

$$\sinh(x) = \frac{e^x - e^{-x}}{2}$$

$$\cosh(x) = \frac{e^x + e^{-x}}{2}$$

$$\sinh^{-1}(x) = \ln(x + \sqrt{x^2 + 1})$$

$$\cosh^{-1}(x) = \ln(x + \sqrt{x^2 - 1}), \quad x \geq 1$$

<Chebyshev Filter>

- For Butterworth Response, Passband Ripple < 1dB, Attenuation@3MHz > 60dB should be satisfied.
- For Chebyshev Response, Passband Ripple=1dB, Attenuation@3MHz > 60dB should be satisfied.

- A. Determine the order of each filter (Butterworth Response & Chebyshev Response) when you satisfy the above specification. [10 points]

$$\text{Butterworth} \quad \frac{1}{1 + \left(\frac{f_2}{f_0}\right)^{2n}} > 10^{-\frac{1}{20}} \quad \frac{1}{\left(\frac{f_2}{f_0}\right)^{2n}} > \frac{1}{0.89125^2 - 1} \quad \left\{ \begin{array}{l} \left(\frac{f_2}{f_0}\right)^{2n} > 3.8620 \times 10^6 \\ n > 6.37869 \end{array} \right. \Rightarrow n = 7$$

$$\frac{1}{1 + \left(\frac{f_2}{f_0}\right)^{2n}} < 10^{-\frac{55}{20}} \quad \left(\frac{f_2}{f_0}\right)^{2n} > \frac{1}{0.89125^2 - 1}$$

여기까지 4점

$$\text{Chebyshev} \quad 2 \log \sqrt{A_{\infty}^2} = 1 \Rightarrow \varepsilon = 0.509$$

$$\frac{1}{1 + 0.509^2 c_0 h^2 (N_0 h^2)^3} < 0.8911718 \quad n > 4.3695 \Rightarrow n = 5$$

여기까지 4점

- B. Using determined n above for the Butterworth response, get the range of ω_0 . [10 points]

$$f_0^{2n} < \frac{\left(\frac{f_2}{f_0}\right)^{2n}}{0.89125^2 - 1} \quad f_1 < f_0 < \frac{f_2}{\left(0.89125^2 - 1\right)^{1/4}}$$

$$f_0^{2n} > \frac{f_1^{2n}}{0.89125^2 - 1}$$

1.10M 1.214M

여기까지 4점

$$\omega_0 = \sqrt{6.91983 \times 10^6 \text{ rad/s}}$$

$$\omega_0 = \sqrt{17.6284 \times 10^6 \text{ rad/s}}$$

여기까지 10점

- C. If you want to achieve higher attenuation in the stopband with the same order (n=constant), how will you place zeros in the s-plane? Explain why. [5 points]

$$+j, -j \quad s^2 + 1 \rightarrow \sqrt{(1-w^2)^2} \quad \text{attenuation } M$$

imaginary axis Like Notch filter

$$|H(j\omega)| =$$

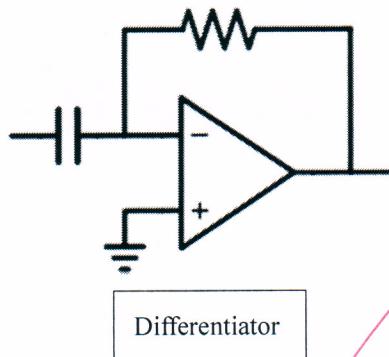
여기까지 5점

* 그 외 답안 *

- 실수축에 놓는다.
- 좌축에 2개를 넣는다. $-1j, +1j \Rightarrow s^2 + 2s + 2 = s + j\sqrt{3} + 1$ $\frac{j\sqrt{3}(s+1)}{s+1+j\sqrt{3}}$ $(2-w^2)^2 + (2w)^2 = w^4 + 4$: 5점
- $|H(s)| = s^2 + 25$
- $H(j\omega) = -\omega^2 - 25$
- $|H(j\omega)| = \omega^2 + 25 \rightarrow 0점$
- 우축 91 25로 넣는다. $s^2 + 2s + 2 \xrightarrow{\text{notch}} \frac{s^2 + 4s + 12}{s^2 + 4s + 12} \xrightarrow{\text{위배}} 0점$
- $s + j\omega$ 로 넣는다. $H(j\omega) = j\omega^2 + 1 \xrightarrow{\text{notch}} \frac{(\omega^2 + 1)^2}{(\omega^2 + 1)^2} \xrightarrow{\text{위배}} 0점$
- $\Rightarrow |H(j\omega)| = \sqrt{\omega^2 + 1} \xrightarrow{\text{위배}} 0점$
- 여기까지 -2점

[2] In the textbook, KHN biquad is realized in integrator-based biquads. This time, we want to realize biquad of given transfer function $H(s)$ in differentiator-based biquads. Answer the following questions. (Hint: Differentiator looks like below.)

$$H(s) = \frac{w_n^2}{s^2 + \frac{w_n}{Q}s + w_n^2} = \frac{V_{out}}{V_{in}}$$



시작점 - 1점.

$$\sim \frac{w_n^2}{s^2} V_x$$

- A. Draw the flow diagram. (**Caution:** You cannot put differentiated or integrated input into the amplifier. You can only put input by multiplying coefficient. If you violate this rule, you will get zero credit.) [10 points]

<Diff>

$$V_{out} s^2 + V_{out} \frac{w_n}{Q} s + \boxed{\frac{w_n^2}{Q} V_{out}} = w_n^2 V_{in}$$

$$V_{out} = -\frac{s^2}{w_n^2} V_{out} - \frac{1}{Q w_n} s V_{out} + V_{in}$$

5 10

Integrator

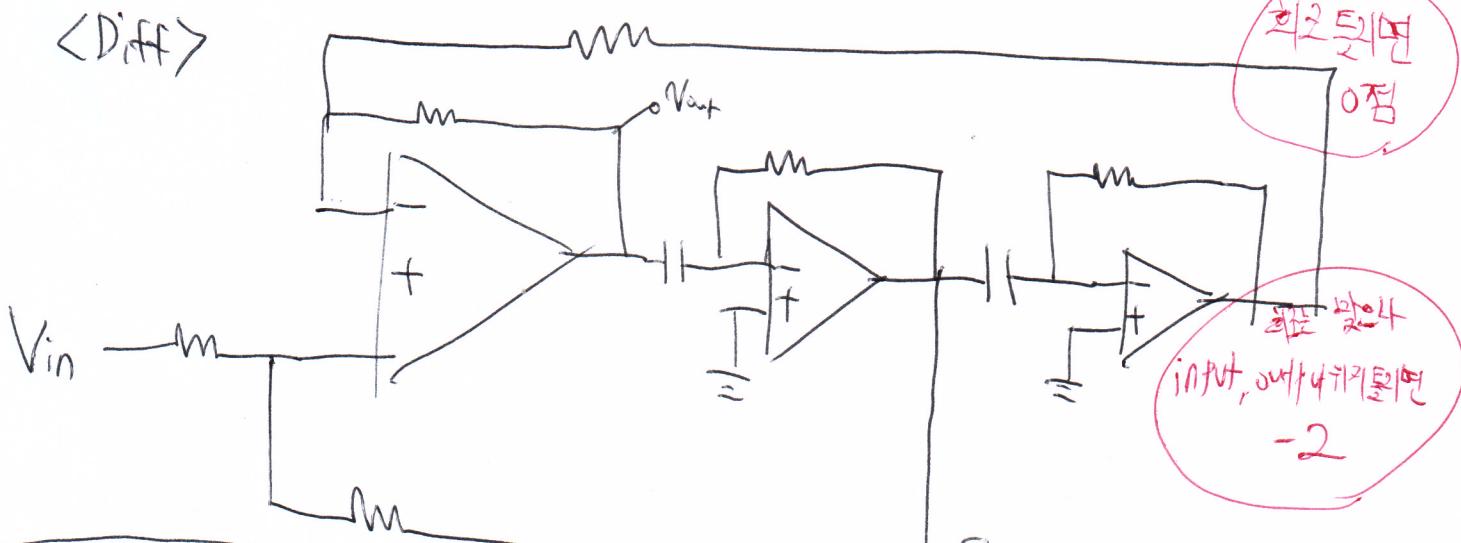
$$\frac{V_{out}}{V_{in}} = \frac{s^2 w_n^2}{s^2 + \frac{w_n}{Q} s + w_n^2} \cdot \frac{1}{s^2}$$

$$V_{out} = \frac{s^2 w_n^2}{s^2 + \frac{w_n}{Q} s + w_n^2} V_{in}$$

$$V_X = w_n^2 V_{in} - \frac{w_n}{Q} \frac{V_X}{s} - \frac{w_n^2}{s^2} V_X$$

- B. Draw circuit diagram of the filter and annotate V_{in} and V_{out} . Use resistors, capacitors and ideal OP-Amps only. You don't need to find the value of each component. [10 points]

<Diff>



최고 톤미연
0점

회로 맞나
input, output 위치 틀리면
-2

X Integrator 2 한계점

⇒ A. 5점 감점 시작
B. 5점 감점 시작