GUJARAT TECHNOLOGICAL UNIVERSITY

BE-4 SEMESTER – OLD PAPER – S22 TO W25 – QUESTION BANK ANSWER

Subject Name & Code:

ANALOG CIRCUIT DESIGN (3141002)

(Disclaimer: The purpose of these AI-generated responses is just education and reference. Utilise them to grasp topics and structure, but always rewrite in your own words and double-check)

Unit 3: Feedback Amplifiers

Q.1 – Compare and contrast the effects of negative and positive feedback on amplifier performance.
(3 marks)
Appeared in: S23 (Q3a)
Ans:

Parameter	Negative Feedback	Positive Feedback
Gain (A_f)	Decreases (A_f = A/(1+Aβ))	Increases (A_f = A/(1−Aβ))
Bandwidth	Increases	Decreases
Stability	Improves	Degrades (may oscillate)
Distortion	Reduces	Increases
Input/Output impedance	Modifies (depends on topology)	Opposite effect
Applications	Linear amplifiers, oscillators (with Aβ=1)	Oscillators, Schmitt triggers

Conclusion: Negative feedback trades gain for stability and linearity; positive feedback is used for oscillation and regenerative circuits.

Q.2 – List and explain characteristics of an amplifier that are modified by negative feedback.
(7 marks)
Appeared in: S23 (Q3c)
Ans:
Negative feedback modifies the following amplifier characteristics:
1. Gain (Desensitivity)

- Closed-loop gain: $A_f = \frac{A}{1+A\beta}$
- Gain becomes less sensitive to variations in A. Desensitivity factor $D = 1 + A\beta$.

2. Bandwidth

- Gain-bandwidth product remains constant.
- Lower cutoff frequency f_L decreases by factor D, upper cutoff f_H increases by factor D.

- $f_{Hf} = f_H(1 + A\beta), f_{Lf} = f_L/(1 + A\beta)$

3. Input Impedance

- **Voltage mixing (series):** $Z_{if} = Z_i(1 + A\beta)$ – increases
- **Current mixing (shunt):** $Z_{if} = Z_i/(1 + A\beta)$ – decreases

4. Output Impedance

- **Voltage sampling (shunt):** $Z_{of} = Z_o/(1 + A\beta)$ – decreases
- **Current sampling (series):** $Z_{of} = Z_o(1 + A\beta)$ – increases

5. Nonlinear Distortion

- Harmonic distortion reduces by factor D.
- $D_f = \frac{D}{1+A\beta}$

6. Noise

- In-band noise reduces for external noise; internally generated noise is also reduced (except source noise).

7. Stability

- Phase margin improves; prevents oscillations in amplifiers.

Real-world application: Operational amplifiers use negative feedback to achieve precise, stable gain (e.g., inverting/non-inverting configurations).

Q.3 – Draw the four types of feedback amplifier topologies.
(4 marks)
Appeared in: S23 (Q3b)
Ans:
The four feedback topologies are classified based on:

- **Sampling (output)** – voltage or current
- **Mixing (input)** – series or shunt

Diagram prompt (one prompt for all four):
[DG PROMPT]
Title: Four types of feedback amplifier topologies
Description: Draw four separate block diagrams, each with an amplifier triangle (gain A) and a feedback network box (β). Label input signal X_s, output X_o, feedback signal X_f, error signal X_e.

1. **Voltage-series (series-shunt):** Input: voltage mixing (series) – add X_s and X_f in series at input; Output: voltage sampling (shunt) – feedback network in parallel with output.
2. **Voltage-shunt (shunt-shunt):** Input: current mixing (shunt) – X_s and X_f connect to same node; Output: voltage sampling (shunt).
3. **Current-series (series-series):** Input: voltage mixing (series); Output: current sampling (series) – feedback network in series with output.
4. **Current-shunt (shunt-series):** Input: current mixing (shunt); Output: current sampling (series).
   Label each topology name below the diagram. Use arrows to show signal flow.

Summary table:

Topology	Input Mixing	Output Sampling	A_f = X_o/X_s	Z_if	Z_of
Voltage-series	Series (voltage)	Shunt (voltage)	V_o/V_s	↑	↓

Topology	Input Mixing	Output Sampling	A_f = X_o/X_s	Z_if	Z_of
Current-series	Series (voltage)	Series (current)	I_o/V_s	↑	↑
Voltage-shunt	Shunt (current)	Shunt (voltage)	V_o/I_s (transimpedance)	↓	↓
Current-shunt	Shunt (current)	Series (current)	I_o/I_s (current gain)	↓	↑

Real-world application: Voltage-series (non-inverting op-amp), current-series (CE with unbypassed Re), voltage-shunt (transimpedance amplifier), current-shunt (current amplifier).

Q.4 – Explain the advantages of negative feedback in amplifiers.
(4 marks)
Appeared in: S22 (Q4b)
Ans:
Advantages of negative feedback:

- **Gain desensitivity** – Gain becomes less dependent on active device parameters and temperature.
- **Increased bandwidth** – Both upper and lower cutoff frequencies improve, making the amplifier useful over a wider frequency range.
- **Reduced distortion** – Nonlinearities (harmonic distortion) are reduced by factor $1 + A\beta$.
- **Reduced noise** – Internal noise (e.g., from transistors) is suppressed.
- **Input/output impedance control** – Can be increased or decreased as required by the topology.
- **Improved stability** – Prevents oscillations and improves phase margin.

Disadvantage (trade-off): Overall gain decreases, requiring additional gain stages.
Real-world application: Audio power amplifiers use negative feedback to achieve low distortion (<0.01%) and flat frequency response.

Q.5 – Derive the expression for output resistance for a current-series feedback amplifier using BJT.
(7 marks)
Appeared in: W24 (Q3c)
Ans:
Given: Current-series feedback (series-series topology). Output current (collector current) is sampled and a voltage proportional to it is fed back in series with the input. Example: CE amplifier with unbypassed emitter resistor R_E (Re provides feedback).
To find: Output resistance with feedback R_{of}
Assumptions:

- Basic amplifier output resistance without feedback = R_o ($\approx r_o$ or R_C in parallel with r_o)
- Feedback network is ideal (no loading)

Derivation using series-series feedback concept:

1. **Series-series topology** – Output sampling is current, input mixing is series (voltage).

The feedback factor $\beta = \frac{V_f}{I_o}$. For the circuit, $V_f = I_o R_E$ (if feedback is from emitter resistor), so $\beta = R_E$.

2. **Open-loop output resistance** R_o is the resistance seen looking into the collector with input open (or with source resistance R_s considered). For a CE stage, $R_o \approx r_o \parallel R_C$.
3. **Effect of feedback on output resistance for current sampling:**
When output is current-sampled, the feedback increases output resistance. Formula:
$$R_{of} = R_o(1 + A\beta)$$

where A is the open-loop transconductance gain (I_o/V_i).

4. **Derivation using test voltage method:**
   - Replace load with a test voltage source V_t at output, measure I_t.
   - Feedback introduces a voltage $V_f = \beta I_t$ at input (series mixing).
   - The input voltage becomes $V_{in} = -V_f$ (assuming source is zero).
   - Then $I_t = \frac{V_t - AV_{in}}{R_o} = \frac{V_t + A\beta I_t}{R_o}$
   - Rearr: $I_t R_o = V_t + A\beta I_t \Rightarrow V_t = I_t(R_o - A\beta)$? Wait carefully:

Correct derivation:
Without feedback, $I_t = V_t/R_o$. With feedback, $V_{in} = -V_f = -\beta I_t$. Then the dependent source $AV_{in} = -A\beta I_t$. The output current $I_t = \frac{V_t - (-A\beta I_t)}{R_o} = \frac{V_t + A\beta I_t}{R_o}$.
Multiply: $I_t R_o = V_t + A\beta I_t \Rightarrow V_t = I_t(R_o - A\beta)$ – but $A\beta$ is positive? For negative feedback, loop gain $A\beta$ is positive in magnitude. The sign convention: The feedback voltage subtracts, so $V_t = I_t R_o - A\beta I_t$? Let's use standard formula.
Standard result: For current-series (series-series), output resistance increases by $(1 + A\beta)$.
$$R_{of} = R_o(1 + A\beta)$$

Where A is the open-loop **transresistance** or transconductance? Actually for current output, the gain $A = I_o/V_i$ (transconductance). Then loop gain $T = A\beta = (I_o/V_i) \cdot (V_f/I_o) = V_f/V_i$ (dimensionless). So correct.

5. **For BJT current-series (unbypassed R_E):**
Open-loop $R_o \approx r_o \parallel R_C$.
$A = g_m$ (approximate transconductance), $\beta = R_E$.
Loop gain $T = g_m R_E$.
$$R_{of} \approx (r_o \parallel R_C)(1 + g_m R_E)$$

Final Answer:

$$\boxed{R_{of} = R_o(1 + A\beta)}$$

For CE with R_E: $R_{of} \approx (r_o \parallel R_C)(1 + g_m R_E)$
Real-world application: Current-series feedback increases output impedance, useful in current sources and transconductance amplifiers.

Q.6 – A CE amplifier with un-bypassed emitter resistance providing current series feedback is to be designed for $g_m = -1\ mA/V$, $A_v = -4$, and desensitivity = 50. Given $R_s = 1\ k\Omega$, $h_{fe} = 150$, find R_E, R_C, R_1, R_2, I_C.
(7 marks)
Appeared in: W23 (Q3c)
Ans:

Given:
$g_m = -1\ mA/V$ (magnitude = 1 mS)
$A_v = -4$ (closed-loop voltage gain)
Desensitivity $D = 1 + A\beta = 50$
$R_s = 1\ k\Omega$ (source resistance)
$h_{fe} = \beta_{dc} = 150$ (assuming DC current gain)
To find: R_E, R_C, R_1, R_2, I_C
Assumptions:

- CE amplifier with unbypassed R_E (current-series feedback)
- $g_m = I_C/V_T$, $V_T = 26\ mV$ at room temperature
- Desensitivity is for voltage gain? Or loop gain? Given $D = 1 + A\beta = 50$, where A is open-loop gain. For current-series, $A = g_m R_C$ (approx), and $\beta = R_E$ (since $V_f = I_o R_E$ and $I_o \approx I_C$). But careful: Voltage gain with feedback $A_{vf} = A_v = -4$.
- Also $A_{vf} = \frac{A}{1+A\beta} = -4$. And $1 + A\beta = 50$. So $A = A_{vf} \times (1 + A\beta) = (-4) \times 50 = -200$.
  So open-loop voltage gain $A = -200$.

Solution:
Step 1: Find R_C
Open-loop voltage gain $A = -g_m R_C$ (since CE stage, neglecting r_o).
Magnitude: $200 = g_m R_C = (1\ mS) \times R_C$
$R_C = 200/(1 \times 10^{-3}) = 200\ k\Omega$? That is too high. Let's check: $g_m = 1\ mA/V = 0.001S$.
Then $A = g_m R_C$ gives $R_C = 200/0.001 = 200{,}000\ \Omega = 200\ k\Omega$. That is possible but large.
Alternatively, g_m may be negative sign, but magnitude.
Step 2: Find R_E from loop gain

Given $g_m = 1\ mS = 0.001\ S$.
So $1 + 0.001 \times R_E = 50 \Rightarrow 0.001R_E = 49 \Rightarrow R_E = 49{,}000\ \Omega = 49\ k\Omega$.
Step 3: Find R_C from A_{vf}

$$A_{vf} = \frac{-g_m R_C}{1 + g_m R_E} = -4$$

$\frac{0.001 \times R_C}{50} = 4 \Rightarrow 0.001R_C = 200 \Rightarrow R_C = 200{,}000\ \Omega = 200\ k\Omega$.
Step 4: Find I_C from g_m
$g_m = I_C/V_T \Rightarrow I_C = g_m \times V_T = (0.001) \times 0.026 = 26 \times 10^{-6} = 26\ \mu A$.
Step 5: Find R_1 and R_2 (biasing resistors)
Given $h_{fe} = 150$, $R_s = 1\ k\Omega$. Need to bias for $I_C = 26\ \mu A$. Assume V_{CC} not given – typical value take $V_{CC} = 12\ V$ (common assumption).
Base current $I_B = I_C/h_{fe} = 26\ \mu A/150 = 0.173\ \mu A$.
For stability, let current through R_1 and R_2 be $10I_B \approx 1.73\ \mu A$.
Voltage at base $V_B = V_{BE} + I_E R_E$. Assume $V_{BE} = 0.7\ V$, $I_E \approx I_C = 26\ \mu A$.
$V_B = 0.7 + (26 \times 10^{-6})(49 \times 10^3) = 0.7 + 1.274 = 1.974\ V$.
Then $R_2 = V_B/(10I_B) = 1.974/(1.73 \times 10^{-6}) \approx 1.141\ M\Omega$.
$R_1 = (V_{CC} - V_B)/(10I_B) = (12 - 1.974)/(1.73 \times 10^{-6}) = 10.026/1.73 \times 10^{-6} \approx 5.795\ M\Omega$.
Final Answer:

$$\boxed{R_E = 49\ k\Omega, R_C = 200\ k\Omega, I_C = 26\ \mu A, R_1 \approx 5.8\ M\Omega, R_2 \approx 1.14\ M\Omega}$$

(Use standard resistor values in practice.)

Q.7 – Derive expressions for voltage gain and input resistance with feedback for an emitter follower circuit.
(7 marks)
Appeared in: W23 (Q5c)
Ans:
Given: Emitter follower (common-collector) amplifier. It has inherent voltage-series feedback (output voltage sampled, feedback voltage in series with input).
Circuit description: BJT with collector at V_{CC}, base as input, emitter as output. R_E from emitter to ground.
To find: Closed-loop voltage gain A_{vf} and input resistance R_{if}.
Derivation:
1. Voltage gain without feedback (open-loop) – But the circuit is already feedback. Better to derive directly using hybrid-π model.
Let V_i = input at base, V_o = output at emitter.

$$V_o = I_E R_E = (I_B + I_C)R_E = I_B(1+\beta)R_E$$

Also $V_i = V_{BE} + V_o = I_B r_\pi + V_o$ (since $r_\pi = \beta/g_m$)
Substitute $V_o = I_B(1+\beta)R_E$:

$$V_i = I_B r_\pi + I_B(1+\beta)R_E = I_B[r_\pi + (1+\beta)R_E]$$

Then $A_{vf} = V_o/V_i = \frac{I_B(1+\beta)R_E}{I_B[r_\pi+(1+\beta)R_E]} = \frac{(1+\beta)R_E}{r_\pi+(1+\beta)R_E}$
Since $r_\pi = \beta/g_m$ and $\beta \gg 1$, $(1+\beta) \approx \beta$.
Also $g_m R_E$ is large, so $A_{vf} \approx \frac{\beta R_E}{r_\pi+\beta R_E} = \frac{\beta R_E}{\beta/g_m+\beta R_E} = \frac{R_E}{1/g_m+R_E} = \frac{g_m R_E}{1+g_m R_E}$.
Thus:

$$A_{vf} = \frac{g_m R_E}{1+g_m R_E} \approx 1 \text{ (for large } g_m R_E\text{)}$$

2. Input resistance with feedback
$R_{if} = V_i/I_B$ (from above)

$$R_{if} = r_\pi + (1+\beta)R_E$$

Using $r_\pi = \beta/g_m$:

$$R_{if} = \frac{\beta}{g_m} + (1+\beta)R_E \approx \beta\left(\frac{1}{g_m} + R_E\right)$$

For large β, $R_{if} \approx \beta R_E$.
Final expressions:

$$\boxed{A_{vf} = \frac{g_m R_E}{1+g_m R_E} \approx 1}$$
$$\boxed{R_{if} = r_\pi + (1+\beta)R_E \approx \beta R_E}$$

Real-world application: Emitter follower as buffer (high input impedance, low output impedance) in analog circuits, e.g., between stages to avoid loading.

Q.8 – Compare voltage-series feedback amplifiers with current-series feedback amplifiers.
(4 marks)
Appeared in: W24 (Q3b)
Ans:

Feature	Voltage-Series (Series-Shunt)	Current-Series (Series-Series)
Sampling	Output voltage	Output current
Feedback signal	Voltage proportional to V_o	Voltage proportional to I_o
Input mixing	Series (voltage)	Series (voltage)
Closed-loop gain	Voltage gain $A_{vf} = V_o/V_s$	Transconductance I_o/V_s
Input impedance	Increases ($Z_{if} = Z_i(1 + A\beta)$)	Increases
Output impedance	Decreases ($Z_{of} = Z_o/(1 + A\beta)$)	Increases ($Z_{of} = Z_o(1 + A\beta)$)
Typical circuit	Non-inverting op-amp, CE with Re	CE with unbypassed Re (output taken from collector)
Application	Linear voltage amplifier	Voltage-to-current converter, current source

Real-world application: Voltage-series (audio preamp), current-series (transconductance amplifier for driving LEDs).

Q.9 – Compare current-series feedback with current-shunt feedback. (4 marks)
Appeared in: W23 (Q3b)
Ans:

Feature	Current-Series (Series-Series)	Current-Shunt (Shunt-Series)
Input mixing	Series (voltage)	Shunt (current)
Output sampling	Series (current)	Series (current)
Feedback signal	Voltage proportional to I_o	Current proportional to I_o
Closed-loop gain	Transconductance (I_o/V_s)	Current gain (I_o/I_s)
Input impedance	Increases	Decreases
Output impedance	Increases	Increases

Feature	Current-Series (Series-Series)	Current-Shunt (Shunt-Series)
Typical circuit	CE with unbypassed Re (output from collector)	Common-base with feedback? Or multistage current amplifier
Application	Transconductance amp, current source	Current amplifier (e.g., photodiode amplifier)

Key difference: Input mixing – series gives high input impedance, shunt gives low input impedance.

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