Lecture 28: Concept of feedback in amplifiers: Negative and Positive

Feedback in amplifiers

DI02011011: Electronics Circuit and Application (ECA)

Lecture Agenda & Outline

- 1. Output Signal Sampling: Voltage (Node/Shunt) vs. Current (Loop/Series) Sampling Mechanics
- 2. Input Signal Summing: Series (Voltage Comparison) vs. Shunt (Current Comparison) Mixing Mechanics
- 3. Two-Port Parameter Matrices: Selection of h, g, y, and z Parameters for Feedback Networks
- 4. Feedback Loading Analysis: Derivation of Input/Output Loading Resistances (r_11 and r_22)
- 5. The Systematic 5-Step Feedback Analysis Algorithm for Discrete Transistor Circuits
- 6. Step-by-Step Circuit Calculations: Voltage-Series and Current-Series Transistor Amplifier Case Studies

Output Signal Sampling: Voltage (Shunt) vs. Current (Series)

- Voltage (Shunt) Sampling Mechanism: The feedback network is connected in PARALLEL across output load terminals to sense output voltage V_o.
- Ideal Voltage Sampler Properties: To avoid loading the output, an ideal voltage sampler presents infinite input impedance looking into the feedback network (R_in,beta -¿ infinity).
- Effect on Output Impedance: Voltage sampling stabilizes output voltage V_o, resulting in a DRAMATIC REDUCTION of closed-loop output resistance: R_of = R_o / (1 + A * beta).
- Current (Series) Sampling Mechanism: The feedback network is connected in SERIES with output load loop to sense output current I_o.
- Ideal Current Sampler Properties: To avoid loading the output loop, an ideal current sampler presents zero insertion impedance looking into the feedback network (R_in,beta -¿ 0).
- Effect on Output Impedance: Current sampling stabilizes output current I_o, resulting in a DRAMATIC INCREASE of closed-loop output resistance: R_of = R_o *(1 + A* beta).

Input Signal Summing: Series (Voltage) vs. Shunt (Current)

- Series (Voltage Comparison) Summing: The feedback signal V_f is connected in SERIES with signal source V_s at input: V_i = V_s - V_f.
- Ideal Series Summer Properties: Series mixing requires high input impedance for voltage sensing. Closed-loop input resistance INCREASES: R_inf = R_in $(1 + A$ beta).
- Voltage Source Matching: Ideal for signal sources with low source resistance R_s (Thevenin equivalent voltage sources).
- Shunt (Current Comparison) Summing: The feedback signal I_f is connected in PARALLEL (shunt) with signal source I_s at input node: I_i = I_s - I_f.
- Ideal Shunt Summer Properties: Shunt mixing draws current from input node. Closed-loop input resistance DECREASES: R_inf = R_in / (1 + A * beta).
- Current Source Matching: Ideal for signal sources with high source resistance R_s (Norton equivalent current sources).

The Four Basic Feedback Topologies & Ideal Amplifier Models

- 1. Voltage-Series (Series-Shunt) Topology: Samples V_o, sums V_f in series. Ideal Voltage Amplifier (V_o / V_s). High R_inf, Low R_of.
- 2. Current-Series (Series-Series) Topology: Samples I_o, sums V_f in series. Ideal Transconductance Amplifier (I_o / V_s). High R_inf, High R_of.
- 3. Voltage-Shunt (Shunt-Shunt) Topology: Samples V_o, sums I_f in shunt. Ideal Transresistance Amplifier (V_o / I_s). Low R_inf, Low R_of.
- 4. Current-Shunt (Shunt-Series) Topology: Samples I_o, sums I_f in shunt. Ideal Current Amplifier (I_o / I_s). Low R_inf, High R_of.
- System Design Selection: Choice of topology depends entirely on source impedance R_s and load impedance R_L requirements.

Two-Port Network Representations of Feedback Networks

- Purpose of Two-Port Formulation: Practical feedback networks are 2-port resistive networks. Two-port analysis decouples forward transfer from feedback loading effects.
- Voltage-Series (h-parameters): Hybrid matrix where $V_1 = h_{11} I_1 + h_{12} V_2$ and $I_2 = h_{21} I_1 + h_{22} V_2$. Feedback factor beta = $h_{12} = (V_1 / V_2)|_{I_1=0}$.
- Current-Series (z-parameters): Impedance matrix $V_1 = z_{11} I_1 + z_{12} I_2$ and $V_2 = z_{21} I_1 + z_{22} I_2$. Feedback factor beta = $z_{12} = (V_1 / I_2)|_{I_1=0}$.
- Voltage-Shunt (y-parameters): Admittance matrix $I_1 = y_{11} V_1 + y_{12} V_2$ and $I_2 = y_{21} V_1 + y_{22} V_2$. Feedback factor beta = $y_{12} = (I_1 / V_2)|_{V_1=0}$.
- Current-Shunt (g-parameters): Inverse hybrid matrix $I_1 = g_{11} V_1 + g_{12} I_2$ and $V_2 = g_{21} V_1 + g_{22} I_2$. Feedback factor beta = $g_{12} = (I_1 / I_2)|_{V_1=0}$.

Feedback Network Loading Analysis: r_11 and r_22 Resistances

- Concept of Loaded Open-Loop Circuit: Real feedback networks load both the amplifier input and output nodes. We construct a basic amplifier WITHOUT feedback (A') by incorporating loading resistances r_11 and r_22.
- Input Loading Resistance (r_11): Resistance looking into port 1 of feedback network with port 2 properly terminated:
- For Voltage Output (V_o sampled): Port 2 is SHORT-CIRCUITED (V_2 = 0). r_11 = Input resistance looking into feedback network with output shorted.
- For Current Output (I_o sampled): Port 2 is OPEN-CIRCUITED (I_2 = 0). r_11 = Input resistance looking into feedback network with output open.
- Output Loading Resistance (r_22): Resistance looking into port 2 of feedback network with port 1 properly terminated:
- For Series Input (V_f mixed): Port 1 is OPEN-CIRCUITED (I_1 = 0). r_22 = Output resistance looking into feedback network with input open.
- For Shunt Input (I_f mixed): Port 1 is SHORT-CIRCUITED (V_1 = 0). r_22 = Output resistance looking into feedback network with input shorted.

Systematic 5-Step Algorithm for Analyzing Feedback Amplifiers

- Step 1 (Identify Topology): Determine if output sampling is Voltage or Current, and if input mixing is Series or Shunt. Identify the 4 basic topologies.
- Step 2 (Determine Feedback Factor beta): Find beta = Signal_fed_back / Output_signal (e.g., V_f / V_o, V_f / I_o, I_f / V_o, or I_f / I_o) with input signal set to zero.
- Step 3 (Construct Loaded Open-Loop Circuit A'): Draw basic amplifier without feedback. Include source resistance R_s, load R_L, input loading r_11, and output loading r_22.
- Step 4 (Calculate Open-Loop Gain A and Loop Gain T): Compute open-loop gain A = Output / Input of the loaded circuit. Compute loop gain T = A * beta.
- Step 5 (Compute Closed-Loop Parameters): Calculate closed-loop gain A_f = A / (1 + A * beta), closed-loop input resistance R_inf, and closed-loop output resistance R_of.

Voltage-Series (Series-Shunt) Topology Formulation

- Signal Variables: Source voltage V_s, feedback voltage V_f, error voltage V_i = V_s - V_f, output voltage V_o.
- Feedback Factor: beta_v = (V_f / V_o) —_{I_1=0} (dimensionless ratio).
- Loading Resistances: r_11 = h_11 = (V_1 / I_1) —_{V_2=0} (Port 2 shorted); r_22 = 1 / h_22 = (V_2 / I_2) —_{I_1=0} (Port 1 open).
- Loaded Open-Loop Circuit (A_v): Basic amplifier voltage gain including loading: A_v = (V_o / V_i)—_{loaded}. Input resistance R_in = R_s + r_11 + r_pi; Output resistance R_o = R_C —— r_22 —— R_L.
- Closed-Loop Gain: A_vf = V_o / V_s = A_v / (1 + A_v * beta_v).
- Closed-Loop Resistances: Input resistance R_inf = R_in (1 + A_v beta_v); Output resistance R_of = R_o / (1 + A_v * beta_v).

Current-Series (Series-Series) Topology Formulation

- Signal Variables: Source voltage V_s, feedback voltage V_f, error voltage V_i = V_s - V_f, output current I_o.
- Feedback Factor: beta_z = (V_f / I_o) —_{I_1=0} (has units of Ohms, Ohms = V / A).
- Loading Resistances: r_11 = z_11 = (V_1 / I_1) —_{I_2=0} (Port 2 open); r_22 = z_22 = (V_2 / I_2) —_{I_1=0} (Port 1 open).
- Loaded Open-Loop Transconductance Gain (A_m): A_m = (I_o / V_i)—_{loaded} (has units of Siemens, A / V).
- Loop Gain Product: T = A_m * beta_z (dimensionless, Siemens x Ohms = 1).
- Closed-Loop Parameters: Transconductance A_mf = A_m / (1 + A_m *beta_z). Voltage gain A_vf = V_o / V_s = -A_mf* R_L.
- Closed-Loop Resistances: Input resistance R_inf = R_in *(1 + A_m* beta_z); Output resistance R_of = R_o *(1 + A_m* beta_z).

Voltage-Shunt & Current-Shunt Formulations

- Voltage-Shunt Topology (Shunt-Shunt):
- Feedback factor beta_g = I_f / V_o (Siemens, A/V). Open-loop transresistance A_r = V_o / I_i (Ohms, V/A). Loop gain T = A_r * beta_g.
- Closed-Loop Gain: A_rf = A_r / (1 + A_r * beta_g). Voltage gain A_vf = V_o / V_s = -A_rf / R_s.
- Resistances: BOTH input and output resistances DECREASE: R_inf = R_in / (1 + A_r *beta_g), R_of = R_o / (1 + A_r* beta_g).
- Current-Shunt Topology (Shunt-Series):
- Feedback factor beta_i = I_f / I_o (dimensionless current ratio). Open-loop current gain A_i = I_o / I_i (dimensionless).
- Closed-Loop Current Gain: A_if = A_i / (1 + A_i * beta_i).
- Resistances: Input resistance DECREASES, Output resistance INCREASES: R_inf = R_in / (1 + A_i *beta_i), R_of = R_o* (1 + A_i * beta_i).

Step-by-Step Analysis: Voltage-Series BJT Feedback Stage

- Circuit Parameters: Two-stage BJT amplifier with feedback resistor R_F = 10 kOhm from Stage 2 emitter to Stage 1 emitter. R_E1 = 100 Ohm, R_C1 = 4 kOhm, R_C2 = 2 kOhm, r_pi1 = r_pi2 = 1 kOhm, h_fe1 = h_fe2 = 100.
- Step 1 (Topology): Output voltage V_o is sampled at Stage 2 collector/emitter node; feedback voltage V_f across R_E1 is in series with Stage 1 base-emitter input =¿ Voltage-Series Feedback.
- Step 2 (Feedback Factor beta_v): beta_v = V_f / V_o = R_E1 / (R_E1 + R_F) = 100 / (100 + 10,000) = 0.0099 approx 0.01.
- Step 3 (Loading Resistances): r_11 (output shorted) = R_E1 —— R_F = 100 —— 10,000 approx 99 Ohm.
- r_22 (input open) = R_E1 + R_F = 100 + 10,000 = 10.1 kOhm.
- Step 4 (Open-Loop Gain A_v): Loaded first stage gain A_v1 = -h_fe1 *R_C1 / (r_pi1 + (1+h_fe1)*r_11) = -100 *4k / (1k + 101*99) = -36.3.
- Loaded second stage gain A_v2 = -h_fe2 *(R_C2 —— r_22) / r_pi2 = -100* (2k —— 10.1k) / 1k = -165.3.
- Total Open-Loop Gain A_v = A_v1 *A_v2 = (-36.3)* (-165.3) = +6000 (75.56 dB).
- Step 5 (Closed-Loop Gain A_vf): A_vf = A_v / (1 + A_v *beta_v) = 6000 / (1 + 6000* 0.01) = 6000 / 61 = 98.36 (39.85 dB).

Step-by-Step Analysis: Current-Series Transconductance Stage

- Circuit Parameters: Single-stage BJT Common-Emitter amplifier with unbypassed emitter resistor R_E = 500 Ohm. Transistor parameters: g_m = 40 mS, r_pi = 2.5 kOhm, R_C = 5 kOhm, R_s = 1 kOhm.
- Step 1 (Topology): Output current I_c is sampled through emitter loop; feedback voltage V_f = I_e * R_E is in series with base input =¿ Current-Series Feedback.
- Step 2 (Feedback Impedance beta_z): V_f = I_o * R_E =¿ beta_z = V_f / I_o = R_E = 500 Ohm.
- Step 3 (Loading Resistances): Output open (I_o = 0) =¿ r_11 = R_E = 500 Ohm; Input open (I_i = 0) =¿ r_22 = R_E = 500 Ohm.
- Step 4 (Open-Loop Transconductance A_m): Loaded open-loop transconductance (without feedback loop): A_m = I_o / V_i = g_m = 40 mS.
- Loop Gain T: T = A_m *beta_z = 40 mS* 500 Ohm = 20.
- Step 5 (Closed-Loop Parameters): Closed-loop transconductance A_mf = A_m / (1 + T) = 40 mS / (1 + 20) = 1.905 mS.
- Closed-Loop Voltage Gain: A_vf = -A_mf *R_C = -1.905 mS* 5 kOhm = -9.525. (Note: -R_C / R_E = -5000 / 500 = -10!).
- Input Resistance Transformation: R_inf = (R_s + r_pi) *(1 + T) = (1k + 2.5k)* (1 + 20) = 3.5 kOhm * 21 = 73.5 kOhm!

Comprehensive Summary & Two-Port Matrix Overview

- Feedback Topologies Summary:
- 1. Voltage-Series: beta_v = V_f / V_o, R_inf = R_in *(1 + A_v* beta_v), R_of = R_o / (1 + A_v * beta_v) [Voltage Amp].
- 2. Current-Series: beta_z = V_f / I_o, R_inf = R_in *(1 + A_m* beta_z), R_of = R_o *(1 + A_m* beta_z) [Transconductance Amp].
- 3. Voltage-Shunt: beta_g = I_f / V_o, R_inf = R_in / (1 + A_r *beta_g), R_of = R_o / (1 + A_r* beta_g) [Transresistance Amp].
- 4. Current-Shunt: beta_i = I_f / I_o, R_inf = R_in / (1 + A_i *beta_i), R_of = R_o* (1 + A_i * beta_i) [Current Amp].
- Two-Port Rule: Input series mixing INCREASES R_in; Input shunt mixing DECREASES R_in. Voltage output sampling DECREASES R_out; Current output sampling INCREASES R_out.
- Methodology: Always execute the systematic 5-step algorithm incorporating r_11 and r_22 loading resistances.