Characterization of Amplifiers

Non Ideal Behavior

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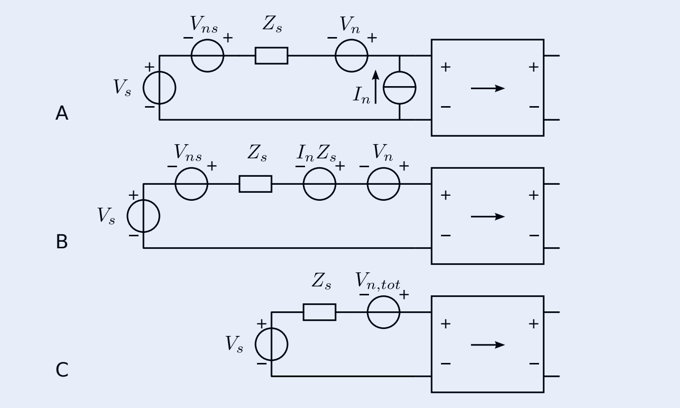
Amplifiers noise behavior

Example

Amplifier with voltage type signal source and equivalent-input noise sources



Amplifiers noise behavior

Example with equivalent input noise sources

- Represent total noise by one equivalent source:
  - similar type as signal source
  - location of signal source

$$S_{Vn,tot} = S_{V_{ns}} + S_{V_n} + S_{I_n} \left|Z_s\right|^2$$

- If noise associated with source then characterization with noise figure:

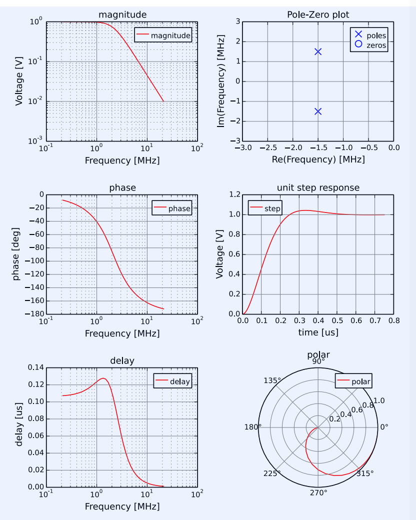
$$F = \frac{\text{(weighted) total equivalent input noise power}}{\text{(weighted) source noise power}}$$

$$F = \frac{\int_0^\infty S_{V_{n,tot}} \left|W(f)\right|^2 df}{\int_0^\infty S_{V_{ns}} \left|W(f)\right|^2 df}$$

- Else model with source equivalent spectral density or total RMS noise

Amplifier small-signal dynamic behavior

Modeling as linear time-invariant dynamic system



Model behavior with:

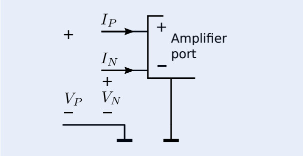
- Magnitude and phase versus frequency
- Delay versus frequency
- Polar magnitude and phase plot
- Step or impulse response
- Pole-zero diagram and (DC) gain

Amplifiers small-signal dynamic behavior

Characterization of step response

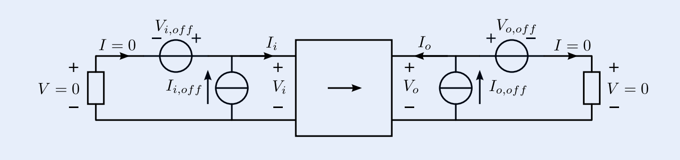
Amplifiers static nonlinear behavior

Modeling as time-invariant instantaneous linear system



- Input port static $v - i$ curve
- Output port static $v - i$ curve
- Input - output port static transfer curve
- Operating point, offset and gain

- Port bias quantities $V_B = \frac{V_P + V_N}{2}$, $I_B = \frac{I_P + I_N}{2}$



Amplifiers static nonlinear behavior

Characterization of nonlinear behavior

Description methods for static nonlinear behavior

- Nonlinearity
- Differential gain
- Harmonic distortion (has relation to diff. gain)
- Intermodulation distortion (has relation to diff. gain)
- Voltage and/or current limiting
- Gain compression (has relation to diff. gain)
- Operating point shift
- Hysteresis (rate-independent)
- Dead zone

Amplifier large-signal dynamic behavior

Characterization of large signal dynamic behavior

Description methods for dynamic nonlinear behavior

- Frequency-dependent differential phase and differential gain
- Frequency-dependent harmonic distortion
- Frequency-dependent intermodulation distortion and intermodulation intercept points
- Power limiting
- Gain compression
- Operating point shift
- Hysteresis (rate-dependent)
- Overdrive recovery
- Slew rate

Interconnected amplifiers

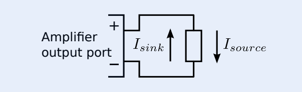
Error propagation in interconnected amplifiers

- Some examples for cascaded amplifiers have been given in text book.
- Some relevant properties of series connected or parallel connected two ports will be introduced at a later stage.
    - High-level description is always preferred: if a property can be derived for an amplifier, modeled as a two-port, than it holds for all implementations of amplifiers that can be modeled as a two port: from one single biased transistor to a collection of interconnected amplifiers.

Power losses and amplifier classes

Power loss modeling strongly depends on amplifier output stage operation

- Definition of source and sink current:
  - Independent of orientation of load voltage
  - Source: current flow from '+ output terminal' into load
  - Sink: current flow from load into '+ output terminal'
  - if one output terminal is grounded, this one is referred to as '- terminal'



- Amplifying devices are unipolar: they can carry current in one direction
- Output stage requires at least one amplifying device (source or sink) and one bias or offset element (sink or source) or a resonator

- Topology and operating mode of output stage defines amplifier class.

Amplifier classes

Overview of amplifier classes

- Class A: current flow in both sink and source device during sink and source phase
    - full overlap
    - small signal amplifiers
    - low power efficiency
- Class B: current flow in source device during source phase and current flow in sink device during sink phase
    - no overlap
    - no dead zone
    - no practical use
- Class AB: between class A and class B
    - partly overlap
    - operational amplifiers and most non-switching power amplifiers
    - medium power efficiency

Amplifier classes

Overview of amplifier classes

- Class C: dead zone between source and sink, sometimes source or sink only, usually combined with resonator load
  - Dead zone
  - RF narrow-band output stages (transmitters)
  - Medium - high efficiency
- Class D: wide-band switching output stage (PWM stage with low-pass filter)
  - Non resonant switching
  - High EMI
  - High efficiency
  - Modern low-frequency power amplifiers
- Class E: narrow-band output stage
  - Resonant switching
  - Low EMI
  - Very high efficiency
  - RF output stages (transmitters)

Amplifier classes

Overview of amplifier classes

- Class F: narrow-band switching output stage
  - Class D output stage
  - Resonant switching with multiple resonator filter
  - Complex output filter requires tuning
  - High efficiency
- Class G: class AB with power supply step wise adapted to required load voltage
  - Old car radio, replaced by class D
  - Medium efficiency
- Class H: class AB with power supply continuously adapted to required load voltage
  - Low switching current ripple
  - Medium efficiency