Using NF:

The properties of the feedback amplifier are modified in respect with the properties of the basic amplifier:
- the gain is reduced
- other properties are improved:
  - the gain sensitivity is reduced
  - the nonlinear distortion is reduced
  - the bandwidth is extended
  - the effect of the noise is reduced
  - the input and output impedances are enhanced
1 Reduction in gain

\[ A = \frac{a}{1 + ar} \]

\( ar > 0 \)

\[ |A| < |a| \]

- If \( ar \gg 1 \) (e.g. for op amp \( a \to \infty \)) \[ A \approx \frac{1}{r} \]
2 Reduction in the gain sensitivity
(desensitize the gain)

- The gain of the basic amplifier depends generally on certain factors (temperature, parameters of active devices, OP, etc.)
- What is the relative variation of the feedback gain in comparison with the relative variation of the basic gain?

\[ A = \frac{a}{1 + ar} \]

\[ \frac{dA}{da} = \frac{(1 + ar) - ar}{(1 + ar)^2} = \frac{1}{(1 + ar)^2} \]

\[ \frac{dA}{da} = \frac{a}{1 + ar} \cdot \frac{1}{a} \cdot \frac{1}{1 + ar} = A \cdot \frac{1}{a} \cdot \frac{1}{1 + ar} \]

\[ \frac{dA}{A} = \frac{1}{1 + ar} \cdot \frac{da}{a} \]
2 Reduction in the gain sensitivity (desensitize the gain)

Illustration:

\[ 1 + ar = 100 \]

\[ \frac{da}{a} = 10\% \quad \frac{dA}{A} = 0.1\% \]

NF improves the stability of the feedback gain (reduces the sensitivity of the gain against the action of some perturbing factors.)
3 Reduction in the nonlinear distortion

- Generally the gain is linear for small-signal, around the operating point.
- If the output signal increases, the gain becomes nonlinear.

\[
A_1 = \frac{a_1}{1 + a_1 r}
\]

\[
A_2 = \frac{a_2}{1 + a_2 r}
\]
The range of the input signal increases

<table>
<thead>
<tr>
<th>Basic Amplifier</th>
<th>NF Amplifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>([-x_{i2}; x_{i2})]</td>
<td>([-x_{s2}; x_{s2})]</td>
</tr>
</tbody>
</table>

\[
\frac{A_2 - A_1}{A_1} = \frac{1}{1 + a_2 r} \frac{a_2 - a_1}{a_1}
\]

Illustration

\(a_1 = 100\) \(a_2 = 50\) \(r = 0,09\)

\[
A_1 = \frac{100}{1 + 100 \cdot 0,09} = 10
\]

\[
A_2 = \frac{50}{1 + 50 \cdot 0,09} = 9,1
\]

\[
\frac{a_2 - a_1}{a_1} = 50\%
\]

\[
\frac{A_2 - A_1}{A_1} = 9\%
\]

Price: reduction of the gain

Solution: use a preamplifier

Increases the input signal range for linear behaviour
Low-pass-type amplifier

\[ a(j\omega) = \frac{a_0}{1 + j\frac{\omega}{\omega_H}} \]

\[ f_H = \frac{\omega_H}{2\pi} \]

\[ A(j\omega) = \frac{a(j\omega)}{1 + a(j\omega)r} \]

\[ A(j\omega) = \frac{a_0}{1 + a_0r} \]

\[ f_{Hr} = f_H (1 + a_0r) \]

\[ A_0 = \frac{a_0}{1 + a_0r} \]
Gain bandwidth product is constant

If the high-frequency response is characterized by a single pole

Introducing NF, the number of times that reduces the gain is equal to the numbers of times that extends the bandwidth – amount of feedback
Band-pass-type amplifier

\[ |a|, |A| \quad [\text{dB}] \]

\[ a_0 \]

\[ A_0 \]

\[ f_{Lr} \quad f_L \quad B \quad f_H \quad f_{Hr} \]

Basic amplifier

NF amplifier

\[ (1+a_0 r^*) \]

\[ (1+a_0 r^*) \]
Increasing the signal-to-noise ratio

\[ x_o = x_{os} + x_{on} \]

\[ (s/n)_o = \frac{x_{os}}{x_{on}} = \frac{ax_s}{x_n} = \frac{x_s}{x_n} = (s/n)_i \]

\[ x_{os} = \frac{aa_e}{1 + aa_e r} x_s \]

\[ x_{on} = \frac{a}{1 + aa_e r} x_n \]

\[ (s/n)_o = \frac{x_{os}}{x_{on}} = \frac{aa_e x_s}{x_n} = a_e x_s = a_e (s/n)_i \]
## 6 Enhancement of the input and output impedances

<table>
<thead>
<tr>
<th></th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Series</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Voltage</td>
<td>$R_{ir} = R_i (1 + ar)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R_{or} = R_o (1 + ar)$</td>
</tr>
<tr>
<td><strong>Parallel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Current</td>
<td>$R_{ir} = \frac{R_i}{1 + ar}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R_{or} = \frac{R_o}{1 + ar}$</td>
</tr>
</tbody>
</table>

**Notes:**
- $R_i$: Input resistance
- $R_o$: Output resistance
- $ar$: An variable related to the configuration of the circuits.