FEEDBACK, STABILITY, & COMPENSATION

- ***Properties of Negative Feedback*:**
  - ***Reduction in gain***

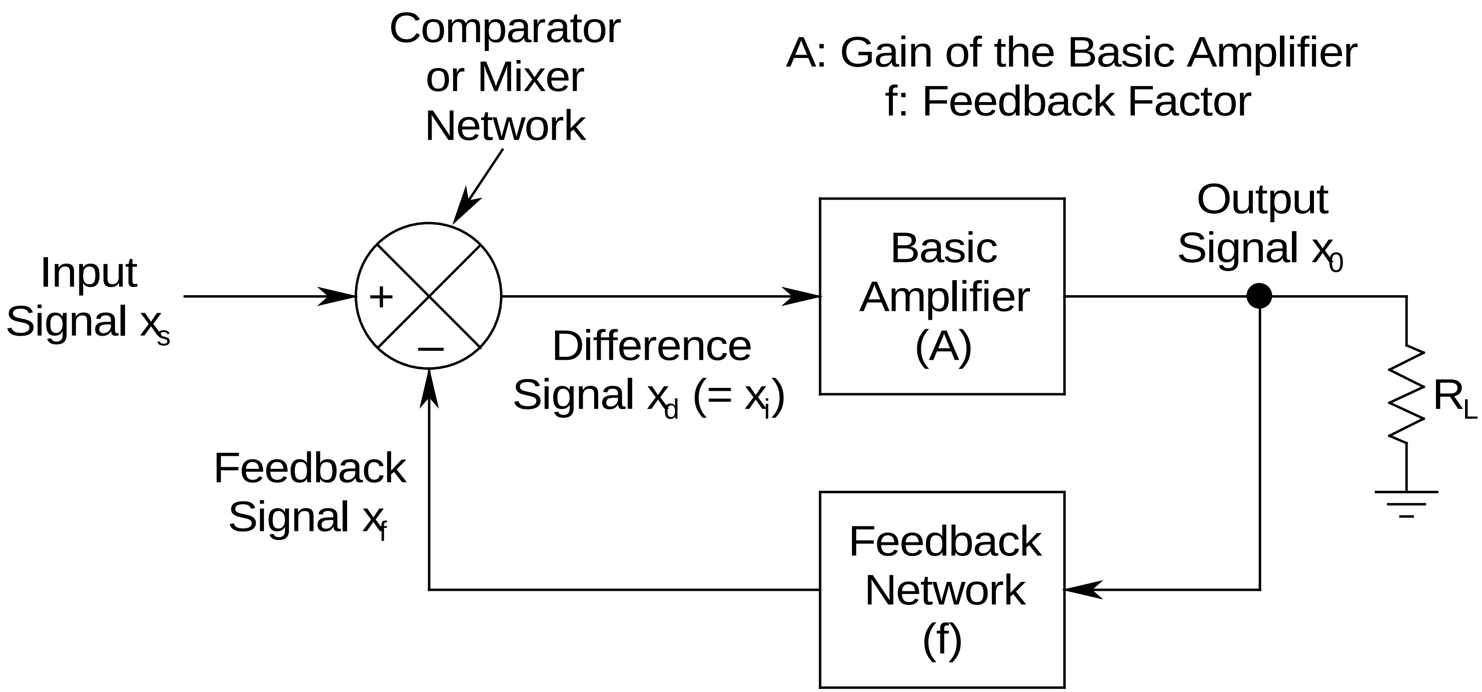
    $\Rightarrow$ ***Improvement in bandwidth***

    (***Due to constant GBP***)
  - ***Tailoring of input and output resistances***
  - ***Desensitization of gain***
    - ***Gain becomes almost independent of the properties of the active device***
  - ***Minimization of frequency and phase distortion***

- ***Reduction in nonlinear distortion***
  - ***By suppression of harmonics present in the output***
- ***Reduction of noise***
- ***If not properly designed*, *can have problem of stability***

- ***Properties of Positive Feedback*:**
  - ***Inherently unstable***
    - ***Due to its regenerative nature***
    - ***This property can be effectively utilized in the design of oscillators*, *which do not need any input***

- ***Mathematical Foundation of Negative Feedback*:**



Block Schematic of a Negative Feedback System

- ***3 Main Blocks***:
  - ***The Basic Amplifier*** (***Gain A***)
  - ***The Feedback Network*** (***Feedback Factor f***)
  - ***The Mixer*** (***note the negative sign***)
- ***Defining Relations***:
  - ***Input Signal*** x_s
  - ***Output Signal*** $x_0 = Ax_i$
  - ***Feedback Signal*** $x_f = fx_0$
  - ***Difference Signal*** $x_d = x_i = x_s - x_f$
- ***Gain with feedback***: $A_f = x_0/x_s$

- Thus:

$$A_f = \frac{x_0}{x_s} = \frac{x_0}{x_i}\frac{x_i}{x_s} = A\frac{x_s - x_f}{x_s} = A\left(1 - \frac{x_f}{x_s}\right)$$

$$= A\left(1 - \frac{x_f}{x_0}\frac{x_0}{x_s}\right) = A\left(1 - fA_f\right)$$

- Gives the ***fundamental expression*** for ***negative feedback***:

$$A_f = \frac{A}{1 + fA}$$

- ***Some Definitions***:
  - ***Loop Gain*** (L) = fA
  - ***Return Difference*** (D) = 1 + L
  - ***Amount of Feedback*** (N) = 20 $\log_{10}$D (dB)
- ***Positive Feedback***:
  - ***Output fed back to the input through the mixer***, ***but now with a positive sign***

    $\Rightarrow$ ***Feedback signal gets added to the input signal***

- ***Under this condition***:

$$A_f(j\omega) = \frac{A(j\omega)}{1 - f(j\omega)A(j\omega)} = \frac{A(j\omega)}{1 - L(j\omega)}$$

- This is a ***general expression***, taking both A and f as ***frequency dependent***
- Note: As $L \to 1$, $A_f \to \infty$
  - ***Implies that output is possible even without any input***
  - This is the ***basic principle of oscillation***

- ***Conditions for Oscillation***:

  Barkhausen's Criteria:

  - ***L becoming unity implies that the signal has completely regenerated itself while traversing once through the loop***

    $\Rightarrow$ ***There is no need for any input any more***, ***since the loop has become self-sustained***!

  - ***Since A and f are frequency dependent***, hence, ***there may exist a frequency*** ω_0, at which:

    $L(j\omega_0) = f(j\omega_0)A(j\omega_0) = 1$

- Since ω_0 is a ***particular frequency***, for which ***this condition holds***, hence, the output will be a ***pure sinusoid*** of ***this frequency***
  - Similar to ***picking out*** f_0 only from a ***Fourier Spectrum***
  - This phenomenon is known as ***Sinusoidal Oscillation***
- German physicist ***Heinrich Georg Barkhausen*** summed this up by ***two conditions***, came to be known as the ***Barkhausen's Criteria***:

1. $|L(j\omega_0)| = 1$ and
2. $\angle L(j\omega_0) = 0°$

- ***Barkhausen’s Criteria in words***:

  For a feedback system to oscillate, the magnitude of the loop gain must at least be unity, and the total phase shift around the loop should be 0° or 360°

- ***If these criteria are satisfied exactly***, then the ***oscillations would go on forever***, and ***can be stopped only by shutting the power off for the system***

- However, for ***practical circuits***, the ***exact conditions for oscillations*** are ***very difficult to achieve***

- If |L| becomes ***slightly less than 1***, but ∠ L is ***exactly 0°***, then with ***each pass around the loop***, the ***amplitude of oscillation*** would keep on ***going down***, and eventually, it will ***die down*** on its own
  - Thus, ***under this condition***, ***sustained sinusoidal oscillation won't be achieved***
- On the other hand, if |L| becomes ***slightly larger than unity***, but ∠ L is ***exactly 0°***, then with ***each pass around the loop***, the ***amplitude*** of the signal will ***keep on growing***
  - Will eventually ***get limited*** by the ***nonlinearities*** present in the circuit

Stability

- ***2 Types of Systems***:
  - ***Stable***
  - ***Unstable***
- ***Stable System***:
  - ***Any transient disturbance would result in a response that will die down with time***
  - ***The system will be able to get rid of the disturbance on its own***

- ***Unstable System***:
  - ***Any transient disturbance would result in a response that will persist or even blow up with time***
    - ***Eventually gets limited by the nonlinearities of the system***
  - ***Positive feedback systems are inherently unstable***
    - ***They are designed as such***, e.g., ***oscillators***
  - ***Negative feedback systems are inherently stable***

- ***However, there may be situations when they may become unstable and break out into spontaneous oscillations***
- ***Potentially dangerous situation***, and the ***system should be protected against it***

- ***How does a negative feedback system become unstable***?
  - Write the ***loop gain*** expression in ***polar form***:

    $L(j\omega) = f(j\omega)A(j\omega) = |f(j\omega)A(j\omega)|\exp[j\phi(\omega)]$

    $\phi(\omega)$: ***Frequency dependent phase of the system***

- Consider a ***particular frequency*** ω_x, at which $\phi(\omega_x) = 180°$
- At ω_x, L would be a ***real number*** with ***negative sign***

  $\Rightarrow$ ***The feedback turns positive at this frequency***
- ***3 conditions may arise at ω_x***:
  - $|L| < 1$:
    - $A_f(j\omega_x) > A(j\omega_x)$, but the ***system will be stable***
  - $|L| = 1$:
    - $A_f(j\omega_x) \rightarrow \infty$, and ***output will appear without any input***

      $\Rightarrow$ ***Oscillator***

- $|L| > 1$:
  - $A_f(j\omega_x) < A(j\omega_x)$, but the ***output will oscillate with gradually increasing amplitude***, and will ***eventually get limited by the nonlinearities present in the system***

- Thus, for a ***negative feedback system*** to turn into a ***positive feedback one***, the ***loop gain*** (L = fA) being ***equal to or less than –1*** is a ***sufficient and necessary condition***
- ***For this to happen***, the ***magnitude of the loop gain*** (L) ***should be equal to or greater than unity***, and the ***total phase around the loop should be 180°***