Asymptotic gain feedback model

Why do we need a feedback model if we can analyse our circuits using MNA and SPICE?

Haha, we need it for designing feedback circuits!

How does that work?

Two-step design approach for negative feedback amplifiers

1. Determine the requirements for the amplifier's transmission-1 matrix parameters A, B, C and D, and design the amplifier type and its ideal gain using:
   * load voltage (output parallel) sensing to fix A and/or C
   * load current (output series) sensing to fix B and/or D
   * a feedback network to generate a copy of the source signal from the load signal
   * source voltage (input series) comparison to fix A and/or B
   * source current (input parallel) comparison or to fix C and/or D
   * a nullor as ideal controller
     - nullator sets the condition for comparison
     - norator provides the extra degree of freedom to satisfy this condition
2. Design the controller (error amplifier) such that the difference between the gain and the ideal gain is small enough.

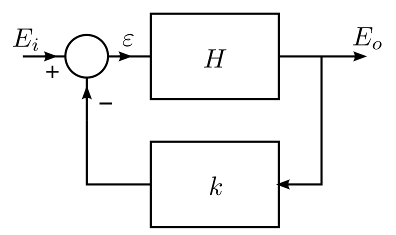
Still don't get it: you just increase the gain of the controller until the error is small enough!

Good luck with this trial-and-horror method!
Multiple cascaded amplifier stages may give a lot of gain AND a lot of phase shift that may turn the negative (corrective) feedback into positive (regenerative) feedback!

A feedback model tells us how the performance aspects of the controller relate to those of the amplifier. From this, we can define target specifications for the controller and then design it according to those specifications.

Wow, that sounds like a great idea; must have been a smart person who discovered this!

Black presented a basic feedback model:



$\frac{E_o}{E_i} = \frac{1}{k}\left(\frac{Hk}{1+Hk}\right)$

H: Controller gain

k : Feedback gain = reciprocal value of ideal gain

Hk: Loop gain = measure for correspondence between ideal gain and gain

Okay, looks great let's use it!

All models are wrong, but some are useful! (G. Box)
Models should be as simple as possible, but not simpler! (A. Einstein)

The idea is great: if the loop gain approaches infinity, the gain approaches the ideal gain. However, in many cases this model is far too simple.

- The loop gain is not the only contributer to the mismatch between the ideal gain and the actual gain:
  * Direct transfer through the feedback network
  * Parasitic impedances in series of in parallel with elements of the feedback network
  * Parasitic impedances in series or in parallel with the signal source and/or the load
  * Finite common-mode impedance of floating controller ports
  * Finite common-mode rejection in the case of floating controller ports
- As a result of interactions between the controller, the source, the load and the feedback network, the loop gain cannot easily be written as the product of the controller gain H and the feedback gain k.

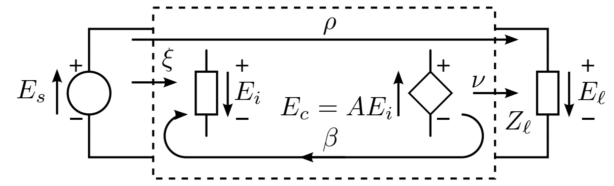
Hm, and now?

Use a better model! TUDelft

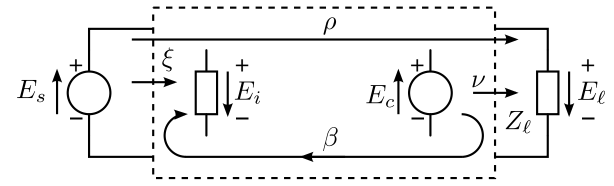
Please explain!

Superposition model

1. In a network, the gain of an arbitrarily selected controlled source is taken as reference variable A



2. This controlled source is replaced with an independent source, while we note: $E_c = AE_i$



3. We now have a network with two independent sources and two dependent variables and write:

$$\begin{pmatrix} E_\ell \\ E_i \end{pmatrix} = \begin{pmatrix} \rho & \nu \\ \xi & \beta \end{pmatrix} \begin{pmatrix} E_s \\ E_c \end{pmatrix}$$

4. Calculate the source-to-load transfer (the gain) using: $E_c = AE_i$ to eliminate E_c

$$A_f = \frac{E_\ell}{E_s} = \rho + \frac{\nu\xi A}{1-A\beta}$$

5. Calculate the asymptotic gain: $A_{f\infty} \triangleq \lim_{A\beta\to\infty} A_f$

$$A_{f\infty} = \rho - \frac{\nu\xi}{\beta}$$

6. Substitute the expression for the asymptotic gain in the expression for the gain:

$$A_f = A_{f\infty}\frac{-A\beta}{1-A\beta} + \frac{\rho}{1-A\beta}$$

This is the asymptotic gain model

Looks like Black's model again!

But it is NOT!

$-A \neq H$
$\beta \neq k$
$-A\beta \neq Hk$ although both are called loop gain
A_f as obtained from MNA!

Quite confusing; what's the fun?

No fun yet!

It becomes useful if the asymptotic gain equals the ideal gain! The latter one one has been designed in the first design step. If this is the case, the expression for the gain simplifies to:

$$A_f = A_i\left(\frac{-A\beta}{1-A\beta} + \frac{\rho}{A_i}\frac{1}{1-A\beta}\right)$$

$$A_f \approx A_i\left(\frac{-A\beta}{1-A\beta}\right)$$

Gain (A_f)
Ideal gain (A_i)
Loop gain ($-A\beta$)
Servo function ($\frac{-A\beta}{1-A\beta}$)

We then have our two-step design:

1. Design of the ideal gain
2. Design of the controller such that its contribution to the loop gain is large enough (servo function approaches unity).

So when does that happen?

Never! (All models are wrong but ...)

If the controller becomes a nullor when the reference variable appoaches infinity:

If the controller behaves as a nullor when the selected controlled source is replaced with nullor then asymptotic gain equals the ideal gain.

And what if this is not the case?

Then, the loopgain is NOT the unique measure for the correspondence between the gain and the ideal gain.

So its all about the two-step design?!

Seems you got the message!

So what's the problem?

1. The number of nodes of the controller
2. Local feedback loops in the controller.

A nullor is a natural two-port

From a network theoretical point of view, a two-port model for a network is always accurate if that network has only three nodes.

So this model is useless anyway?

No, its very useful!

1. The source-to-load transfer calculated from the asymptotic gain model equals the one calculated from modified nodal analysis
2. Correspondence between the asymptotic gain and the ideal gain tells us about the meaning of the loop gain; no other model provides such a check!
3. At an early stage of the design this correspondence can be made very good by using relative simple device models that provide the right design information.

Sounds nice but ...

We will teach you!

Time for an example?

Pffff, finally!

Example 10.1: Model of Black
Controller type matches amplifier type: Hk can easily be identified in the loop gain expression.

Example 10.2: Model of Black
Controller type opposite to amplifier type: Hk cannot easily be identified in the loop gain expression; source and load impedance enter the expression.

Example 10.3: Asymptotic-gain model
Selection of loop gain reference such that the ideal gain corresponds with the asymptotic gain.

Example 10.4: Asymptotic-gain model
Influence of parasitic impedance on the asymptotic gain (two-port conditions).