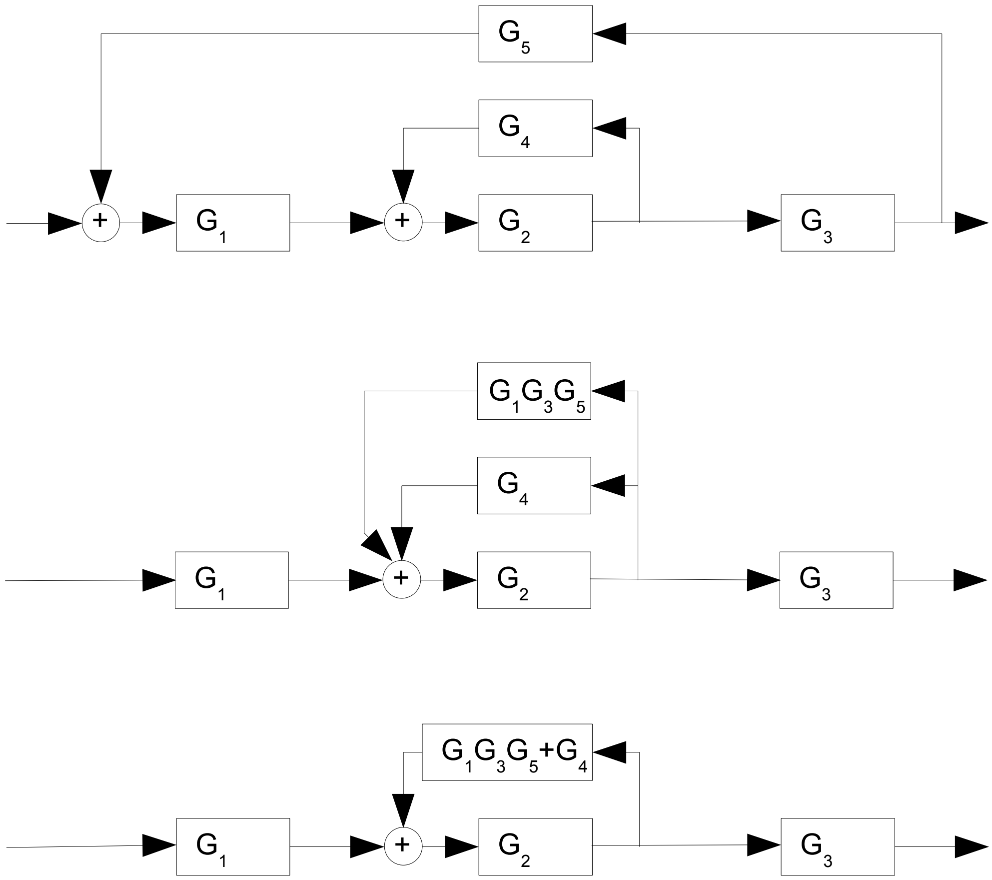
Matthias 'matze', April 2013

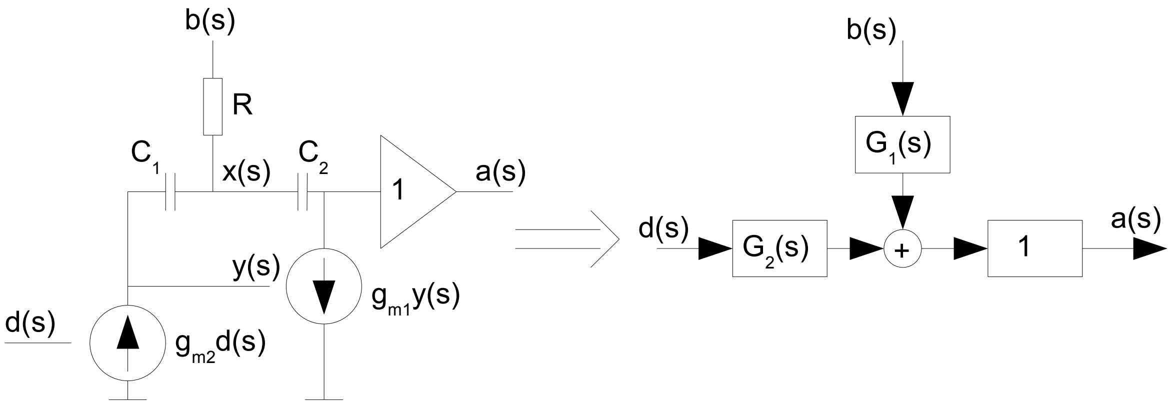
Analysis of “Transitional Miller Compensation“ (TMC)

Principle

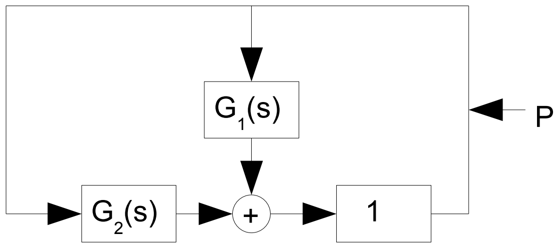
Manson's rule [1, chapter 2] states the following equivalence rule for linear control systems.



Lurie names this rule in [1] as evident, and in fact it appears to be obvious. For instance, it does not matter whether the output signal of the block with gain G_5 first goes to the input of the whole chain, or whether this signal is transformed according to G_1 and added at the input of the second block in the forward path. The system is linear.
In order to apply this result to TMC, we need to develop a model that follows the required structure. One possibilty is as follows.



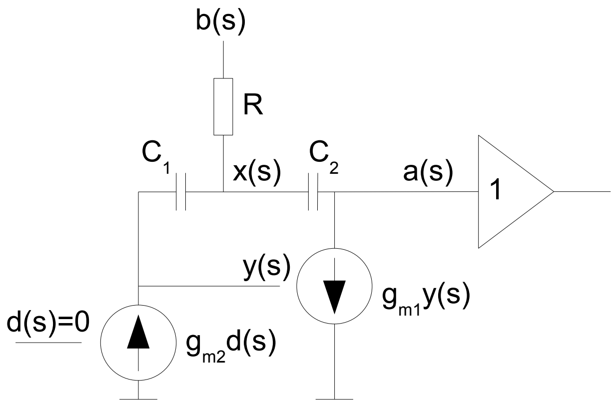
The transfer functions $G_1(s)=a(s)/b(s)$ and $G_2(s)=a(s)/d(s)$ are calculated below. As the system is linear, we have $a(s)=G_1(s)b(s)+G_2(s)d(s)$. If we include the global feedback network into $G_2(s)$, we get the following structure of the complete amplifier.



According to Manson's rule and as can be seen directly, the total amount of feedback around the output stage is $G_1(s)+G_2(s)$. It seems to be clear that this feedback is exactly the loop gain measured e.g. by a probe at point P between (1) amplifier output and (2) connection of TMC resistor and global feedback network. The numerical example below will confirm that.

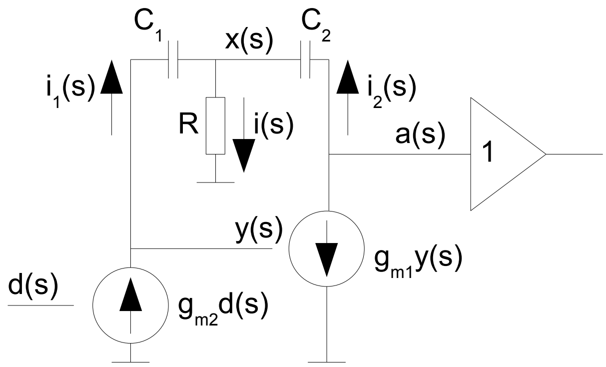
Transfer function $G_1(s)$

The input signal d(s) is zero, thus no current flows via C_1, and $y(s)=x(s)$.



$$a(s) = x(s) - \frac{1}{sC_2} g_{m1} y(s) = x(s)\left(1 - \frac{g_{m1}}{sC_2}\right)$$
$$x(s) = b(s) - g_{m1} R y(s) = b(s) - g_{m1} R x(s)$$
$$x(s) = \frac{1}{1+g_{m1}R} b(s)$$
$$a(s) = \frac{1}{1+g_{m1}R} \frac{sC_2 - g_{m1}}{sC_2} b(s) = \frac{s - g_{m1}/C_2}{s(1+g_{m1}R)} b(s)$$
$$G_1(s) = \frac{a(s)}{b(s)} = \frac{s - g_{m1}/C_2}{s(1+g_{m1}R)}$$

Transfer function $G_2(s)$
The input signal b(s) is zero.

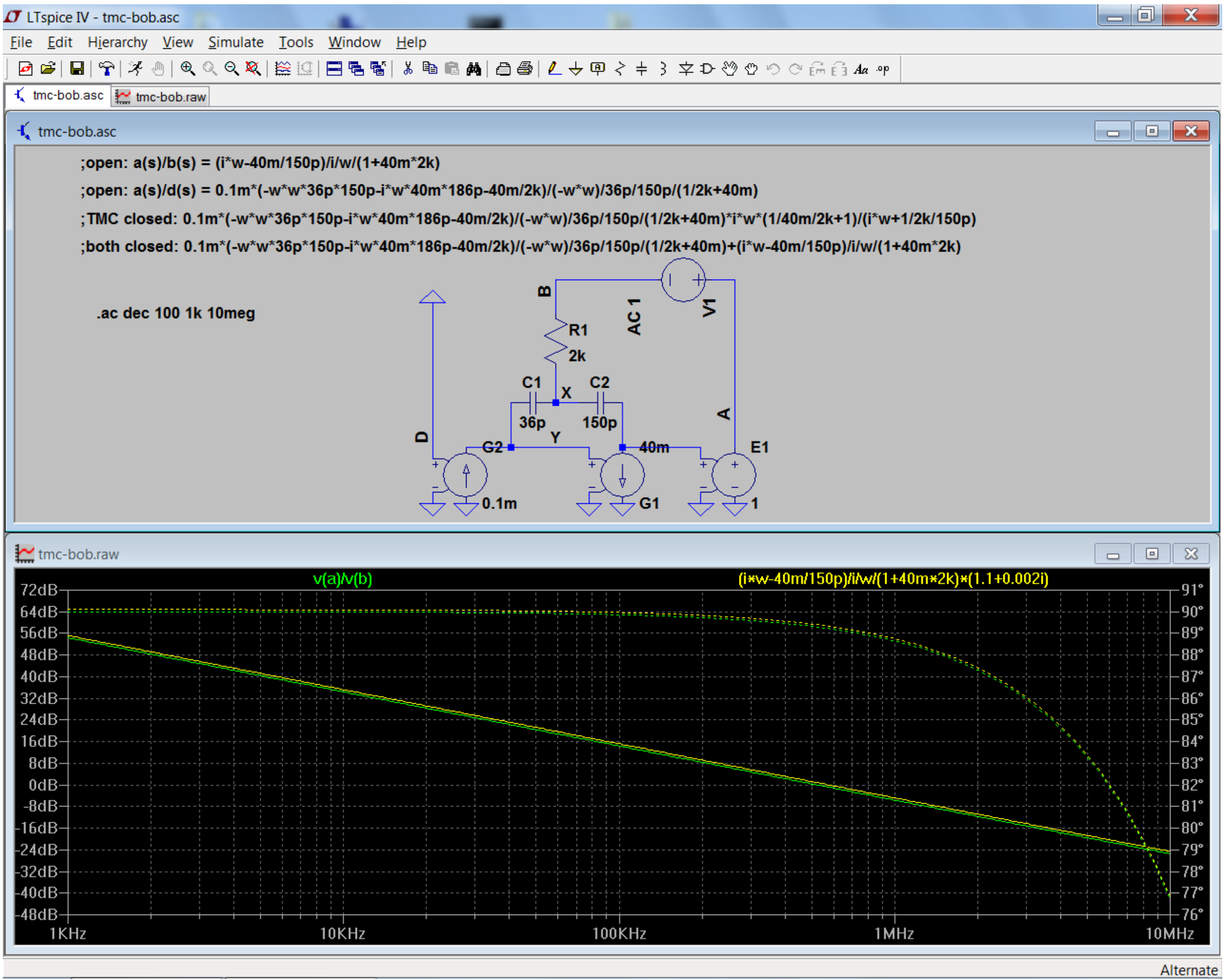


$$i_1(s) = g_{m2} d(s)$$
$$i_2(s) = -g_{m1} y(s)$$
$$x(s) = Ri(s) = R(g_{m2} d(s) - g_{m1} y(s))$$
$$y(s) = x(s) + \frac{g_{m2}}{sC_1} d(s)$$
$$x(s) = Rg_{m2} d(s) - Rg_{m1}(x(s) + \frac{g_{m2}}{sC_1} d(s))$$
$$x(s)(1+Rg_{m1}) = Rg_{m2}(1 - \frac{g_{m1}}{sC_1}) d(s)$$
$$x(s) = g_{m2} \frac{s - g_{m1}/C_1}{s(1/R + g_{m1})} d(s)$$
$$a(s) = x(s) + \frac{1}{sC_2} i_2(s) = x(s) - \frac{g_{m1}}{sC_2} y(s)$$
$$= x(s) - \frac{g_{m1}}{sC_2}(x(s) + \frac{g_{m2}}{sC_1} d(s)) = x(s)(1 - \frac{g_{m1}}{sC_2}) - \frac{g_{m1} g_{m2}}{s^2 C_1 C_2} d(s)$$
$$= \ldots = g_{m2} \frac{s^2 C_1 C_2 - sg_{m1}(C_1 + C_2) - g_{m1}/R}{s^2 C_1 C_2 (1/R + g_{m1})} d(s)$$
$$G_2(s) = \frac{a(s)}{d(s)} = g_{m2} \frac{s^2 C_1 C_2 - sg_{m1}(C_1 + C_2) - g_{m1}/R}{s^2 C_1 C_2 (1/R + g_{m1})}$$

Numerical example

Ltspice allows to plot transfer functions G(s)=G(jω), since the built-in variables w and i stand for ω and j, respectivelly. As example, we use a TMC amplifier similar to that in Bob's book, page 182.

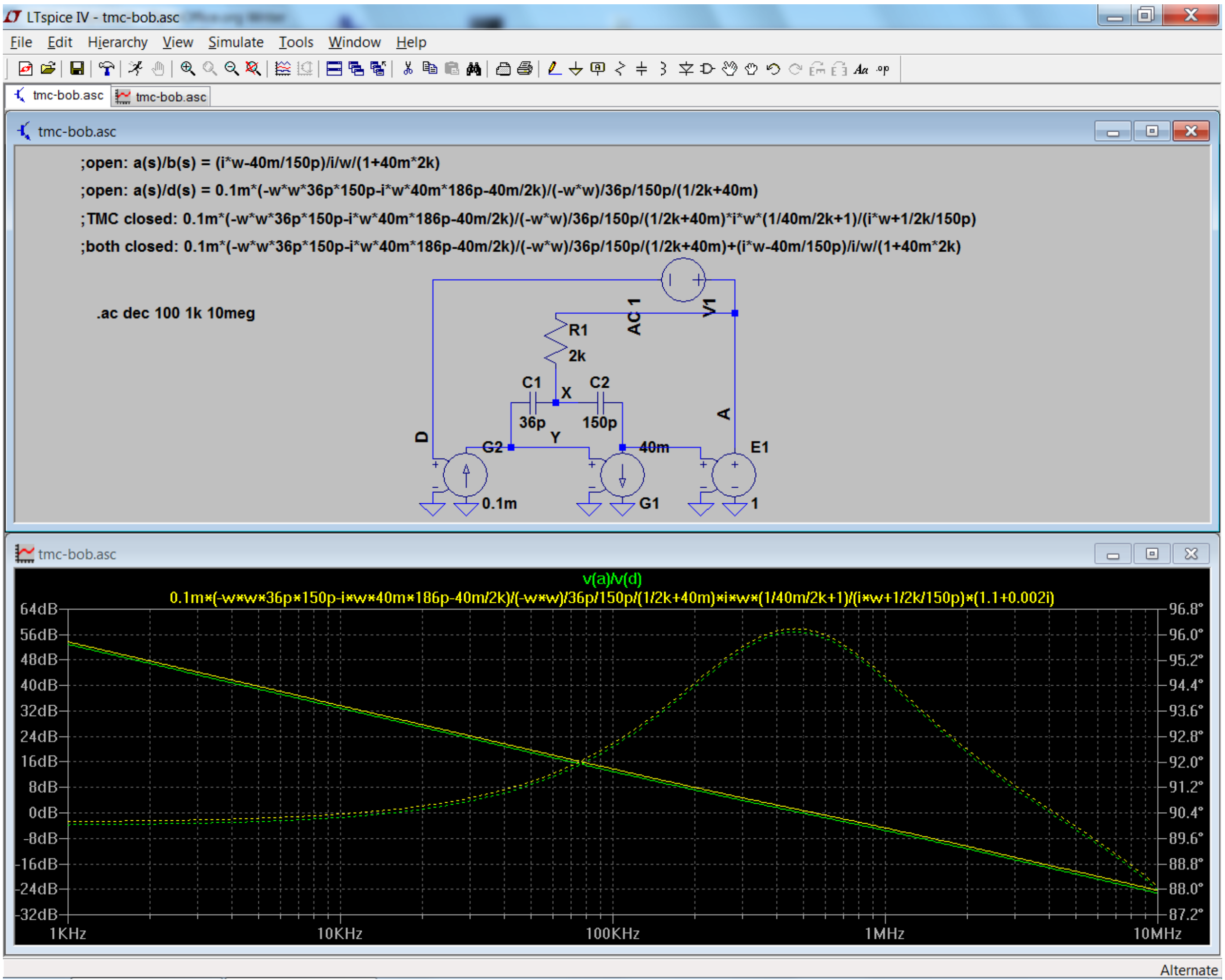
First, the loop gain in the TMC loop. It equals $G_1(s)$ and is of first order. For plotting, the calculated transfer function is multiplied by (1.1+0.002j), so that it is slightly shifted in picture.



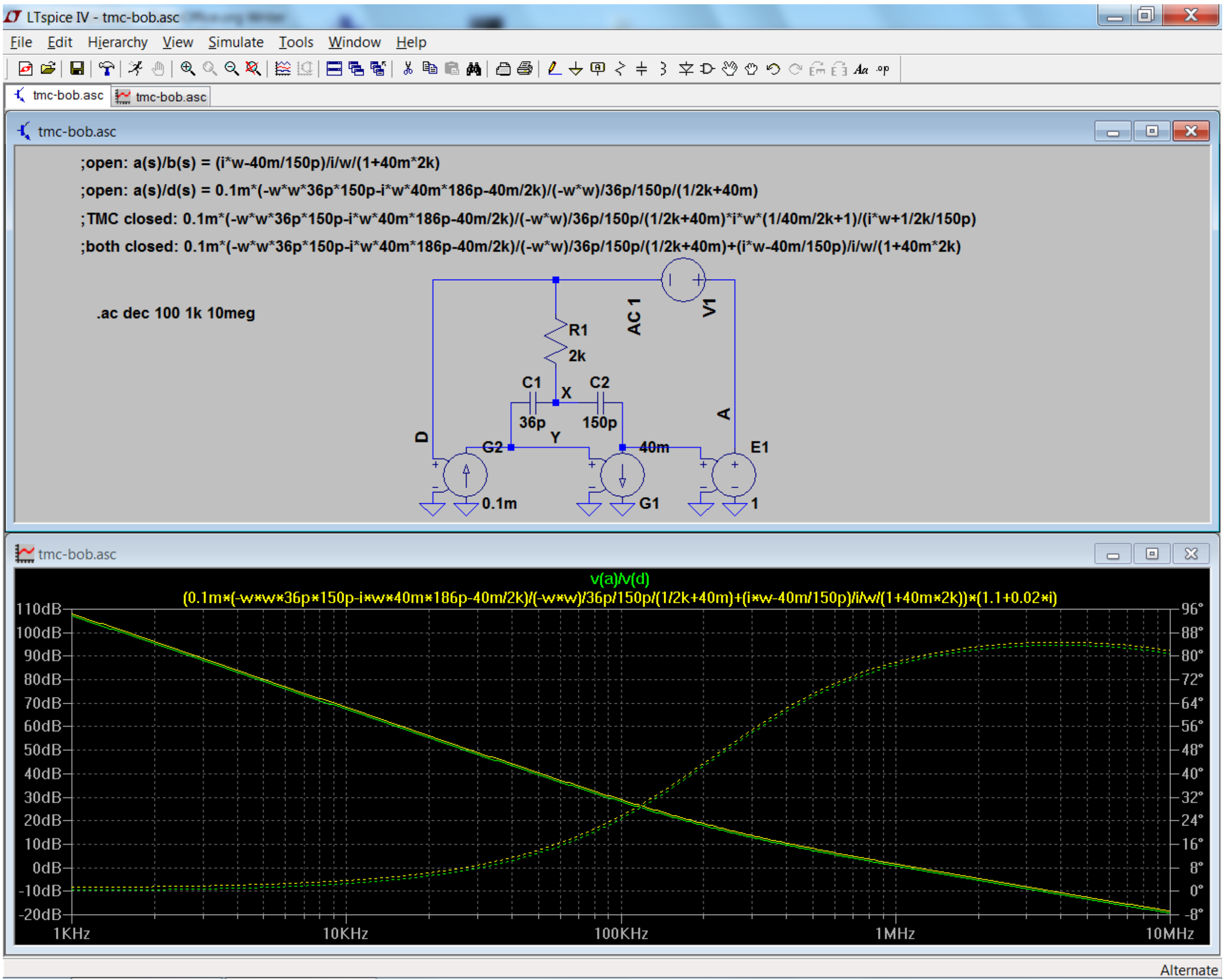
Second, the gain of the global feedback loop, the TMC loop being closed. The closed-loop gain of the TMC loop amounts to $1/(1-G_1(s))$, so the considered transfer function is $G_2/(1-G_1(s))$. For the chosen values, it resembles somewhat a first-order function. With an additional pole in the output stage, the similarity probably will become greater.

$$\frac{1}{1-G_1(s)} = \frac{s(1/(g_{m1}R)+1)}{s+1/(RC_2)}$$

Again, the calculated function is shifted by the factor (1.1+0.002j).



Finally, the total NFB $G_1(s)+G_2(s)$ around the output stage, which is clearly of second order. In the example, the ULGF is about the sum of the values in inner and outer loop.
Again, the calculated gain has been shifted in the plot.



Acknowledgements

This treatment is result of a fruitful discussion with diyaudio members 'jcx', 'jxdking', 'dadod', and 'dave zan'. Additionally, it would not have been possible without the nice tool LTspice.

Reference

[1] Boris J. Lurie: Classical Control Theory.