A Design Strategy Based on g_m/I_D Method for Critically Damped Ring Amplifiers

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***Abstract*—This paper presents a design strategy for critically damped ring amplifiers using the g_m/I_D method based on data tables obtained through the electrical simulation of a simple CMOS inverter. Using the open-loop transfer function of the critically damped ring amplifier with the data tables allows for an understanding of how the amplifier's performance metrics change with varying design parameters, offering valuable insights. Based on this analysis, two designs are proposed: one optimized for maximum gain and the other for maximum speed, emphasizing power efficiency. The results of these designs are then compared to the electrical simulations of the amplifiers to confirm the validity of the proposed design strategy.**

***Keywords*—ADC, pipeline, RA, residue amplifier, ring amplifier, gm/ID method, CMOS**

SUMMARY

A promising option for the residue amplifier in high-speed, low-power pipeline ADCs is the critically damped ring amplifier. It offers rail-to-rail output swing in low-voltage scaled environments, achieves high slew rates even with small transistors, and leverages scalability with advancing semiconductor technologies. Owing to its simple inverter-based configuration maintaining the same operation region for most of its operation, enables a design approach utilizing the g_m/I_D method Therefore, a CMOS inverter circuit with its input shorted to its output is simulated to obtain a set of transistor parameter values (g_m, g_{ds}, etc) for different transistor's channel lengths and widths. These values can then be effectively employed to streamline the design process by integrating them into the relevant open-loop analytical expressions, facilitating adjustments to the design variables as needed.

The design strategy can be summarized by Table I that shows the relationship between amplifiers stage variables and amplifier performance metrics, enabling an easier evaluation of trade-offs.

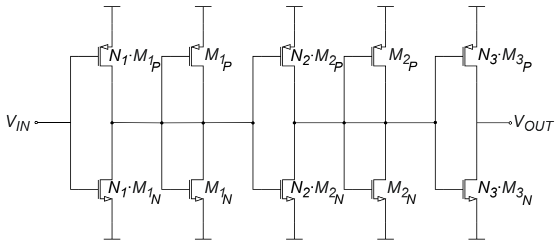

Fig. 1. Critically damped ring amplifier.

- To maximize gain increase the lengths L_1, L_2, L_3, and the multipliers N_1 and N_2.
- To maximize speed increase the lengths L_1 and L_2, reduce L_3, and also increase the multipliers N_1, N_2 and N_3.
- For stability the non-dominant poles must at least 2.5 times the GBW, requiring a decrease in L_1 and L_2. This change adversely impacts performance in terms of gain, speed, and efficiency.
- Stability can be defined by a phase margin of at least 60°, requiring a decrease in multipliers N_1, N_2, and N_3. The first two adjustments reduce both gain and speed, while the last one impacts only speed.
- Increasing the scale factor K_{S_1} enhances stability by shifting f_{p_1} to higher frequencies without affecting other poles. This is an effective strategy for achieving stability while leaving the other poles unaffected, although at the cost of efficiency.
- Increasing, K_{S_2} not only shifts f_{p_2} to higher frequencies but also shifts f_{p_1} to lower frequencies. Similarly, increasing K_{S_3} can enhance speed by extending the bandwidth to higher frequencies and moving f_{p_2} to lower frequencies.
- The multipliers N_1, N_2, and N_3 are a more effective tool for achieving stability than the lengths L_1, L_2, and L_3, they have a greater effect on both gain and speed.

TABLE I
PERFORMANCE METRICS ASSOCIATED WITH DESIGN VARIABLES. THE SYMBOLS INDICATE THE FOLLOWING: $\nearrow$ FOR DIRECT PROPORTIONALITY, $\searrow$ FOR INVERSE PROPORTIONALITY, – FOR STATIC RESPONSE, AND $\sim$ FOR VARIABLE RESPONSE.

	A	BW	GBW	P_d	PM	f_{p_1}	f_{p_2}
L_1	$\nearrow$	–	$\nearrow$	$\searrow$	$\sim$	$\searrow$	–
N_1	$\nearrow$	–	$\nearrow$	$\nearrow$	$\searrow$	$\sim$	–
K_{S_1}	–	–	–	$\nearrow$	$\nearrow$	$\nearrow$	–
L_2	$\nearrow$	–	$\nearrow$	$\searrow$	$\sim$	$\searrow$	$\searrow$
N_2	$\nearrow$	–	$\nearrow$	$\nearrow$	$\searrow$	$\searrow$	$\sim$
K_{S_2}	–	–	–	$\nearrow$	$\sim$	$\searrow$	$\nearrow$
L_3	$\nearrow$	$\searrow$	$\searrow$	$\searrow$	$\sim$	–	$\searrow$
N_3	–	$\nearrow$	$\nearrow$	$\nearrow$	$\searrow$	–	$\searrow$
K_{S_3}	–	$\nearrow$	$\nearrow$	$\nearrow$	$\sim$	–	$\searrow$