Differential Difference Amplifier – The Forgotten Building Block

Shraga Kraus
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What is It All About?

• Every analog engineer is familiar with:

• But what are these?
What is a DDA?

- A differential difference amplifier (DDA) is an op amp with 4 input nodes.
- It enables implementation of:
  - Complex circuits with a single op amp
  - Voltage mode circuits with “infinite” input resistance
  - Fully differential active filters of various topologies
History


A Versatile Building Block: The CMOS Differential Difference Amplifier

EDUARD SÄCKINGER, STUDENT MEMBER, IEEE, AND WALTER GUGGENBÜHL, SENIOR MEMBER, IEEE

Abstract — An extension of the op-amp concept featuring two differential inputs is presented. In a closed-loop environment this circuit forces two floating voltages to the same value, and thus has many interesting applications in the analog circuit domain. The formal description of such a circuit, its nonidealities, and restrictions are given. A monolithic integration of this differential difference amplifier (DDA) in a double-poly CMOS technology and the measured characteristics are described. Many applications of this circuit, including a voltage comparator with floating inputs, a voltage inverter without resistors, and an instrumentation amplifier with only two external gain-determining resistors, are discussed.

I. INTRODUCTION

BEFORE discussing the differential difference amplifier, a short refresh of the op-amp principle is given. The classical operational amplifier acts as a device which, if completed with a negative feedback loop, adjusts its output in order to reduce the differential input voltage to a negligible value. For an ideal op amp with infinite gain this voltage goes to zero. If the voltage at the noninverting input terminal is called \( v_p \) (for positive) and the voltage at the inverting input \( v_n \) (for negative) the operating principle of the ideal op amp can be summarized:

\[
E_{pp} - E_{nn} = E_{pn} = E_{np} = E_{pp} - E_{nn}
\]

Please note that analogous to the normal op amp (2) is a comparison and therefore the DDA does not require absolutely precise device parameters. The symbol in Fig. 1 might suggest that this circuit can be realized by a combi-
Principle of Operation
\[ v_{out} = \left[ g_m(v_1 - v_2) + g_m(v_3 - v_4) \right] A_z \]

\[ = g_m A_z (v_1 - v_2 + v_3 - v_4) \]
Closed Loop Equation

- Assuming $g_m A_z \to \infty$
- $(v_1 - v_2 + v_3 - v_4) \to 0$
- $(v_1 - v_2) = (v_4 - v_3)$
Basic DDA Circuits

\[(v_1 - v_2) = (v_4 - v_3)\]

• Balun with unity gain

\[A_v = 1\]

• Balun with >1 gain

\[A_v = 1 + \frac{R_2}{R_1}\]
Basic DDA Circuits

\[ (v_1 - v_2) = (v_4 - v_3) \]

- Level shifter
  \[ A_v = 1 \]

  \[ A_v = 1 + \frac{R_2}{R_1} \]
Basic DDA Circuits

\[(v_1 - v_2) = (v_4 - v_3)\]

• Gain of 2 without resistors
  \[A_v = 2\]

• Summing amplifier
  \[v_{out} = v_{in1} + v_{in2}\]
FDDA Structure

• A fully differential version
  – Requires common mode feedback
Basic FDDA Circuits

\[(v_1 - v_2) = (v_4 - v_3)\]

- Fully differential buffer
  \[A_v = 1\]

- Fully differential amp
  \[A_v = 1 + R_2/R_1\]
Implementation in CMOS
DDA Implementation

\[
\frac{g_m}{2} (v_{1-2} + v_{3-4})
\]

\[
g_m (v_{1-2} + v_{3-4})
\]

\[
\frac{g_m}{2} v_{1-2}
\]

\[
\frac{g_m}{2} v_{1-2}
\]

\[
\frac{g_m}{2} v_{3-4}
\]

\[
\frac{g_m}{2} v_{3-4}
\]
FDDA Implementation
Large Input Signal

• Feedback does not assure small signal at the inputs
• The differential pairs should be degenerated

\[(v_1 - v_2) = (v_4 - v_3)\]
• When input/output common modes differ, 
\[ V_{\text{ICM}} \neq V_{\text{OCM}} , \]
the differential pairs are under asymmetric conditions

\[
(v_1 - v_2) = (v_4 - v_3)
\]
Which Technology?
DDA Headroom

• Differential pairs have to deal with large signals – both differential and common
  – DDA (with single ended output) is more suitable for high voltage technologies

• However, if the circuit has high gain, the input signal is probably small
  – If input signal is sufficiently small, low voltage technologies can also be OK
FDDA Headroom

- If $V_{ICM} = V_{OCM}$ the differential pairs face only small signals.

- Hence headroom is similar to a standard phase-preserving amplifier.
  - If phase-preserving amplifier is feasible in the technology, FDDA is also feasible.
## Feedback Type

<table>
<thead>
<tr>
<th></th>
<th>Current Feedback</th>
<th>Voltage Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single-Ended</strong></td>
<td>![Diagram 1]</td>
<td>![Diagram 2]</td>
</tr>
<tr>
<td><strong>Fully Differential</strong></td>
<td>![Diagram 3]</td>
<td>![Diagram 4]</td>
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</tbody>
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Selected Applications
DDA Applications

- Balun/instrumentation amplifier
- Floating current source
- Common mode feedback that does not load the outputs
- RF amplifier gain control
FDDA Applications

- Rx baseband pre-amplifier that does not load the predecessive mixer
- Amplifier coming right after a passive LC filter
- Interfacing an on-chip temperature sensor with an ADC
- Implementation of some active filter topologies –
• Fully differential dual-buffer ("minimum sensitivity") stage:
FDDA in Active Filters

- Fully differential Sallen-Key stage:
Thank You!