CONSTANT FRACTION DISCRIMINATOR

F. Loddo & C. Tamma – INFN Bari
**Principle of Operation**

Creation of a variable threshold tracking the signal always at a certain fraction of its amplitude

\[ V_{OUT}(t) = V_{IN}(t - T_d) - f \times V_{IN}(t) \]

The output bipolar signal has a zero crossing time \( T_0 \) depending only on network parameters \( (T_d, f) \)

\[ T_d > (1-f) \times T_p \quad TRUE \ \CONSTANT \ FRACTION \ TIMING \ TCF \]

\[ T_d < (1-f) \times T_p \quad AMPLITUDE \ AND \ RISE \ TIME \ COMPENSATED \ TIMING \ ARC \]
**Proposed Shaping Network**

*Cross coupling topology*

Main Advantage:
The fully differential structure provides very good rejection of common mode noise injected in the substrate by the switching digital logic.

S. Garbolino, S. Martoiu and A. Rivetti

*Implementation of Constant-Fraction-Discriminators (CFD) in Sub-micron CMOS Technologies*

2011 IEEE Nuclear Science Symposium Conference Record
Shaping Network

To minimize timing jitter, the rms noise must be minimized while the signal slope through the threshold crossing must be maximized.

\[
\begin{align*}
f &= 0.5 \\
T_d &= 50\% \, T_p
\end{align*}
\]

To matches the peak of the input signal \( T_p \) and the amplitude tracking threshold is set to the 50% of the amplitude of the input signal.
Shaping Network

Cross coupling topology

Moreover, once the fraction is fixed a higher order filter has a higher slope (less jitter)

**Design Specifications:**
- filter order \( n = 3 \) as compromise between timing precision and area occupied
- fraction factor \( f = 0.4 \)
- Time delay \( T_d = 0.6 \times T_p \) programmable with \( T_p \) through switches
- TCF configuration with Crossing Time \( T_0 = T_p \)
- Use of polysilicon resistors and vertical natural capacitors

- New: Possibility to compensate parameter process variations using additional capacitors (enabled by switches)
Shaping Network

One or more “$S_1$” analog switches can be closed to reach the desired $T_d$.

- **+3σ case:**
  - $S_{1i}$ closed.
  - $S_{2i}$ and $S_{3i}$ opened.

- **typical case:**
  - $S_{1i}$ and $S_{2i}$ closed.
  - $S_{3i}$ opened.

- **-3σ case:**
  - $S_{1i}$, $S_{2i}$ and $S_{3i}$ closed.

Optimization of $T_d$ with process variations
Example: \( T_p = 75 \text{ ns} \)

- \( V_{IN} \)
  - Amplitude = 100 mV
  - \( T_p = 75 \text{ ns} \)

- \( V_{OUT} \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossing time ( T_0 )</td>
<td>75.12 ns</td>
</tr>
<tr>
<td>Delay time ( T_d )</td>
<td>43.41 ns</td>
</tr>
<tr>
<td>Fraction factor ( f )</td>
<td>0.422</td>
</tr>
</tbody>
</table>
Example: $T_p = 75$ ns

Amplitude Compensation

Amplitude $= 10 \div 1000$ mV

$T_p = 75$ ns

<table>
<thead>
<tr>
<th>$T_0$</th>
<th>$74.98 \div 75.12$ ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T_0$</td>
<td>0.14 ns</td>
</tr>
<tr>
<td>$T_p$ [ns]</td>
<td>Crossing Time $T_0$ [ns]</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>25</td>
<td>24.75</td>
</tr>
<tr>
<td>50</td>
<td>49.77</td>
</tr>
<tr>
<td>75</td>
<td>75.12</td>
</tr>
<tr>
<td>100</td>
<td>100.45</td>
</tr>
<tr>
<td>200</td>
<td>199.96</td>
</tr>
</tbody>
</table>
Based on two identical comparators with hysteresis (60 µA + digital inverters)

Working on differential signals

The use of a leading edge arming comparator provides energy selection capability and prevents the sensitive zero-crossing device from triggering on the noise.
CFD simulations ($T_p = 75$ ns)

- $T_{peak} = 75$ ns
- $10$ mV (close to $V_{th}$) $\leq V_{in} \leq 1000$ mV

- CFD output
- ZCC output
- Arming output

- Time walk $< 1$ ns in all configurations: ($T_p = 25$ ns, 50 ns, 75 ns, 100 ns and 200 ns)

- In case of $T_p = 400$ ns, using the CFD settings for 200 ns we get $\Delta T_0 \sim 3$ ns
CFD Status

• CFD preliminary results look promising

• The Zero-crossing section quite mature (corner simulations looks fine)

• Arming section: 2 options
  1. Single-ended shaper output (and AC coupling)
  2. Differential outputs (same as CFD shaping network)

• We are working on Threshold network for option 2

• Probably not ready for August submission