History of translinear (TL) circuits (I)

1968: Barrie Gilbert surprises the electronic society with a new class of analog circuits: Translinear Circuits
1970 – 1980: various standard building blocks become available
1980 – 1990: interest in TL circuits drops
    - Better performance with digital equivalents
    - Better performance (dynamic range and speed) with comparable linear analog circuits
1990: TL circuits have become curiosities
History of translinear (TL) circuits (II)

1990 – ??: Revival of TL circuits
Low voltage operation:
- TL circuits in up-down topology operate at 1 volt: one junction voltage +
  two saturation voltages from rail to rail
- TL circuits provide instantaneous companding
- TL circuits operate in the current domain

Low power operation:
- Series parasitic impedances have little effect
- No overhead of AD and/or DA conversion
- No large resistors required
- Class-AB operation possible

The name “Translinear”

- transconductance of a bipolar transistor is linearly
  proportional to its collector current.
- This fact is a consequence of the logarithmic relation
  between the collector current and the base-emitter
  voltage

\[
V_{BE} = V_T \ln(I_C / I_S(t))
\]

\[
\frac{di_c}{du_{be}} = g_m = \frac{I_C}{V_T}
\]
Translinear principle

\[ e^{a+b} = e^a e^b \]

Translinear components (I)

- The bipolar transistor
- The diode
- The MOS transistor in weak inversion (NB: body effect)
  - SOI, SOA
  - Bulk-driven
  - Triode region
- Voltage-translinear principle: MOSTs in strong inversion; quadratic relation between drain current and gate-source voltage
Translinear components (II), BJT

Translinear components (III), MOS
Translinear principle

Gilbert:

In a closed loop containing an even number of forward biased junctions, arranged so that there are an equal number of clockwise facing and counterclockwise facing polarities, the product of the current densities in the clockwise direction is equal to the product of the current densities in the counterclockwise direction.

\[
\sum_{k=1}^{n} V_{V_k} = 0 \\
\prod_{k=1}^{n} \frac{I_k}{I_{V_k}} = 1 \\
\prod_{C}^{C_{n}} \frac{I_k}{I_{V_k}} = \prod_{C}^{C_{n}} \frac{I_k}{I_{V_k}} \\
\prod_{CW}^{CCW} J = \prod_{CW}^{CCW} J
\]
Translinear applications

- (Controllable) amplifiers
  - Current mirror
  - Current amplifier
- Non-linear signal processing functions
  - Multiplication/division,
  - RMS-DC conversion,
  - Vector summation,
  - Squaring and square-rooting.
- Low-voltage and low-power circuits

Translinear analysis

- In the loops: KVL converted into current-mode polynomials
- In the nodes: KCL provides current relations
Conclusion:
- Translinear circuits can be completely described by current-mode polynomials
The current mirror

\[ I_{C1} = \frac{I_{C2}}{A_1} \]

\[ I_{C2} = \frac{A_2}{A_1} \left( \frac{I_{C1}}{x_f} + 1 + \frac{1}{B_F} \right) \]

Class-A amplifier/attenuator

\[ I_{C1} = I_{C2} \]

\[ I_{C2} = \frac{A_2}{A_1} I_{C1} \]

\[ i_{in} \]

\[ i_{out} \]
Two-quadrant multipliers, principle

Up-down topology

Stacked topology

The A-cell with biasing

(1+W)I_y (1-X)I_x = (1-W)I_y (1+X)I_x
⇒ I_w = 2XI_y

Suitable for 1-V electronics!
**The B-cell with biasing**

\[
(1+W)I_y(1-X)I_x = (1-W)I_y(1+X)I_x \\
\Rightarrow I_W = 2XI_y
\]

Not suitable for 1-V electronics!
Base current errors

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**Application of the B-cell (I): the “Gilbert gain cell”**
Application of the B-cell (II)

“Six-pack” analog multiplier/divider
The cross-quad (I), principle

Caprio’s quad (I)
Caprio’s quad (II)

Caprio’s quad (III)
Class-AB output stage (I)

Class-AB output stage (II)
Systematic TL synthesis procedure (I)

1. Function approximation
   \[ \sin x \equiv \frac{x - \frac{x^3}{3}}{1 + \frac{x^2}{2}}, \text{ for } |x| \leq 1 \]

2. Function decomposition
   \[ \prod_{n=1}^{N/2} I_{2n} = \lambda \prod_{n=1}^{N/2} I_{2n-1}, \text{ where } \lambda = \prod_{n=1}^{N/2} \frac{A_{2n}}{A_{2n-1}} \]
   \[ \frac{1 + z + x}{1 - z - x} = (1 + x)^2 \]
   \[ \frac{1 + z + x}{1 - z - x} = (1 - x)^2 \]

Systematic TL synthesis procedure (II)

3. Circuit realization techniques (incl. biasing)
Measurements

[Graph showing measurements and fitted data]