Translinear Circuits

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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

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The name "Translinear"

- trans conductance of a bipolar transistor is lin early proportional to its collector current.
- This fact is a consequence of the logarithmic relation between the collector current and the base-emitter voltage

$$V_{BE} = V_T \ln\left(I_C / I_S(t)\right)$$

$$\frac{di_c}{du_{be}} = g_m = \frac{I_C}{V_T}$$

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Translinear principle

$$e^{a+b} = e^{a} e^{b}$$

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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

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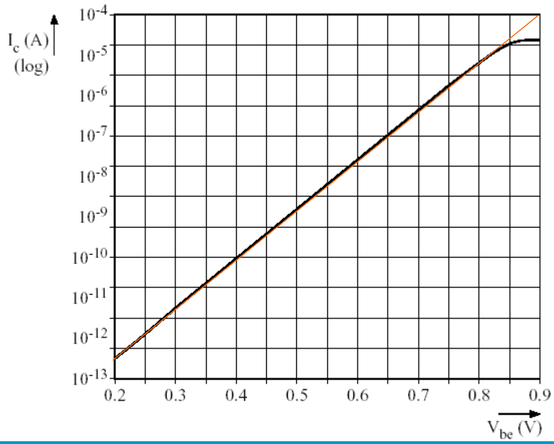
Translinear components (II), BJT



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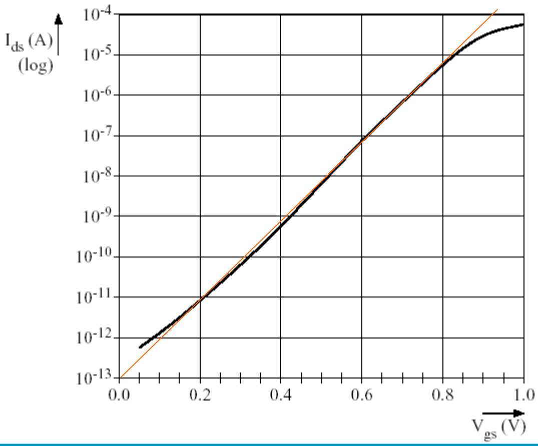
Translinear components (III), MOS



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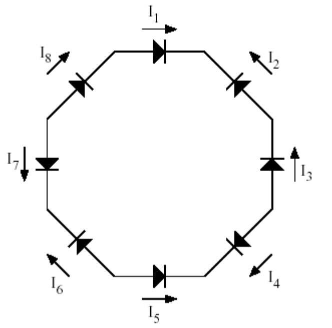
Translinear principle



$$\sum_{k=1}^{k=n} V_{FK} = 0$$

$$\prod_{k=1}^{k=n} \frac{I_k}{I_{sk}} = 1$$

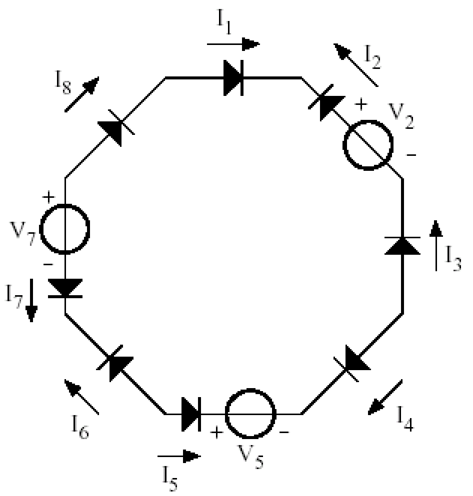
$$\prod_{CW} \frac{I_k}{I_{sk}} = \prod_{CCW} \frac{I_k}{I_{sk}}$$

$$\prod_{CW} J = \prod_{CCW} J$$

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.

Translinear network



$$\sum_{k=1}^{k=n} V_T \ln \frac{I_k}{I_{sk}} = V_L$$

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

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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

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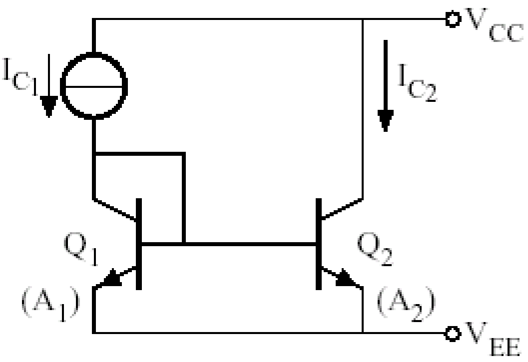
The current mirror



$$\frac{I_{C1}}{A_1} = \frac{I_{C2}}{A_2}$$

$$I_{C2} = \frac{I_{C1}}{\frac{A_1}{A_2}\left(1+1/B_F\right)+1/B_F}$$

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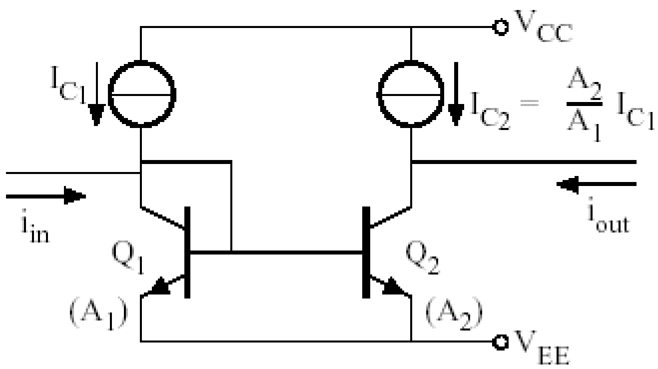
Class-A amplifier/attenuator



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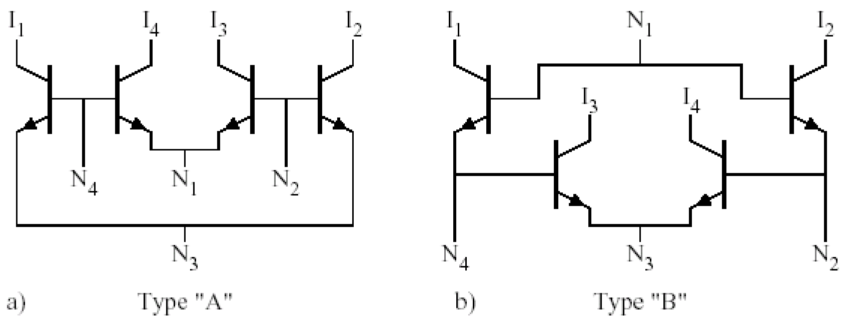
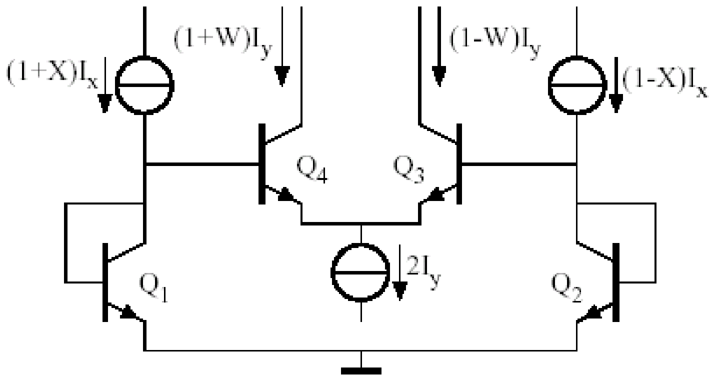
Two-quadrant multipliers, principle



Up-down topology | Stacked topology

The A-cell with biasing

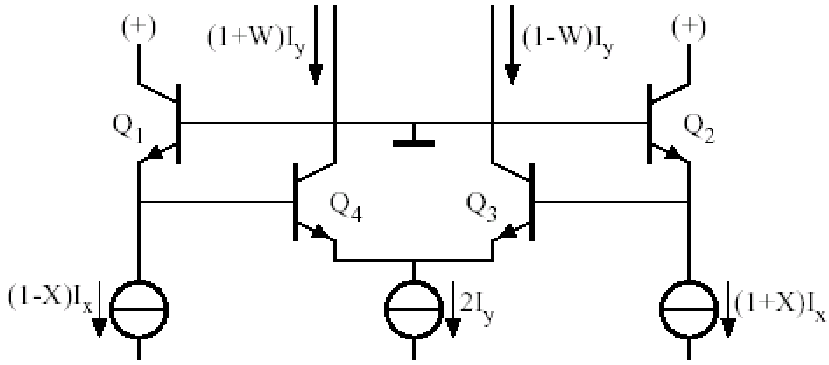


$$(1+W)I_y(1-X)I_x = (1-W)I_y(1+X)I_x$$

$$\Rightarrow I_W = 2XI_y$$

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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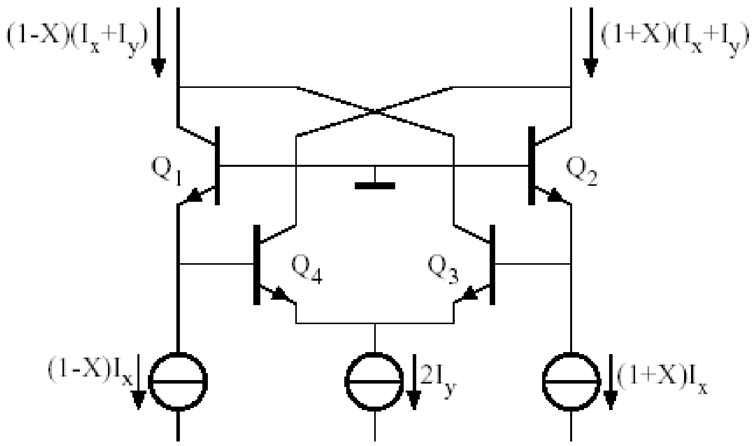
Application of the B-cell (I): the "Gilbert gain cell"



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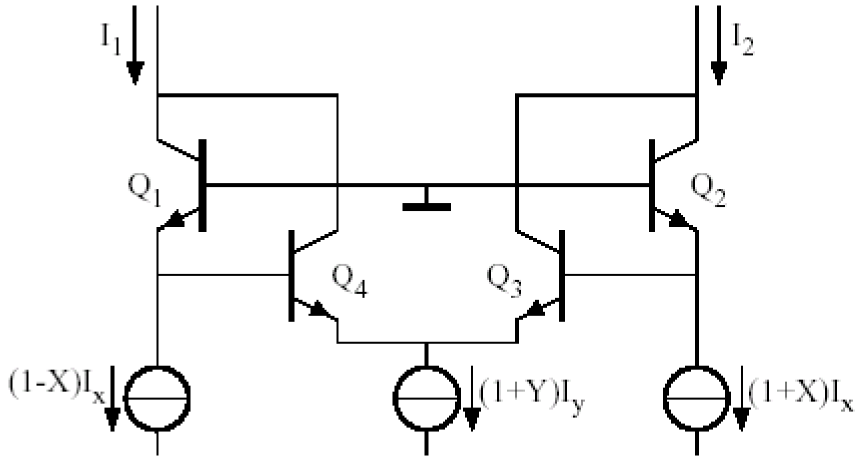
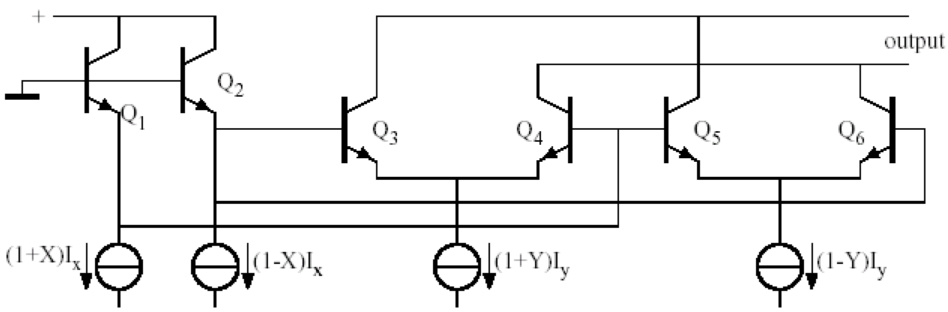
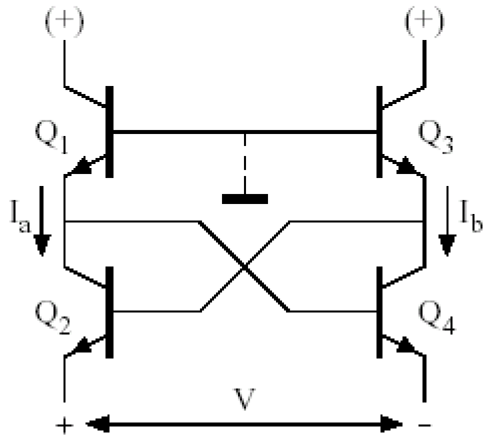
Application of the B-cell (II)



“Six-pack” analog multiplier/divider



The cross-quad (I), principle



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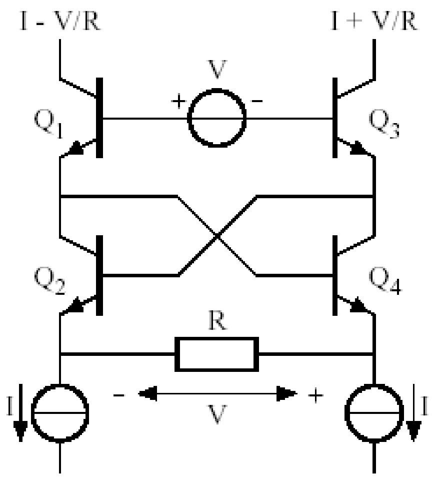
Caprio's quad (I)



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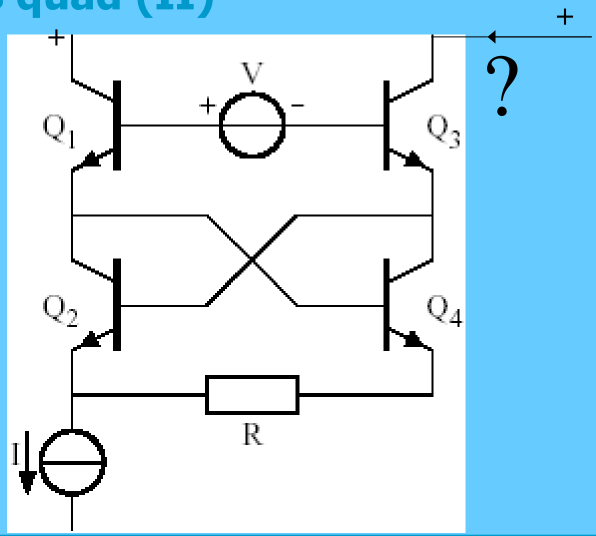
Caprio's quad (II)



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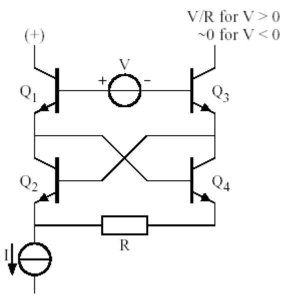
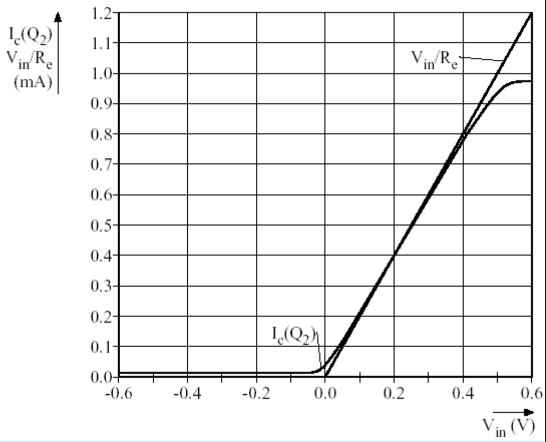
Caprio's quad (III)





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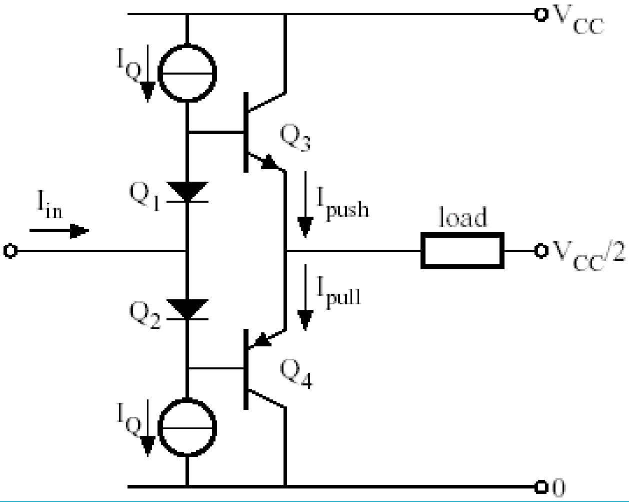
Class-AB output stage (I)



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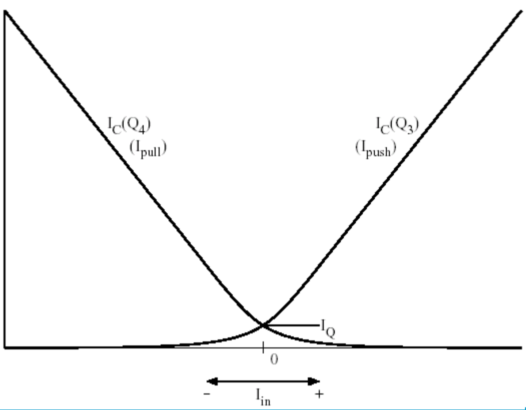
Class-AB output stage (II)



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Systematic TL synthesis procedure (I)

1. Function approximation

$$\sin \pi x \cong \frac{x - x^3}{1 + x^2}, \text{ for } |x| \leq 1$$

2. Function decomposition

$$\prod_{n=1}^{N/2} I_{2n} = \lambda \prod_{n=1}^{N/2} I_{2n-1}, \text{ where } \lambda = \prod_{n=1}^{N/2} \frac{A_{2n}}{A_{2n-1}}$$

$$\frac{1 + z + x}{1 - z - x} = \frac{(1 + x)^2}{(1 - x)^2}$$

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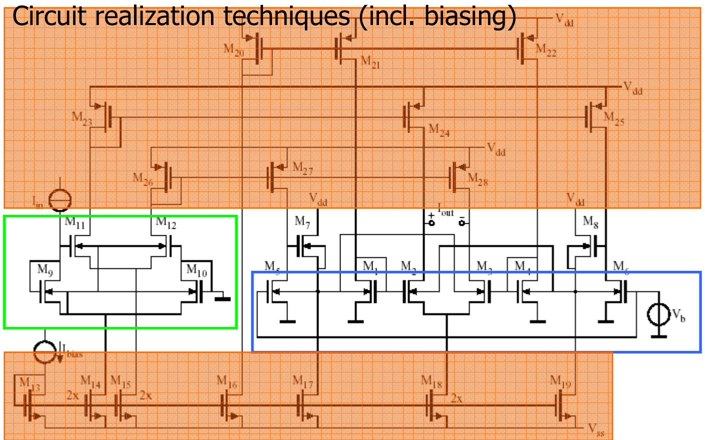
Systematic TL synthesis procedure (II)

3. Circuit realization techniques (incl. biasing)



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Measurements