

# Development of the Bandgap Voltage Reference Circuit, Featuring Dynamic-Threshold MOS Transistors (DTMOST's) in 0.13um CMOS Technology.

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## Abstract

A CMOS bandgap voltage reference circuit, featuring dynamic-threshold MOS transistors (DTMOST's) has been developed in the 0.13um CMOS technology. Insensitive to temperature and power supply variations, this cell is going to be a key component for high quality data converters.

The proposed circuit fits well into the low supply-voltage range of the current and future deep sub-micron technologies. We have carried out pre-design characterizations of the DTMOST structures taken from an experimental submit. Design and specifications of the bandgap voltage reference circuit have been presented. The circuit was submitted in a CERN organized submit in May 2004.

## I. Introduction.

With steadily decreasing power supply voltages ( $V_{dd}$ ) in present and future deep sub-micron CMOS technologies a design of any voltage/current reference on-chip becomes a non-trivial task.

The classical voltage summing bandgap reference circuit (BGR) featuring parasitic diodes (p-diffusion in N-well) [1] is not suited for a 0.13um CMOS technology with a maximum  $V_{dd}$  of 1.2V. It is so because the value of bandgap voltage in silicon (1.12V) turns out to be very close to the maximum  $V_{dd}$  admissible in the technology. This causes the circuit to fail.

We intend to use a new structure called a dynamic-threshold MOS transistor (DTMOST) in place of conventional diodes in the circuit (see Fig.1). Such a combination will constitute a high-quality reference circuit able to fit into the reduced supply voltage range of the 0.13um CMOS technology.

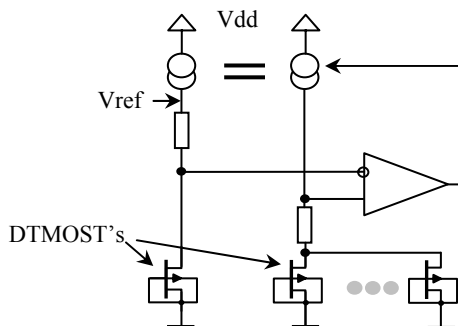


Fig.1. Architecture of the bandgap voltage reference circuit, featuring DTMOST's.

## II. Dynamic-Threshold MOS Transistor.

In 1999 Anne-Johan Annema proposed to use DTMOST structure in CMOS technologies [2]. It is in fact a p-channel MOS (PMOS) transistor with gate, drain and substrate contacts connected together (see Fig.2). This device behaves similar to a conventional diode with an exception. It needs far lower bias voltage to operate (see Fig.3).

The exponential behaviour of the voltage-to-current characteristic is of primary importance because it enables us to construct a current source, which delivers a current that is proportional to the absolute temperature (PTAT). This can be used to implement a mechanism of temperature compensation in a bandgap reference circuit [3]. The conventional diode has an exponential voltage-to-current relationship above 650mV while the DTMOST configuration is exponential within a region from 100mV to 220mV (see Fig.3).

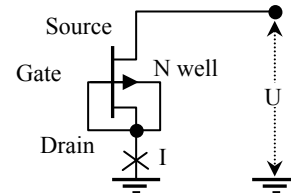


Fig.2. DTMOST configuration on the basis of a PMOST.

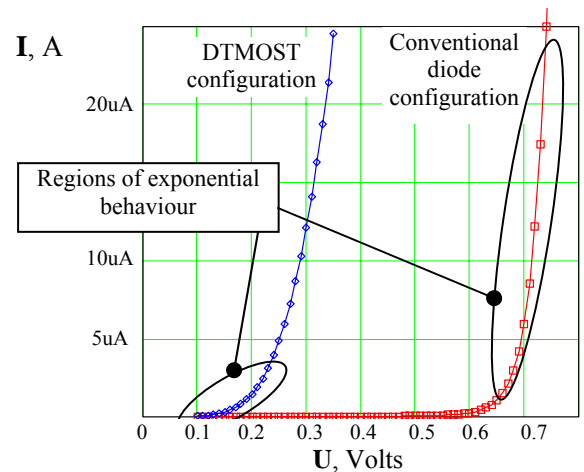


Fig.3. Current-to-voltage characteristics for both DTMOST configuration and conventional diode configuration.

In order to design a complete bandgap reference circuit the DTMOST structures have been characterized and modelled. The current-to-voltage characteristic  $I_d(V_{gs})$  of the DTMOST has been measured at various temperatures in a temperature chamber. The DTMOST structures came from an experimental submit in the  $0.13\mu\text{m}$  CMOS technology. As expected, voltage across the DTMOST is conversely proportional to absolute temperature (see Fig.4). By the approximation the lines to the low temperature region the effective bandgap voltage is estimated to be  $410\text{mV}$  (see Fig.4).

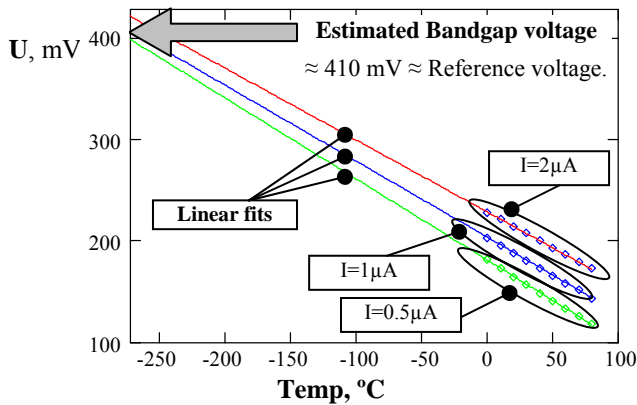


Fig.4. Voltage across the DTMOST at various currents as a function of temperature.

### III. Voltage reference circuit.

The complete voltage bandgap reference circuit consists of the DTMOST devices, a pair of cascoded current sources and a two-stage operational amplifier (see Fig.5). According to the measurements voltage across the DTMOST is Conversely Proportional to Absolute Temperature (CTAT). On the other hand, the voltage across the chain of resistors is Proportional to Absolute Temperature (PTAT) since the current through the DTMOST's goes up as temperature rises.

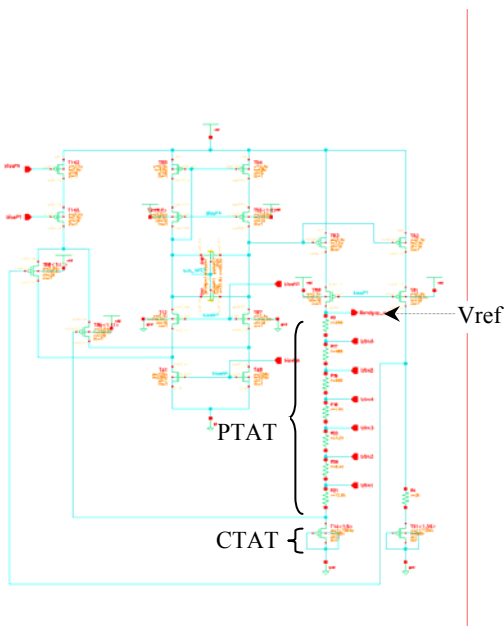


Fig.5. Schematic of the voltage reference circuit featuring DTMOST's.

After an appropriate adjustment, superposition of the PTAT and the CTAT voltages results in a temperature insensitive reference voltage (see Fig.6).

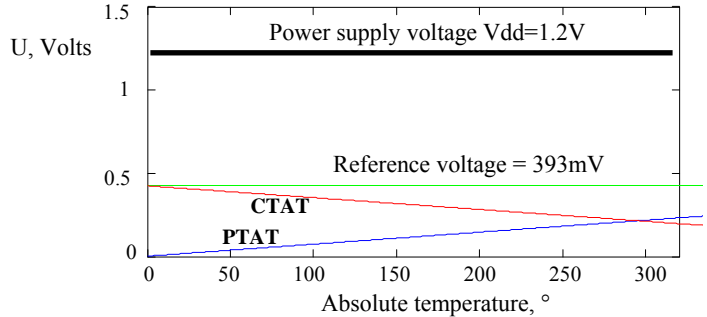


Fig.6. Temperature behaviour of the voltages in the circuit.

All the biases needed for operation of the circuit are generated on-chip. The main specifications of the circuit taken from SPECTRE simulations are listed here:

- Reference voltage:** 393mV
- Temperature sensitivity:**  $\pm 1.5\text{mV}$  (within a temperature range from  $0^\circ\text{C}$  to  $80^\circ\text{C}$ ) (See Fig.6).
- Shift of the Reference voltage caused by supply voltage variations:**  $\pm 0.25\text{mV}$  (if the supply voltage varies in range from  $0.9\text{V}$  to  $1.4\text{V}$ ).
- Power consumption:**  $60\mu\text{W}$  ( $50\mu\text{A}$  vs  $1.2\text{V}$ )
- Spread of the Reference voltage due to fabrication process variations:**  $\sigma=1.2\text{mV}$ .
- Occupied area on the chip:**  $250\mu\text{m}$  vs  $60\mu\text{m}$

### IV. Conclusions.

The  $0.13\mu\text{m}$  CMOS Technology provides designers with a wide set of attractive options, in particular, those who develop electronics to operate in high radiation environment.

The Voltage Bandgap Reference circuit needs revision in order to fit into the reduced power supply voltage range of the technology.

Dynamic-Threshold MOS Transistors (DTMOST) are able to replace diodes in the classical Voltage Bandgap Reference circuit as to be suited for the reduced power supply range.

### V. References.

- [1] Jiang Yueming and Lee Edward, *Design of Low-Voltage Bandgap Reference Using Transimpedance Amplifier*, IEEE TCAS II, vol.47, pp.552-555.34, pp. 76-80, June 2000.
- [2] Anne-Johan Annema, *Low-Power Bandgap References Featuring DTMOST's*, IEEE Journal of Solid-State Circuits, vol.34, No.7, July 1999.
- [3] Robert Pease, *The Design of Band-Gap Reference Circuits: Trials and Tribulations*. IEEE 1990 Bipolar Circuits and Technology Meeting, pp 214-218, 1990.