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Optical interaction in active analog circuit elements

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ABSTRACT

This publication introduces (spectral) photon emission (PEM) and electro-optical frequency mapping (EOFM/LVI) measurements to analog circuit elements (simple, cascode and low-voltage current mirrors). Different operating conditions of the devices are probed and the voltage dependence of the signals is analyzed. Results partly show close similarities to optical probing of digital IC's, but also differences in voltage dependence and signal levels due to more complicated voltage and signal distributions along the devices.

1. Introduction

In recent times the interest in the application of common digital IC failure analysis techniques e.g. photon mission microscopy (PEM) and electro-optical frequency mapping (EOFM/similar to LVI) to analog or mixed-signal circuits has grown. Therefore we carried out optical investigations with these techniques on various operating points of different current mirrors as typical elements of analog and mixed-signal circuits. Additionally we observed EOFM and PEM signals for different size transistors in different operating points but in same technology, as the current mirrors were realized with different transistor setups and sizes (see Fig. 1).

2. Devices and experimental setup

The test structures were specially self-designed by TU Berlin to have all current mirror types accessible as single test structures in geometric dimensions ideal for the optical observations. The structures were manufactured by IHP research institute, Frankfurt (Oder), Germany, in 240 nm technology with a nominal voltage of 2.5 V. The exact transistor geometries are indicated in Table 1. All transistors had threshold voltages V_{th} ~ 0.6 V.

The samples under investigation were different types of current mirrors frequently used in analog and mixed-signal circuits: simple current mirror no. 2 and 3 with current amplification factors of 4 and 8, two cascode current mirror no. 1 and 2 and two low-voltage current mirrors no. 1 and 2 with current amplifications of 1×, but differing transistor sizes. All current mirrors were realized with nFETs only.

Current mirrors can reproduce an input current by a specified factor depending on the input and output transistors widths, as long as both transistors are operating in saturation condition. For the basic simple current mirror (Fig. 1), gate and drain of the input transistor and the gate of the output transistor are shorted internally to always ensure saturation mode on the input side. Applying a suitable output voltage $V_{out} > V_g - V_{th}$ at the output side guarantees saturation mode here, too.

Extension of the simple current mirror towards a cascode current mirror enhances electrical behaviour and output stability due to higher output resistance. The step from cascode towards a low-voltage current mirror expands the operating conditions towards lower currents/voltages, while maintaining the cascodes' advantage of higher output resistance.

As all measurements were taken from the backside, the chip had to be bonded and consecutively the substrate was thinned down and polished to a remaining substrate thickness of ~100 µm. Unaltered

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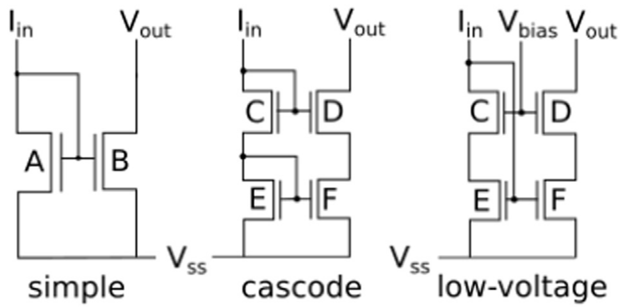

Fig. 1. Overview of the different current mirror types (simple, cascode and low-voltage) and different transistor geometries (A–F, see Table 1) used for the experiments.

Table 1
Geometric dimensions of current mirror nFET transistors.

Transistor ID	Number of parallel transistors	Gate length × width per single transistor
A	2	1,4 μm × 2 μm (all simple current mirrors)
B	8 (simple c.m. no. 2) 16 (simple c.m. no. 3)	1,4 μm × 2 μm (all simple current mirrors)
C, D	4	720 nm × 4,95 μm (cascode + low-voltage no. 1) 240 nm × 1,65 μm (cascode + low-voltage no. 2)
E, F	4	720 nm × 4,95 μm (cascode + low-voltage no. 1 + 2)

electrical performance was checked by additional electrical measurements before and after each investigation (Fig. 2).

2.1. PEM setup

For all photon emission measurements and especially for the spectra acquisition we used a carefully calibrated InGaAs-camera Peltier cooled to −70 °C. Integration time was 80 s. For the spectral measurements we inserted an additional prism as dispersive element into the optical path (Fig. 3) of our Hamamatsu Phemos-1000. All voltages were applied and monitored via a 4-channel HP 4145-A semiconductor parameter analyzer and one external voltage supply. The conformity of ground levels of both devices was ensured via external connections. To avoid spectral inaccuracies we used a 20× lens to ensure that the single nFET emission spot was almost point-like. Several calibration measurements for the transmission/sensitivity of the optical system and InGaAs camera were carried out with a black-body radiator at a color temperature of 1900 K. First we used a calibrated spectroscope to measure the spectral

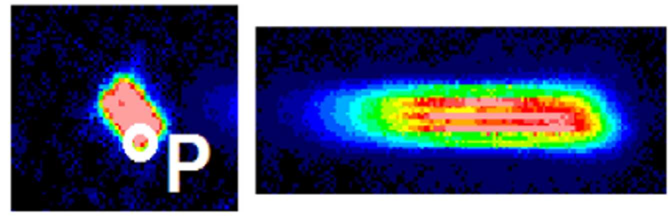

Fig. 3. Photon emission of simple current mirror no. 2 at an angle of 45° without (left) and with prism (right) inserted into the optical path. The image on the left shows the emission of all 8 output-side FETs. The emission of every single FET is almost point-like (~3 × 3 pixels). The probing point for spectra extraction is indicated with P.

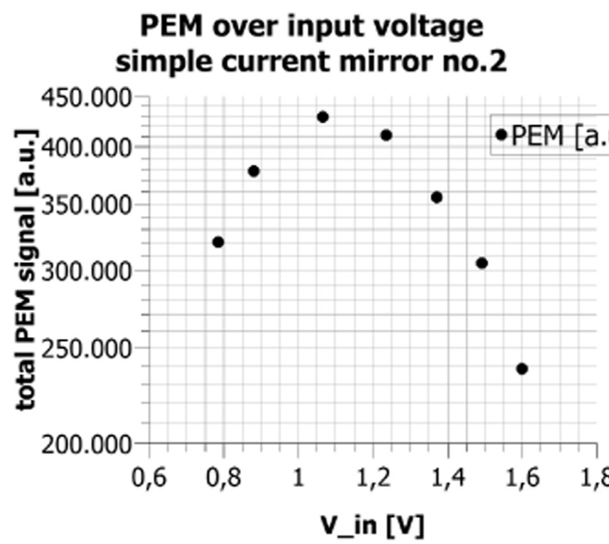

Fig. 4. Summarized photon emission intensity over input voltage with $V_{out} = 2$ V for current mirror no. 2.

emission curve of the black body radiator in the range from 900 to 1700 nm (measurement 1). Then we repeated this measurement with same conditions and integration time with the Phemos-1000 system with installed InGaAs camera (measurement 2). We obtained the overall correction factor by dividing the emission intensity of the second and first measurement for every data point/wavelength.

2.2. EOFM setup

For the detection of the EOFM signals we used the standard Advantest U3851 2-channel cross domain analyzer belonging to Phemos-1000. To prevent signal reflections at high-ohmic (>1 kΩ)

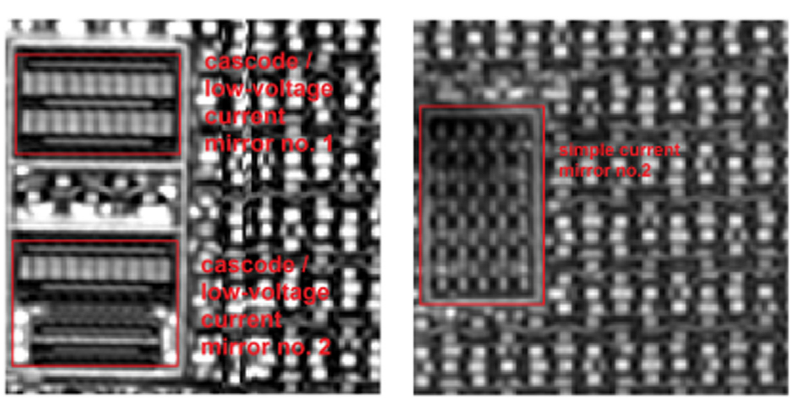

Fig. 2. Pattern images of cascode/low-voltage current mirror no. 1 (left, upper half) and no. 2 (left, lower half) and simple current mirror structure no. 2 (right).

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