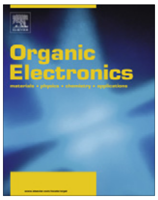
Organic Electronics 11 (2010) 1357–1362

Contents lists available at ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel



Analog techniques for reliable organic circuit design on foil applied to an 18 dB single-stage differential amplifier

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ARTICLE INFO

Article history:
Received 17 February 2010
Received in revised form 12 May 2010
Accepted 15 May 2010
Available online 4 June 2010 4 June 2010

Keywords:
Amplifier
Foil
V_t
Bias stress
Backgate
Pentacene

ABSTRACT

In this work we present design strategies for organic V_t-insensitive circuit design tailored to organic p-type transistor technology, and we demonstrate them by application on a single-stage differential amplifier. Specifically, to reduce the V_t-sensitivity, we implement common-mode feedback, bootstrapped gain enhancement, cascoding and backgate steering. The effectiveness of the design strategies is demonstrated by showing a single-stage amplifier performing with 18 dB gain and losing only 4 dB gain after several months of exposure to ambient environment.

1. Introduction

Organic electronics technology is a relatively new technology intended to provide a platform for low-cost and low-frequency printable electronics on a variety of substrates, including flexible plastic substrates. Interesting applications are flexible electronics such as displays [1,2], low-cost electronics with limited chip complexity, such as RFID-tags, and applications demanding integration of several functions on a (flexible) surface, such as smart-sensor systems with integrated sensors, actuators and analog-to-digital (AD) and digital-to-analog (DA) interfaces. The state-of-the-art in organic circuit design has focused on digital design of RFID-tags [3] and only a few publications discuss analog designs [4,5]. The latter ideally require a stable technology with predictable and repeatable behavior, high yield and a specifically adapted design strategy to overcome shortcomings. This work summarizes the major technological challenges and applies a proposed design strategy to a mainstream example of analog circuits, a single-stage differential amplifier. Experimental results are included to verify the proposed design strategies.

2. Technology

The most mature thin-film organic electronics technology applies pentacene as semiconductor. Despite being the most mature organic electronics technology, it still suffers from considerable limitations. In this section, we discuss the different technological parameters, their main limitations, and the impact of these limitations on design of analog circuitry.

The hole mobility of pentacene in a full process [1] is typically about 0.1–1 cm^2/V s. The electron mobility is typically lower and quite unreliable when the transistor is operated in air. We therefore consider pentacene, as most other organic semiconductors, to be p-type only. Extensive work is being done to find stable n-type organic semiconductors that lead to n-type organic thin-film transistors (OTFTs) for complementary circuits [5–9]. In this work a

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doi:10.1016/j.orgel.2010.05.006

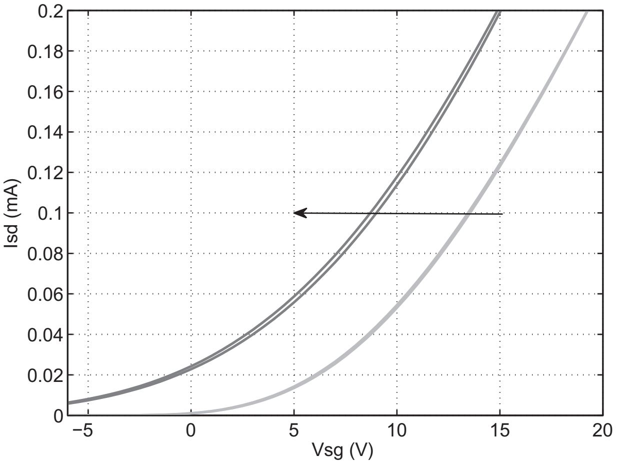

Fig. 1. Effect of bias stress on the transfer curve. The stress conditions are $V_{SG} = V_{SD} = 15$ V, for 24 h under ambient conditions, i.e., with exposure to O_2, H_2O, light and temperature fluctuations. The effect is mainly a V_t shift.

design strategy for technologies with p-OTFTs only is presented.

The second most important technological issue for analog circuit design is the shift of the mean threshold voltage (V_t) value. This V_t shift can have different causes. Run-to-run variations at production-time can result in a shift of the mean V_t value. Moreover, bias stress as well as trapping caused by water and oxygen occur at run-time and cause V_t shift over time. Bias stress in organic semiconductors follows from carrier trap states at the dielectric–semiconductor interface or in the dielectric that compensate for the applied electric field [10,11]. Bias stress can be exacerbated by the presence of water and oxygen molecules at the semiconductor, as well as by light [12–14]. The effect of oxygen is explained by chemical reaction with the pentacene molecule, according to Refs. [15,16]. Other Refs. [17,18] explain the behavior by diffusion of O_2 in the pentacene. Bias stress at negative V_{SG} (with the pentacene transistor in the off-state or mild electron accumulation) is faster and more degrading than bias stress at positive V_{SG} (transistor in on-state with hole accumulation) [11]. As can be seen in Fig. 1, our measurements confirm that V_t shifts over several volts when the transistor is biased in the O_2- and H_2O-containing ambient environment, where also light and temperature changes are present. From this figure it can be concluded that V_t shift is a very important and hardly predictable effect to deal with when designing analog circuits.

A third technological effect that needs to be considered for circuit design is mobility (μ) variation. A certain variation of mobility is present on wafer as well as from run-to-run. Moreover, mobility degradation occurs when transistors are biased or exposed to ambient environment, containing O_2 and H_2O, for long time [19]. Mobility variation influences the current through a transistor. In a main amplifier and assuming that all transistors undergo the same mobility change, this effect results in a bandwidth variation only. As the current through each transistor varies linearly with the mobility, the DC behavior of the circuit is not affected. Mobility variation becomes an issue when transistors are biased in the linear region as resistors, i.e. as a resistor in an RC integrator. Then the exact value of R is important for the RC product. In general, μ variation is to first instance of less importance for basic analog design than V_t shift.

A fourth important drawback of the technology is the mismatch between V_t of different transistors, resulting from on-wafer variations. Despite certain variability over

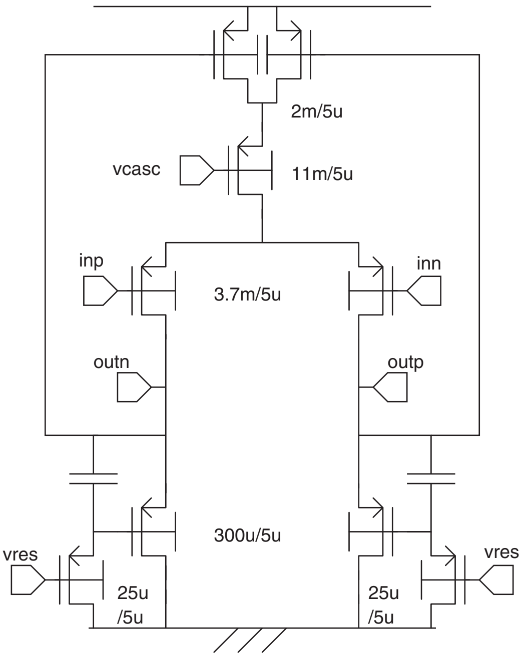

Fig. 2. Proposed schematic of the single-stage differential amplifier with p-type load, bootstrapped gain enhancement, CMFB, cascoding and backgate steering.