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TEST METHODS FOR THE CHARACTERIZATION OF ORGANIC TRANSISTOR-BASED RING OSCILLATORS

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The text of this standard is based on the following documents:

IEEE Std	FDIS	Report on voting
IEEE Std 1620.1™-2006	113/185/FDIS	113/195/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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A bilingual version of this standard may be issued at a later date.

IEEE Standard for Test Methods for the Characterization of Organic Transistor-Based Ring Oscillators

Sponsor
Microprocessor Standards Committee
of the
IEEE Computer Society

Approved 8 June 2006

IEEE-SA Standards Board

Abstract: Recommended methods and standardized reporting practices for electrical characterization of printed and organic ring oscillators are covered. Due to the nature of printed and organic circuits, significant measurement errors can be introduced if the electrical characterization design-of-experiment is not properly addressed. This standard describes the most common sources of measurement error, particularly for high-impedance electrical measurements commonly required for printed and organic ring oscillators. This standard also gives recommended practices in order to minimize and/or characterize the effect of measurement artifacts and other sources of error encountered while measuring printed and organic ring oscillators.
Keywords: electrical characterization, high-impedance printing, organic transistor, printed electronics, ring oscillator

IEEE Introduction

This introduction is not part of IEEE Std 1620.1-2006, IEEE Standard for Test Methods for the Characterization of Organic Transistor-Based Ring Oscillators.

This standard covers recommended methods and standardized reporting practices for electrical characterization of organic transistor-based ring oscillators. Due to the nature of organic transistors and circuitry, significant measurement errors can be introduced if not properly addressed. This standard describes the most common sources of measurement error and gives recommended practices in order to minimize and/or characterize the effect of each.

Standard reporting practices are included in order to minimize confusion in analyzing reported data. Disclosure of environmental conditions and design-of-experiment are included so that results can be appropriately assessed by the research community. These reporting practices also support repeatability of results, so that new discoveries may be confirmed more efficiently.

The practices in this standard were compiled from research and industry organizations developing organic transistor devices, materials, circuitry, and manufacturing techniques. These practices are based on standard operating procedures utilized in laboratories worldwide.

The development of this standard was initiated in 2004 to facilitate the evolution of organic transistor circuitry from the laboratory into a sustainable industry. Standardized characterization methods and reporting practices create a means of effective comparison of information and a foundation for manufacturing readiness.

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Test Methods for the Characterization of Organic Transistor-Based Ring Oscillators

1. Overview

1.1 Scope

This standard describes a method for characterizing organic electronic transistor-based ring oscillators, including measurement techniques, methods of reporting data, and the testing conditions during characterization.

1.2 Purpose

The purpose of this standard is to provide a method for systematically characterizing organic transistor-based ring oscillators. This standard is intended to maximize reproducibility of published results by providing a framework for testing organic ring oscillators, whose unique properties cause measurement issues not typically encountered with inorganic-based circuitry. This standard stresses disclosure of the procedures used to measure data and extract parameters so that data quality may be easily assessed. This standard also sets guidelines for reporting data, so that information is clear and consistent throughout the research community and industry.

1.3 Electrical characterization overview

1.3.1 Testing apparatus

Testing shall be performed using an electronic device test system with an accuracy and resolution of at least ±0.1% of the measurement values for both signal level and timing or frequency measurements. In order to maintain the necessary accuracy, this test method requires that the instrumentation be calibrated against a known and appropriate set of standards [e.g., National Institute of Standards and Technology (NIST)]. These calibrations may be performed by the equipment user or as a service by the equipment vendor. Calibration is not performed against a known organic field-effect transistor (OFET), organic circuit, or other FET-type device; the basic instrument operations (e.g., voltage, current, and resistance) are calibrated against some method traceable to a NIST (or similar internationally recognized standards organization) physical standard. Recalibration is required according to the instrument manufacturer's recommendations or when the instrument is moved or when the testing conditions change significantly (temperature change greater than 10 °C, relative humidity change greater than 30%, etc.).

1.3.2 Measurement techniques

1.3.2.1 Required measurements

Characterization of the organic ring oscillator shall include at minimum the following primary set of measurements:

- A ring of an odd number (at least three) of inverter stages, operated at a single supply voltage, characterizing output voltage from a single node versus time in seconds. The number of inverter stages should be chosen to be as large as practically possible. Ideally the ring oscillator should comprise at least seven or more stages. Shorter ring oscillators can often oscillate with signal level not closely related to their saturation values. While this results in faster oscillation, the timing numbers so obtained are much less useful in understanding realistic digital circuit speeds. In addition, ring oscillators with few stages are more affected by the way in which the output voltage is measured, and, in particular, measurement results will depend more on the capacitance with which the node being measured is loaded by the measurement. For all ring oscillators particular care should be taken to report the conditions of the signal measurement at the output node. In all cases the value of the load capacitance in relation to the input capacitance of an inverter stage should be reported.
- Both output frequency and output signal level and swing shall be reported.
- Static measurements of inverter transfer characteristics. Preferably, the inverters for static measurements should have the same size and geometry as those used in the ring oscillator. Geometry information shall be provided for both ring oscillators and static inverters.

1.3.2.2 Recommended measurements

The following additional measurements are strongly recommended:

- Measurement of ring oscillator output using multiple supply voltages.
- Simultaneous measurement of ring oscillator output at two or more nodes, using buffer stages between the ring oscillator and measurement apparatus. This is in addition to, and should not be instead of, measurement of ring oscillator output at one node.

1.3.3 Repeatability and reporting sample size

Sample performance between different devices may vary due to variations in the fabrication process. Additionally, it is useful to determine the repeatability of the reported results. Therefore, sample size is to be reported thus:

- If no sample size is reported, it is assumed that the data represents a sample size of a single device (i.e., may not represent repeatable results).
- For sample sizes larger than one, the sample size is reported with the method of sampling (e.g., whether all devices were characterized, a randomly-chosen fraction of the total sample set).

A description of what the reported data demonstrates (e.g., average values, worst-case) is also required.

1.3.4 Application of low-noise techniques

In order for comparability between different device structures and eventual compatibility to nanoelectronics, voltages and applicable geometries are given so that electrical fields (V/cm) may be determined. For example, film thickness is reported along with VGS values, and channel length is reported with VDS data. Preferably, electrical field values are specified.

Due to optical sensitivity of some organic semiconducting materials, all measurements should be conducted inside a light-insulating enclosure that is preferably earth (safety) grounded. Optical isolation is recommended if exposure to ambient light causes a change of more than 1% from values obtained in the dark.

Due to the high impedances and extremely low current values being measured, proximity of personnel, heavy machinery, or other potential electromagnetic/radiofrequency interference (EMI/RFI) sources should be maintained as far away from the measurement system while in operation. This is of particular concern when measured voltages are below 1 mV or when current values are less than 1 μA.

1.3.5 Characteristics and effects of instrument probing

The probe means used for characterizing ring oscillator output will affect the waveform due to loading of the ring oscillator nodes. Methods of measuring the oscillator wave include direct probing of the ring oscillator with an oscilloscope probe (passive or active), or indirect probing where the oscillator output is connected to a suitable buffer amplifier (for example, another inverter; this mimics the loading effects when the circuit is used in typical applications).

Effects of all types of measurements include:

— Introduction of capacitance, which may reduce ring oscillator speed

— Introduction of shunt resistances, which may reduce voltage swing and/or affect oscillator speed

It is recommended that a buffer stage or stages be added to the ring oscillator for frequency output measurement. This buffer is typically an additional inverter (often, but not necessarily, with the same physical design of the inverters used to construct the ring oscillator) with the input terminal connected to the output of one stage of the oscillator. The output of the buffer stage or stages is then measured. This method of measuring the operating frequency of a ring oscillator helps to minimize the effect of capacitive loading from the measurement on oscillator performance.

Depending on circuit and measurement details, measured buffer stage output voltage level and swing may not correspond well to internal circuit values. Direct probing of internal nodes using a low-capacitance, high-impedance active probe can provide additional information about ring oscillator signal level and, for ring oscillators with buffered output, the change in operation frequency with internal node probing provides additional circuit operation information and should be reported. Direct probing of ring oscillator output with a low-capacitance, high-impedance active probe is also an acceptable alternative to the use of a buffer stage or stages. For such measurements the capacitance and resistance or current burden of the probe should be reported.