

Finger Typed Electrode Based Electro-Optical Demodulator Fabricated on High Resistivity Silicon

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Received: 10 December 2012 Accepted: 5 January 2013 Published: 15 January 2013

Abstract

This paper focus on a finger typed electrode based electro-optical photo mixing demodulator. This device is fabricated on high resistivity silicon in custom technology. The main performance indicators such as DC characteristics, DC and AC demodulation contrast and phase-linearity measurement of a test sample are experimentally characterized. Experimental results exhibit a good DC charge separation and good dynamic demodulation capabilities from 100Hz to 30MHz. The average linearity error of finger typed electrode device for square wave 4.09

Index terms— electro-optical demodulator, high resistivity silicon, demodulation contrast, photonic device, modulation frequency.

1 INTRODUCTION

Recently a lot of effort has been concentrated to develop standard 3D vision imagers due to the drastic increase in demand of 3D imaging system. The 2D-imaging system can evaluate only the intensity projection of a scene, there is no information about the depth of the 3D objects.

Range-imaging sensors acquire three-dimensional (3D) maps from a scene and can be used in a variety of applications such as bio medical appliances, surveillance system; several applications in automobiles, robotics, single point measurement etc. 3D image is extracting information from the geometric estimation of third co-ordinate of a scene.

In this work, we present a finger typed field assisted electro-optical demodulator fabricated in custom technology. After reviewing related research work in Section 2, the device architecture with its working principle and ISE-TCAD simulation are introduced in Section 3. In Section 4 the electro-optical characteristics of the device is reported. Finally the paper is concluded in Section 5.

A number of applications that can detect the time or phase information of reflected light for 3D imaging are available in the literature. Depth information can be determined by correlating the incoming modulated light signal from the scene with a reference signal synchronous with the modulation signal of the light source [1]. In time-of-flight optical ranging, the phase information is used to plot the distance map of the observed scene, thus enabling the reconstruction of the shape and position of the observed objects [2]. TOF technique provides the best performance in terms of acquisition speed, reliability, overall cost of the system and is most suited to integrate electronic circuitry with more functionality. Several studies on image capturing techniques using specialized pixels coupled with active illumination have reported to produce images with information even at a low intensity level [3, 4]. TOF based 3D imagers so far reported in different literatures depending on the type of photo detector used in the pixels.

The time or phase information in addition to signal intensity is based on a variety of light sensitive devices such as: p-i-n photodiodes, linear or Geiger mode avalanche photodiodes and photomultiplier tubes. Several works [5-8] reported a standard photodiode coupled with complex readout circuitry using indirect time-of-flight.

The key element of 3D range camera of photo demodulators have been implemented with different types of technologies such as: Charged Couple Device (CCD), Complementary Metal Oxide Semiconductor (CMOS) and

45 CMOS/CCD hybrid approach. The photo generated charge is mixed on two or more photo-gates thus achieving
46 an intrinsic demodulation effect [9-12]. The advantage is the read-out channel simplicity which results in a
47 small pixel size. The disadvantages are the lower sensitivity due to the presence of the "photo-gate", the lack of
48 immunity to the ambient light and the cost of the nonstandard technology. A Photonic Mixer Device (PMD) is an
49 interesting solution for dynamic 3D-vision that is reported in [3]. An alternative demodulating detector structure,
50 the Current Assisted Photonic Demodulator (CAPD) has been reported in [14]. The function of detection and
51 demodulation in a single device uses a modulated electric field that infiltrates deeper into the substrate to enhance
52 the charge separation and collection mechanism. A linear Current Assisted Photonic Mixing Device fabricated on
53 high resistivity silicon has been described in [15].

2 III. DEVICE ARCHITECTURE AND WORKING PRINCIPLE

56 A finger-typed electrode based electro-optical demodulator consists of multiple strips. The cross sectional view
57 and the layout of the device is shown in Figure 1 (a) and (b) respectively. The above Figure 1(a) shows an active
58 pixel that contains a finger typed photonic mixing demodulator that is integrated with a read out circuit and a
59 row select transistor for each collecting electrode. This device has four electrodes, two of them known as collecting
60 electrodes and connected to V_{ce1} and V_{ce2} and rest of them are known as modulating electrodes and connected
61 to V_{me1} and V_{me2} . These modulated electrodes are connected to the device substrate. This device consists
62 of nine collecting electrodes. Among these electrodes, the seven central regions (from region 2 to region 8 as
63 shown in Figure 1) consist of a p+ type detection junction and two n+ type substrate contacts. The rest of
64 collection regions contain one collecting junction and one substrate contact, like the region 1 and 9 (Figure 1)
65 [16].

66 All of the substrate contacts and the collection junctions are connected as shown in the device cross sectional
67 diagram. The collecting electrode V_{ce1} and the modulating electrode V_{me1} are connected to the 2, 4, 6 and 8
68 regions according to the detection junctions and substrate contacts. On the other hand, the collecting electrode
69 V_{ce2} and the modulating electrode V_{me2} are $V_{me2} - V_{me1}$ is applied at the modulated electrode V_{me2} .
70 An electric field formed inside the substrate of the device guides the photo-generated charge carriers towards the
71 detection electrode V_{ce2} .

72 At 780 nm light incident on the device surface the hole current density of this device shown in Figure 2.

73 his simulated photograph shows the region 1 and 2 according to the cross sectional view of the device shown
74 in Figure 1(a). Most of the generated holes move toward the collecting electrode V_{ce2} , guided by the electric
75 field with a voltage difference applied between two modulating electrodes i.e. $V_{me2} > V_{me1}$.

3 IV. PERFORMANCE CHARACTERISTICS OF THE DEVICE

78 The customize Fabricated structure is characterized electrically and optically. The demodulation contrast of the
79 device and the effect of frequency and modulation voltage on it are assessed. Phase measurements are carried
80 out to evaluate linearity of the device. connected to the region 1, 3, 5, 7 and 9 accordingly. This device is also
81 enclosed with an n+ bulk-contact, shared along the array and placed at a minimum distance of about 20 μ m
82 from the pixel boundary. A p+ ring is surrounded by n+ bulk-contact at a distance of about 20 μ m for better
83 isolation of each device. The distance between the neighboring modulating electrodes is 20 μ m and the total
84 area of this device is 0.4mm \times 0.4mm. Firstly, the device simulation software ISE-TCAD is used to investigate
85 the operational behaviour of the device. In this device a potential difference is applied between the modulating
86 electrodes to direct the signal charges towards the two detection regions. Now we can calculate the demodulation
87 contrast by using the following equation. The device shows a maximum DC demodulation contrast larger than
88 90%, thus indicating that, this device is potentially enabling a very efficient mixing process.

4 b) Dynamic Characteristics

90 In order to measure average current at the collecting electrodes and the dynamic demodulation contrast we
91 have conducted an experiment. The schematic representation of this experiment set up is shown in Figure 5.
92 characterizations Two sinusoidal waves are generated by using a function generator. One of the two sinusoidal
93 waves is used to modulate a laser emitter and illuminate the device. The other is connected to the input of a
94 differential amplifier. The differential amplifier outputs with 180 $^\circ$ phase shift are connected to the modulating
95 electrodes V_{me1} and V_{me2} of the device. The electric field formed in the substrate average current through
96 the collecting electrodes V_{ce1} and V_{ce2} is read out with a Semiconductor Parameter Analyzer. For this
97 measurement, the sinusoidal signal for laser emitter and two modulating signals are needed to use with an
98 appropriate synchronization. At different modulation frequencies, the average current is measured under a 650nm
99 red laser with 90% modulation depth used to illuminate the test device. The capability to separate and transfer
100 the charges of a sensor to the corresponding output node can be expressed as a demodulation contrast. For data
101 acquisition a LABVIEW software program was developed for the interface with PC and the experimental set-up.

102 The dynamic demodulation contrast is the most important performance indicator for this device. The
103 demodulation contrast depends on both the amplitude of the modulation voltages and frequencies. The dynamic
104 demodulation contrast can be defined as:

105 Where I_{max} and I_{min} are the photo-generated currents flowing at collecting electrodes V_{ce1} and V_{ce2} .
106 The demodulation contrast for the finger typed device as a function of the modulation voltage amplitude at eight
107 different frequencies from 100Hz to 30MHz is shown in Figure : 6.

108 By increasing the modulation voltage it should be possible to increase the majority current that cause the drift
109 of the minority carriers, namely holes. When the modulation voltage is applied to the modulating electrodes, the
110 photo generated holes arrive at the collecting electrode of the device. If applying more voltages, the electric field
111 penetrates deeper in the substrate so that more holes reach detection node resulting in a higher demodulation
112 contrast. Due to the larger voltage applying at the modulating electrodes the power consumption is increased.
113 So the amplitude of modulation voltage should be carefully chosen. By increasing of the modulating frequency
114 the decrease of the demodulation contrast can be described with respect to diffusion time. The photo-generated
115 charges in the deeper of the substrate need more time to reach the active region where the demodulating electric
116 field is present and thus reduces the demodulation contrast.

117 The phase linearity measurements performed between the applied phase and measured phase of the device.
118 In these measurements a variable phase delay V is applied between the laser input to illuminate the device and
119 two modulation electrodes of the device. The value of V can be recovered acquiring four amplitude measurements
120 with four different phase shifts 11° , 12° , 21° and 22° applied to the modulated laser signal considered as -180° , -90° ,
121 0° and $+90^\circ$ respectively [17]. The phase shift can be calculated with the equation (ii) given below: At three
122 different frequencies-3MHz, 1 MHz and 100 kHz the C-V response of the device is shown in Figure ?? 9. Due to a
123 larger depletion width the higher reverse bias produces a lower capacitance. At lower frequency, the capacitance
124 is larger than at higher frequency. Because of their finite charging and discharging time the deep-level impurities
125 in the space charge region make the capacitance to be frequency dependent [18,19].

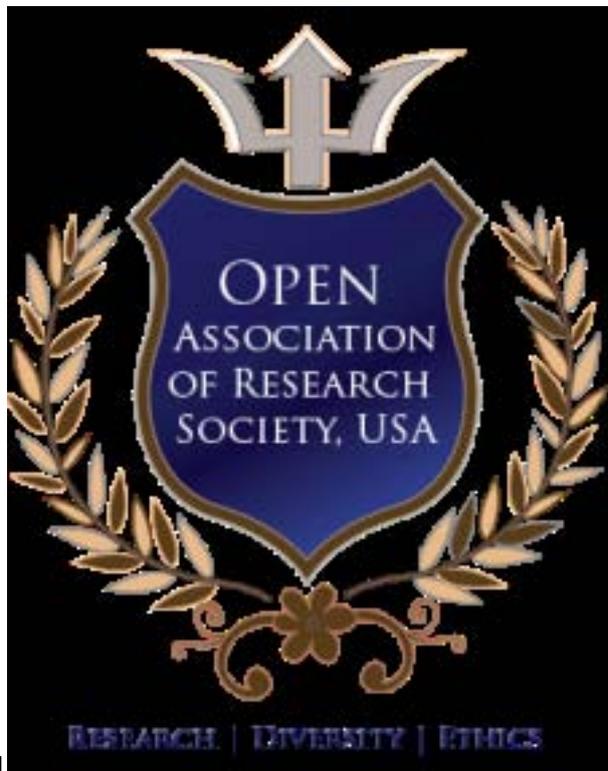
126 5 CONCLUSION

127 This paper has described the characterization of a finger typed electro-optical demodulator fabricated in a custom
128 technology on high resistivity silicon substrates. A $400\text{ m} \times 400\text{ m}$ structure with finger typed electrodes has
129 been considered and tested in terms of electrical and electro-optical performance. The maximum phase linearity
130 error between the applied phase and the measured phase is 4.09% for square wave. In particular, the DC and
131 dynamic demodulation performance of the multiple strip devices has been investigated. The measured dynamic
132 demodulation contrast is more than 20% at 20 MHz modulation frequency. This customize device corresponds
133 to understand field assisted photo mixing demodulator in term of optimizing the performance to make them in
134 complementary metal-oxide-semiconductor technology. ^{1 2 3}

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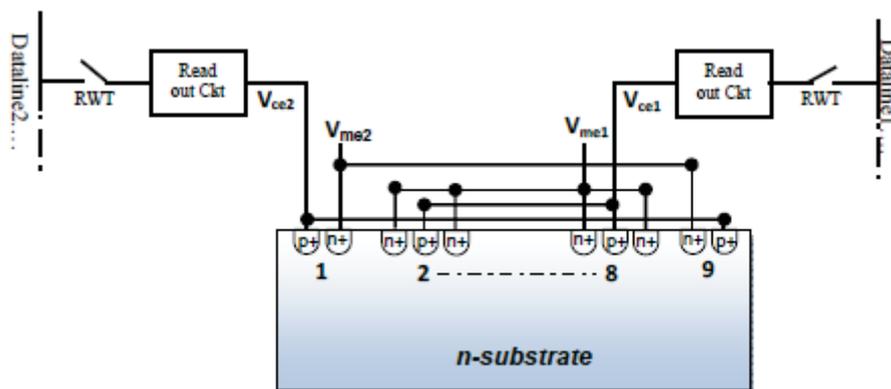
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1

Figure 1: Figure 1 :



2

Figure 2: Figure 2 :

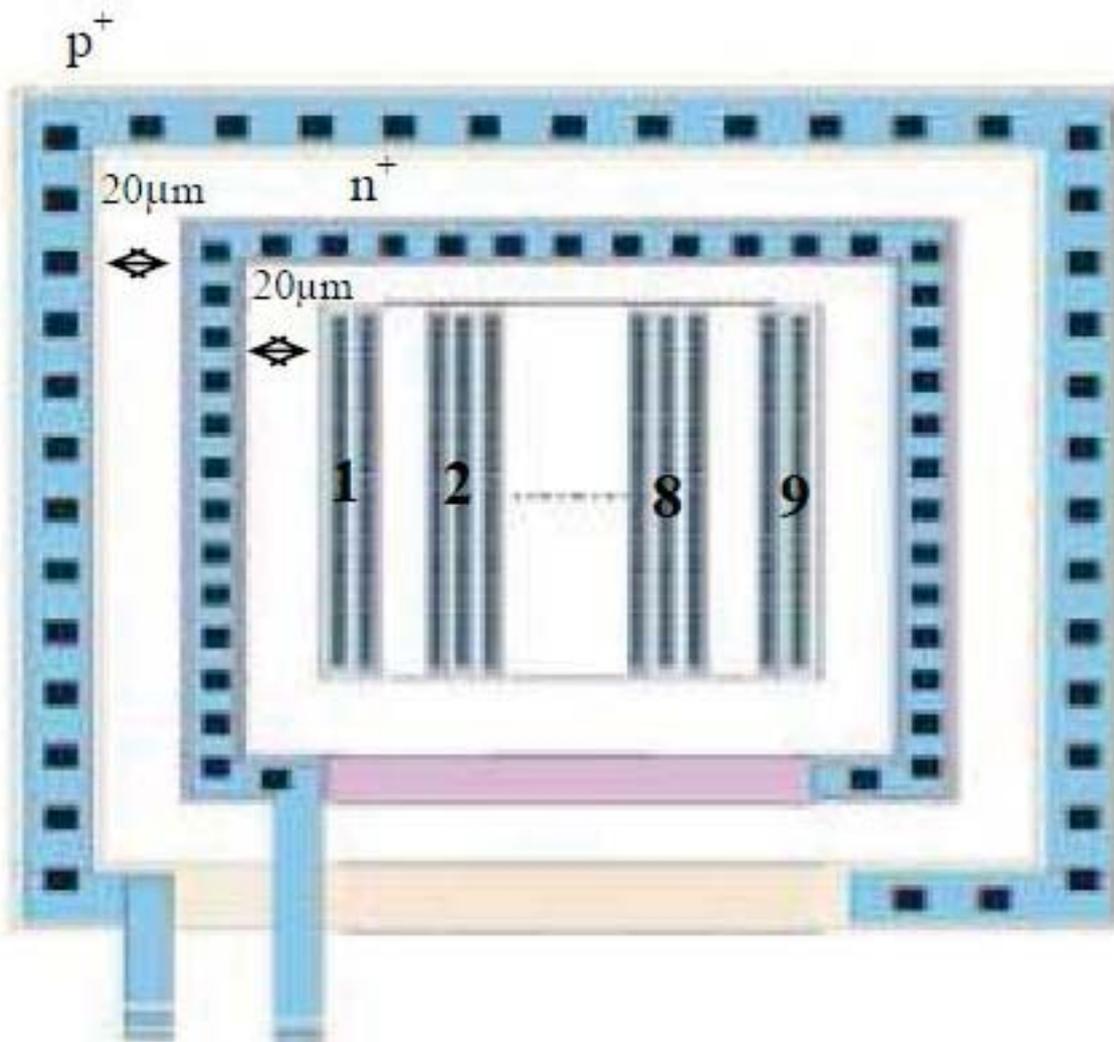


Figure 3: Finger

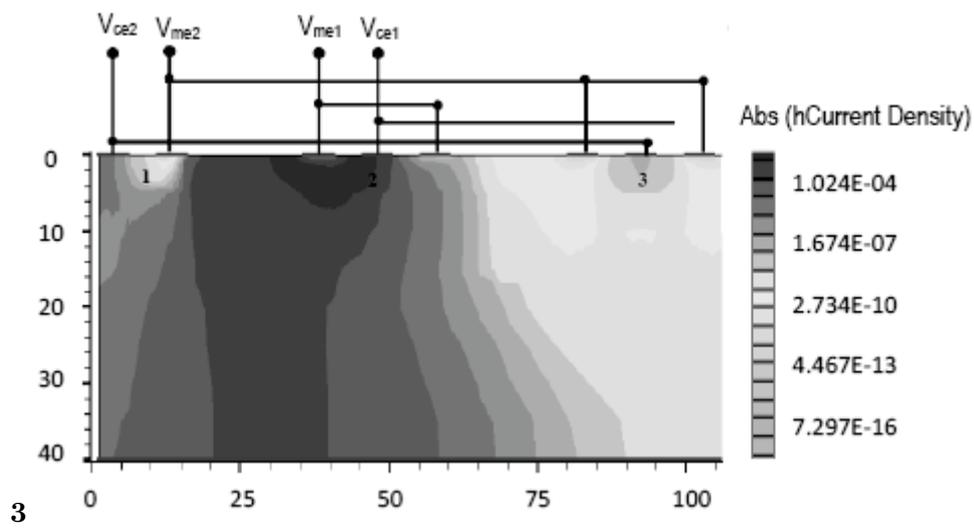
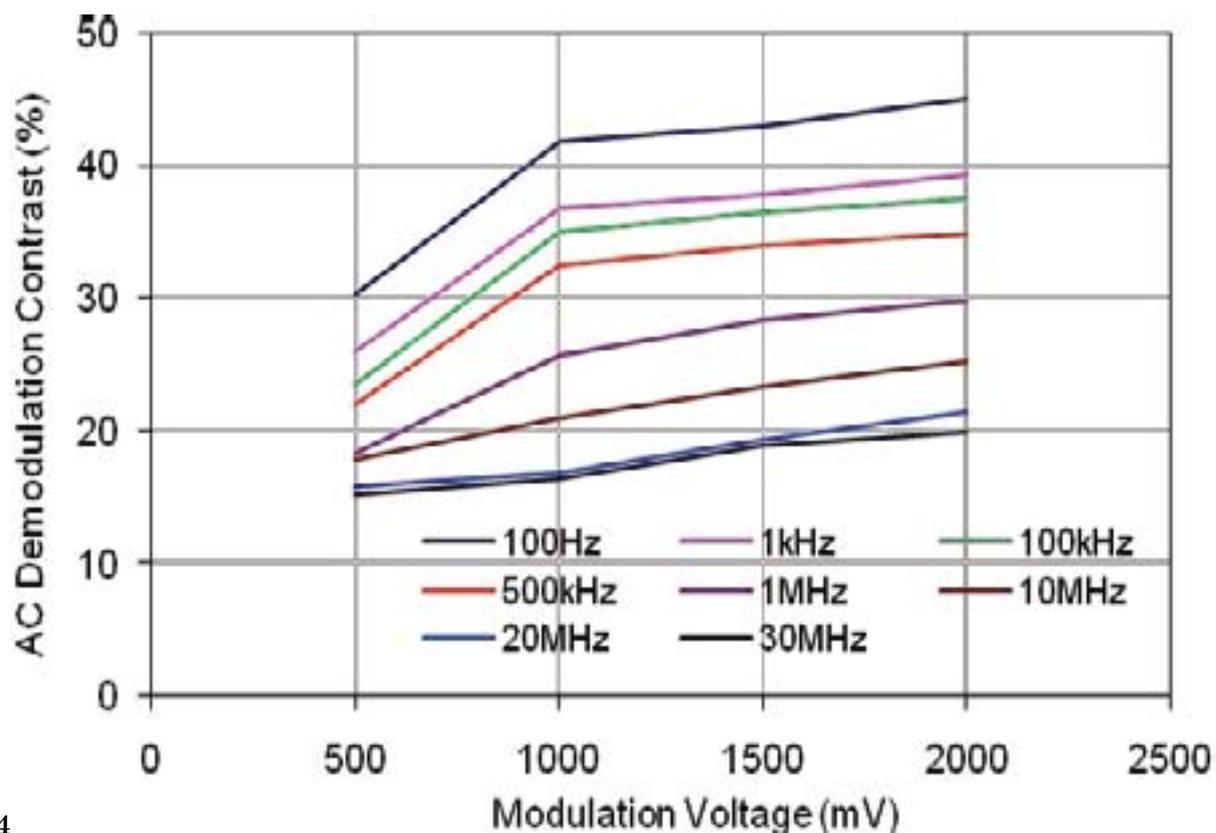
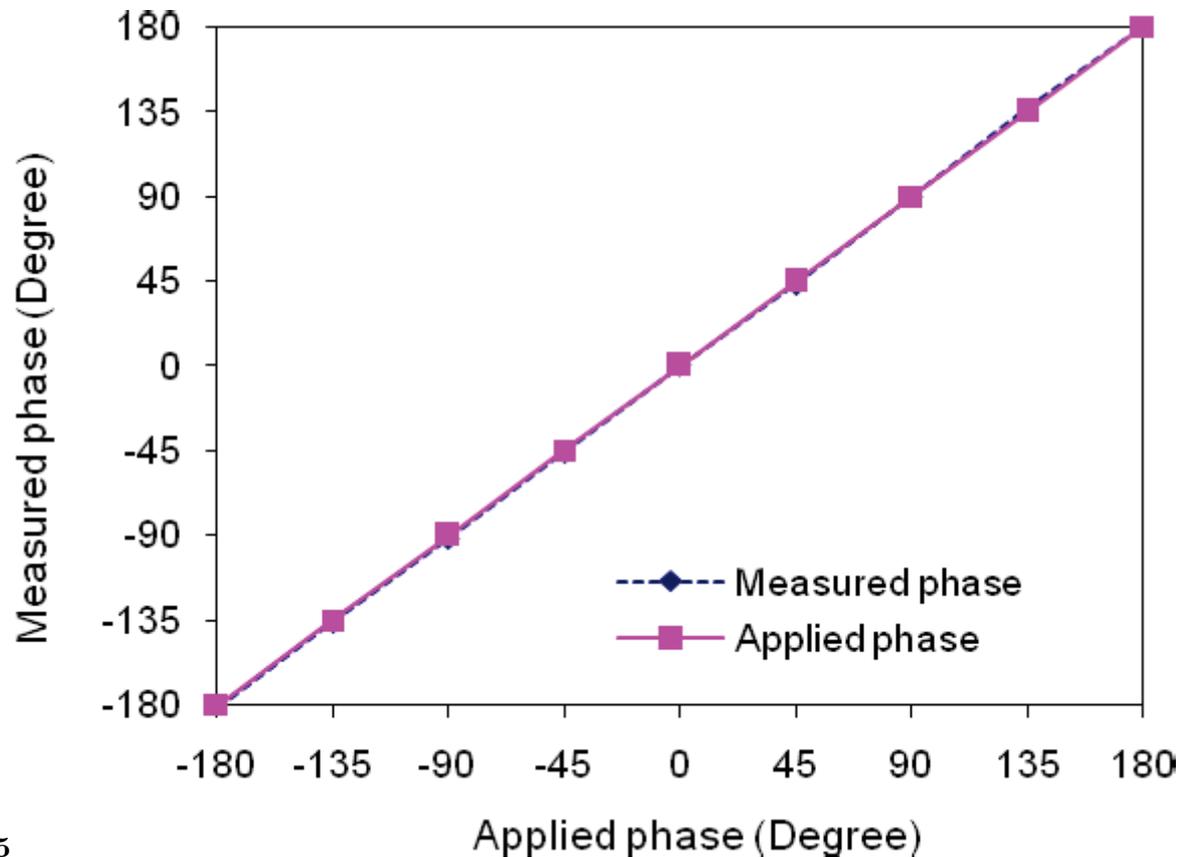


Figure 4: Figure 3 :



4

Figure 5: Figure 4 :



5

Figure 6: Figure 5 :

1

V me2 (V)	I ce1 (?A)	I ce2 (?A)
0.000	0.442	20.280
0.200	0.932	19.790
0.400	1.895	18.820
0.600	3.324	17.480
0.800	5.006	15.840
1.000	6.783	14.150
1.200	8.282	12.740
1.400	9.392	11.740
1.600	10.250	10.970
1.800	10.930	10.380

Figure 7: Table 1 :

.1 ACKNOWLEDGEMENTS

- 135 This work has been funded by "Netcarity" European Integrated Project (www.netcarity.org) and supported by
 136 the Fondazione Bruno Kessler (FBK), Trento, Italy.
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