

# Mixed-Signal IC design for Heterogeneously Integrated Multi-Analyte Chemical Sensor Arrays

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Thesis submitted to the Faculty of the  
Virginia Polytechnic Institute and State University  
in partial fulfillment of the requirements for the degree of

Master of Science  
in  
Electrical and Computer Engineering

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Blacksburg, Virginia

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## Virginia Tech ETD Fair Use Analysis Results

*This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.*

Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.13: (b) Current source based readout circuit Source:T. Cho, K. Lee, J. Kong, and A. Chandrakasan, "A 32-mu W 1.83-kS/s Carbon Nan- otube Chemical Sensor System," IEEE Journal of Solid-State Circuits, vol. 44, no. 2, pp. 659-669, 2009.

Report generated on: 12-16-2010 at : 23:42:58

### Based on the information you provided:

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Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.9: Nanotube Field Effect Transistor Source: S. Liu, Q. Shen, Y. Cao, L. Gan, Z. Wang, M. Steigerwald, and X. Guo, "Chemical functionalization of single-walled carbon nanotube field-effect transistors as switches and sensors," Coordination Chemistry Reviews, 2009.

Report generated on: 12-16-2010 at : 23:33:29

### Based on the information you provided:

#### Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *against fair use*

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Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

#### Factor 4

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.11: Cross reactive sensor arrays Source:K. Albert, N. Lewis, C. Schauer, G. Sotzing, S. Stitzel, T. Vaid, and D. Walt, "Cross- reactive chemical sensor arrays," Chem. Rev, vol. 100, no. 7, pp. 2595-2626, 2000.

Report generated on: 12-16-2010 at : 23:37:09

### **Based on the information you provided:**

#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *against fair use*

#### **Factor 3**

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 2.2: (b) Noise shaping in modulators Source:G. Bourdopoulos, V. Anastassopoulos, and T. Deliyannis, Delta-Sigma modulators: modeling, design and applications. Imperial College Pr, 2003.

Report generated on: 12-16-2010 at : 23:44:29

### Based on the information you provided:

#### Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

#### Factor 4

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.10: Metal oxide sensors with integrated heater Source: D. James, S. Scott, Z. Ali, and W. O'Hare, "Chemical sensors for electronic nose systems," Microchimica Acta, vol. 149, no. 1, pp. 1-17, 2005.

Report generated on: 12-16-2010 at : 23:35:00

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#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *against fair use*

#### **Factor 3**

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

#### **Factor 4**

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*This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.*

Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.6: Hydrogel based chemical sensors Source: M. Lei, A. Baldi, E. Nuxoll, R. Siegel, and B. Ziaie, "Hydrogel-based microsensors for wireless chemical monitoring," Biomedical Microdevices, vol. 11, no. 3, pp. 529-538, 2009.

Report generated on: 12-16-2010 at : 23:17:41

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#### Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.7(a): MEMS cantilever based chemical sensors Source: T. Pearce, S. Schiman, H. Nagle, and J. Gardner, Handbook of machine olfaction: electronic nose technology. Wiley-Vch, 2006

Report generated on: 12-16-2010 at : 23:23:05

### **Based on the information you provided:**

#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *against fair use*

#### **Factor 3**

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

#### **Factor 4**

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.7(b): MEMS chemical sensor based on capacitor measurement  
Source: D. Baselt, B. Fruhberger, E. Klaassen, S. Cemalovic, C. Britton, et al., "Design and performance of a microcantilever-based hydrogen sensor," Sensors and Actuators B: Chemical, vol. 88, no. 2, pp. 120-131, 2003.

Report generated on: 12-16-2010 at : 23:24:13

### Based on the information you provided:

#### Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *against fair use*

#### Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

#### Factor 4

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1 from Mica2 datasheet, Pg 1  
(<https://www.eol.ucar.edu/rtf/facilities/isa/internal/CrossBow/DataSheets/mica2.pdf>)

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### **Based on the information you provided:**

#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### **Factor 3**

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Description of item under review for fair use: Figure 1 from MicaZ datasheet, Pg 1  
([http://www.openautomation.net/uploadsproductos/micaz\\_datasheet.pdf](http://www.openautomation.net/uploadsproductos/micaz_datasheet.pdf))

Report generated on: 12-16-2010 at : 22:44:31

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#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### **Factor 3**

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.8(a): Optical sensor design for optical fiber coated on one end by functionalized chemicals and Figure 1.8(c): CO2 sensor presented Source: J. Fraden, "Handbook of modern sensors," 1996.

Report generated on: 12-16-2010 at : 23:28:50

### **Based on the information you provided:**

#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *against fair use*

#### **Factor 3**

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.8(b): Optical sensors using functionalized microspheres at tips of fibers Source: M. Aernecke and D. Walt, "Optical-Fiber Arrays for Vapor Sensing," Sensors and Actuators B: Chemical, 2009.

Report generated on: 12-16-2010 at : 23:30:38

### **Based on the information you provided:**

#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *against fair use*

#### **Factor 3**

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.12: (a) PEDOT Nanowire, (b) Assembly setup (c) Measurement results Source:Y. Cao, A. Kovalev, R. Xiao, J. Kim, T. Mayer, and T. Mallouk, "Electrical transport and chemical sensing properties of individual conducting polymer nanowires," Nano Lett, vol. 8, no. 12, pp. 4653-4658, 2008.

Report generated on: 12-16-2010 at : 23:39:09

### **Based on the information you provided:**

#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### **Factor 3**

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 2.2: (b) RMS noise vs. oversampling ratio for different orders of sigma delta modulators Source:S. Norsworthy, R. Schreier, G. Temes, et al., Delta-sigma data converters: theory, design, and simulation. IEEE press New York, 1997.

Report generated on: 12-16-2010 at : 23:45:57

### **Based on the information you provided:**

#### **Factor 1**

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### **Factor 2**

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### **Factor 3**

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.13: (c) Resistance-to-period converter based readout circuit  
Source:A. Flammini, D. Marioli, and A. Taroni, "A low-cost interface to high-value resistive sensors varying over a wide range," Instrumentation and Measurement, IEEE Transactions on, vol. 53, pp. 1052 - 1056, aug. 2004.

Report generated on: 12-16-2010 at : 23:41:53

### Based on the information you provided:

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#### Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### Factor 3

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Name: Nikhil Kakkar

Description of item under review for fair use: Figure 1.13: (a) Wheatstone bridge based readout circuit Source:A. Narayanan, Y. Dan, V. Deshpande, N. Di Lello, S. Evoy, and S. Raman, "Dielectric-trophoretic integration of nanodevices with CMOS VLSI circuitry," IEEE transactions on nanotechnology, vol. 5, no. 2, p. 101, 2006.

Report generated on: 12-16-2010 at : 23:40:35

### Based on the information you provided:

#### Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

#### Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

#### Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

#### Factor 4

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