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INVITED PAPERS

Intelligent Networks: Foundation for Information Societies	2
W. Melody Delft University of Technology, Netherlands	
Technology Trends and Design Challenges in Microprocessors	7
S. Borkar Intel Corp., United States	
Wireless Integrated Network Sensors: Low Power Systems on a Chip	9
G. Asada ¹ , M. Dong ¹ , T.S. Lin ¹ , F. Newberg, ¹ G. Pottier ¹ , W.J. Kaiser ¹ , H.O. Marcy ² ¹ University of California, Los Angeles, United States ² Rockwell Science Center, Thousand Oaks, CA, United States	
The Impact of Shrinking Sizes on Circuit Design	17
J.P. Schoellkopf STMicroelectronics, France	
System and Circuit Aspects of Nanoelectronics	18
K. Goser, Ch. Pacha University Dortmund, Germany	
Low-Cost All-Polymer Integrated Circuits	30
C.M. Hart, D.M. de Leeuw, M. Matters, P.T. Herwig, C.M.J. Mutsaerts, C.J. Drury Philips Research Laboratories, Eindhoven, Netherlands	
The Future of Communications	35
J. Danneels CEO Alcatel Microelectronics, Zaventem, Belgium	
Digital goes Analog	44
H. Veendrick Philips Research Laboratories, Eindhoven, Netherlands	
RFIC Packaging and Test: How Will We Cut Costs	51
E. Strid Cascade Microtech, Inc., United States	

CONTRIBUTED PAPERS

1.1: 0.25 μ RF-CMOS

A 0.25 μm CMOS I/Q-Channel Downconversion Mixer with Active Coil for DCS-1800 Applications	56
J. Janssens ¹ , M. Steyaert ¹ , T. Ohguro ² ¹ Katholieke Universiteit Leuven, Heverlee, Belgium ² Toshiba Corporation, Kawasaki, Japan	
A High Linearity, Single-Ended Input Double-Balanced Mixer in 0.25 μm CMOS	60
F. Piazza, Q. Huang ETH Zurich, Switzerland	
A 0.25 μm CMOS Fully Integrated IF-Baseband-Strip for a Single Superheterodyne GSM Receiver	64
P. Orsatti, F. Piazza, Q. Huang ETH Zurich, Switzerland	

1.2: Broad-Band Communication Circuits

A High-Speed, Direct Up-Conversion Transmitter for Cable Applications using Very Linear 0.5 μm "Cold" CMOS Mixers	68
M. Borremans, M. Steyaert Katholieke Universiteit Leuven, Heverlee, Belgium	
Transformerless Line Interface Solution for Baseband Modems	72
A. Kahl, J. Hauptmann Siemens Entwicklungszentrum für Mikroelektronik, Villach, Austria	

1.3: RF Front-End and Back-End Circuits

A 1.9GHz 1W CMOS Class E Power Amplifier for Wireless Communications	76
K.-C. Tsai, P.R. Gray University of California, Berkeley, United States	
A 5.5-GHz Low Noise Amplifier in SiGe BiCMOS	80
H.A. Ainspan ¹ , C.S. Webster ² , J.-O. Plouchart ¹ , M. Soyuer ¹ ¹ IBM T.J. Watson Research Center, Yorktown Heights, NY, United States ² IBM Microelectronics, Essex Junction, VT, United States	
A Dual-band Transceiver for GSM and DCS1800 applications	84
T. Yamawaki ¹ , M. Kokubo ¹ , K. Irie ¹ , H. Matsui ¹ , K. Hori ¹ , T. Furuya ¹ , Y. Shimizu ¹ , M. Katagishi ¹ , T. Endou ¹ , B. Henshaw ² , J.R. Hildersley ² ¹ Hitachi Ltd., Tokyo, Japan ² The Technology Partnership plc, United Kingdom	

1.4: Oscillators I

Resonance-mode selection and Crosstalk Elimination Using Resonator-Synchronised Relaxation Oscillators	88
J.R. Westra ¹ , C.J.M. Verhoeven ² , A.H.M. van Roermund ² ¹ Philips Research Laboratories, Eindhoven, Netherlands ² Delft University of Technology, Netherlands	
A Q=100 SC bandpass filter	92
A. Baschiroto ¹ , G. Bollati ² , A. Fassina ² , F. Montecchi ¹ , F. Stefani ² ¹ Università di Pavia, Italy ² SGS-Thomson Microelectronics, Cornaredo (MI), Italy	
A Coupled Sawtooth Oscillator combining Low Jitter and High Control Linearity	96
S.L.J. Gierkink ¹ , A.J.M. van Tuijl ² ¹ University of Twente, Enschede, Netherlands ² Philips Semiconductors B.V., Nijmegen, Netherlands	
1.5: DC/D Conversion	
High Efficiency Charge Pump Circuit for Negative High Voltage Generation at 2 V Supply Voltage	100
M. Bloch, C. Lauterbach, W. Weber Siemens AG, Munich, Germany	
A New CMOS On-Chip High-Voltage Generator	104
P. Favrat, M.J. Declercq Swiss Federal Institute of Technology, Lausanne, Switzerland	
1.6: Analogue Low-Voltage, Low-Power Techniques	
Compact Low-voltage PTAT-Current Source and Bandgap-Reference Circuits	108
K.J. de Langen, J.H. Huijsing Delft University of Technology, Netherlands	
A CMOS Class-AB Instrumentation Amplifier for Micropower Applications	112
J.A. De Lima, S.F. Silva Universidade Estadual Paulista, Guaratingueta, Brazil	
Low-Power Bandgap References featuring DTMOSTs	116
A.-J. Annema Philips Research Laboratories, Eindhoven, Netherlands	
1.7: High Speed I/O	
Serial Interface Macrocells for 2.5 Gb/s in 0.35µm CMOS	120
H. Preisach ALCATEL Corporate Research Center, Stuttgart, Germany	
16-Gbit/s Measurements on a 0.8-µm CMOS Sub-Sampling Circuit	124
H.O. Johansson, C. Svensson Linköping University, Sweden	

A High Speed 3.3V IO Buffer with 1.9V Tolerant CMOS Process	128
G. Singh Sun Microsystems Inc., Palo Alto, CA, United States	

1.8: Digital Processing I

A 600MHz Superscalar Floating Point Processor	132
M. Matson, R. Badeau, J. Clouser, R. Dupcak, B. Grundmann, M. Lamere, S. Samudrala, R. Allmon, N. Fairbanks Digital Equipment Corporation, Acton, MA, United States	
A 5.2 nS Cycle Time Floating Point Unit Macrocell	136
R. Hossain, J.C. Herbert, J.F. Gouger, R. Bechade Mentor Graphics Corporation, Warren, NJ, United States	

1.9: Digital Processing II

An Area-Efficient Circuit Concept for Dynamical Conflict Management of N-Port Memories with Multi-Gbit/s Access Bandwidth	140
K. Yamada, H. Lee, T. Murakami, H.J. Mattausch Hiroshima University, Higashi-Hiroshima, Japan	
A Multimedia-oriented Embedded RISC Processor with a Rambus DRAM Controller	144
K. Suzuki ¹ , M. Daito ¹ , T. Inoue ¹ , K. Naehara ¹ , M. Nomura ¹ , T. Iima ¹ , T. Fukuda ² ¹ NEC Corporation, Sagamihara, Japan ² NEC IC Microcomputer Systems, Ltd., Kumamoto, Japan	
A Digital Clock Generator for an ATM Switch Implemented with Multiphase Clock	148
F. Mu, C. Svensson Linköping University, Sweden	

2.1: IF Analogue-Digital Conversion

Digital Controlled Variable Gain Amplifier (DVGA) for IF to Digital Conversion	152
R. Roovers Philips Research Laboratories, Eindhoven, Netherlands	
A combined LC/gmC 4th order continuous-time bandpass Sigma-Delta Modulator	156
J. van Engelen, R. van de Plassche Eindhoven University of Technology, Netherlands	

2.2: Oversampled Analogue-Digital Conversion

A 16 mW, 120 dB Linear Switched-Capacitor Delta-Sigma Modulator with Dynamic Biasing	160
D.B. Kasha, W.L. Lee, A. Thomsen	

Cirrus Logic Inc., Austin, TX, United States	
A CMOS Multi-Bit Sigma-Delta Modulator for Video Applications	164
J. Vink, J. van Rens Philips Research Laboratories, Eindhoven, Netherlands	
A 3.3 V 15-bit Delta-Sigma ADC with a Signal Bandwidth of 1.1 MHz for ADSL-Applications	168
Y. Geerts, A. Marques, M. Steyaert, W. Sansen Katholieke Universiteit Leuven, Heverlee, Belgium	
2.3: Digital-Analogue Conversion	
A 800 MHz Ultra Low Glitch Energy 6-bit CMOS D/A Converter	172
A. Van den Bosch, M. Steyaert, W. Sansen Katholieke Universiteit Leuven, Heverlee, Belgium	
A 16-bit D/A Interface with Sinc Approximated Semidigital Reconstruction Filter and Reduced Number of Coefficients	176
M.A.T. Sanduleanu ¹ , A.J.M. van Tuijl ² , R.F. Wassenaar ¹ , H. Wallinga ¹ ¹ University of Twente, Enschede, Netherlands ² Philips Semiconductors B.V., Nijmegen, Netherlands	
2.4: Signal Processing I	
A Real-Time Digital VCR Encode/Decode and MPEG2 Decode LSI Implemented on a Dual-Issue RISC Processor	180
A. Mohri, A. Yamada, T. Yoshida, H. Sato, H. Takata, L. Nakakimura, K. Tsuchihashi, Y. Shimotsuna Mitsubishi Electric Corporation, Hyogo, Japan	
MIGHTI: A High Performance 16-bit DSP for Mobile Communication Applications	184
T.H. Kim, B.S. Kwon, J. Yang, K.H. Lim, J.W. Kim, J.E. Lee, H.S. Nam, Y.G. Kim, J.P. Kim, S.J. Byun, K.H. Kim, B. Kim KAIST, Taejeon, Korea (South)	
2.5: Advanced Digital	
Low Cost On-Die CMOS Distributed Voltage Regulation for Microcontrollers	188
R. Nair, B. Tang Intel Corporation, Hillsboro, OR, United States	
A 1.0V 180Mhz 85μW/Mhz 8kx16b SRAM in a standard 0.25μm CMOS	192
C. Frey, S. Dugalleix, F. Genevaux, J.-P. Schoellkopf SGS-Thomson Microelectronics, Crolles, France	
Low Power SOI CMOS Multipliers: 2D vs. 3D	196

S.J. Abou-Samra¹, J. Arweiler², A. Guyot¹
¹TIMA Laboratory, Grenoble, France
²Technische Hochschule Darmstadt,
Germany

2.6: Signal Processing II

SACHEM, a versatile DMT-based modem transceiver for ADSL	200
L. Kiss, K. Adriaensen, M. Huysmans, E. Hanssens, C. Gendarme, F. Van Beylen, H. Van De Weghe Alcatel Antwerp, Belgium	
A Low Logic Depth Complex Multiplier	204
A. Berkeman, V. Öwall, M. Torkelson Lund University, Sweden	

2.7: Image Sensors

A Smart Range Image Sensor	208
M. de Bakker ¹ , P.W. Verbeek ¹ , E. Nieuwkoop ² , G.K. Steenvoorden ² ¹ Delft University of Technology, Netherlands ² TNO Institute of Applied Physics, Delft, Netherlands	
Smart 2048-Pixel Linear CMOS Image Sensor	212
W. Brockherde, B.J. Hosticka, M. Petermann, M. Schanz, R. Spors Fraunhofer Institute of Microelectronic Circuits and Systems, Duisburg, Germany	

2.8: Low-Noise Sensor Readout Circuits

Integrated Readout Electronics for Geiger Mode Avalanche Photodiodes	216
W.J. Kindt, K.J. de Langen Delft University of Technology, Netherlands	
A CD analog front-end in BiCMOS technology	220
G. Brasca ¹ , V. Colonna ¹ , P. Cusinato ¹ , G. Gandolfi ¹ , F. Stefani ¹ , D. Tonietto ¹ , A. Baschirotto ² ¹ SGS-Thomson Microelectronics, Cornaredo (MI), Italy ² Università di Pavia, Italy	
A CMOS IC for X-Ray Computer Tomography	224
Q. Huang ¹ , A. Biber ² , M. Oberle ¹ ¹ Swiss Federal Institute of Technology, Zurich, Switzerland ² CSEM Zurich, Switzerland	

2.9: Sensor Busses

Monolithic Data Circuit-Terminating Unit (DCU) for a One-Wire Vehicle Network	228
C.A. Dos Reis Filho, E.P. da Silva Jr., E. de L. Azevedo, J.A.P. de Seminário, L. Dibb State University of Campinas, Brazil	
IC for Interbus Loop System	232

G. Bontempo ¹ , G. Calabrese ¹ , P. Colletti ¹ , F. Pulvirenti ¹ , R. Ursino ¹ , J. Bartelheim ² , V. Detert ² ¹ SGS-Thomson Microelectronics, Catania, Italy ² Phoenix-Contact GmbH, Blomberg, Germany	
3.1: Flash Analogue-Digital Conversion	
A 500 MSample/s 6-Bit Nyquist Rate ADC for Disk Drive Read Channel Applications	236
I. Mehr ¹ , D. Dalton ² ¹ Analog Devices, Inc., Wilmington, United States ² Analog Devices, Inc., Limerick, Ireland	
An 8 bit, 200Ms/s, full Nyquist, 3.3V, differential interpolated flash A/D Converter in BiCMOS technology	240
A. Boni ¹ , C. Morandi ¹ , S. Padoan ¹ , G. Melcher ² ¹ University of Parma, Italy ² Austria Mikro Systeme Int. AG, Unterpremstätten, Austria	
3.2: Analogue-Digital Conversion	
A Multi-Bit Sigma-Delta Modulator in Floating Body Silicon-on-Sapphire CMOS Technology for Extreme Radiation Environments	244
C.F. Edwards ¹ , W. Redman-White ¹ , M. Barcey ¹ , B.M. Tenbroek ¹ , M.S.L. Lee ¹ , M.J. Uren ² ¹ University of Southampton, UK ² Defence Evaluation and Res. Agency, Malvern, United Kingdom	
A 40MHz CMOS Sample&Hold operating at 1.2 V	248
A. Baschiroto Università di Pavia, Italy	
A 10b 50-Msample/s CMOS ADC in ASIC Process	252
A. Wada, K. Kato, K. Tani, H. Shimizu Sanyo Electric Co., Ltd., Anpachi-Gun, Gifu, Japan	
3.3: Prescaler Design and Analysis	
A single-ended 1.5 GHz 8/9 dual-modulus prescaler in 0.7µm CMOS with low phase noise and high input sensitivity	256
B. De Muer, M. Steyaert Katholieke Universiteit Leuven, Heverlee, Belgium	
On the Evaluation of Phase Noise in Frequency Dividers	260
B. De Smedt, G. Gielen Katholieke Universiteit Leuven, Belgium	
A GSM Demodulator Based on a Delta-Sigma Frequency Discriminator with Improved Input Sensitivity	264
W.T. Bax ¹ , M.A. Copeland ¹ , P. Schvan ² ¹ Carleton University, Ottawa, Canada ² Nortel, Ottawa, Canada	
3.4: Oscillators II	
A Universal 0.03 mm² One Pin Crystal Oscillator in CMOS	268
J.A.T.M. van den Homberg Philips Research Laboratories, Eindhoven, Netherlands	
Reduction of Intrinsic 1/f Device Noise in a CMOS Ring Oscillator	272
S.L.J. Gierink ¹ , E.A.M. Klumperink ¹ , T.J. Ikkink ¹ , A.J.M. van Tuijl ² ¹ University of Twente, Enschede, Netherlands ² Philips Semiconductors B.V., Nijmegen, Netherlands	
3.5: High-Frequency Analogue Techniques	
A Programmable Analog Polynomial Predistortion Circuit for Linearising Radio Transmitters	276
T. Rahkonen, T. Kankaala, M. Neitola University of Oulu, Finland	
A 0.7 µm CMOS 1Gb/s Optical Receiver with Rail-to-Rail Output Swing	280
M. Ingels, M. Steyaert Katholieke Universiteit Leuven, Heverlee, Belgium	
A Video Frequency Low-Voltage Filter in CMOS Technology	284
J. Sabadell, C. Aldea, S. Celma, P.A. Martinez Universidad de Zaragoza, Spain	
3.6: Amplifiers	
A Power Efficient Audio Amplifier Combining Switching and Linear Techniques	288
R.A.R. van der Zee ¹ , A.J.M. van Tuijl ² ¹ University of Twente, Enschede, Netherlands ² Philips Semiconductors B.V., Nijmegen, Netherlands	
A Low Power, Low Noise, Variable Gain Amplifier	292
C.H.J. Mensink Philips Semiconductors B.V. Nijmegen, Netherlands	
MOS/Bipolar active Input Current Mirrors with 13-Decades Gain Adjustment Range	296
T. Serrano-Gotarredona ¹ , B. Linares-Barranco ¹ , A.G. Andreou ² ¹ Centro Nacional de Microelectrónica CSIC, Sevilla, Spain ² The Johns Hopkins University, Baltimore, United States	
3.7: Analogue Image Processing Circuits	
An Analog Beam-Forming circuit using Switched-Current Delay Lines	300

B. Stefanelli ¹ , I. O'Connor ¹ , L. Quiquerez ¹ , A. Kaiser ¹ , D. Billet ² ¹ IEMN - ISEN, Lille, France ² Thomson Marconi Sonar, Sophia Antipolis, France	
Analog VLSI Implementation of Early Vision Edge Detection with Noise Suppression and Image Segmentation	304
C.-H. Yi, R. Schlabbach, H. Kroth, A. Karner, J. Höhn, H. Klar Technical University of Berlin, Germany	
3.8: CMOS Imagers	
A CMOS Image Sensor with Local Brightness Adaptation and High Intrascene Dynamic Range	308
R. Haunschild, M. Hillebrand, B.J. Hosticka, J. Huppertz, T. Kneip, M. Schwarz Fraunhofer Institute of Microelectronic Circuits and Systems, Duisburg, Germany	
A Circuit for the Correction of Pixel Defects in Image Sensors	312
G. Meynants, B. Dierickx IMEC, Leuven, Belgium	
A High Frame Rate Image Sensor in Standard CMOS-Technology	316
N. Stevanovic, M. Hillebrand, B.J. Hosticka, U. Iurgel, A. Teuner Fraunhofer Institute of Microelectronic Circuits and Systems, Duisburg, Germany	
3.9: Sensors and Control Systems	
Fully Integrated Ultrasonic Motor Speed Control System with Fine Output Frequency Resolution, Power Stage and Digital Controller	320
R. Bardelli ¹ , L. Fontanella ¹ , M. Tateoka ² , K. Kataoka ³ , S. Yamamoto ³ ¹ SGS-Thomson Microelectronics S.r.l., Cornaredo, Italy ² SGS-Thomson Microelectronics, Tokyo, Japan ³ Canon Inc., Tokyo, Japan	
A Low-Power and High-Performance CMOS Fingerprint Sensing and Encoding Architecture	324
S. Jung ¹ , R. Thewes ¹ , T. Scheiter ¹ , K. Goser ² , W. Weber ¹ ¹ Siemens AG, Munich, Germany ² Universität Dortmund, Germany	
Design of Spiral Inductors on Silicon Substrates with a Fast Simulator	328
J. Lee, A. Kral, A.A. Abidi, N.G. Alexopoulos University of California, Los Angeles, United States	
4.1: Poster Session Communications	
Fully-Monolithic 3V SiGe Differential Voltage- Controlled Oscillators for 5GHz and 17GHz Wireless Applications	332
J.-O. Plouchart, B.-U. Klepser, H.A. Ainspan, M. Soyuer IBM T.J. Watson Research Center, Yorktown Heights, NY, United States	
Low DC Power Monolithic Cascode LNAs for 1.6 and 5.2 GHz Wireless Applications	336
J.J. Kucera, U. Lott Swiss Federal Institute of Technology (ETH Zurich), Switzerland	
A CMOS Quadrature Baseband Frequency Synthesizer/Modulator	340
M. Kosunen, J. Vankka, M. Waltari, L. Sumanen, K. Koli, K. Halonen Helsinki University of Technology, HUT, Finland	
A Chip-Set for TETRA Digital Mobile Radio	344
D. Hossack ¹ , P. Frith ¹ , G. Mcleod ¹ , V. Cook ² ¹ Wolfson Microelectronics Ltd., Edinburgh, United Kingdom ² Simoco, Cambridge, United Kingdom	
A Low Power Quadrature Direct Digital Frequency Synthesizer Using Non-linear Resistor String DACs	348
S. Morteza pour, K.F. Lee Iowa State University, Ames, IA, United States	
A Novel Phase Detector with No Dead Zone and a Chargepump with Very Wide Output Voltage Range	352
R. Ahola, S. Lindfors, J. Routama, K. Halonen Helsinki University of Technology, HUT, Finland	
A 155 Mbit/s fully digital bit synchronizer	356
M. Burzio, P. Pellegrino CSELT - Centro Studi e Laboratori Telecomunicazioni, Torino, Italy	
D-FIRE: A DAB Receiver System on a Chip	360
M. Bolle, K. Gieske, F. Hofmann, T. Mlasko, G. Spreitz Robert Bosch GmbH, Hildesheim, Germany	
A 2.4 GHz CMOS VCO with MCM-inductor	364
P. Kinget, R. Frye Bell Laboratories, Murray Hill, NJ, United States	
Maximum-Likelihood PPM Frame Synchronization	368
M.A.H.G. Joosen, L.P. de Jong, R. Otte, A.H.M. van Roermund Delft University of Technology, Netherlands	
A 100MHz Programmable CMOS Gm-C Analog Equalizer for 100Base-TX Application	372
Z. Tang ¹ , D. Frey ² ¹ Bell Labs, Allentown, PA, United States	

² Lehigh University, Bethlehem, PA, United States	
A Study of CMOS 2.0V Low Power Pager Receiver for the FLEX TM Paging System	376
T. Takada ¹ , Y. Suzuki ¹ , S. Tanaka ² , K. Nagai ²	
¹ Kokusai Electric Co., Sendai, Japan	
² Hitachi Ltd., Tokyo, Japan	
A Comparison between Two 1.8GHz CMOS VCOs Tuned by Different Varactors	380
P. Andreani	
Lund University, Sweden	
4.2: Poster Session Analogue	
A low switching noise power supply technique for CMOS IC's	384
J.L. González Jiménez, J. Bosch, A. Rubio	
Universitat Politècnica de Catalunya, Barcelona, Spain	
A 1-Volt 300 MHz Fully Integrated Oscillator	388
J. Tomas, Y. Deval, J.B. Begueret, P. Fouillat, J.P. Dom	
Université Bordeaux I, Talence, France	
Current-Ratio Temperature Compensation in Bipolar Relaxation Oscillator	392
M.H. Splithof ¹ , A.J.M. van Tuijl ¹ , S.L.J. Gierink ² , E.A.M. Klumperink ²	
¹ Philips Semiconductors B.V., Nijmegen, Netherlands	
² University of Twente, Enschede, Netherlands	
An enhanced Colpitts UHF oscillator for TV tuners	396
L. Heslen, E. Stikvoort	
Philips Research Laboratories, Eindhoven, Netherlands	
A 2.7V Elliptical All-MOS g_mC-OTA Filter	400
S. Lindfors ¹ , K. Halonen ¹ , M. Ismail ²	
¹ Helsinki University of Technology, HUT, Finland	
² Ohio State University, Columbus, United States	
Design and Application of SOI CMOS OTAs for High-Temperature Environments	404
D. Flandre ¹ , L. Demeûs ¹ , V. Dressard ¹ , A. Viviani ¹ , B. Gentinne ² , J.-P. Eggermont ²	
¹ Katholieke Universiteit Leuven, Louvain-la-Neuve, Belgium	
² Alcatel Microelectronics, Oudenaarde, Belgium	
4.3: Poster Session A/D Conversion	
Adaptive Compensation of Analog Circuit Imperfections for Cascaded Delta-Sigma Analog-to-Digital Converters	408
T. Sun, A. Wiesbauer, G.C. Temes	
Oregon State University, Corvallis, OR, United States	
An 8-bit Resolution, 12-bit Accuracy, 500 MS/s Update Rate, Sub-pV.s Glitch Energy CMOS D/A Converter	412
A. Marques, J. Bastos, M. Steyaert, W. Sansen	
Katholieke Universiteit Leuven, Heverlee, Belgium	
A Bandpass A/D Converter and its I/Q Demodulator for Integrated Receivers	416
E. Andre, G. Martel, D. Morche, P. Senn	
France Telecom, Meylan, France	
A Sub-Binary-Weighted Current Calibration Technique for a 2.5V 100MS/s 8bit ADC	420
M. Mitsuishi, H. Yoshida, M. Sugawara, Y. Kunisaki, S. Nakamura, S. Nakaigawa, H. Suzuki	
NEC Corporation, Kanagawa, Japan	
A 10-Bit 20-Msample/s Sub-Ranging ADC for Low-Power and Low-Voltage Applications	424
G. Sou, G.-N. Lu, G. Klisnick, M. Redon	
Université Pierre et Marie Curie, Paris, France	
4.4: Poster Session Digital	
A Threshold Logic Full Adder Based on Resonant Tunneling Transistors	428
Ch. Pacha ¹ , K. Goser ¹ , A. Brennemann ² , W. Prost ²	
¹ Universität Dortmund, Germany	
² Gerhard-Mercator-Universität Duisburg, Germany	
Signal-Transition Graph-based Design of Speed-Independent CMOS Circuits	432
C. Piguet ¹ , J. Zahnd ²	
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A Smart Range Image Sensor

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Abstract

In the present paper we discuss a smart image sensor, specifically designed for sheet of light range imaging. The image sensor is capable of measuring the projection of a light stripe on an object. The sensor consists of an array of Position Sensitive Detectors (PSD's), as well as some on-chip electronics. The sensors are made in a standard 3GHz bipolar process. Each PSD measures a light center of gravity, and this way the line of light is sampled in the plane of the image sensor. 3D information is computed by means of triangulation. On chip circuitry takes care of preamplification of the sensor signals, and multiplexing of the different sensor signals to a single output channel.

1. Introduction

The last couple of years, a lot of effort has been devoted to the development of camera's that are capable of measuring the 3D shape of an object, rather than an ordinary intensity image. These, so called, range finding camera's can be useful in a wide number of automation applications. To name a few, one could think of bin picking, robotic assembly of industrial parts, robot navigation, quality inspection and product classification. An extensive overview of various methods for acquiring range information has been given by P.J. Besl [1].

One of the approaches described in [1] is sheet of light range imaging. This technique was first introduced by Y. Shirai [2]. The idea is depicted Figure 1. A sheet of light is projected onto the object that has to be measured. In the situation of Figure 1 this is a semisphere on an flat background. The cross sectional line of the sheet of light with the object is projected onto an image sensor. 3D coordinates are derived from the sensor signals using triangulation. In order to do this, the only extra information needed is the angle between the lightsheet and the optical axis of the camera lens. If a complete surface has to be measured, the object has to be moved perpendicularly with respect to the lightsheet. This can be accomplished, e.g., by placing the object on a conveyor belt.

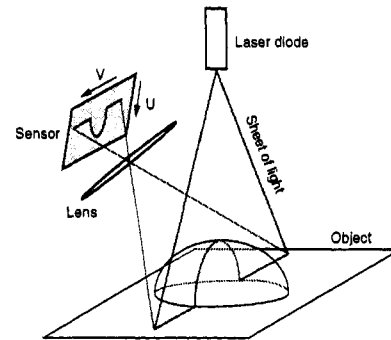


Figure 1: Sheet of light range imaging

The sensor of Figure 1 that is being developed consists of an array of Position Sensitive Detectors (PSD's) [3] [4]. For each discrete V-value in the image plane of the camera, a PSD measures the position of the incident illumination. In the next section is explained how a PSD works. Each separate PSD has a length of 2 cm (in the U-direction), and the pitch in the array (in the V-direction) is $28\mu\text{m}$. On-chip electronics take care of preamplification of the sensor signals and multiplexing of the sensor signals to a single output channel. This is the topic of Section 3. AD-conversion and computation of the range values proceeds off-chip. The goal is to be able to record 2 million range values per second at a 12 bits resolution.

In this paper we will start with the basic theory on Position Sensitive Detectors. Next, some details are given on the signal processing that takes place on the image sensor, and we will explain how we produced PSD's that exceed the standard die size for the chosen process (i.e. 1 cm^2). The paper ends with some measurements on a prototype device containing 6 PSD's and on-chip electronics.

2. Position Sensitive Detectors

In the present section we will tentatively describe how a PSD works. We regard a planar pn-junction (like the one depicted in Figure 2, and we will start by describing

the effects that occur if this pn-junction is illuminated at a specific position. Due to the photo electric effect electron hole pairs are generated, and if they are generated close enough to the depletion layer, they can be separated by the electric field. Once the holes have arrived at the p-type layer a (hole-)current will flow to the end-contacts of the layer (if they are placed at a proper potential).

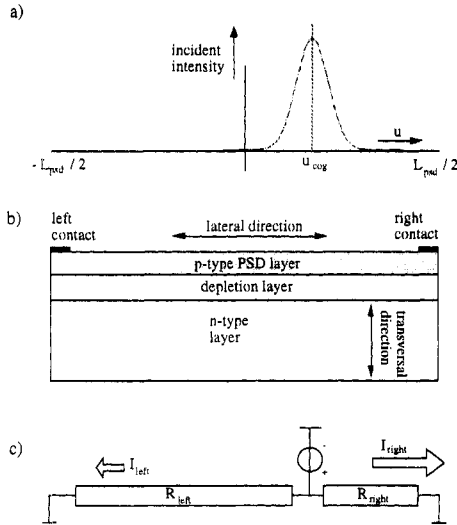


Figure 2: Model of a pn-junction under non-uniform illumination.

Figure 2 gives an idea of what happens: Figure 2a shows the incident illumination that has its center of gravity at U_{cog} . At this point optically generated electron hole pairs will be separated by the depletion layer. The holes will flow to the end-contacts, as indicated in Figure 2c: because there is a large resistance to the left contact only a small current will flow to the left side, and a large current will flow to the right side (according to Ohm's law).

Now suppose the implanted p-type layer has a perfectly homogeneous resistivity. In the one dimensional situation this means that the resistance to the left and right sides are perfectly proportional to the distance to the left and right contact, respectively. This implies that the ratio of the left and right lateral current gives us the exact position of incidence as follows [see Figure 2 for the parameters]:

$$\frac{I_{left}}{I_{right}} = \frac{R_{right}}{R_{left}} = \frac{.5L_{PSD} - U_{cog}}{.5L_{PSD} + U_{cog}} \quad (1)$$

If we solve Eq. 1 for U_{cog} , we get:

$$U_{cog} = .5L_{PSD} \frac{I_{right} - I_{left}}{I_{right} + I_{left}} \quad (2)$$

Eq. 2 is the well-known PSD-equation [5]: the center of gravity of a Position Sensitive Detector can be determined from the photocurrents to the left and right side.

The PSD's have been fabricated in a standard bipolar process, DIMES-01 [6], at our university IC-facility

DIMES (the Delft Institute for Micro Electronics and Sub-microntechnology). With regard to reaction speed and noise considerations it is possible to compute what the ideal implantation level for the PSD's should be [4]. In order to be able to use the standard process, a p-type implantation from DIMES-01 was used that was closest to the ideal implantation level.

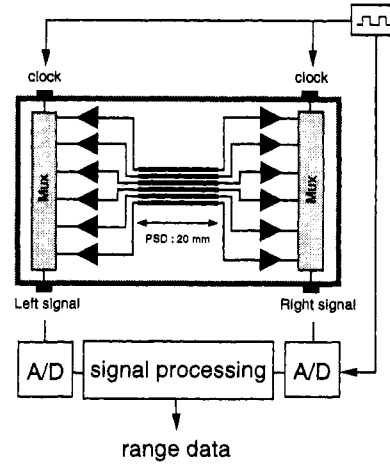


Figure 3: Prototype of the smart PSD sensor containing 6 PSD's and on-chip circuitry. A/D-conversion and further signal processing proceeds off-chip.

3. On chip circuitry

The on-chip electronics consists of two preamplifiers for each PSD-strip (one for the left, and one for the right current) and two multiplexers. The preamplifiers perform low-pass filtering on the sensor signals at 16kHz (video linespeed).

The main reason for the on-chip electronics is that we wish to perform multiplexing on-chip. This way we avoid having to make a chip with a large amount of bonding pads (i.e. twice the number of PSD's since each PSD produces two photocurrents). The on-chip multiplexer is implemented in ECL technology. The ECL-signals drive the switches of the preamplifiers. Each PSD is connected to the output node once, every $64\mu s$. The values that are presented at the output node can be regarded as the average of the photocurrent over the last $64\mu s$.

In Table 1 we have enclosed a number of characteristics of the PSD-chip. Figure 3 gives the idea of the on-chip signal processing for a prototype device that consists of 6 PSD's, 12 preamplifiers and 2 multiplexers.

4. Exceeding the standard die-size

In order to be able to make PSD's with a length that exceed the standard die-size in the IC-process used (i.e. 1 by 1 cm), and also be able to integrate electronics on the same die a special trick in the photolithographic process had to be performed. Two separate masksets were

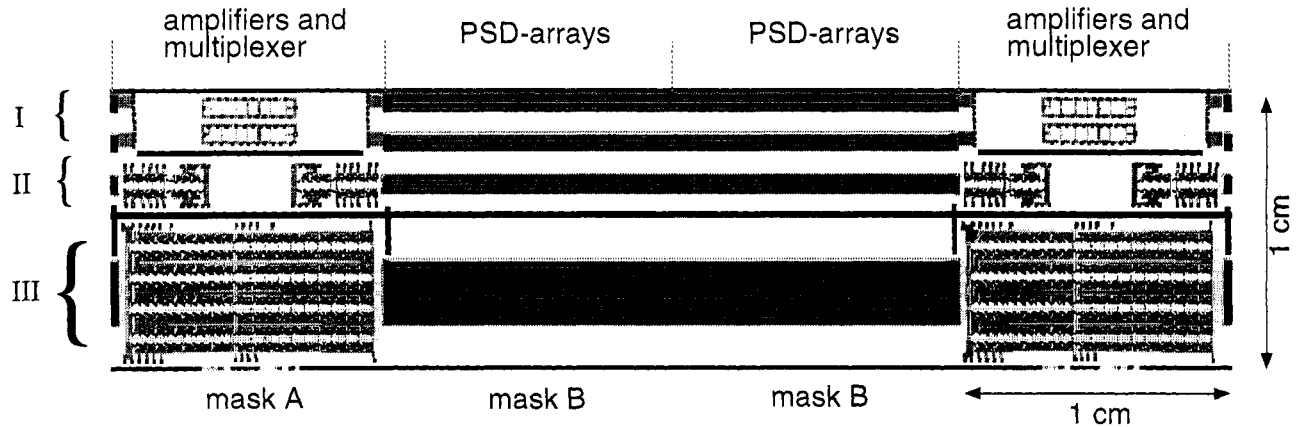


Figure 4: Masksets of the PSD-chip: area I separated PSD arrays and electronics, area II array of 6 PSD's connected to the on-chip electronics, area III array of 80 PSD's connected to the on-chip electronics

Table 1: Specifications of the prototype PSD-chip

Die size for 80 PSD's	1.5cm ²
Nr. of PSD's	6 or 80
Size of PSD's	2cm by 20 μ m
Supply voltages	+/- 5V
Total power dissipation	0.5mW per PSD
Linearity	1:2000
Nr. of bits	12
Clock readout frequency	500kHz
Light source (type/power)	LASER-diode 5mW
Sensitivity of PSD's	0.6A/W for $\lambda=780$ nm
Input current noise	55pA (BW=16kHz)
(analog) Outputsignal	4-5 V

designed: one containing the electronics, and one containing the PSD-arrays. By accurate alignment during illumination, the PSD's and the electronics were "stitched" together. This can be seen in Figure 4. Using this technique, a wafer has been produced that contains PSD's with a length of 2 cm.

5. The prototype device

In the present section we will discuss the prototype PSD-chip. In this section we will start with the measurement results on the linearity of the PSD's. Finally, we will show some examples of the sensor signals for different circumstances of illumination.

5.1. Linearity

The most important feature of a PSD is its high linearity. As explained in Section 2 for a highly linear PSD, a very homogeneous PSD layer is needed. Otherwise the relations of Eqs. 1 and 2 lose validity. What we would like to know is if linearity is maintained if we produce 2cm PSD's by stitching two adjacent dice, as explained in Sec. 4. In order to determine this, a laserdiode was placed on

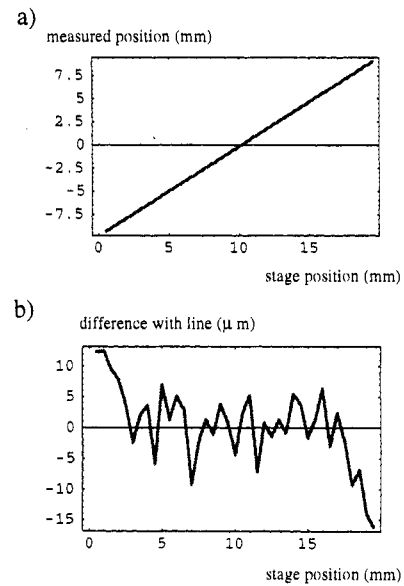


Figure 5: Linearity measurements: a) Measured position vs. translation stage position b) difference of Figure 5a with a linear fit.

a translation stage. The laserbeam was focused on one of the separated PSD's [see Figure 4]. In this experiment, the PSD-signals were measured with an off-the-shelf opamp.

In Figure 5a the horizontal axis represents the position of the translation stage. The vertical axis contains the measured data, i.e. the position as determined from the PSD signals. The PSD position measurement has its origin at the center of the PSD (this is due to the factor .5 L_{PSD} in Eq. 2). Figure 5b gives the difference of Figure 5a with a linear fit through the data as a function of the stage position. From Figure 5b can be seen that the PSD stays linear within 10 μ m for the inner cm of the PSD. It is possible to calibrate for the deviation from linearity at the outer regions of the PSD.

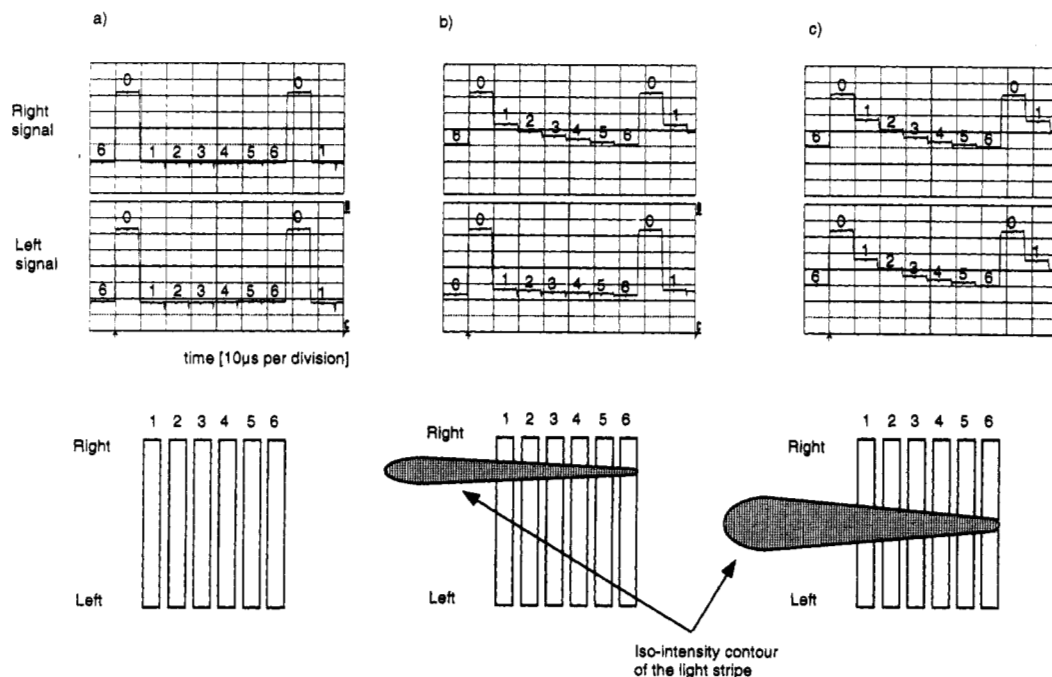


Figure 6: The sensor signals: a) no light signal: the preamplifier offset values, b) projected light stripe at right side of the PSD's, c) projected light stripe at the center of the PSD's.

5.2. The sensor signals

In the present section we will shortly describe the sensor signals that are produced by the smart PSD-chip. Figure 6 shows the signals for the prototype chip containing 6 PSD's. Three situations are taken into consideration. Figure 6a shows the situation where no light falls onto the sensor. The upper oscilloscope signals correspond to the photocurrents to the right side of the PSD's, and the lower signals to the left photocurrents. The numbers in the scope plots correspond to the PSD that is placed to the output channel by the multiplexer. The difference in signal-level in the "dark-image" of Figure 6a, is due to offset differences between the on-chip preamplifiers. This will be corrected for by off-chip signal processing. In this particular example the readout frequency was 100kHz.

In Figure 6b the center of gravity of the incident illumination is at the right side of the PSD's. In Figure 6c the PSD's are illuminated near the center. In Figures 6b and Figure 6c PSD nr.1 captures the highest light intensity, and the amount of light decreases for PSD 2-6. This is indicated by the iso-intensity contours, depicted below the scope signals.

6. Conclusions

In the present paper we discussed a smart image sensor, specifically designed for sheet of light range imaging. We have succeeded in making a prototype sensor with 6 PSD's and on-chip circuitry consisting of 12 preamplifiers and two multiplexers implemented in ECL technology.

Present work concentrates on a redesign of the electronics in order to improve linearity and readout frequency. It was shown that long PSD's can be made by aligning two masks in the lithographic process. For these stitched PSD's a linearity has been measured of 1:2000.

References

- [1] Besl P.J. Active, optical range imaging sensors. *Machine Vision and Applications*, 1:127-152, 1988.
- [2] Shirai Y. Recognition of polyhedrons with a range finder. *Pattern Recognition*, 4:243-250, 1972.
- [3] Verbeek P.W., Groen F.C.A., Steenvoorden G.K., and Stuivinga M. Range cameras at videospeed based on a psd-array or on ccd-interpolation. In *Proc. of the IASTED Int. Symp. on Robotics and Automation*, pages 67-69, 1985.
- [4] de Bakker M., Verbeek P.W., and Steenvoorden G.K. Design considerations for a range image sensor containing a psd-array and an on-chip multiplexer. In *Proc. Int. Conf. on Recent Advances in 3-D Digital Imaging and Modeling*, pages 11-18, May 1997.
- [5] Noorlag D.J.W. *Lateral-photoeffect position sensitive detectors*. PhD thesis, Delft University of Technology, 1982.
- [6] Nanver L.K., Goudena E.J.G., and van Zeijl H.W. Dimes-01, a baseline bifet process for smart sensor experimentation. *Sensors and Actuators A*, 36:139-147, 1993.