PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Gerardo Castellano

XXX Cycle

Training and Research Activities Report – First Year

Tutor: Davide De Caro

1. Information

I received the M.S. degree cum laude in Electronic Engineering the 26th March 2014 from University of Napoli "Federico II". From June to October 2014 I received a scholarship as part of the research project "VEM, Virtual Energy Management". I belong to XXX cycle of ITEE PhD and Marvell (Italia) - DIETI finance my fellowship in VLSI systems. My tutor is Prof. Davide De Caro.

2. Study and training activities

Module	Type	CFU
The Entrepreneurial Analysis of Engineering Research Project	Ad-Hoc Module	3
Modelli, metodi e software per l'ottimizzazione	Ad-Hoc Module	4
Designing and writing scientific manuscripts for publication in English language scholarly journals	Ad-Hoc Module	3
Gruppo Elettronica PhD School – Siena 2015 http://www.congressi.unisi.it/gruppoelettronica2015/ph-d-school	Doctoral School	4
Cadence training course - "Analog Modeling with Verilog-A vMMSIM11.1 (iLS)"	External Module	1
Cadence training course - "Virtuoso AMS for Digital Designers v12.1 (iLS)"	External Module	1

Seminar	Date	CFU
Smoothed Particle Machine Perception: a proposed method for sensor fusion and physical-spacial perception	14/01/2015	0.2
Risk management meets model checking: fault tree analysis and model-based testing via games	20/01/2015	0.4
The iCub project: An open platform for research in robotics & artificial intelligence	18/03/2015	0.3
A New Look at Electro-Magnetic Induction	19/03/2015	0.5
Affidabilità di dispositivi e moduli elettronici di potenza	24/03/2015	1.2
Agents with Truly Perfect Recall	28/04/2015	0.2
Passivity-based control of nonlinear physical systems: A port-Hamiltonian approach	27/05/2015	0.4
Lagrangean relaxation and Set Covering	03/06/2015	1
On the complexity of Temporal Equilibrium Logic	22/10/2015	0.2

	Credits year 1							
		1	2	3	4	5	6	
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary
Modules	**20**	0	3	0	7	1	5	**16**
Seminars	**5**	0	0,6	2,2	1,4	0	0,2	**4,4**
Research	**35**	10	6	8	2	9	5	**40**
	60	10	9,6	10	10	10	10	**60**

3. Research activity

The main theme of my research activity is VLSI Digital systems. In this first year I focused on two challenges:

a) the real-time denoising of fluoroscopic videos (circuits for image processing);
b) duplexer-less RF, digitally assisted, transceivers toward full-duplex radios for next generation wireless mobile terminals.

a) X-ray fluoroscopy devices are widely employed in the operating theatres and in applications as diagnosis and therapy. Fluoroscopy allows real-time screening of a patient's body with an acceptable low dose of X-rays.
The clear requirement to reduce the number of X-rays used for image formation determines the limited availability of photons per pixel, producing the so called *quantum noise*, which is by far the most dominant noise in fluoroscopic images. Opportune real-time noise filtering improves doctors' visual perception and allows dose reduction.
Quantum noise can be well represented by as a Poisson distribution [1], [2], and various methodologies were proposed to specifically filter Poisson noise [3], [4], [5], [7], [8], [9]. However, these approaches are computationally complex and, therefore, hardly suited for real-time processing of fluoroscopic sequence.
Thus it is proposed a new methodology for real time noise filtering of fluoroscopy video, that takes into account the characteristics of the local quantum noise and performs a conditioned spatio-temporal averaging of pixels to reduce the noise in fluoroscopic image without degrading its details. To validate the novel approach a FPGA implementation has been deeply investigated.
The designed system can be split in two subsections: the first one elaborates every single pixel across the frames, while the second one, for each pixel on the same frame, performs a spatial average between neighbouring pixels.
It is known [10] that, for a random variable with independent samples, as the luminance value of single pixel belonging to different frames, the best filtering technique is realized with a moving average system that equally weighs all samples in a predefined temporal window (e.g. length M). This description corresponds to a FIR filter of order M that, although it is very simple to realize, presents poor quality in terms of performance and required resource for its implementations.
Therefore it is proposed an N-th order IIR system, with N<<M, that approximates the impulse response of a moving average FIR filter, reducing the system complexity; to design the IIR filter with the desired features for an efficient hardware implementation an appropriate optimization problem has been studied.
Moreover, a conditional filtering approach allows to reduce the motion blur effects that can rise by a temporal filtering of the images.

The spatial denoising, for each pixel of the output temporal filter, performs a conditional mean operation between the spatial neighbour pixels within a fixed spatial window. As in the temporal filtering case, to avoid annoying effects (as smoothing effects on objects' edges); therefore the filtering is conditioned in such a way that only similar pixels (i.e. pixels belonging to the same object) are jointly processed.

In order to quantify the effectiveness of proposed approach we have compared its performances with some of the most efficient state of the art denoising methods [7], [8], [9], although not all are not suitable for a real-time elaboration and a hardware implementation. Tested on a static scenario, the designed filter is able to obtain performance higher than the state-of-the-art denoising method and can be easily and efficiently implemented.

[1] Lo CM, Sawchuk AA (1979) Nonlinear restoration of filtered images with Poisson noise. In: Applications of digital image processing III, proceedings of the seminar, San Diego, California, USA, SPIE Proceedings, pp 84–95.

[2] Cerciello T, Cesarelli M, Paura L, Bifulco P, Romano M, Allen R (2011) Noise-parameter modeling and estimation for X-ray fluoroscopy. In: Proceeding of the 4th international symposium on applied sciences in biomedical and communication technologies, Barcelona, Spain, ACM Proceedings, pp 1–5.

[3] MAT. Figueiredo, JM. Bioucas-Dias. Restoration of Poissonian images using alternating direction optimization.IEEETrans.ImageProcess.2010;19(12):3133–3145.

[4] F. Luisier, T. Blu, M. Unser. Image denoising in mixed Poisson–Gaussian noise, IEEE Trans.ImageProcess.20(3)(2011)696–708.

[5] M. Elad, M. Aharon. Image denoising via sparse and redundant representations over learned dictionaries. IEEE Trans. Image Process.15(12)(2006): 3736–3745.

[6] Yu-Li You, M. Kaveh, "Fourth-order partial differential equations for noise removal", *IEEE Transaction on Image Processing*, vol. 9, no. 10, 2000.

[7] K. Dabov, A. Foi, V. Katkovnik, K. Egiazarian, "Image denoising by sparse 3-D transform-domain collaborative filtering", IEEE Transactions on Image Processing, vol. 16, no. 8, pp. 2080–2095, 2007.

[8] K. Dabov, A. Foi, K. Egiazarian, "Video denoising by sparse 3D trasform-domain collaborative filtering", European Signal Processing Conference (EUSIPCO), Poznań, Poland, September 3-7, 2007.

[9] A. Foi, "Clipped noisy images: Heteroskedastic modeling and practical denoising", Signal Processing 89 (12), pp. 2609–2629, 2009.

[10] Raman B. Paranjape "Foundamental Enhanced Techniques" in "Handbook of Medical imaging" editor-in-chief ISAAC N. Bankman, Academic Press, London.

b) Wireless networks have evolved from the first simple analog circuits to today's extremely advanced mixed signal (analog/RF/digital) systems. In these last years special emphasis has been dedicated to hand-held wireless terminals, which continue to evolve from simple feature phones to ever more complicated and versatile smart computing machines. Therefore, an even greater evolution is required to keep up with the explosive increasing in the demand of data rates and services, preserving at the same time sizes and costs of devices. The exponentially increasing complexity of such smartphone is due to the ever growing demand of performance, which leads to larger bandwidth and the adoption of newer techniques like carrier aggregation and MIMO, and to the growing number of standard, modes of operations (WiFi, Bluetooth, NFC, etc) and bands to be supported.

Size and cost of today's terminals is associated primarily to the electronic circuitry; however, while by moving to deeply scaled technologies, over the years the cost of each individual active component (especially the purely digital ones) has been reduced, this has only marginally occurred for the passives ones. Therefore, to optimize the designing of a mixed signal System-on-Chip (SoC), it is required to act on two fronts: first, its level of integration must be drastically increased, e.g. all transceivers, power amplifiers, audio and power management chips should be integrated together with the digital processors; second, through an optimized co-design of the chip (especially the transceiver), the off-chip passive components required by the platform, like SAW and duplexer filters, should be drastically reduced.

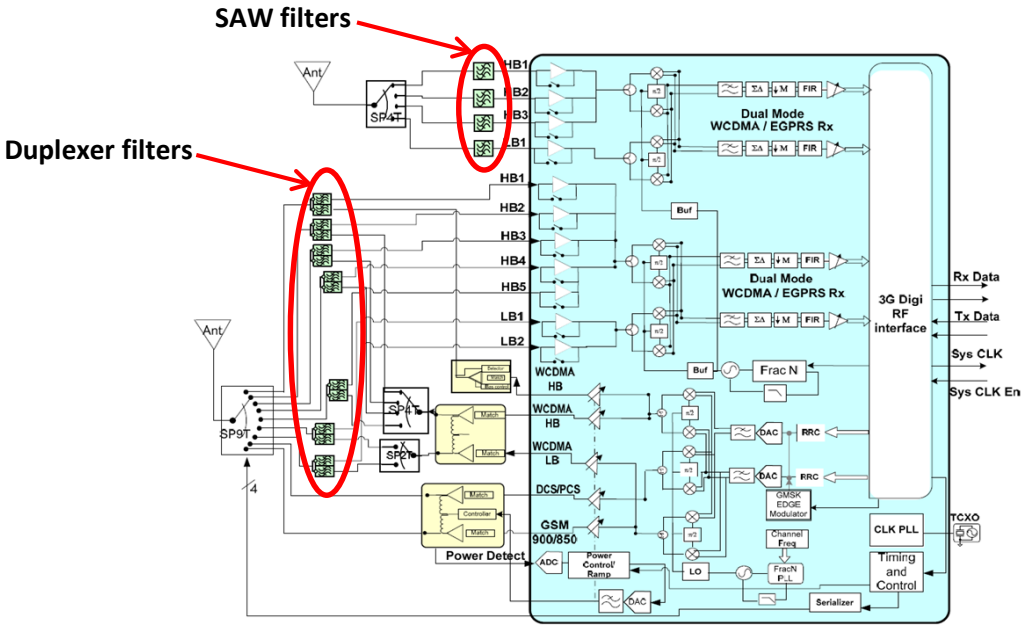

Figure 1. Block diagram of an Advanced LTE transceiver board

This is because, given their narrow band nature, their number rapidly increase as the number of standards, bands and parallel RX and TX paths supported by the transceiver; moreover, being devices designed for radio-frequency applications, they are electromechanical devices constructed on a piezoelectric crystal or ceramic, unintegrable on chip.
Thus, solutions that make possible to replace duplexer and SAW filters with an equivalent integrable circuit are highly desirable.
A duplexer filter is used for FDD (frequency division duplexing) communications to isolate the two paths of transmission and reception, allowing to operate simultaneously sharing the same antenna. Different solutions that realize an integrated tunable RF duplexer based on electrical balance of a hybrid transformer [1] are been proposed in literature [2], [3].

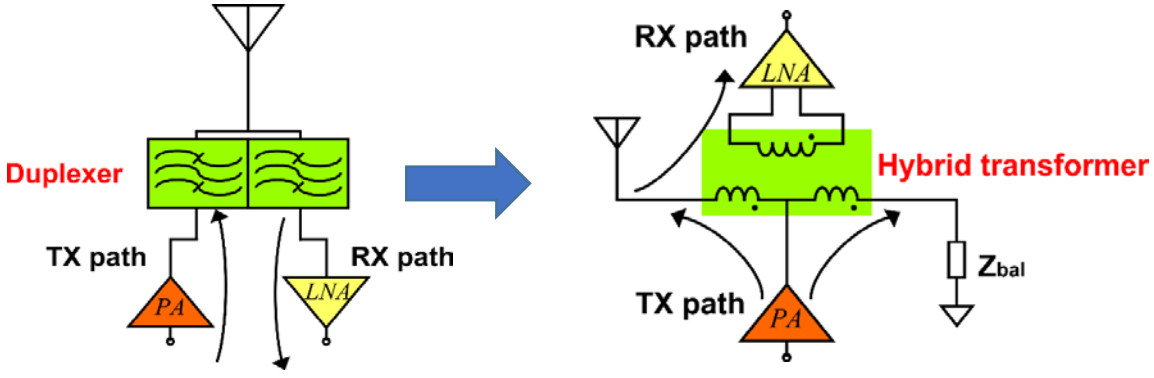

Figure 2. Conceptual replacement of a duplexer filter with a hybrid transformer for FDD applications

A hybrid transformer is a four-ports circuits that has several desirable properties: a biconjugacy between alternate sets of ports, an impedance match at each port, and the ability to split power in any desired proportion between two receiving ports. These features, under well-determined conditions, allow to isolate the transmitter (TX) from the receiver (RX) path.

In an ideal world the perfect TX-RX isolation is obtained if the balance impedance (Z_{bal}) perfectly matches the equivalent antenna impedance; realistically, the antenna impedance is frequency-dependent (its value varies over the useful bandwidth) and time-variant for the result of interactions between the antenna and the user's head and hand and the surrounding environment. This causes a significant change in the antenna impedance that leads to degrade the TX-RX isolation, unless the variations are tracked by a balance network opportunely designed.

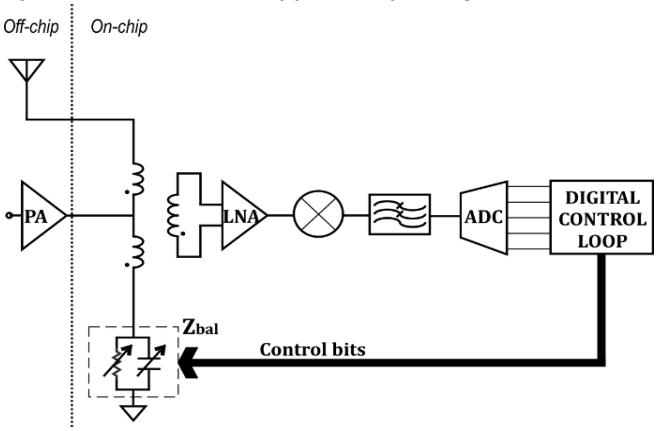

Figure 3. Tracking loop for hybrid transformer balancing

The idea is realize a tracking loop composed by a digitally controlled impedance (e.g. a RC circuit realized by an array of switched resistors and switched capacitors), whose control bits are generated by an algorithm that can measure the downconverted TX leakage generated by the mismatch in the hybrid transformer and opportunely correct the balance impedance to track the antenna variations and improve the TX-RX isolation.

An optimization algorithm, based on a simple binary search method, sets the two variables (resistance and capacitance values) of the balance impedance to minimize the TX leakage power, so that in an initial stage is minimized the mismatch between the antenna and the balance impedance and afterwards tracking the antenna impedance during the normal activity of the system as it change.

At every step of the optimization process the gradient of the objective function (i.e. the TX leakage power) gives the right direction toward which move the balance impedance value.

Although it is sufficient to estimate only the sign of the gradient, the noise naturally present on the signal and that introduced by the processing chain bring to have an error probability proportional to the noise power superimposed to the signal.

A Monte Carlo technique models the information evaluated by the algorithm as a random variable, whose variance allows to estimate the error probability; the algorithm adapts the measurement time for every single case according to the noise level, in order to have an error probability less than the maximum tolerated.

In this way, the balancing of the hybrid transformer occurs in a time lapse that, also in critical cases, is valued some orders of magnitude lower than the change rate of antenna impedance [4]. Although it is sufficient an update rate of $10ms$, the designed system can detect the initial optimal value in less than $20\mu s$ and to track the variations in less than $10\mu s$. However, the performance reported have been obtained by an analytical model, thus the next step will be the hardware implementation of the whole system.

As previously described, all the off-chip devices should be removed or substituted by integrable circuits; currently the possible solutions that allow to eliminate the SAW filters in MIMO diversity receivers are being investigated and this will represent the core of the activity research in the next years.

[1] E. Sartori, "Hybrid transformers," IEEE Trans. Parts, Mater., Packag.,vol. PMP-4, no. 8, pp. 59–66, Sep. 1968
[2] M. Mikhemar, et al., "A Multiband RF Antenna Duplexer on CMOS: Design and Performance," Solid-State Circuits, IEEE J., vol. 48, no. 9,pp. 2067–2077, 2013.
[3] S.H. Abdelhalem et al, "Tunable CMOS Integrated Duplexer With Antenna Impedance Tracking and High Isolation in the Transmit and Receive Bands", IEEE Trans. on Microwawe Theory and Technique, vol. 62, no. 9, Sept 2014
[4] L. Laughlin, *et al.*, "Electrical balance duplexing for small form factor realization of in-band full duplex," *IEEE Commun. Mag.*, vol. 53, no. 5, pp. 102–110, May 2015.

4. Products

a. Journal papers
   I. G. Castellano, D. Esposito, P. Bifulco, D. De Caro, E. Napoli, N. Petra, M. Cesarelli, A.G.M. Strollo, "Spatio-temporal IIR Filter for Real-time Denoising of Fluoroscopic Videos", IEEE Trans. On Biomedical Circuits and Systems, submitted.
   II. S. Balamurugan, A. Biswal, G. Castellano, D. De Caro, R. Marimuthu, E. Napoli, N. Petra, P.S. Mallick and A.G.M. Strollo," Design of Low Power Fixed-Width Multipliers with Column Bypassing", IEEE Transactions on VLSI Systems, submitted.

b. Conference papers
   I. E. Napoli, G. Castellano, D. Esposito, A.G.M. Strollo, "Digital Circuit for the Generation of Colored Noise Exploiting Single Bit Pseudo Random Sequence", 2016 7th IEEE Latin American Symposium on Circuits and Systems, submitted.
   II. E. Napoli, G. Castellano, D. Esposito, A.G.M. Strollo, "Programmable Delay Circuit for Low Transition Probability Signals", 2016 IEEE International Symposium on Circuits and Systems, submitted.
   III. D. Esposito, G. Castellano, D. De Caro, E. Napoli, N. Petra, A.G.M. Strollo," Approximate Adder With Output Correction for Error Tolerant Applications and Gaussian Distribuited Inputs", 2016 IEEE International Symposium on Circuits and Systems, submitted.

5. Conferences and Seminars

No Conference or Seminar has been kept in this year.

6. Activity abroad

No activity abroad has been carried out in this year.

7. Tutorship

Correlator of M.S. thesis "Progetto ed implementazione su FPGA di un filtro spazio-temporale per applicazioni fluoroscopiche basato su approccio IIR", Student: Antonino Battaglia - 20 hours.