Volume 6, Issue 2
April 2017

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

# Power Conditioning System Architecture for Remote Smart Sensor Applications

**[1]Alhassan Mumuni, [2] Fuseini Mumuni**
[1]Department of Electrical/Electronics Engineering, Cape Coast Technical University, Cape Coast, Ghana
[2]Department of Electrical and Electronics Engineering, University of Mines and Technology, Tarkwa, Ghana
E-mail: [1]alascay2k@yandex.ru, [2]mkpay2k@yahoo.com

## ABSTRACT

Wireless sensor networks (WSNs) are increasingly becoming more important in application areas such as environmental monitoring, access control, and automation. Current technology trends towards low power consumption, high speed, high resolution data conversion and noise-sensitive electronic components make the task of designing power supplies for WSNs challenging. This is particularly so when utilizing energy harvesting technologies rather than conventional energy sources to power sensor systems. Currently, available literature does not offer comprehensive treatment of power conditioning system design which takes into account all the properties and requirements of WSNs. This paper presents a high-level design of a power conditioning circuit, taking into account the unique requirements of WSNs. The approach taken was to analyze WSN requirements and investigate different power conditioning circuit topologies and design techniques necessary to meet these requirements. Further, all the proposed schemes and techniques are synthesized into a single power conditioning architecture.

**Keywords:** *Current conveyor , feed-forward ripple cancelation (FFRC),energy harvesting, precision rectifier, WSN*

## 1. INTRODUCTION

Ubiquitous computing systems are increasingly enabling new applications in automation of technological processes, environmental monitoring, e-health devices, security and home automation systems. The basis of ubiquitous computing systems is smart sensor networks. A smart sensor network consists of multiple sensors, computing units, actuators and communication interfaces. Traditional sensor systems generally consist of transducers that convert physical, biological, or chemical variables into electrical signals. In contrast, modern smart sensor systems are highly integrated systems that incorporate complex RF, analog and digital signal processing circuits to perform advanced functions such as intelligent processing of sensor data, generation of calibration curves, self-identification and self-testing [1]. Typically, a smart sensor network contains a large number of sensor nodes and a base station. Each node comprises a set of sensors, actuators, a power source, power conditioning system, microprocessor, and a transceiver - which may operate as a transmitter, receiver, or repeater. A single node usually incorporates a variety of sensors, for example, temperature, pressure, humidity, light, vibration and chemical sensors. The base station, which may be located several kilometers away from the sensor nodes, has transceivers and information processing equipment such as personal computers or workstations. The basic structure of a remote smart sensor node is shown in Fig. 1.

A major problem that limits the deployment of smart sensor networks is the availability of economical, continuous power supply to power sensor nodes at remote locations. Since the devices are not connected by wires, they cannot receive the energy needed for performing all operations required in the network from a main power supply line. In such networks, devices may be equipped with built-in portable batteries. However, at present, there are no compact batteries capable of powering such network nodes for considerable durations that approach the service life of the network [2]. Consequently, wireless sensor networks often need to be monitored and batteries replaced on a regular basis. In some applications this can complicate or interfere with the normal operation of the system. Also, smart sensor systems are sometimes deployed in areas where it is impossible to reach. As a result, the use of portable batteries to power sensor devices limits their field of application due to the reduction of autonomy in the operation of the systems. These difficulties stimulate the search for new techniques for implementing self-powered sensor systems. Self-powered sensor systems are essential for applications where battery replacement is disruptive, inconvenient or impossible, particularly in cases that require continuous operation of sensors out of the reach of human operators. The concept of self-powered sensor systems is based on the availability of affordable energy in various forms - thermal, mechanical, optical and RF in the natural environment. The energy harvested from the environment can be used to power

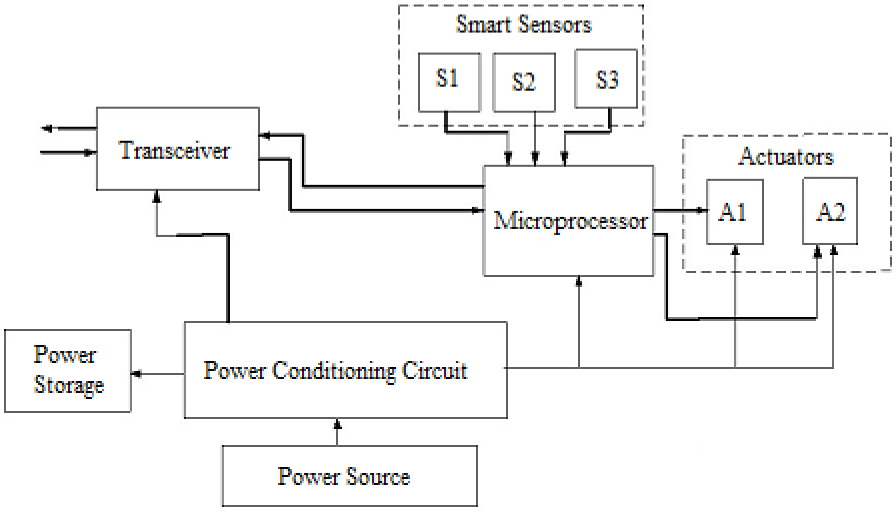


Fig. 1: Typical structure of remote smart sensor node.

remote wireless sensor nodes and other components. There is also the possibility of a combined use of different available sources of energy such as vibration, RF and thermal energy to ensure continuous, uninterrupted supply. This is a promising direction in the evolution of wireless smart sensor systems.

The energy obtained from the environment is typically of low power, unsteady and noisy. Consequently, the use of traditional power conditioning schemes may not be adequate to meet the stringent requirements of performance and economy of operation associated with smart sensor systems. The power conditioning system, also loosely referred to as power management system, is arguably one of the most important components of a smart sensor node. It rectifies and stabilizes the ambient energy, feeds the sensors, microprocessor, transceiver, as well as stores any excess energy for future use. As an integral part of smart sensor systems, power supply must strictly comply with certain requirements, which are generally defined by the specifications of the smart sensor system, and the conditions imposed on the power supplies and their function as part of the system.

This study examines the features and requirements of smart sensor networks and synthesizes a generalized architecture of power conditioning system for smart sensor networks based on their unique requirements. The study is subject to a number of objectives, which are:

- To study the requirements for a power conditioning circuit in stabilizing harvested ambient energy for WSNs.
- To investigate different approaches and identify the most effective techniques which are required for the realization of schematic solutions of the basic units of a power conditioning system
- To synthesized an architecture for the power conditioning system

The current work focuses on a high-level design of a typical power conditioning circuit and its critical elements. In a future study, the various circuit elements will be modeled at the transistor level. This will allow computer simulations that accurately describe the different characteristics of the power conditioning system (frequency, transient response, noise rejection, etc.) to be carried out. Analysis conducted on the basis of these simulations will allow the proposed architecture to be validated and refined for practical applications.

## 2. GENERAL CHARACTERISTICS AND REQUIREMENTS OF REMOTE SMART SENSOR SYSTEMS

Generally, for a given application a large number of sensor nodes (typically 100-10,000 units) are deployed - usually in harsh conditions. In many situations, the network may not be accessible once deployed. Such systems are also prone to failure because of the many components involved, and consequently, many interconnections. In recent years there has been a steady decline of wired sensor networks in favor of wireless solutions. The wireless systems provide numerous networking capabilities, including dynamic authentication, flexible routing mechanisms and self-organization [2-4]. Wireless communication eliminates the need for wired interfaces and the associated cost involved in purchasing and installation of wiring, specialized switches and routers. This greatly expands the range of applications for smart sensor systems and enables seamless implementation of telemetry systems, especially in applications where the use of traditional communication channels was impossible or not economically viable. In many cases the installation of a wireless sensor network (WSN) is reduced to a simple arrangement of sensor nodes. This allows thousands of smart sensor nodes to be easily deployed within a remote geographical area for a particular application. Another major trend in WSN technology is the incorporation of mesh topology, where every node is able to communicate with every other node in the network. This enables sensor nodes to coordinate and co-process sensor information in an efficient manner.

The deployment of distributed sensor systems in hostile, remote locations requires robustness against harsh environmental conditions such as windstorms, physical intrusions, rain and outdoor temperature. The implementation of WSN also requires the use of low-cost sensors and associated components. The need for low-cost components is obvious, since the deployment of WSN usually involve large numbers of nodes. In addition, size and weight limitations mandate that nodes be implemented with the smallest possible dimensions. As a result, WSN nodes are usually implemented on system-on-chips (SOCs) [5]. Because of the need to save energy WSN should operate in different power down modes, providing different low power supply options [5-6]. A device or node should be fully active only when necessary.

Most applications of modern smart sensor systems require complex information processing and communication capabilities amidst high technical and economic specifications and the capability of long-term operation without maintenance or interruption. These tightened requirements have resulted in a high demand for power systems that meet the new requirements for performance, autonomous operation, long-life and economy of operation. Recently, energy harvesting power systems, in particular piezzoelectric, thermal and RF micro generators, have been widely studied as alternative power for WSNs. For example, in [7-10] sensor systems completely powered by energy harvesting power systems have been realized. These have been made possible owing to the fact that smart sensor components are characterized by extremely low power consumption. In comparison with conventional devices they require several times less energy. These energy harvesting solutions allow autonomous operation of WSNs. Such solutions can be used to power wireless sensors in telemetry systems in remote environments or in the moving parts of equipment, making it possible to monitor equipment condition and plan maintenance. Also, the use of energy harvesting technology increases the reliability and extends the lifetime of a WSN, which operates without requiring regular replacement of power.

In the design of WSNs, several factors need to be considered. In particular, all system components must meet the basic requirements for modern smart sensor networks: high performance, long operating lifetime, low-power consumption, low cost, simplicity of design, fault-tolerance, compactness and low maintenance. The following sections look into the technical aspects of designing power conditioning circuits for WSNs.

## 3. AMBIENT ENERGY CONDITIONING CHALLENGES

The amount of energy achievable with commercially available energy harvesting devices is still very limited, typically, a few miliwatts or microwatts. This is usually insufficient to meet the energy needs of most applications. The use of multiple energy harvesting transducers employing different energy conversion mechanisms to guarantee sufficient and continuous collection of energy from the environment has been proposed to solve this problem [11]. That is, in one system different energy harvesting modules can be mounted. Energy from several sources can then be collected on a what-is-available basis with the appropriate module. Fig. 2 shows a block diagram of a typical WSN energy harvesting power supply using this approach. Due to the simplicity of design and the redundancy introduced by multiple energy harvesting modules, such a power supply has a high reliability and durability, with service life exceeding ten years under normal use. However, the task of designing a high-quality power conditioning system is made more difficult, as the different energy harvesting modules produce power that exhibit different characteristics. Moreover, environmental conditions are constantly changing. As a result, the nature and characteristics of the harvested ambient energy continually changes. Hence the power generated is characterized by variable amplitudes with significant ripples and wide dynamic range of frequencies. In addition, the presence of environmental noise can further affect these dynamics. A review of a number of energy harvesting systems [9-10, 12-13] reveals a wide variation of output power characteristics (Table 1). At the same time, modern CMOS loads require low noise and ripple together with fast transient response and short settling time. Also, as already noted, precision sensors and electronic components are characterized by extremely low power consumption. In power-down and idle modes, WSN nodes operate with a few miliwatts or even microwatts [6]. It is therefore, crucial to be able to accurately rectify and regulate low voltages down to a small fraction of a milivolt and over a wide range of frequencies under the influence of random noise and external factors. Thus, nodes forming part of remote sensor networks present

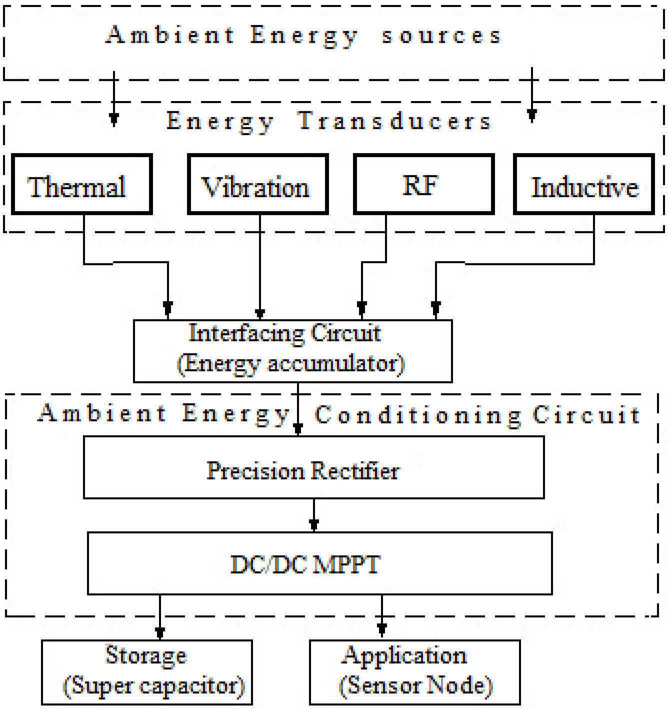


Fig. 2: Power Supply system incorporating a variety of ambient energy sources.

Table 1: Power characteristics of different energy harvesting devices [9-10, 12-13].

| Device description and operating mode | Output power, (μW) | Frequency (Hz) |
|---|---|---|
| Piezoelectric, vibration | 375 | 120 |
| Powcast P2110, Electromagnetic, vibration | 0.3 | 4400 |
| RF Energy transducer* | 3500 | 915 |
| Electrostatic , vibration | 1052 | 50 |

**Power of 3.5mW is RF transmitter is located at a distance of 0.6 meters from energy transducer. The power reduces significantly with increasing distance. At 11 meters power produced is only 1 μW.*

stringent requirements for the power conditioning system: precision rectification and regulation of extremely low voltages, wide bandwidth and high power supply rejection ratio (PSRR). And with all these, the power conditioning system must be low-cost, and have the smallest possible dimensions. Because of these requirements, conventional rectifiers and regulators do not offer satisfactory performance.

The task of designing a high-quality power supply system, therefore, requires a careful consideration of all these constraints. The first step in this process is to analyze the requirements and all available options in order to realize a power supply that will best meet the requirements and provide the needed capabilities. In this regard, it is necessary to take into account a number of factors determined by the operating conditions, load characteristics and the technical limitations of the application.

## 4. DESIGN OF POWER CONDITIONING SYSTEM

As described in sections 2 and 3, the requirements of a power supply for powering WSN are very demanding. Given the nature of the input power, constraining the output parameters to be within the required levels may not always be feasible using classical analog circuits. Depending on the application requirements and available power sources, minimum fluctuations of the output voltage may not be guaranteed for all operating conditions. The problem of conditioning noisy, low voltage EH power supplies in order to obtain acceptable values of output parameters has has two main aspects:

- Precision rectification of the harvested ambient energy
- Regulation of the DC output voltage, which amounts to the suppression of the effects of noise, input ripples and load changes to provide a stable output

This section evaluates analog electronic components and alternative topologies of the basic building blocks of a power conditioning system, mainly the precision rectifier and regulator. A suitable power conditioning system architecture is designed based on the requirements of WSN outlined in previous sections.

### 4.1. Precision Rectifier Circuit

Conventional precision rectifiers are realized using operational amplifiers, diodes and other passive components. A simple precision rectifier circuit can be implemented with a pair of operational amplifiers in conjunction with six precision resistors and two diodes (Fig. 3). This enables rectification of low voltages with minimal distortion. This topology is one of the simplest precision rectifier implementations because of the low component count and simplicity. A major shortcoming of this type of precision rectifier circuit is the need to use precision resistors or to perform resistor trimming. Also, such a circuit performs poorly at very low voltages this type of precision rectifier circuit is the need to use precision resistors or to perform resistor trimming. Also, such a circuit performs poorly at very low voltages because of commutation effects of the diodes' reverse recovery time [14]. To overcome these problems, a number of designs based on modifications of the classical operational amplifier-based precision rectifier circuit have been explored. For example, Collin and Ting [15] presented precision full-wave rectifier circuit that performs well at signal levels below 5mV. However, to attain such performance, as many as ten capacitors, several resistors, and many other components were used. This means increased size, complexity, power consumption and cost. In addition, because of the small gain-bandwidth product and limited slew-rate of practical operational amplifiers [14] the performance of such circuits degrades significantly at frequencies above 50kHz. Traditionally, in many applications the operational transconductance amplifier (OTA) has often been used to overcome the classical operational amplifier's limited bandwidth and slew rate problems. However, its high temperature sensitivity constrains its use in harsh environments many remote smart sensor applications usually operate in. Also, the OTA is still not suitable for rectifying very small voltages. The review of several studies [16-19] shows that the most rational solution of precision rectification is achieved using current-mode circuits, particularly current conveyors. Several implementations of high precision rectifying circuits based on current conveyors exist. However, when designing for WSN applications, it is important to keep in mind the specific requirements of remote smart sensor systems,

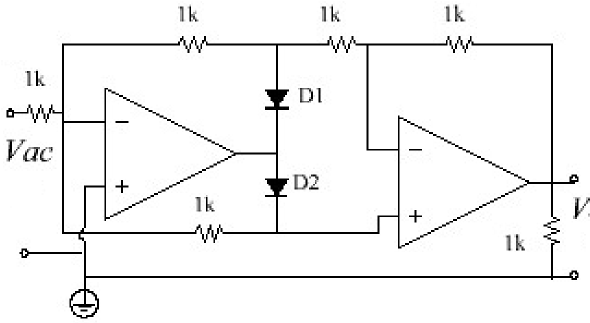


Fig. 3: A basic conventional precision rectifier circuit.

particularly design simplicity. The circuit diagram of a second generation current conveyor (CCII) is shown in Fig. 4. It is a three-terminal device with terminals usually designated as X, Y and Z. The relationship between the terminal currents and voltages of a positive polarity second generation current conveyor is detailed by the matrix equation (1).

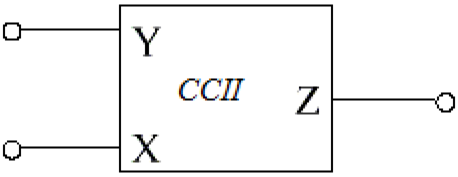
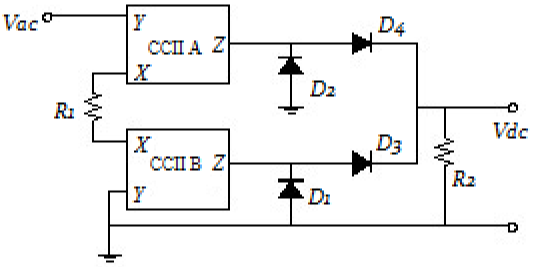


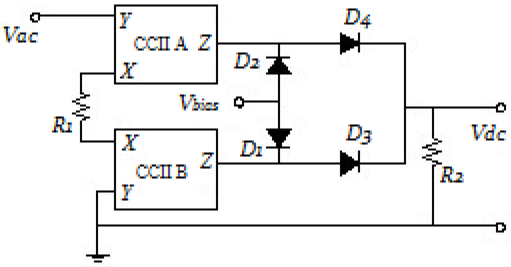
Fig. 4: A second generation current conveyor (CCII) schematic symbol.

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix} \qquad (1)$$

That is, $I_y = 0$, $V_x = V_y$, and $I_z = I_x$. This means any voltage applied at node Y is replicated at node X, and any current applied at node X is replicated at node Z. Consequently, terminal Y is an infinite input impedance terminal while X is a zero input impedance terminal. Also, the output terminal Z behaves like an infinite impedance terminal. These properties make the CC an ideal component for precision rectifier circuits. A basic CC based precision rectifier has the structure shown in Fig. 5 [17]. For a positive input, a current equal to Vin/R1 flows from the Z-terminal of CCII. This forward-biases diodes D2 and D4. The configuration allows the output voltage Vdc to be taken across R2 as shown in Fig. 5 a. For a negative input voltage, diodes D3 and D1 conduct, again leading to an output voltage Vdc across R2. Thus, the circuit functions as a full-wave rectifier circuit, giving a dc voltage Vdc at the output. However, some crossover distortions still occur when rectifying extremely low voltages because of the diode commutation problems. One solution is to pre-bias the diodes with a voltage of about 0.7V. This has been demonstrated to offer significant improvement in the performance of the rectifier [17-19]. Nonetheless, its high temperature sensitivity makes it unsuitable for remote sensor applications. Stiurca [19] showed how current mirror- based biasing can be used to solve this problem. However, obtaining this biasing current is not practicable in many smart sensor applications. A straightforward analysis of the current conveyor, taking into account its terminal properties allows the structure of the precision rectifier in Fig. 5 to be greatly simplified AS shown Fig. 6 [20]. In this structure, CCII A serves as a bi- phase amplifier, while CCII B is a non- inverting comparator. CCII B, in conjunction with the transistor T, serves as a voltage-controlled switch.. When positive polarity voltage is applied the switch is open, and the output voltage Vo is given by Vo=Vin. For a negative input voltage the switch is close, leading to an output relationship of Vo=-Vin. Thus, the simplified circuit in Fig. 6, in effect, realizes a precision rectifier circuit. It offers significant improvement over the conventional precision rectifier topology which typically employs two current conveyors, two resistors and up to four diodes. This architecture also avoids the small-signal problem associated with diode switching.



(a) Precision rectifier without bias signal.



(b) Precision rectifier with voltage bias.

Fig. 5. Precision rectifier based on second generation current conveyor (CCII).

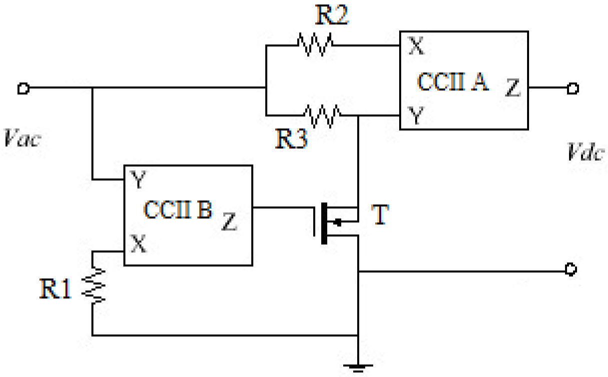


Fig. 6: A simplified precision rectifier circuit based on second CCII and a MOSFET transistor.

### 4.2. Regulator Design

In the most general form any voltage regulator can be regarded as a voltage divider consisting of the load impedance and impedance of pass element in series or in parallel with it. The regulator in this sense is a kind of compensating resistor $R_c$ connected between the input and output terminals. As such the compensating device (pass element) may be a resistor, a transistor or other electronic device. The impedance of the pass element is proportional to the load voltage. This is achieved by using voltage feedback from the load to control the resistance of the pass element (usually a transistor) through an amplifier (Fig. 7).

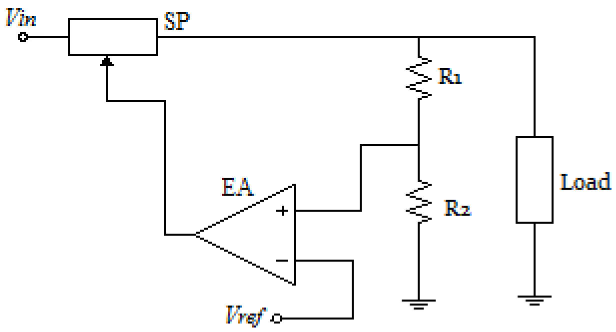


Fig. 7: General form of a voltage regulator.

The proportion of voltage fed back is given by the feedback factor $\beta = R_1/(R_1+R_2)$. When considering such a scheme the output voltage is defined as the difference between the input voltage and the voltage drop across $R_c$:

$$V_L = V_{in} - I_{sp}R_{sp} \qquad (2)$$

Change in the input voltage $\Delta V_{in}$ is distributed in the series pass element $\Delta V_{sp} = I_{sp}R_{sp}$ and load $\Delta V_L$.

$$\Delta V_{in} = \Delta V_{sp} + \Delta V_L = (1+\beta G_{ea})\Delta V_L \qquad (3)$$

and

$$\frac{\Delta V_{in}}{\Delta V_L} = (1+\beta G_{ea}) \qquad (4)$$

To maintain a constant output voltage, the ratio $\frac{\Delta V_{in}}{\Delta V_L}$, known as line regulation, must be very large. Specially, the stabilization factor $S_V$ is defined as the ratio of relative instability of input voltage $\left(\Delta V_{in}/V_{in}\right)$ to the relative instability of the load voltage $\left(\Delta V_L/V_L\right)$ at a constant load resistance in the absence of other destabilizing factors. Thus, mathematically,

$$S_V = \left(\Delta V_{in}/V_{in}\right)/\left(\Delta V_L/V_L\right) \qquad (5)$$

Taking into consideration equation (4), $S_V$ can be written as

$$S_V = (1+\beta G_{ea})\frac{V_L}{V_{in}} \qquad (6)$$

From the last equation, it is obvious that higher values of $S_V$ can only be achieved by increasing the dc amplifier gain $G_{ea}$.

However, very large values of $S_V$ cannot be achieved only by increasing $G_{ea}$ alone since the analysis does not take into account the impact of external destabilizing factors on the parameters of the regulator. For example, random noise from the energy transducers, sudden load changes, ambient temperature variations, and other environmental conditions can impact negatively on the stability of the output. To account for these factors, it is necessary to represent the regulator as an automatic control system (Fig. 8). In this representation, input noise and load resistance changes are presented in explicit form as D, setpoint disturbances as $V$. It is clear that to ensure a high quality output amidst these factors, the regulator must necessarily have a very high power supply rejection ratio (PSRR). In many applications, this issue is addressed by utilizing RC filtering, cascading LDOs, or other complex control schemes [21]. These techniques are not suitable for energy harvesting applications because of the high power consumption and large dropout voltages. In addition, these approaches do not provide sufficient power supply ripple rejection (PSRR) at required ripple frequencies.

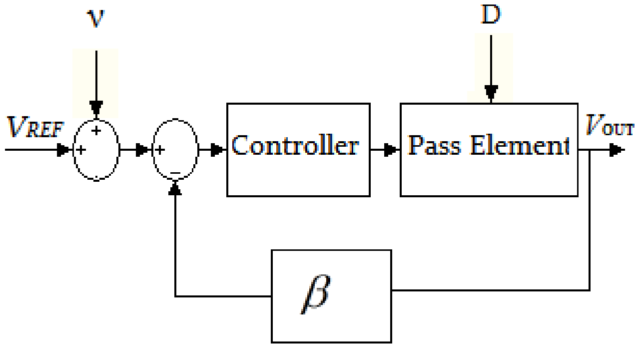
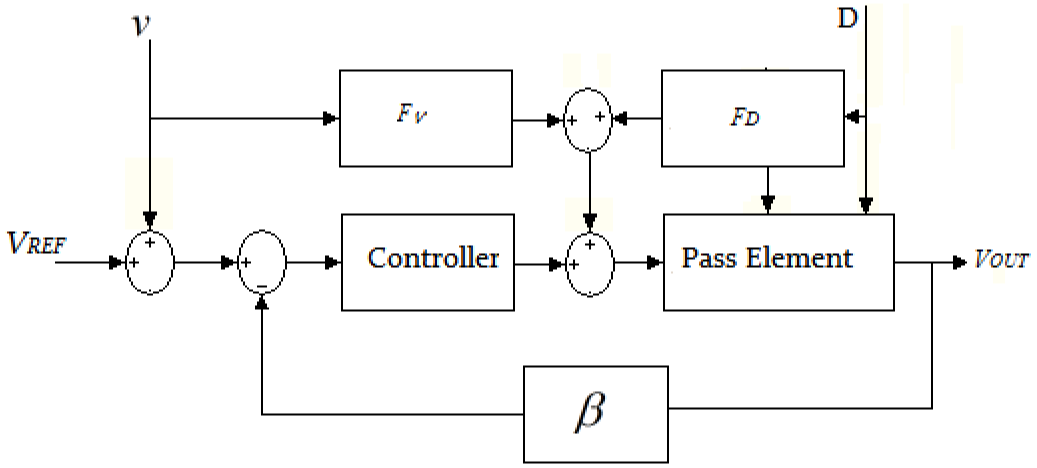
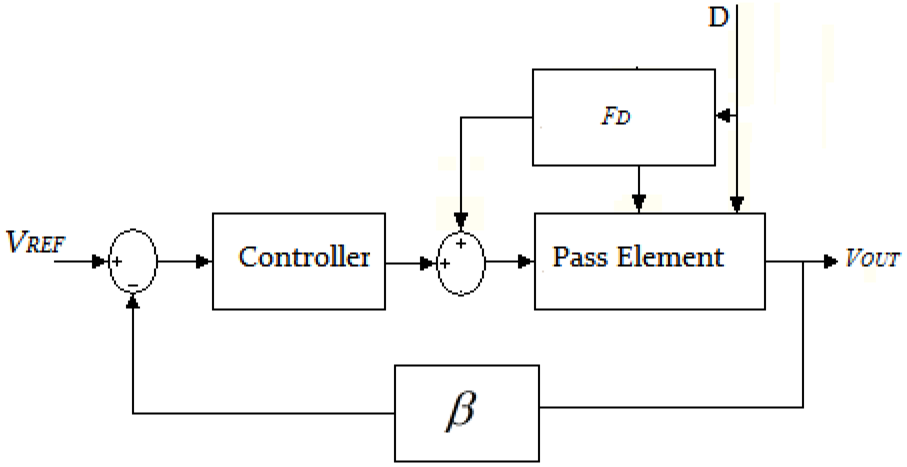


Fig. 8: Simplified block diagram representation of the regulator as a close loop control system.

A rigorous solution of this problem is practically possible using feedforward control. Indeed, El-Nozahi et al [22] achieved a PSR of about 57dB at up to 10 MHz using feedforward ripple cancellation technique. Feedforward control is generally used in combination with a feedback control. A generalized block diagram of a feedforward control system is shown in Fig. 9 [23]. It incorporates two fee forward controllers do deal with both set point variations and plant disturbances (Fig. 9a). The feedforward provides the ability of the control system to act in response to any disturbance before the effect of the disturbance manifests in the plant output. In the context of the current study, disturbance due to setpoint fluctuations can be neglected since high precision voltage references can operate with reasonable stable outputs over a wide range of conditions. As a result, the feedforward structure can be greatly simplified (Fig. 9b).



(a). Structure of feed forward regulator with set point disturbance.



(b). Structure of feed forward regulator without set point disturbance.

Fig. 9. Generalized block diagram of a regulator with Feed-Forward Ripple Cancellation approach.

Practically, feedforward control can be implemented by replicating the ripples on the external supply line at the gate of the series pass transistor using feedforward amplifier circuit. This effectively eliminates the effect of ripples at the output of the pass transistor. It is important to keep in mind that feedforward performance can be adversely affected by the accuracy of the feedforward gain, feedforward noise and the timing of the feedforward signal. Because of these potential issues the phase delay of the compensating signal must be appropriately matched with that of the power supply line and appropriate values of resistors selected to ensure the right gain is achieved. As sudden load resistance changes can also constitute a destabilizing factor, it may be necessary to incorporate the effect of load resistance changes in the feedforward loop. This can be accomplished practically with the help of a current sensing circuit. The circuit realization of the regulator using Feed-Forward Ripple Cancellation technique is presented in Fig. 10.

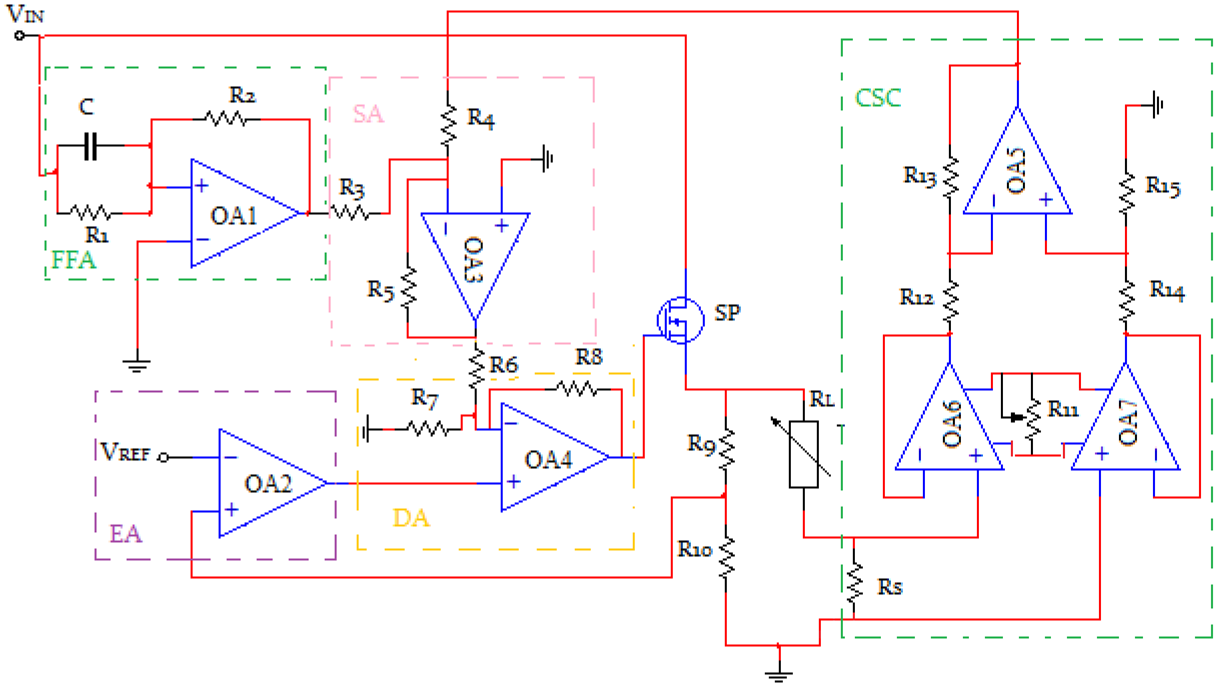
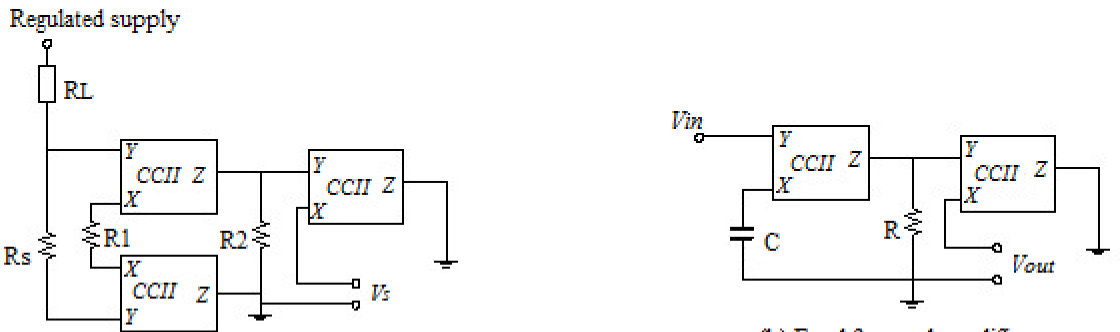


Fig. 10 Circuit diagram of a regulator based on feed forward ripple cancellation.

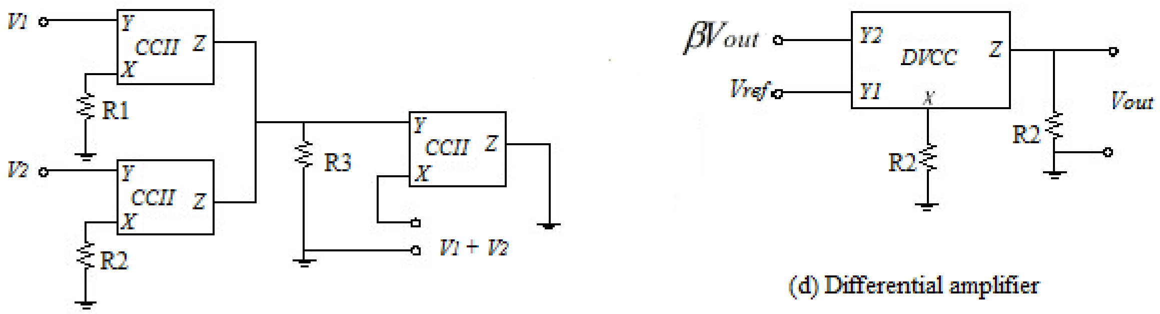
In the implementation above, ripples on the external supply line are compensated for by the feed forward amplifier (FFA). Also, if load resistance suddenly changes, it leads to a proportional change in load current and, effectively, to a change in output voltage. To provide for timely compensation of this effect, the load current change is measured by the current sensing circuit (CSC) and fed forward to offset output voltage change. This is added to the feedforward signal by the summing amplifier (SA). The differential amplifier (DA) subtracts the effects of this two disturbance signals from the error signal produced by the error amplifier (EA).

As noted earlier, the limited bandwidth and finite slew-rate of classical operational amplifier circuits are well-known problems which ultimately degrade system performance at high frequencies. Current conveyors - with their virtually unlimited slew rate and significantly large bandwidth, are the ideal components that meet the stringent requirements of integrated energy harvesting systems at a relatively low cost. Hence, for an improved performance, the basic units of the regulator subsystem (i.e. the FFA, CSC, SA, EA and the DA) are realized using current conveyors. On the basis of the principle of operation of the CCII outlined in section 4.1, the elementary functional elements of the regulator can be realized with very simple schemes [24]. For instance, an excellent current sensing circuit can be made using only two CCIIs and two resistors (Fig. 11 a). The realization of the FFA circuit, which basically is a voltage integrator, based on current mode components is shown in Fig. 11 b. Similarly, the rest of the associated building blocks of the regulator subsystem (SA and the DA) built using CCII are shown in Fig. 11 c and d, respectively. It is important to note that the error amplifier is a form of differential amplifier implemented using differential voltage current conveyor (DVCC).



(a) Current sensing circuit

(b) Feed forward amplifier



(d) Differential amplifier

(c) Summing amplifier

Fig. 11: The basic building blocks of the regulator implemented with current conveyors.

## 5. SUMMARY OF RESULTS

This paper reviews the general attributes of WSNs as well as the technical requirements for the power conditioning system of remote smart sensor nodes. In particular, the needs, components, functions, performance, and quality requirements of the power conditioning circuit are described. The analysis of the characteristics and requirements of WSNs shows that harvesting energy from the environment is the most rational means of powering remote sensor nodes. The study also assesses the nonfunctional requirements such as autonomy of operation, cost, size and weight. In addition, several design constraints that are to be considered when designing power conditioning systems for WSNs based on energy harvesting technology are described. As per the assessment, a quality power conditioning system for remote smart sensor networks requires the following essential features:

- High power supply ripple rejection (PSRR)
- Wide bandwidth operation ( from a few Hz up to a few GHz)
- Ultralow spot noise performance
- Small size
- Low cost

Thus, having identified the major factors necessary to provide a comprehensive power conditioning system design, a number of power conditioning circuit topologies and design techniques were analyzed. This made it possible to identify the appropriate schemes that offer the right balance of performance and complexity. Further, all the proposed schemes and techniques were used to synthesize, separately, a precision rectifier circuit and a voltage regulator. The regulator, together with the precision rectifier, forms a complete power conditioning system capable of meeting the requirements outlined above. The circuit diagram of the power conditioning system is shown in Fig. 12. Such a circuit can be built from low cost, off-the-shelf commercial current conveyor ICs like the AD844.

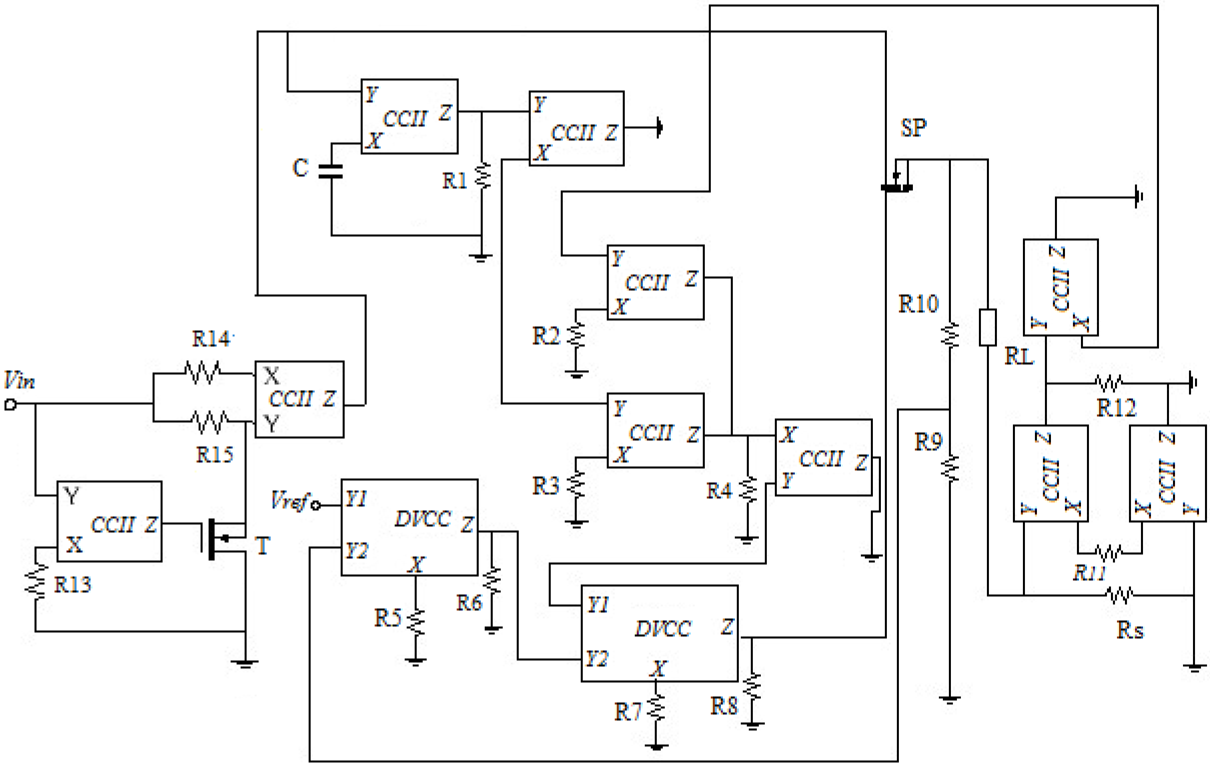


Fig. 12: Complete CCII realization of ambient energy harvesting power conditioning system.

The structure of the scheme includes a precision rectifier and a linear voltage regulator, which stabilizes the output voltage and removes any ripple arising from the power supply, abrupt load changes, ambient disturbance or other external factors. Within the voltage regulator subsystem are several blocks: the series pass transistor circuit SP, the feedback circuit, and the feedforward circuit. The feedforward circuit consists of input voltage feed-forward as well as load current sensing circuit. This architecture allows noisy, ultra low voltage, wide bandwidth voltage signals to be accurately regulated and a high PSRR to be achieved simultaneously.

## 6. CONCLUSION

In this paper a generalized architecture of a power conditioning system for remote smart sensor networks was investigated and designed. Based on initial analysis of the technical requirements, several power conditioning schemes were reviewed. It was concluded that the most appropriate scheme in this case is realized using current conveyors. Following recommendations as reflected in scientific literature, appropriate circuit topology was synthesized. The current work covers such issues as the technical requirements of energy harvesting power conditioning system, the choice of the electric circuits, and the development of a generalized power conditioning system architecture. Future work will involve the analysis of the dynamic properties of the power conditioning system, the calculation of the energy performance of the power conditioning. The focus will be on validating and refining the current design.

## REFERENCES

[1] H. Eren, Wireless sensors and instruments: networks, design, and applications. Boca Raton: CRC Press, 2005.

[2] Y.K. Tan and S.K. Panda, “Review of energy harvesting technologies for sustainable wireless sensor network,” Sustainable Wireless Sensor Networks, pp.15-43, 2010.

[3] O. S. Jahrom and P. Aarabi, “Distributed signal processing in sensor networks,” In R. Zurawski (ed.), Embedded Systems Handbook, chapter 38, Taylor and Francis, Boca Raton, FL, 2006.

[4] C. P. Chen, C. L. Chuang and J. A. Jiang, "Ecological Monitoring Using Wireless Sensor Networks — Overview, Challenges, and Opportunities," Advancement in Sensing Technology, pp. 1-21, 2013.

[5] C.C. Enz, A. El-Hoiydi, J.D. Decotignie and V. Peiris, “WiseNET: an ultralow-power wireless sensor network solution,”. Computer, vol. 37 no.8, pp.62-70, 2004.

[6] R. Min, M. Bhardwaj, S.H. Cho, E. Shih, A. Sinha, A.Wang and A. Chandrakasan, “Low-power wireless sensor networks,” Proc. IEEE International Conference on VLSI Design, 2001.

[7] M.J. Hamel, S.W. Arms and C.P. Townsend, Remotely powered and remotely interrogated Wireless digital

sensor Telemetry system, United States Patent, 7256695, August 14, 2007.

[8] Q. Huang, C. Lu and S. Mark, "Feasibility Study of Indoor Light Energy Harvesting for Intelligent Building Environment Management," International High Performance Buildings Conference, July, 2010.

[9] S. J. Roundy, P. K. Wright and J. Rabaey, “A Study of Low Level Vibrations as a Power Source for Wireless Sensor Nodes,” Computer Communications, vol. 26, no. 11, pp. 1131–1144, 2003.

[10] G. Despesse, T. Jager, J. Chaillout, J. Leger, A. Vassilev, S. Basrour and B. Chalot, "Fabrication and characterisation of high damping electrostatic micro devices for vibration energy scavenging," Proceedings of Design, Test, Integration and Packaging of MEMS and MOEMS, pp 386-390, 2005.

[11] A. A. Bhaskar, R. Champawat and S. A. Bhaskar, “Current Developments of Energy Scavenging, Converting and Storing in WSNs,” International Journal of Computer Applications, vol. 125, No.7, 2015.

[12] C. Shearwood and R. B. Yates, “Development of an Electromagnetic Microgenerator,” Electronics Letters, vol. 33, no. 22, pp. 1883–1884, 1997.

[13] A. M. Zungeru, L. M. Ang, S. Prabaharan and K. P. Seng, “Radio frequency energy harvesting and management for wireless sensor networks,” Green Mobile Devices and Networks: Energy Optimization and Scavenging Techniques, pp. 341-368, 2012.

[14] L. Langhammer and J. Jerabek. "Precision Full-Wave Rectifiers with Current Active Elements and Current Biasing." International Journal of Advances in Telecommunications, Electrotechnics, Signals and Systems, vol. 2, no.2, pp. 79-83, 2013.

[15] W. Collin and Y. Ting, “Single-Supply Low-Input Voltage Optimized Precision Full-Wave Rectifier Reference Design,” [Online], available: http://www.ti.com/lit/ug/tidu024/tidu024.pdf, accessed: December 29, 2015.

[16] K. K. Singh, G. Srivastava, R. S. Mishra and D. Tiwari, “Current Conveyor: A Novel Active Building Block Prevailing Op-Amp Limitations,” International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol.2, no.2, 2013.

[17] C. Toumazou, F. J. Lidgey and S. Chattong, “High frequency current conveyor precision full-wave rectifier,” Electronics Letters, vol. 30, no. 10, pp. 745-746, 1994.

[18] B. Wilson, and V. Mannama, “Current-mode rectifier with improved precision,” Electronics Letters, vol.31, no. 4, pp. 247-248, 1995.

[19] D. Stiurca, "Truly temperature independent current conveyor precision rectifier," Electronics Letters, vol. 31, no. 16, pp. 1302-1303, 1995.

[20] P. Beg, S. Maheshwari, M. S. Ansari,. and I. A. Khan, "Biphase amplifier based precision rectifiers using current conveyors," Proc. IEEE International Conference on Signal Processing, Computing and Control (ISPCC), 2012.

[21] S. V. Pattalwar1 and A. V. Nimkar, “Comparative study on a low drop-out voltage Regulator,” International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol. 3, no. 1, 2015.

[22] M. El-Nozahi, A. Amer, J. Torres, K. Entesari and E. Sanchez-Sinencio, “High PSR Low Drop-Out Regulator with Feed-Forward Ripple Cancellation Technique,” IEEE Journal of Solid-State Circuits, vol. 45, pp. 565-577, 2010.

[23] J. Nandong, “A Unified Design for Feedback-Feedforward Control System to Improve Regulatory Control Performance,” International Journal of Control Automation and Systems, 2015.

[24] R. V. Yenkar, R. S. Pande and S. S. Limaye, “The Survey of Historical - Technical Development in Current Conveyors and Their Applications,” International Journal of Computer Applications, 2012.

## AUTHOR PROFILES

**Alhassan Mumuni** attended Saint Petersburg State Electrotechnical University from 2004 to 2010. He studied in the Department of Robotics Technology and Automation of Technological Processes and received his BSc. and Msc. in 2008 and 2010, respectively. He is currently a lecturer in the Department of Electrical/Electronics Engineering, Cape Coast Technical University, Cape Coast, Ghana.

**Fuseini Mumuni** is currently a lecturer in the Department of Electrical and Electronics Engineering, University of Mines and Technology, Tarkwa, Ghana. He received his BSc. in 2008 and Msc. in 2010, both from Saint Petersburg State Electrotechnical University.