Powerline Communication System for Controlling Appliances in Ghanaian Homes

Attrams Siaw Prince, Osei-Owusu Alexander, Yankey-Antwi Aaron

***Abstract*— The deployment of PLC systems have evolved rapidly over the years with the advent of soaring research and improvement, huge strides have been attained in this sector. The use of such technology especially in developing countries like Ghana require the design and implementation of basic systems that can form the basis for further improvements and subsequently meet the pace of modern systems and designs. The research is aimed at designing and constructing a power line communications system that will interface with a simple computer system to control the lightning system in a typical Ghanaian home. The system will allow a centralized point for controlling all the lightning systems within the household. This is in an effort to providing easy control of the lightning system in a household. The design and construction of the system is presented, with added interfacing functionalities such as voice recognition, text messaging, keyboard and the use of the internet via a network socket to send appropriate signals to the system's receiver.**

***Index Terms* — PLC (Power Line Communication), FDM (Frequency Division Multiplexing), DTMF (Dual Tone Multi Frequency), Control**

I. INTRODUCTION

Power Line Communication (PLC) is a telecommunication technology that adds intelligence to an electric power line in the form of transporting signals through the power lines. In Ghana, the availability of electricity is almost at every part of the country [1] However, it's not utilized to its full potential. Unlike most developed countries especially in Europe and America, most power lines have a centralized network which can control and analyze load variations, support metering services and provide customers with control capabilities in various parts of where the power grid is connected. All this is made possible by power line communications (PLC) [2].

Power Generation, transmission and distribution are done by utility companies in Ghana; Volta River Authority (VRA), Ghana Grid Company (GRID Co) and the Electricity Company of Ghana (ECG). The Northern Electricity Department (NED) is also responsible for distribution in the Northern regions and some selected parts of the Brong-Ahafo Region of Ghana. Supervisory Control and Data Acquisition (SCADA) a popular application of PLC, is used at the transmission point to the feeders feeding the distribution transformers. However, there is no other technology employed from the transformer end to the customer end and as such, current metering methods prove to be quite difficult and thus a more efficient and flexible metering method may be PLC.

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Attrams Siaw Prince, Ghana Technology University Ghana
Osei-Owusu Alexander, Ghana Technology University Ghana
Yankey-Antwi Aaron, Ghana Technology University Ghana

PLCs offer numerous advantages and its applications such as SCADA and Smart Grid offer the creation of Smart Home Area Networks which allows people in a household have full control over their appliances (Echelon, 2013). PLC applications have a broader effect in many other sectors since the power grid in essence is the backbone of productivity in manufacturing, education, health etc. The deployment of PLC Systems/Technology explores the enormous benefits PLCs have to offer [3]. A concrete example is how power line communication internet systems have become an attractive solution that provides broadband data connections required by high-speed home media applications and triple play services in small offices and homes. Also, with the introduction of advanced modulation schemes such as OFDM (Orthogonal Frequency Division Multiplexing) and VLSI design, data rate throughput has spectacularly increased as high as 100 Mbps. (Megabits per second) (Wicomb,2005 p.80)

II. PROBLEM STATEMENT AND OBJECTIVES

Distribution lines connected to consumers in most Ghanaian homes do not have any technology that can enable Smart Home Area Networks. Due to this, controlling of devices and appliances are limited to remote controls and normal switches unlike other countries like the United States of America, UK, and countries in North America that have home automation and control capabilities due to the applications of PLC. Lamp switches in Ghanaian homes like many other homes are normally in different locations within the household, typically installed in various rooms within the household. Though there are no standardized heights for switches in Ghana, the convention of heights between 1900mm to 1200mm is common in most homes and this poses a big challenge more importantly for the aged, especially those in wheel chairs to conveniently control lightning systems in and around their households. This research is aimed at constructing a power line communication system that will centralize the control of appliances (mainly lights) on a computer with added functionalities such as controlling with voice recognition, a computer's keyboard and the internet using a network socket. The main objective is to design and construct a power line communications system that will interface with a simple computer system to control the lightning system in a typical Ghanaian home. The system will allow a centralized point for controlling all the lightning systems within the household. It is to provide easy control of the lightning system in a household.

III. LITERATURE REVIEW

The underlying structure of PLCs consists of PLC transmitters, couplers and receivers. The techniques that aid the transfer of data over the power line involve coupling, decoupling, modulation, demodulation and noise reduction in PLC systems.

The Power Grid According to the Ministry of Energy of Ghana, the power-line network covers most parts of inhabited areas of Ghana. The energy produced from the generating stations is transmitted to ECG and NED through about 4000 circuit km of 161kV and 69kV and it is distributed to most homes and businesses at 120V and 220V. Since transmission lines (power lines) are of different categories depending on the scale and scope of the network, power line communication systems are also structured based on scale and scope. Furthermore, since the distribution lines connected to the households do not have any form of PLC application running on it; it is necessary to design an independent PLC system to perform the various control and tasks.

PLC Transmitters

Technically, PLC systems do not differ from any other communication system in approach; they all have a source, a source encoder, a coupler circuit and so on. What differentiates them is their channel. The channel determines the rules of engagement; a noisy channel requires a different design approach from a 'quiet' channel. And in the case of a PLC system, its channel is one the most hostile for any signal. The encoding schemes used ensure that data is compressed in order to minimize the amount of bits transmitted over the channel which in turn reduces the BER. (Khan Et.al, 2006)

PLC Coupler Circuit

Bilal et al posit that, one of the most important components of any PLC system is its interface circuit or coupling circuit with the power distribution network. "Due to high voltage, varying impedance, high amplitudes and time dependent disturbances, coupling circuit need to be carefully designed to provide both the specific signal transmission with the appropriate bandwidth, and the safety level required by the applicable domestic or international standard". Power system and communication system operate at two extremes with respect to amplitude and frequency. Power systems operate at very low frequencies with very high power, high current and high voltage levels while communication systems operate at much higher frequencies with very low power, low current and low voltage levels. As such it is important to identify characteristics of the power line and the appropriate coupling techniques to suit the PLC system.

Capacitive Coupling vs. Inductive Coupling

Coupling techniques are dependent on the characteristics of the power line and the parameters chosen for circuit design. Capacitive coupling is normally selected based on the basic capacitive reactance equation below.

$$Xc = \frac{1}{\omega C} \dots\dots\dots\dots\dots\dots (eqn\ 1)$$

Where $\omega = 2\pi f \dots\dots\dots\dots\dots (eqn\ 2)$

This obviously makes it clear that the reactance of the capacitor can be regulated by frequency. The higher the frequency, the lower the reactance and vice-versa. This gives an advantage of selecting signals based on their frequency. However, due its dependence on frequency, it has a high response to Electromagnetic Interference (EMI). Inductive coupling on the other hand uses transformers in its design and this also poses a problem. The coils of the transformers provide a high reactance to the high frequency signals as seen in the basic inductive reactance equation below.

$$X(l) = \omega L \dots\dots\dots\dots\dots\dots (eqn\ 3)$$

The higher the frequency, the higher the inductive reactance and vice-versa therefore the coupling transformer needs to be designed to pass high frequency signals in a PLC system. Bilal et al state that despite the many advantages of inductive coupling, it has the disadvantage of difficult design and low noise immunity. They also add that most designers prefer capacitive coupling to inductive coupling due to that disadvantage.

PLC Channel

The channel is the main path of transmission and reception in any communications system. In the case of PLC systems, it is important to analyze and measure the channel carefully in order to effectively transmit the desired signals with low losses. One of the approaches to analyzing the channel of the PLC system is to model the channel according to its Shannon's capacity and randomly assign the frequency responses using statistical models of notches and peaks. In order to achieve an effective way to obtain the transfer function of the channel, Versolatto et al suggests that the individual transfer functions of each unit should be measured using transmission line theory techniques such that the results will be multiplied in order to get the overall channel transfer function (insertion loss).

Modulation Schemes

The modulator is where digital meets analogue by generating information-carrying signal that can safely be propagated over the 'harsh' and highly noisy channel. The modulator has a set of analogue waveforms at its disposal and maps a certain waveform to a binary digit or a sequence of digits. At the receiver, the demodulator tries to detect which waveform was transmitted, and map the analogue information back to a sequence of bits. PLC systems use modulation schemes depending on the data rates and frequencies. Cypress, a leading PLC systems company summarizes some popular modulations based on data rates.

Table 1 PLC technology classification on the bases of data rate (Courtesy Cypress)

	Low Data Rate	Medium Data Rate	High Data Rate
Data Rate	0-10kbps	10kbps-1Mbps	>1Mbps
Modulation	BPSK, FSK, SFSK, QAM	PSK+OFDM	PSK+OFDM
Standards	IEC 61334, ANSI/EIA 709.1, .2, UPB	PRIME, G3, P1901.2	G.hn, IEEE 1901
Frequency range	Upto 500kHz frequency	Upto 500kHz	In MHz
Applications	Contol and Command	Control and command, Voice	Broadband over powerline, home networking

Implementation of PLC using opt couplers by Surplus

The project implemented a PLC system using SPMC75F2413A, a chip that is designated for motor control application, as the main controller to perform DC inversion of an Air condition over the mains and using an optocoupler technique as its coupler. The Air condition is composed of an outdoor unit and an indoor unit which adopts the SPMC701FM0A as the main controller to configure its logic states. The system operated by three main processes. Firstly, the main controller (SPMC75F2413A) of the outdoor unit, continuously received the control command and state information from the indoor unit, and controlled the outdoor unit, a four-way valve and a compressor accordingly. Secondly, the current state and temperature of outdoor unit was fed back to the indoor unit. Finally, the indoor unit coordinated the entire operation process by considering the state and the temperature of the outdoor unit as well as the returned parameters from the outdoor unit. From the design, it is seen that by using the UART module built in the SPMC75F2413A, the circuit provides a reliable communication loop between the indoor unit and outdoor unit. However, the primary limitation of the circuit lies in the use of resistors as part of the coupler circuit. This is obviously because a resistor in the coupling circuit implies a loss of power, either of the communication signal or the power waveform.

IV. METHODOLOGY

This research looks at deploying a simple PLC system in Ghanaian homes. Due to the fact that low voltage lines reaching customer's end do not have any form of PLC technology currently in place does not limit the main use of PLC systems for basic controlling of appliances in homes. The current state of the system was designed to use capacitive coupling with FDM and DTMF techniques to modulate and demodulate the signals respectively. To effectively control the PLC system, a console on a computer was used as the main interface between the PLC system and the user. The console is able to accept instructions from four various channels, i.e. the computer's keyboard, a network socket, voice signals and SMS. The structure of the PLC has a transmitter which is connected to the power line and the computer, and a receiver which is also connected to the power line and the load/home appliance which in this case were lamps. The means of communicating with the system was embedded in the design of the console to allow a flexible means by which the user could control the home appliance. A GSM modem was also connected to the computer to allow the user to send txt messages to control the appropriate device. The modem has an internal SIM card that allows it to receive and send messages.

V. DESIGN AND SPECIFICATION

The system design relies on important components within the system that ensures the reliable communication from the PLC transmitter to the receiver (load).

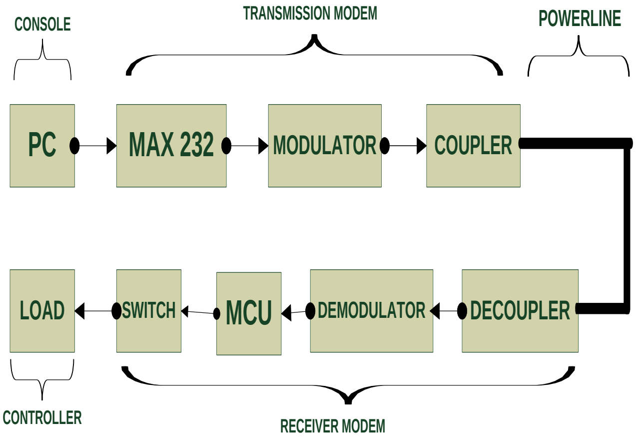

Figure 1 Block Diagram of PLC System

Transmitter Modem

The transmitter modem is the main hub for the digitization of the input signal. It comprises mainly of the modulator which modulates the input signal. The main modulation technique used is the Frequency Shift Keying (FSK). Here, a digital one (1) bit is represented by 50 kHz and a digital zero (0) bit is represented by 0 Hz. The modulated signal is then coupled onto the power line using capacitive coupling. From the review, capacitive coupling offers more resistance to EMI (Electromagnetic Interference) which is very ideal in this case.

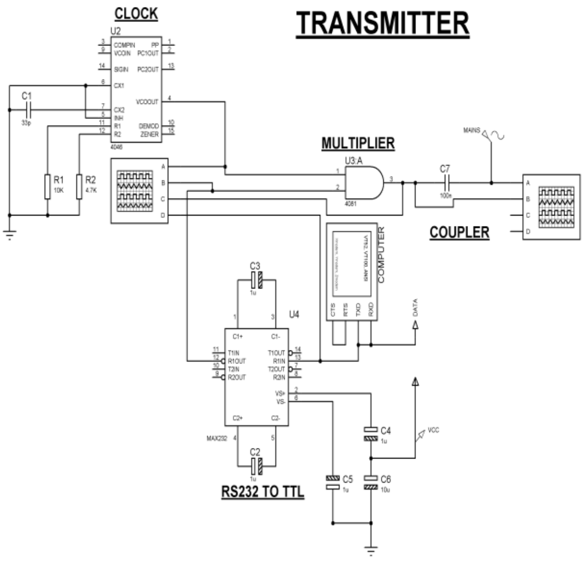

Figure2. Schematic Diagram of PLC transmitter

The MAX 232

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The **MAX 232** is an integrated circuit that converts signals from an RS-232 serial port to signals suitable for use in TTL (Transistor-Transistor Logic) compatible digital logic circuits and back since it is a dual driver/receiver. Here its role in the design circuitry is to carry generated signals from the console with Baud rate of 600Bps (Bytes per second) and convert them to TTL signals suitable for modulation.

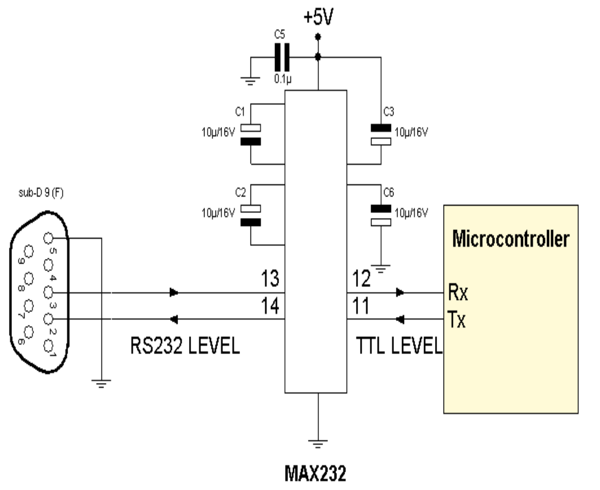

Figure3. The MAX 232

Voltage Controlled Oscillator

In order to generate the carrier frequency a voltage controlled oscillator is used over conventional 555 timers due to its stability and accuracy. The IC 4046 is a phase locked loop chip with a built in VCO that is used in generating its carrier frequencies. This chip was adopted in the design of the system to generate the desired carrier frequency of 50 kHz with a bandwidth of 5 kHz.

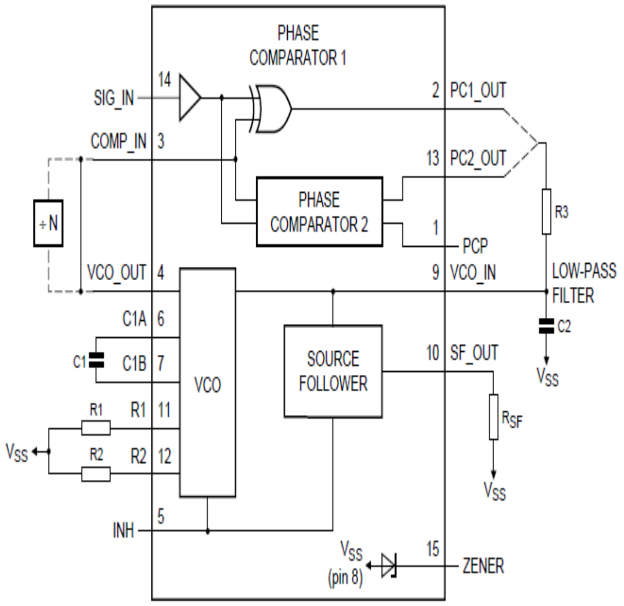

Figure 4. Voltage Controlled Oscillator

In the figure above, the phase locked loop is biased using resistor R1 and R2 with capacitor C1. A close approximation of the centre frequency (f_0) and the bandwidth depends on the values of the components. This was effectively achieved by an equation which helped in the choosing of the various values of the components. For flexibility, R1 was made variable and this helped in the regulation of the bandwidth.

The Switch

The switch is made up of an AND gate depicted by U3:A in Figure 2 which multiplies the pulse signal from the Max 232 and the carrier signal from the VCO to produce the FSK (Frequency Shift Keying) output. Both signals are denoted by pulse 1 and pulse 2 respectively. From Figure 2 again, the carrier signal is modulated by the digital pulses generated from the Max 232.

The Buffer

The role the buffer is to ensure that the signal on the power line is strong enough to be seen on the power line. It is implemented using the same switch since the switch has an operating voltage of 12volts and an output current of about 100mA the output power from the switch is calculated to be about 1.2W which is enough power to be seen on the power line.

The Coupler

The coupler injects the signal or power generated from the buffer unto the power line. The main technique is using capacitive coupling. As stated earlier, capacitive coupling is employed in this system mainly because of its high resistance to Electromagnetic Interference. The main operation of this coupler is its ability to operate as a high pass filter. It basically blocks low frequency signals and allow high frequencies to pass. This in effect means that the low frequency on the power line is blocked from entering into the system whiles high frequency signals from the system is injected unto the power line.

Receiver Modem

The receiver modem comprises of the decoupler, the demodulator, the microcontroller unit, and the switch. The decoupler and the demodulator follow the same principle as in the transmitter. The underlining difference is centered at the microcontroller unit which interprets the signal received to carry out the desired function. As indicated in the system block diagram, the switch is directly connected to the microcontroller which is the controller of the load. The loads in this system are light bulbs connected to various terminals. In other system applications, different devices can be connected to these terminals and will be controlled efficiently by this system.

Decoupler

The function of the decoupler is synonymous to that of the coupler. Here, the reverse is done to retrieve the desired signal from the power line. At the receiving end, the capacitor blocks all low frequencies which are the AC signals with 50 Hz and allows the desired signal which is of a higher frequency (50 kHz) to pass.

Dual-Tone Multi-Frequency (DTMF) Decoder

The DTMF Decoder is used to listen for the frequencies produced from the decoupler. The expected output from the decoupler is 50 kHz which is the desired frequency needed to execute controls in this system. In this system, the NE567 chip is used to listen for the desired signals and raise a flag at low signals. In essence, the DTMF decoder is also a key component that helps in the retrieval of the desired signals.

Controller

The controller is the heart of the system. This is because it executes a chunk of the functions in the system. It interprets the signal, selects the appropriate device, and performs the necessary controls. After the DTMF Decoder interprets the signal, the controller also interprets the signal to perform the right control function. Functions such as the selection of the device, and turning on and off of the device are executed by the controller. Figure 5 shows a schematic diagram of the controller.

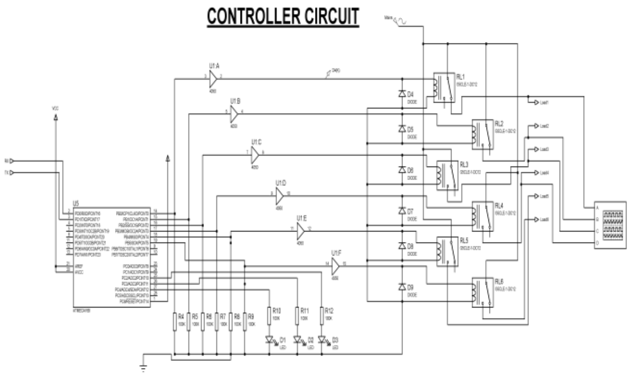

Figure 5. Schematic Diagram of Controller Circuit

ATMEL 168 Microcontroller

The microcontroller is an embedded component in the controller which performs all the logical functions required in the system. It receives instructions from the controller and executes them accordingly. The main microcontroller chip used in this system is the ATMEL 168. This chip is preferred because of its dedicated bus system for the RS232. It was also selected due to the programmability of all of its pins except the I/O pins. Its clocking efficiency forms part of its hallmark.

Buffer Array

The buffer arrays are used in this system to add electrical strength to power the relays. During the design of this system, the power from the microcontroller was not enough to turn on the relays. Hence the buffer array was introduced to raise the power strength and also to shield the microcontroller from back EMF (Electromagnetic Force). The back EMF is undesirable since it can easily destroy the microcontroller.

Relay Board

The relay board simply turns the load on or off. It is connected in series with the load and it does its necessary function.

VI. ANALYSIS

The Transmitter

The main components of the transmitter modem that were analyzed were the console and the modulator. The baseband signals were generated from the console and the modulator is where the baseband signal was superimposed on the carrier signa

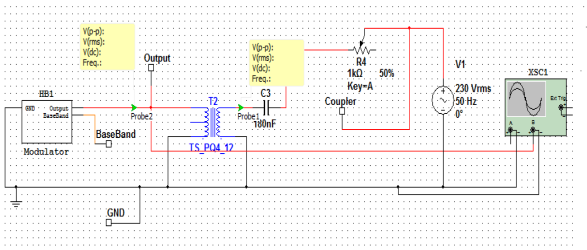

Figure 6. The transmitter Circuit on the Proteus Software

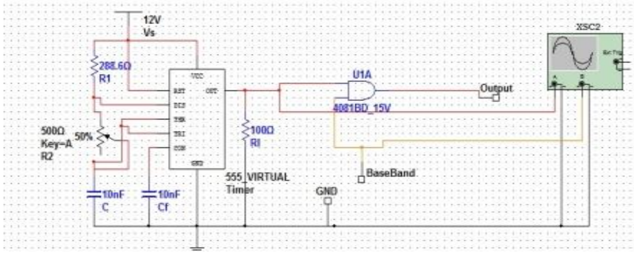

Figure 7. The Modulator on the Proteus Software

The graph results shown are the output of the transmitter. The green represents the clock from the system's voltage controlled oscillator. The red denotes the baseband signal from the console installed on the computer whiles the blue denotes the multiplier. The graph analyzes and shows the modulation between the clock and the baseband signal. The result of the modulation gives the output response denoted in blue. It can be seen that there is always an output response when there is an intersection between the clock signal and the baseband signal.

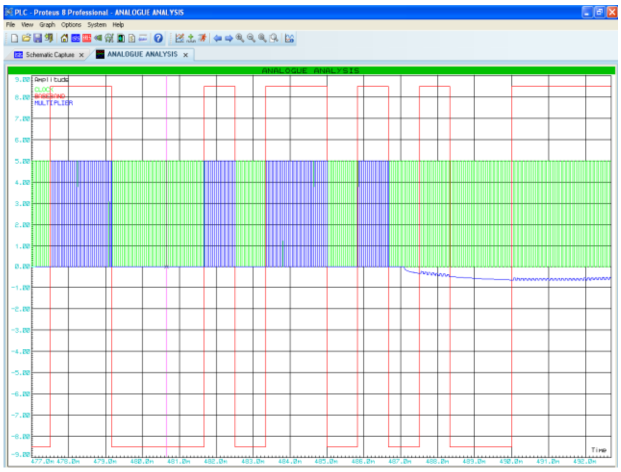

Figure 8. Output waveform of the transmitter on the Proteus Software

Power Line Results and Analysis

From the graph below, the output wave form from the transistor is shown in blue. The pure AC signal from the mains is also denoted by the green waveform. And the desired signal generated from the console and the max 232 is also denoted by red. The thick blue waveform shows that the desired signal has been coupled efficiently on the power line. Since the baseband signal has been modulated unto the AC signal from the mains.

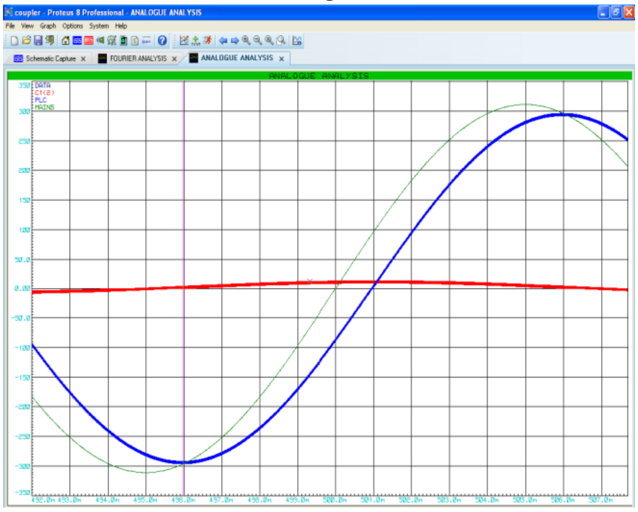

Figure 9. Output graph of the signal on the Power line

A time domain analysis is shown in the graph below. An enlarged view shows the square wave pulses generated by the baseband signal and the sin wave of the AC signal from the mains. As clearly seen, the output waveform takes that of the baseband signal's waveform and as such shows the presence of the baseband signal on the power line.

Figure 10. Time Domain Analysis of Modulated Signal on the Power line

In frequency domain, the modulated signal shows a peak of 50k and other unwanted signals present on the power line.

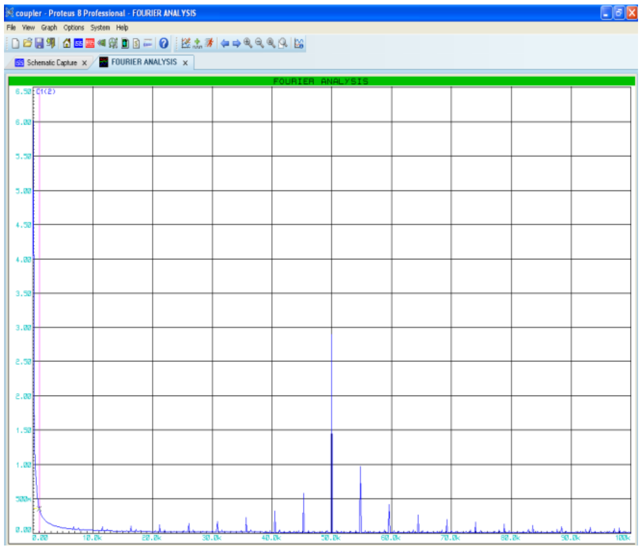

Figure 11. Frequency Domain Analysis of Modulated Signal on the Power line

VII. CONCLUSION AND RECOMMENDATION

Conclusion

In conclusion, the desired objectives to design and construct a power line communication system in a typical Ghanaian home system was met. The system was able to communicate effectively and efficiently over a power line that did not have any PLC technology running on it. Its main purpose to control devices in a home area network and help the aged or persons with disabilities to control these devices has also been met by accepting input controls via a keyboard, via speech, via text messages and via the internet (network socket).

Limitations

The system is designed to operate in a home area network and might not travel along far distances. The maximum distance per the tests made on the system shows a distance of about 900m to 1km. Due to the channel properties of the power line, signals may be lost if there is any form of shocks on the power line although this situation may be in rare cases.

Equipment that requires high voltages or power cannot be used with the PLC system simultaneously since it may introduce a high noise levels on the power line.

Recommendations

Since the system is designed to operate within short distances, the receiver modems should be connected within the limits of the system for optimal system efficiency.

Advanced circuitry and system can increase distance significantly and add more control features. Future system models should employ higher data rates and efficient modulation schemes.

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AUTHORS PROFILE

Prince Siaw Attrams (BSc.) is a young graduate from the Ghana Technology University College who majored in Telecommunications Engineering. Prince has a keen interest in Telecommunications due to the dynamism of the field itself. He is also keen on international relations and diplomacy which has made him an avid Model United Nations participant. He believes it increases his passion to learn each and every day. Prince strongly believes in higher learning and has tied special interest to academia, and setting academic pursuits as his highest priority. Prince Graduated with first class honors, and was selected as the class valedictorian of the graduating class of 2013. He was also adjudged the overall best graduating student having come top of his class. Prince believes this research paper is a stepping stone to higher achievements. His greatest gratitude goes to co both co authors who made this a great work. Prince is currently a research assistant at the Ghana Technology University College and hopes to continue with major research in Telecommunication Engineering.

Alexander Osei-Owusu (BSc, MSc) is a Telecommunications management expert heavily involved in telecommunications research. Alex’s interests are mainly in the areas of telecommunication’s policy formulation and research. He is currently the Research Coordinator at the Graduate School at Ghana Technology University College (GTUC) where he also serves as a supervisor of graduate master’s thesis. Alex is an exceptional scholar. He was adjudged the overall best student and was also presented with the best thesis award during his MSc studies at GTUC where he successfully completed with distinction. Alex has conducted extensive research work in the area of Information and Communications Technology (ICT). Some of his research work has been accepted at international conferences such as the Global Development Network (GDN) conference in Accra, Ghana; the 7th International Research Conference organized by Koforidua Polytechnic in Koforidua, Ghana and the African Finance and Economics Association (AFEA) conference in Boston in March 2014.His recent Journals were on ―Investigating The Applicability of Dynamic Pricing To Ghana’s Telecom Infrastructure Market and Investing the financial Implications of Power Harmonics. Alex Osei-Owusu is currently pursuing a PhD in ICT, and is highly motivated to contribute his quota to the world and his country through cutting edge research.

Yankey-Antwi Aaron (BSc.) As a youngstar, Aaron Yankey-Antwi was indulging in electromechanics for pleasure and practice. He designed and constructed gadgets such as power inverters, audio amplifiers, intrusion detectors, just to mention a few. He obtained his Bachelor of Science degree in Telecommunications Engineering at Ghana Telecommunications University College (GTUC), were he honed his skills by partially and fully assisting is seniors in their final year projects. As an undergraduate, He was critical to the success of the illustrious CanSat project that was launched on the 15th of May 2013 by All Nations University College.This project was the first of its kind in Ghana and the Subsaharan Africa as a whole and it has attracted various National and International awards such as Waves International Award and the Dasebra Award of Excellence, to its credit. He is the co-author of paper; "The prospect of monitoring and detecting oil spillage in Ghana using Synthetic Aperture Radar (SAR)" published in 2014 by ANUJAT;a reputable international Journal. He currently is the Head of Operations at the All Nations University Colleges' Intelligent Space Systems Laboratory, where the first Amateur ground station in Ghana is being built. His hobbies are programming and playing his guitar.