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# 2-LIB: An Efficient 2-Level-Inversion Coding Scheme for Digital Data Transmission over Bandlimited Channels

Dr. Olakanmi Oladayo
Senior Lecturer, Department of Electrical and Electronic Engineering,
University of Ibadan, Nigeria Department of Author, Affiliation, Country
Email: olarad4u@yahoo.com, olakanmi.oladayo@ui.edu.ng

Dr. Nsionu Ifeanyi
Chief Lecturer, Department of Computer Engineering, Federal Polytechnic Oko, Nigeria.
Email: ifeanyinsionu@gmail.com

**Abstract:** *A low bandwidth required coding scheme is needed for an effective digital data transmission over a bandlimited channels. Most of the existing coding schemes have some performance issues such as lack of synchronisation feature, high bandwidth requirement and considerable DC component. These make them imperfect choice especially for digital data transmission between heterogeneous devices over bandlimited channels. In this paper, a new coding scheme called 2-LIB is proposed to replace Non Return to Zero (NRZ) and AMI schemes used in RS232C/EIA-232 and 100-base-T Ethernet signaling respectively. The Power Spectral Density (PSD) of 2-LIB was derived, analysed and compared with that of some of the existing schemes. The results showed that 2-LIB has the best performance in terms of bandwidth requirement, strong synchronisation feature, and no DC component with minimal spectral content. The major strength of the scheme is that it does not only maintain all the good properties of both NRZ and Manchester but consumes the lowest bandwidth.*

**Keyword:** *Power spectral Density; Coding; DC component; Data Communication.*

## 1. INTRODUCTION

Line coding, as shown in Figure 1, is the mapping of the bit stream onto the physical signals. It is one of the major functions of the physical layer [1]. A line coding format consists of a formal definition of the scheme that specifies how a string of binary digits is converted to a line code waveform. There are two major classes of binary line codes: level codes and transition codes. Level codes carry information in their voltage level, which may be high or low for a full bit period or part of the bit period. Level codes are usually instantaneous since they typically encode a binary digit into a distinct waveform, independent of any past binary data. Transition codes carry information in the change in level appearing in the line code waveform. Transition codes may be instantaneous, but they generally have memory, using past binary data to dictate the present waveform. Line coding formats are classified according to the polarity of the voltage levels used to represent the data. If only one polarity of voltage level is used, i.e., positive or negative (in addition to the zero level) then it is called unipolar signaling. If both positive and negative voltage levels are used, with or without a zero voltage level, then it is called polar signaling. This uses two voltage levels, a positive and negative and specifically helps in reducing the DC component problem as against the unipolar encoding.

There are different types of polar encoding, examples are Non-Return to Zero (NRZ), Return to Zero (RZ), Manchester, and Differential Manchester. However, most of these schemes have performance limitations such as DC component, high bandwidth requirement, no synchronisation feature within the scheme which make them unsuitable for some kind of data sequence or data channels. Consequence to these there is need for a coding scheme which will not only effectively represent binary data on channel but simple to implement, with no dc component, low bandwidth, self-synchronization feature against a stream of zeros and ones, and minimize spectral content.

The rest of the paper is organized as follows; Section 2 presents the reviews on the related research works on the existing coding schemes. In Section 3, the principle of the propose scheme is discussed and its PSD is analysed. In Section 4, performance analy-

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sis is done based on the above mentioned performance metrics. Section 5 is the discussion and conclusion.

## 2. RELATED WORKS

Several research efforts had gone into the development of new line coding schemes with a focus on how to overcome some of the performance bottlenecks in the fundamental line codes shown in Table 1. A few research efforts had produced several versions of the fundamental line coding schemes which tried to correct some of the limitation of the fundamental schemes. For example, in [1] eleven ternary line codes were analysed and compared in term of their run length and digital sum variation constraints on the efficiency. It was observed that for the selected codes, the effect of run length constraints on the efficiency was small and the digital sum variation constraints have a larger impact, resulting in a theoretical maximum efficiency of 63% for a digital sum variation of 1, saturating to 95% theoretical maximum efficiency for digital sum variation values of 5 and higher. It was concluded that the more constrained a scheme is, the less efficient it is. Also authors in [2] developed the FC, a new line coding technique by introducing the concepts of fragmental, fragmentation degree, fragmental end, and SWC, which could effectively decrease CITJ in WDM soliton transmission systems. Their simulation results showed that FC was a quite promising technique for DMF systems and due to the simple block code structure of FC, it could be implemented with simple hardware structure and low cost.

Authors in [3] presented permutation encoded OFDM as an alternative modulation scheme for narrow-band power-line communication. Their results showed that it would perform much better in the presence of carrier frequency offsets. Another coding scheme was proposed for two-tone image contours in [4]. The basic idea was to detect digital line segments on the contour and code them using fixed or variablelength codewords; their work deals mainly with fixedlength codewords. It was demonstrated that the conventional contour run length coding by Freeman's chain code was a special case of this scheme. The data compressibility of the scheme was studied and the test results on several contours are presented. The results show that the present scheme was superior to the conventional schemes. A novel slope line code for data transmission and storage on digital communication systems was also proposed in [5]. This scheme operated on the principle of slope coding. The slope encoder transmits alternative slopes (stair-step-like pulses) for the transmission of the 1s and 0s of the input binary data. The decoder detects the received signal using correlative slope technique in order to extract the transmitted binary 1s and 0s from the incoming symbols.

Another line coding scheme was developed in [6] multilevel NRZ coding technique for the transmission of digital signals. The multilevel technique removes certain problems associated with Bipolar and Manchester coding techniques. This multilevel technique utilizes different dc levels for representing a 0 and 1 with an NRZ method. Vivek in [7] described the implementation of various line coding schemes using VHDL on Xilinx Spartans-6 XC6SLX45 FPGA platform for the purpose of security, area optimization and efficient digital communication in varying channel environment. The line encoding schemes used are Unipolar RZ and NRZ, Polar RZ and NRZ, AMI and Manchester coding and Pseudoternary encoding, Coded Mark Inversion format. Select pin impinged on the chip enables the users to select any one of the line encoding technique according to their requirement. The modelling and simulation of various line codes were implemented on Xilinx design tools and Hardware abstraction completed on Spartan-6 FPGA.

In [8], MB810 code, a binary block code, was introduced. It encodes each 8 data bits into 10 line bits as 8B10B does, however with reduced bandwidth. Alexandru in [9] investigated the spectral properties of MB810 code, and determined an explicit formula for the coding factor and power spectral density for the equiprobable case (p = 1, − p = 0.5), where p is the probability of a mark at the coder input. It was observed that no closed formula can be obtained for a generic value of p due to the complexity of the encoding circuit.

Apart from all these, some works and reviews were done in [10] which shows needs and means of improving the existing codes to meet up with performance need of data communication. Authors in [10] elucidate explicit techniques for detection of safety errors, such as depth-first search, directed search, random walk, and bitstate hashing. They concluded that a method may be insufficient to detect errors in data communication, and proposed the use of a set of complementary techniques. Meanwhile, authors in [11] comparatively review recent works on some techniques of optical receiver communication which is used in optical fiber communication. A system in which encoded data are transmitted over a serial link was invented in [12].

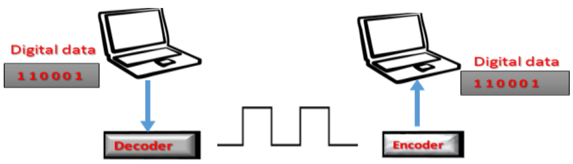


*Figure 1 Block diagram of a digital data communication system*

This invention includes transmitters which can be used to encode data for transmission over a serial link, receivers for receiving such data, and methods for sending encoded data over a serial link. According to

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the invention, the source data to be transmitted are encoded using a subset of a full set of code words. The subset consists of preferred code words. Disjoint clusters of code words in the full set are predetermined. Each cluster includes one or more of the preferred words, and optionally also at least one additional code word that is similar to a preferred word of the cluster in the sense that it is likely to be generated as a result of probable bit errors in transmission, or transmission and decoding, of such preferred word. Also, authors in [13] presented the principle and design concept of MB810 code for 10-Gigabit Ethernet (10GbE). They reviewed all the existing alternatives codes for the 10GbE line coding and proposed a new line code, MB810 with no DC component and falls within Nyquist band, for 10GbE.

## 3. DESIGN PRINCIPLE OF 2-LIB LINE CODE

In this section we described the principle of 2-LIB, a level and transition coded scheme. It uses two polarities and amplitude magnitudes to represent bit 0 and 1. That is, binary 1 is represented by a full amplitude magnitude while binary 0 is represented by a half amplitude magnitude. 2-LIB swings the polarity of the amplitude magnitude of the next bit based on the polarity of the previous bit. Bit 1 forces a high-level amplitude magnitude $V$ or $-V$ while bit 0 forces the either a low amplitude of magnitude $V/2$ or $V/2$. That is, a half negative or a half positive amplitude level is used to represent bit 0 and a full negative or positive amplitude level is used to represent bit 1. The polarity of the next pulses amplitude is the inverse of the polarity of the previous pulse. With this swinging, a transition is guaranteed between every two consecutive bits.

2-LIB uses this transition as timing information which provides a good clock recovery for the receiver. Apart from this, the swinging introduces a 2-bit identification feature which can be used by the receiver to decode 2-bit at once. That is, receiver interprets 2-bit stream as 01 for any transition from low magnitude amplitude to high magnitude amplitude ($|v/2|,|v|$), 2-bit stream as 10 for any transition from high magnitude amplitude to low magnitude amplitude ($|v|,|v/2|$), 2-bit stream as 11 for any transition from high magnitude amplitude to high magnitude amplitude ($|v|,|v|$), and 2-bit stream as 00 for any transition from low magnitude amplitude to low magnitude amplitude ($|v/2|,|v/2|$). This means that the amplitude changing from positive to negative or vice versa not only provides perfect clock recovery, but also increases the bits identification rate at the receiver side. Unlike other line code where bit identification will be performed at the rate of a bit, the 2-LIB allows receiver to use the type of amplitude swing to identify two consecutive bits at a time, therefore, increasing the receiver speed which increases the communication speed if the sender also adjusted accordingly.

Stem waveforms for bit stream 0100001110 of 2-LIB and some other existing codes are shown in Table II. From the 2-LIB waveform, when the sender sends a sequence of bits 01000011110, in the transmitted data signal there will be a transition within the two scaled voltage polarities positive and negative regions. The order of polarity swinging depends on the polarity of the previous bit. This clearly puts 2-LIB above some bipolar schemes because it only uses two polarities (positive and negative) unlike bipolar RZ which uses three voltage values, i.e. positive, negativeand zero (0). From these waveforms, it can be partly concluded that 2-LIB code facilitates synchronisation, eliminates DC component, and minimize transmission hardware. However, the working principle cannot truly show whether it exhibits DC component, minimum spectral content, and efficient bandwidth. Therefore to analyse the performance of 2-LIB we need to consider its Power Spectra Density (PSD) which shows the distribution of the signal power against the frequency. In the next section, an analytical PSD of 2-LIB PSD is generated using a stochastic signal as shown in the next section.

TABLE I SUMMARY OF STRENGTHS AND WEAKNESS OF DIFFERENT SCHEMES

| Scheme | Timing | DC Value | Bandwidth |
|---|---|---|---|
| Bipolar NRZ | No Timing | No DC component | Low Bandwidth |
| Unipolar NRZ | No Timing | High DC component | Low Bandwidth |
| Manchester | Timing Information | No DC component | High Bandwidth |
| RZ | Timing Information | No DC component | High Bandwidth |

### 3.1 Analytical Estimation of Power Spectral Density of 2-LIB Code

2-LIB line coding pulses train y(t) constructed from an information signal x(t) which is repeated at an interval of T with energy strength $a_k$can be represented as:

$$y(t) = \sum[akx(t - kT)] \quad (1)$$

The Power Spectral Density $S_y(\omega)$ of the pulse train deterministic signal y(t) is then:

$$S_y(\omega) = \frac{1}{T}(R_0 + 2\sum_{n=1}^{\infty} R_n \cos n\omega T \quad (2)$$

where $S_x(\omega)$ is the autocorrelation of signal x(t) and is:

$$S_x(\omega) = \frac{1}{T}(R_0 + 2\sum_{n=1}^{\infty} R_n \cos n\omega T \quad (3)$$

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$$S_y(\omega) = \frac{|F|(\omega)|^2|}{T}(R_0 + 2\sum_{n=1}^{\infty} R_n \cos n\omega T \qquad (4)$$

since,

$$F(\omega) = \frac{T \sin(\frac{\omega T}{2})}{\frac{\omega T}{2}} = \frac{T \sin(\frac{2\Pi f T}{2})}{\frac{2\Pi f T}{2}} \qquad (5)$$

Therefore

$$S_y(\omega) = \frac{\left|\left|\frac{T \sin(\frac{2\Pi f T}{2})}{\frac{2\Pi f T}{2}}\right|^2\right|}{T}(R_0 + 2\sum_{n=1}^{\infty} R_n \cos n\omega T \qquad (6)$$

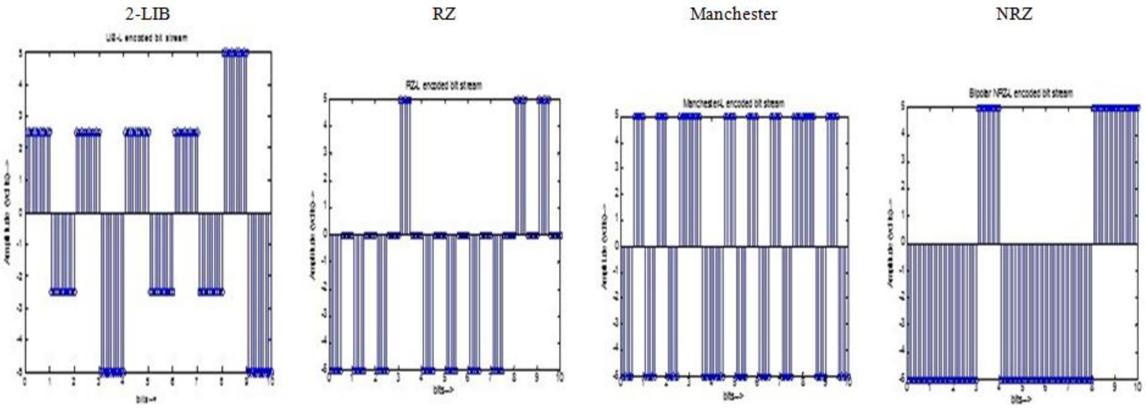
The PSD of any line coding schemes can be obtained using the equation 7 by generating the $R_n$ with frequency $f$. In 2-LIB, as earlier stated, binary 1 is transmitted by a pulse $v(t)$ or $-v(t)$ while binary 0 is transmitted by pulse $v(t)/2$ or $-v(t)/2$. Assuming that in 2-LIB, the pulse strength $a_k$ for bit 1 or 0 may either be one of the following: $a_k = 1$ or $-1$ or 0.5 or $-0.5$.

$$R_n = \lim_{n\to\infty} a_k a_{k+n}$$

when $n = 0$

$$R_0 = \frac{1}{N}\lim_{n\to\infty} a_k{}^2 P_k$$

TABLE II ENCODED “0001000011” WAVEFORMS FOR 2-LIB, RZ, MANCHESTER AND NRZ



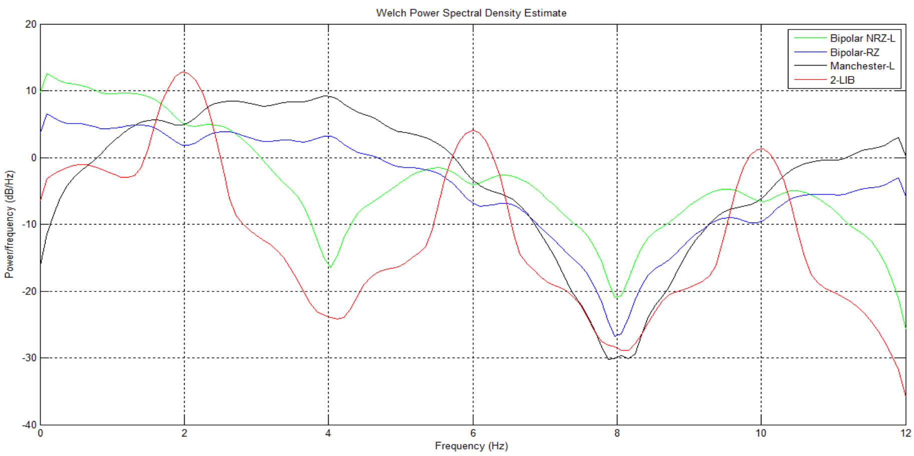




*Figure 2 The Power Spectra Density of 2-LIB, RZ, NRZ and ManchesterSchemes*

$$R_0 = \frac{1}{N}\lim_{n\to\infty} a_k{}^2 P_k$$

$$= \lim_{n\to\infty} \frac{1}{N}\left[\frac{1}{4}\frac{N}{2} + (-1) + \frac{N}{2}\right] \approx \frac{-5}{8} \qquad (7)$$

when $n \geq 1$ and $P_k$ is the probability of the bit occurrence in the data.

$$R_{\geq} = \frac{1}{N}\lim_{n\to\infty} a_k^2 P_k$$

$$= \lim_{n\to\infty} \frac{N}{4}\left[\frac{-1}{4} + \frac{N}{2}.\frac{-1}{2} + \frac{N}{4}(-1)\right]$$

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$$R_{\geq} = \frac{-9N}{16}\frac{1}{N} = \frac{-9}{16} \quad (8)$$

Using $R_0$ and $R_{\geq 1}$ in equation 3

$$S_x(\omega) = \frac{1}{T}\left(\frac{-5}{8} + 2\left(\frac{-9}{16}\cos\omega T\right)\right)$$

So, the PSD of 2-LIB line code is:

$$S_y(\omega) = \left[\frac{-3}{8T}(1 + 3\cos\omega T)\right]\left[\left|T sinc\left(\frac{\omega T}{2}\right)\right|\right] \quad (9)$$

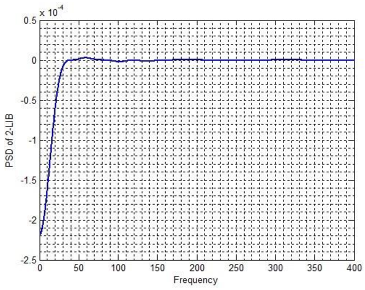
The analytical model of 2-LIB PSD was used to determine the amount of DC components and the bandwidth of 2-LIB code. Although, it is a rough estimate, Figure 2 shows the DC value of 2-LIB obtained at frequency 0Hz, is -0.00175db/Hz which is a negligible DC component. This indicated that 2-LIB code can pass through an AC coupled channel. Also, Table III shows the bandwidth of 2-LIB as 2T (at T=10).

## 4. PERFORMANCE CHARACTERISTICS OF 2-LIB CODE

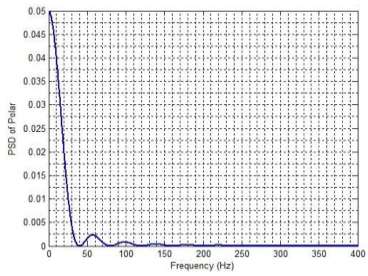
The major performance issues in line coding techniques are the presence of DC component in the coded signal, bandwidth requirement, minimize spectral content, and the inability of the line code to provide self-synchronisation features for the receiver to determine the end of a bit, and what pulses represented in case of stream of 0s or 1s. To complement the analytical results obtained in the previous section, the performance analysis of 2-LIB was done by developing a Matlab emulator for 2-LIB, NRZ, RZ, and Manchester line codes in order to show that the proposed 2-LIB is the best in terms of all the performance metrics mentioned earlier. The emulator was subjected to a randomly generated data stream ”0001000011” to obtain the NRZ, RZ, Manchester, and 2LIB line codes y(t) as shown in Table II and each was used to generate the corresponding PSD and average power of the scheme as shown in Figure 2-3.

TABLE III ANALYTICAL ESTIMATE OF 2-LIB DC COMPONENT AND BANDWIDTH

2-LIB




Polar




Bipolar

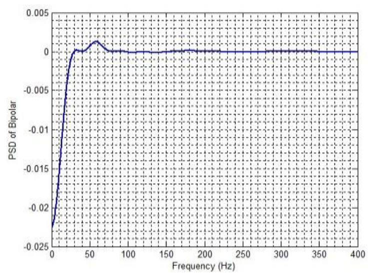



TABLE IV COMPARISON OF STRENGTHS AND WEAKNESS OF 2-LIB WITH OTHER EXISTING POPULAR SCHEMES

| Scheme | Timing | DC Value | Bandwidth | Spectra density |
|---|---|---|---|---|
| Bipolar NRZ-L | No Timing Information | High DC component | Lower Bandwidth | High spectra density |
| Manchester-L | Timing Information | No DC component | High bandwidth requirement | High spectra density |
| Bipolar RZ | Timing Information | Low DC component | High bandwidth requirement | Lowest Spectra density |
| 2-LIB | Timing Information | No DC component | Lowest bandwidth requirement | Lower Spectra density |

### 4.1 DC Component

The obtained PSD as shown in Figure 2 shows that 2-LIB, Bipolar RZ, Bipolar NRZ-L, and Manchester-L have DC values of -4.8db/Hz, 5db/Hz,10db/Hz, and -10db/Hz respectively. This indicates the DC component of the line codes as their frequency go to 0Hz. These show that 2-LIB and Manchester have negligible DC component, meaning that their signals can pass through any channel whether such channel is transformer coupled or not with no distortion on the received signal. With this, it can be concluded that out of all the considered line codes only 2-LIB and Manchester have better performance for a transformer coupled channels, others will suffer DC wander if their signals are passed through such channels.

### 4.2 Bandwidth

Another major performance issue considered in the evaluation is the bandwidth of the line codes. Digital signals need band limitless channels due to infinite

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frequency components in them. However, there is no band limitless channel even the low pass channels have their bandwidth from 0-f Hz. Therefore, line codes for digital data must be bandwidth efficient in order not to aggravate the bandwidth veracity of the digital signals. From the results shown in Table III, 2-LIB has the lowest bandwidth follow by Bipolar NRZ. Manchester and Bipolar RZ have the worst bandwidth.

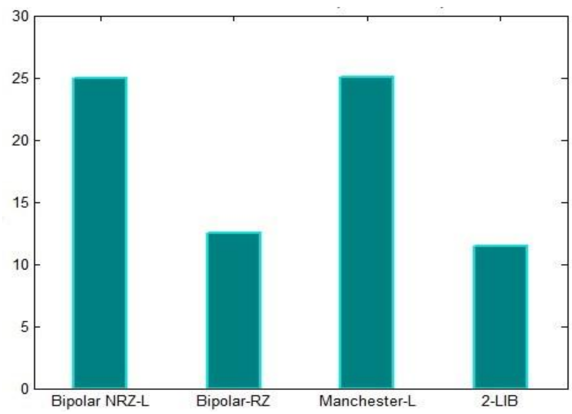


*Figure. 4 Average spectra content analysis for different Schemes*

### 4.3 Average Spectra Power

An efficient line code should have a minimal spectral content. Figure 3 shows the average spectral power in each of the line codes. 2-LIB and bipolar RZ have minimal spectral density. The performances of all these line codes are summarised in Table IV. It suffices to say that 2-LIB line code is perfect in terms of all the considered performance metrics.

## 5. DISCUSSION AND CONCLUSIONS

In this paper, 2-LIB, a simple but efficient line code was developed for digital data communication over a band limitedchannel. The performance evaluation of 2-LIB was carried out using the analytical estimation and simulation results of the PSD obtained for the 2-LIB, RZ, NRZ, and Manchester line codes in order to determine the most efficient line code. The results showed that 2-LIB has the best performance metrics;the lowest bandwidth requirement, very good error detection and correction scheme, and no dc component because the waveform has a zero dc value for any form of a data sequence. Also, it has a 2-bit identifying capability which increases receivers bits identifying rate, and that a long string of 1s or 0s could never result in loss of synchronization since there are transitions during the string duration. The performances of some of the existing line codes and 2-LIB are summarized in Table IV. This shows that 2-LIB is the most efficient line code of all the considered codes, and its use leads to improve data communication.

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## Authors Biography

**Oladayo O. Olakanmi,** is a Senior Lecturer in the Department of Electrical and Electronic Engineering in University of Ibadan. He completed his B.Tech in Computer Engineering at Ladoke Akintola University of Technology, Ogbomoso, M.Sc. in Computer Science and Ph.D. in Computer Engineering at University of Ibadan. His research

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interests are security and privacy, embedded systems, distributed and parallel computing.

**Nsionu Ifeanyi,** Innocentis currently a Chief Lecturer in the Department of Computer Engineering, Federal Polytechnic Oko. He obtained Ph.D. Degree from Enugu State University of Science and Technology. His area of specialization is Telecommunication Engineering. His keen interest is in the area of Adaptive Antenna Array Systems for effective wireless communication networks.

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