DETERMINATION OF SELF/MUTUAL IMPEDANCE AND VOLTAGE DISTRIBUTIONS OF 8dBi MODIFIED DRIVEN ARRAY OF DIPOLES ANTENNA AT UHF/L BAND USING HYBRID FREQUENCY DOMAIN MOMENT METHOD

Alade Olusope Michael[1*], Akande Stephen Funso[2] and Amalu Paul Chigbo[2]

1. Department of Pure and Applied Physics, Ladoke Akintola University of Technology, P.M.B.4000, Ogbomoso, Oyo State, Nigeria. E-mail: aladey2008@yahoo.com
2. Department of Physical Sciences, Ajayi Crowther University, P.M.B. 1066, Oyo, Oyo State, Nigeria. E-mail: akandejos2006@yahoo.com

ABSTRACT

The analyses of self and mutual impedances and voltage distributions of 8dBi Modified Driven Array of Dipoles Antenna at UHF/L (850 – 1150MHz) band using hybrid frequency domain moment method have been presented in this paper. The results of the analyses indicated that the currents distributions lead the voltages distributions in the proposed antenna, and the antenna has the ability to dissipate little or no energy loss as heat, all the energy received by the antenna will be expended as radiation resistance. The antenna's voltages distributions reached the maximum peak values at 1000MHz and 1150MHz resonant frequencies. The analyses also confirmed the supreme performance of the dipole antenna array as compare to the single element dipole antenna in agreement with the previous work by other scientists and engineers. Here, the peak values (maximum of 80±0.1mV and minimum of 70±0.1mV) reached by the voltages distributions of the proposed antenna array are much greater than that of the individual dipole element of the antenna (maximum of 13±0.1mV and minimum of 6.5±0.1mV) at the same resonant frequencies of 1000MHz and 1150MHz. The computed Voltage Standing Wave Ratio (VSWR) is ~1.0 at the frequency band of consideration, and the bandwidth is ±10% of the resonant frequency which doubles ±5% of the individual dipole element of the proposed antenna array at the same resonant frequency.

Keywords: self impedance, mutual impedance, voltage distribution, antenna array, hybrid moment method.

1. INTRODUCTION

The knowledge of self and mutual impedances, current and voltage distributions of array antennas are very important information required to determine accurately the far field radiation patterns, radiation resistance, ohmic losses, gain, VSWR and bandwidth of the antenna array (Kraus et al, 2002; Kun-Chou and Tah-Hsiung, 2005). It is because the presence of another antenna element is an obstacle to other element in the antenna array, and this could alter the current distribution, the field radiated and in turns the self and mutual impedances of the elements (FEKO, 2007; Tian *et al*, 2007). Hence, the antenna array performance depends on the self and mutual interactions of the elements of the array. The experimental measurements of mutual impedances, currents and voltage distributions of antenna arrays are very cumbersome and costly (Vishal et al, 2000; Loredo, 2009). In fact, the experimental and theoretical computational analyses of self and mutual impedances of unequal length and unequal spacing not staggered (linear) antenna arrays are very scarce in the literatures. In this paper, hybrid moment method (HMM) frequency domain is used to calculate the self/mutual impedances and voltages distributions of 8dBi Modified Driven Array of Dipoles Antenna (MDADA) operating at 850 – 1150MHz Band, previously proposed by Alade and Akande (2010). MDADA is a 4-element non-uniform length and non-uniform spacing linear antenna array configuration.

Moment method (MM) is a numerical electromagnetic code (NEC) which has remained a useful computational tool by many scientists for the electrostatic and magnetostatic analyses of antennas' parameters: radiation pattern, polarization pattern, field distribution, radiation resistance, input resistance, (driving-point impedance), self resistance, mutual impedance, VSWR and gain in the field intensity (Kraus et al, 2002; 2004; Balanis, 2005; Jiang et al, 2006; Vasylchenko et al, 2009). However, most applications of MM are found in the single antenna, uniform length and uniform spacing antenna array configurations, the applications of MM in the non-uniform length and non-uniform spacing not staggered array antenna configurations are not common in the literatures.

Moment method numerical electromagnetic code (MMNEC) for a particular array antenna at a specified resonant frequency involved a matrix equation [Z][I] = [V], relating the impedances matrix [Z] of the antenna geometrical configuration, the excitation voltages matrix [V] applied to the antenna (either from transmission lines connected to the antenna or plane waves incident on the antenna), and the individual element currents matrix [I] (Kraus, 1988; Todd, 1991; Kraus et al, 2002; Balanis, 2005; Asoke, 2007; Chen, 2007). In this paper, the experimentally determined currents matrix of the antenna by Alade and Akande (2010) is combined with the calculated impedances matrix of the antenna geometrical configuration using MM to produce HMM for the self/mutual impedances and voltage distributions analyses of the MDADA at 850 – 1150MHz Band.

2. METHODS

2.1 Review of the Fundamentals of MM analysis of Dipole antenna

The fundamental electromagnetic of charge and current distributions from Maxwell equations is given by (Kraus, 1988; Jackson, 1999; Kraus et al, 2002; Balanis, 2005):

$$E = -j\omega\mu_o A - \nabla V \quad (1)$$

Where E is the electric field, A is the vector potential, V is the scalar potential, ω is the angular frequency ($\omega = 2\pi f$), f is the linear frequency and μ_o is the permeability of free space.

Consider a cylindrical conductor of radius *a*, and length *L* ($L = \Delta z_1 + \Delta z_2 + \Delta z_3$) carrying a current **I** and isolated in free space as shown in the figure 1. The boundary conditions are the conductivity ($\sigma = \infty$) and the skin depth $\left(\frac{1}{q} = 0\right)$, so that the radio frequency current is present entirely on the conductor surface.

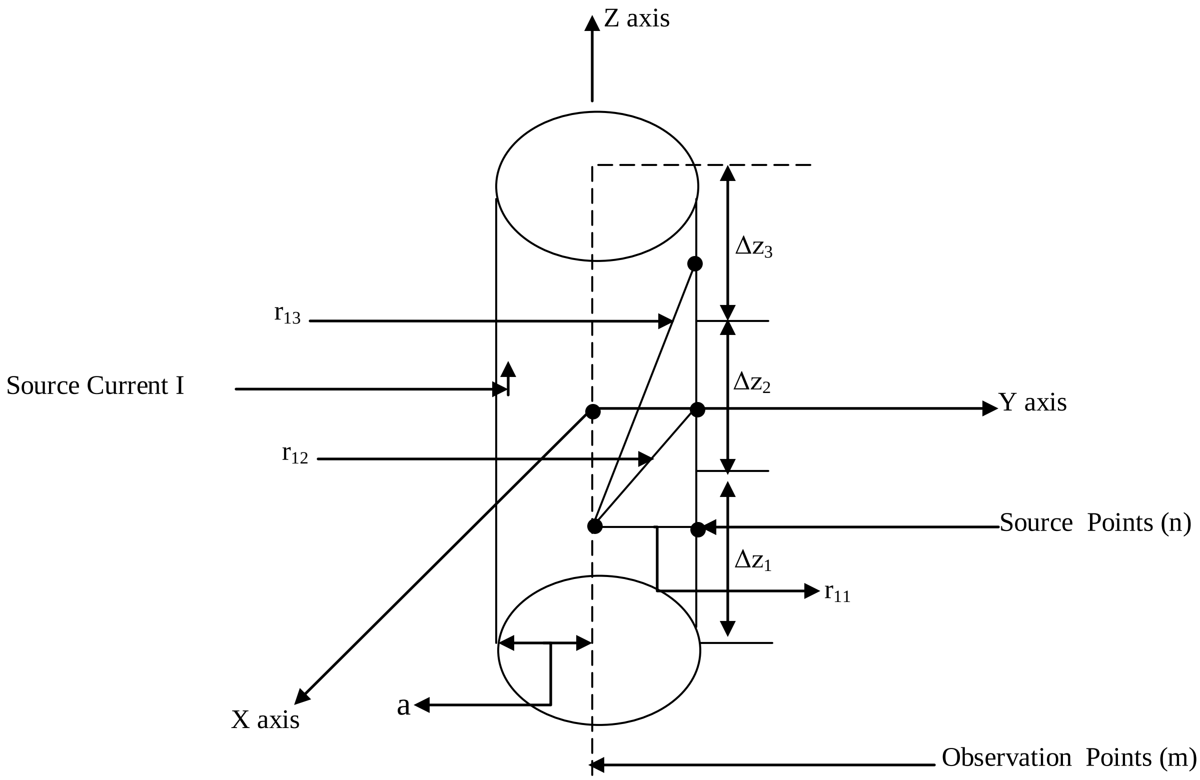


Figure 1: A Cylindrical conductor of radius a carrying current I

Jack Richmond 1965 (Kraus, 1988; Kraus et al, 2002) in his paper titled Digital Computer Solution of the Rigorous Equation for scattering problems presented the solution of the equation (1) for a cylindrical conductor of radius *a* carrying current *I* with the stated boundary conditions (the stated problem) to obtain a simplified integral solution of the form:

$$-V = \Delta z E(z) = \frac{-jZ_o \Delta z_\lambda}{8\pi^2} \int \frac{e^{-j2\pi r_\lambda}}{r_\lambda^3} \left\{ 1 + j2\pi r_\lambda \left[2 - 3\left(\frac{a}{r}\right)^2 \right] + 4\pi^2 a_\lambda^2 \right\} I(z) dz_\lambda \qquad (2)$$

Equation (2) can be simplified further for ease of its application to antenna problems. Therefore E(z) would be written as:

$$-E(z) = \int_{\frac{-L}{2}}^{\frac{L}{2}} I(z) G(r_{mn}) dz \ \text{unitVm}^{-1} \qquad (3)$$

Where,

$$G(r_{mn}) = \frac{-jZ_o}{8\pi^2 \lambda^2} \left(\frac{e^{-j2\pi r_\lambda}}{r_\lambda^3} \right) \left\{ 1 + j2\pi r_\lambda \left[2 - 3\left(\frac{a}{r}\right)^2 \right] + 4\pi^2 a_\lambda^2 \right\} \ \text{unit } \Omega\text{m}^{-2} \qquad (4)$$

I(z) is approximated using a series expansion under the assumption of pulse function such that (Kraus *et al*, 2002; Chen, 2007):

$$-E(z) = \sum_{n=1}^{N} I_n \int_{\Delta z} G(r_{mn}) dz \qquad (5)$$

$$\int_{\Delta z} G(r_{mn}) dz \approx G(r_{mn}) \Delta z = G_{mn} \ \text{unit } \Omega\text{m}^{-1} \qquad (6)$$

$$\rightarrow G_{mn} = \frac{-jZ_o \Delta Z}{8\pi^2 \lambda^2 r_\lambda^3} \left(e^{-j2\pi r_\lambda} \right) \left\{ 1 + j2\pi r_\lambda \left[2 - 3\left(\frac{a}{r}\right)^2 \right] + 4\pi^2 a_\lambda^2 \right\} \ \text{unit } \Omega\lambda^{-1} \qquad (7)$$

$\therefore$ Equation 5 becomes:

$$[G_{mn}]\ [I_n] = [-E_m] \qquad (8)$$

Multiplying both sides of equation (7) by ΔZ

$$\rightarrow \Delta Z\ [G_{mn}]\ [I_n] = -\Delta Z\ [E_m] \qquad (9)$$

Equation (9) can be finally written in matrix form as (Kraus, 1988; Todd, 1991; Kraus *et al*, 2002; Balanis, 2005):

$$\therefore [Z_{mn}][I_n] = -\ [V_m] \qquad (10)$$

Where, r = r_{mn} is the distance from observation point (m) due to source point (n).

$$r_\lambda = \frac{r}{\lambda}, a_\lambda = \frac{a}{\lambda}$$

λ = Wavelength of the resonating frequency.
G_{mn} = Green parameter.
Z_{mn} = Impedance Parameter (Mutual impedances between observation points and source points).
Z_{nn} = Self impedance.
I_n = Current at point n.

V_m = Voltage developed by the field E over ΔZ_λ $\left(\Delta Z_\lambda = \frac{\Delta Z}{\lambda}\right)$

ΔZ = Length of each segment along the Z – axis.
Z_o = Characteristics impedance of free space (Z_o =377Ω).

2.2 Determination of Mutual impedances and Voltage distributions of 8dBi Modified Driven Array of dipoles Antenna (MDADA) at 850 – 1150MHz band

Equation (7) is re-modified to suit the present situation of 4 elements of unequal length and unequal spacing dipole array shown in figure 2 (MDADA) as:

$$G_{mn} = \frac{-jZ_o\Delta Z}{8\pi^2 r^3}\left(e^{-j2\pi r}\right)\left\{(1+j2\pi r)\left[2-3\left(\frac{a}{r}\right)^2\right]+4\pi^2a^2\right\} \text{ unit } \Omega\lambda^{-1} \qquad (11)$$

Therefore, ΔZG_{mn} can be written as:

$$Z_{mn} = \frac{-jZ_o\Delta Z}{8\pi^2 r^3}\left[\cos(360r)-j\sin(360r)\right]\times\left\{(1+j2\pi r)\left[2-3\left(\frac{a}{r}\right)^2\right]+4\pi^2a^2\right\}\lambda \text{ unit } \Omega \quad (12)$$

Where ΔZ now represents length of each element, r = r_{mn}, S_{nn} = spacing between the elements and are given according to the geometrical configuration of the MDADA as shown in the Figure 2(a, b, c, d) as:

ΔZ_1 = 0.173m, ΔZ_2 = 0.1573m, ΔZ_3 = 0.143m, ΔZ_4 = 0.13m, S_{12} = 0.0545m,
S_{23} = 0.0505m, S_{34} = 0.0469m, $S_{13} = S_{12} + S_{23}$ = 0.105m, $S_{14} = S_{13} + S_{34}$ = 0.1519m,
$S_{24} = S_{23} + S_{34}$ = 0.2024m, r_{11} = 0.0865m, r_{22} = 0.07865m, r_{33} = 0.0715m, r_{44} = 0.065m,
and

$$r_{12} = \sqrt{r_{11}^2 + s_{12}^2} \quad r_{13} = \sqrt{r_{11}^2 + s_{13}^2} \quad r_{14} = \sqrt{r_{11}^2 + s_{14}^2} \quad r_{21} = \sqrt{r_{22}^2 + s_{12}^2}$$
$$r_{23} = \sqrt{r_{22}^2 + s_{23}^2} \quad r_{24} = \sqrt{r_{22}^2 + s_{24}^2} \quad r_{31} = \sqrt{r_{33}^2 + s_{13}^2} \quad r_{32} = \sqrt{r_{33}^2 + s_{23}^2}$$
$$r_{34} = \sqrt{r_{33}^2 + s_{34}^2} \quad r_{41} = \sqrt{r_{44}^2 + s_{14}^2} \quad r_{42} = \sqrt{r_{44}^2 + s_{24}^2} \qquad (13)$$

The geometrical configuration data of the MDADA provided above are employed to solve the Equation (12) numerically. Substitution of the results of numerical computations of Equation (12) into Equation (10) yields Equation (14a,b):

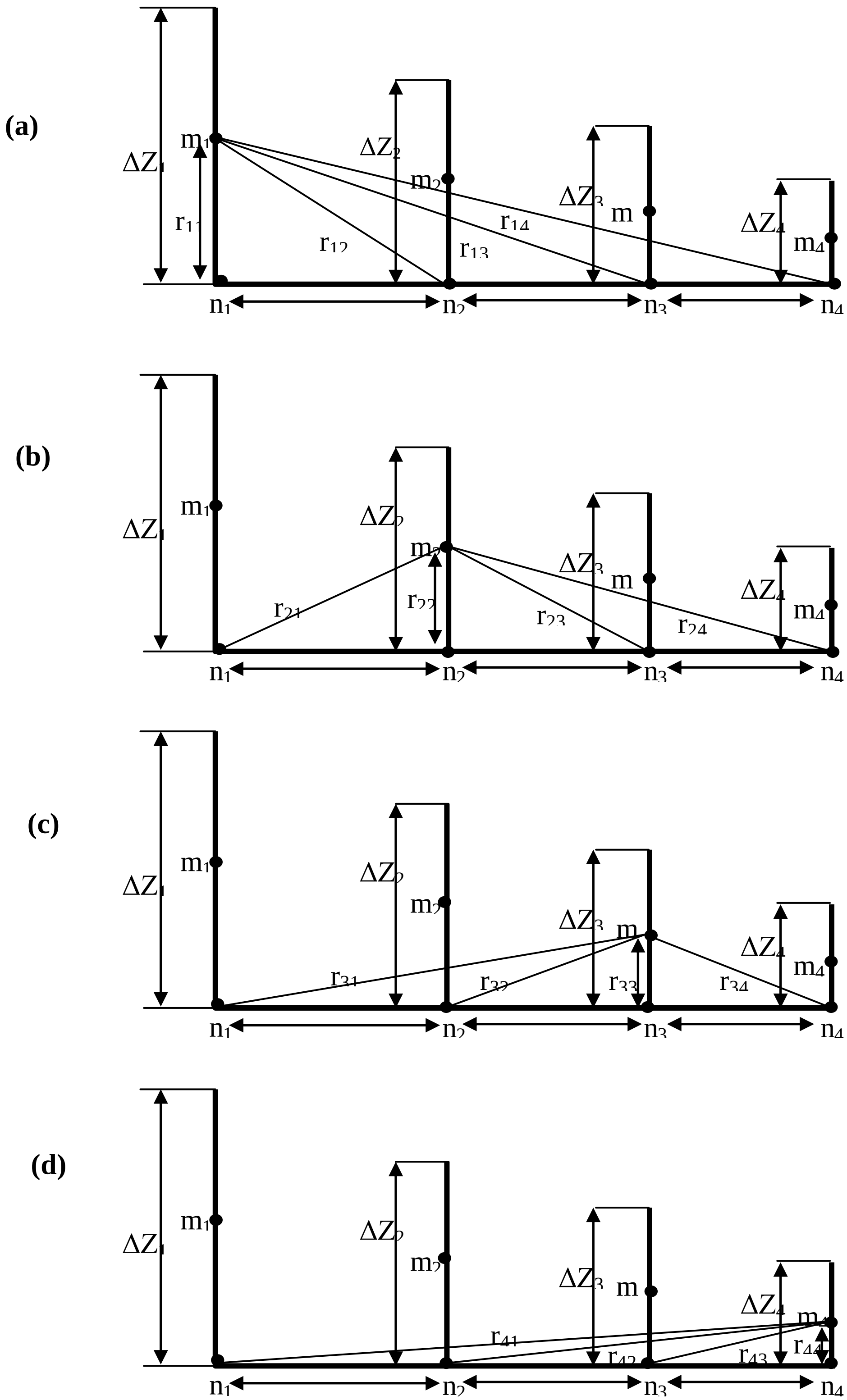


Figure 2 (a, b, c, d): Showing the geometrical configuration and mutual interactions of the array of four dipoles (MDADA), and distances (r_{mn}) from observation points (m) due to source points (n) (n).

$$\begin{pmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{pmatrix} = \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{pmatrix} \quad (14a)$$

$$\begin{pmatrix} [-424.814 - j2709.4]\lambda & [-131.81 - j1828.75]\lambda & [-126.4 - j852.8]\lambda & [-120.50 - j442.14]\lambda \\ [-118.83 - j1988.37]\lambda & [-119.6 - j3420.615]\lambda & [-119 - j2120.3]\lambda & [-102.43 - j225.64]\lambda \\ [-105.4 - j842.55]\lambda & [-83.14 - j105.39]\lambda & [-101.51 - j3793.4]\lambda & [-109 - j2463.87]\lambda \\ [-91.70 - j384.95]\lambda & [-85.43 - j197.50]\lambda & [-100 - j2538.66]\lambda & [-98.53 - j1828.75]\lambda \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{pmatrix} = \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{pmatrix}$$

……….(14b)

Equation (14a,b) is solved with the aids of MatlabR2007a version to determine the self and mutual impedances of the MDADA at various resonant frequencies within the frequency band under consideration. At a particular resonant frequency f, $I_1 = I_2 = I_3 = I_4 = I$. The current distributions (I) as function of frequency were extrapolated from the previous research work by Alade and Akande, 2010 and displayed in Table 1. Having computed the impedances of the antenna array from the impedance matrix of Equation (14a,b), the voltage distributions of the antenna were determined.

3. RESULTS AND DISCUSSION

The self and mutual impedances and voltages distributions of of 8dBi Modified Driven Array of unequal length and spacing of Dipoles Antenna (MDADA) at 850 – 1150MHz Band have been analyzed using hybrid frequency domain moment method numerical electromagnetic code. The impedance matrix of Equation (14b) contains both the resistive (real part, R_{nn} or R_{mn}) and reactive (imaginary part, X_{nn} or X_{mn}) components of the self and mutual impedances of the proposed antenna. The results of the computation of the impedance matrix component of Equation (14b) were plotted graphically (Figure 3a,b,c,d) with the aid of matlabR2007a version. The values of the impedances obtained and current as function of frequency extrapolated from the previous work on MDADA by Alade and Akande (2010) were then substituted into Equation (14b) to obtain the voltage distributions (Figures 4 & 5) of the proposed antenna.

Figure (3a,b,c,d) shows the variations of the resistive and reactive components of the self and mutual impedances of the antenna as the resonant frequency is varied from 850MHz to 1150MHz. There is no significant effect of frequency increase from 850MHz to 1150MHz particularly on the resistive components of the self and mutual impedances of the proposed antenna, flat response is obtained. The values of the resistive components of the impedances obtained are very small (average minimum and maximum values are about 49Ω and 66Ω respectively, which ensure good matching with 75Ω coaxial cable transmission line) at all resonant frequencies within the band of consideration. Though, the reactive components of the impedances tend to increase gradually as the resonant frequency increases, almost flat response is obtained. Therefore, the flat response of the impedances over the wide frequency band of consideration makes the proposed antenna array a wide bandwidth type. In addition, it can be deduced from the results analysis that the current distributions lead the voltage distributions in the antenna because all the reactive components of the impedances are negative. Consequently, the proposed antenna will dissipate little or no energy loss as heat, almost all the energy received will be expended as radiation resistance (ohmic losses <<< radiation resistance).

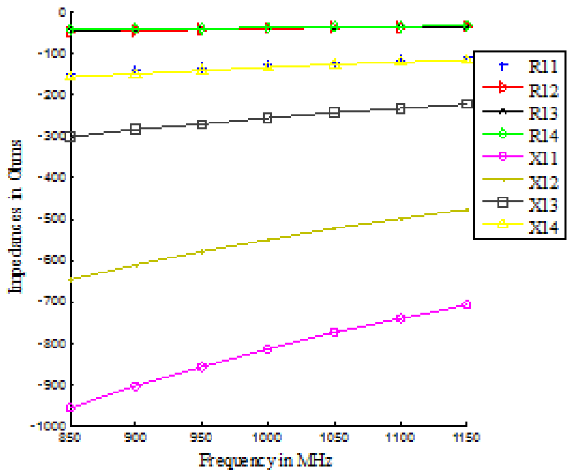
Figure 4 shows the individual dipole element's voltage distributions of the proposed antenna (MDADA) as function of the resonant frequency. As the element length decreases, the voltage distributions increase. The voltage distributions reached the peak values (range from 6.5±0.1mV to 13±0.1mV) at 1000MHz and 1150Mz resonant frequencies. The bandwidth is about 5% of the peak resonant frequency.

Figure 5 represents the resultant total voltage distributions of the antenna as function of resonant frequency. There are uniform voltage distributions between 900MHz and 1050MHz resonant frequencies. At 1000MHz and 1150MHz resonant frequencies, the antenna's voltage distributions are at the maximum peak values (range from 70±0.1mV to 80±0.1mV), which are much greater than that of the individual dipole element of the Figure 4. It is also noticed that the bandwidth has increased to about10% which doubles ±5% of the individual dipole element of

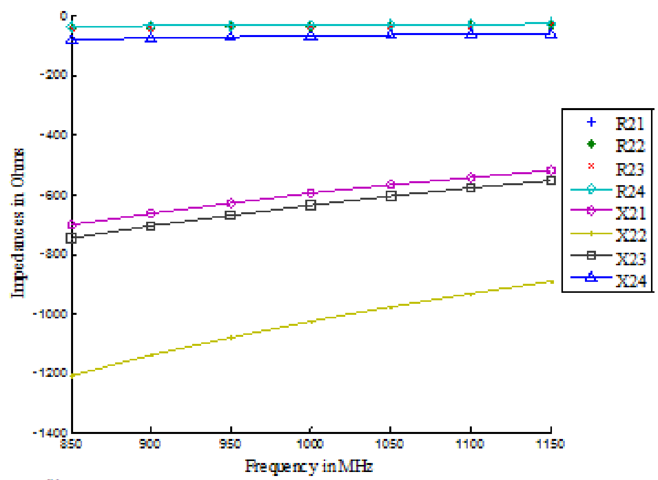
the proposed antenna array at the same resonant frequency. The analyses also confirmed the supreme performance of the dipole antenna array as compare to the single element dipole antenna in agreement with the previous work by Kraus *et al* (2002), Hui (2004), Asoke (2007), FEKO (2007) and Yang *et al* (2008).
Figure 6 is the plot of the computed VSWR of the proposed antenna versus the frequency. Almost Flat response of VSWR is obtained at the design frequency band (850 – 1150MHz) of the antenna. The compute values of VSWR at all resonant frequency are approximately equal to 1.0.

Table 1: Extrapolated currents distributions of MDADA at various frequencies, f within the desired frequency band (Alade and Akande, 2010).

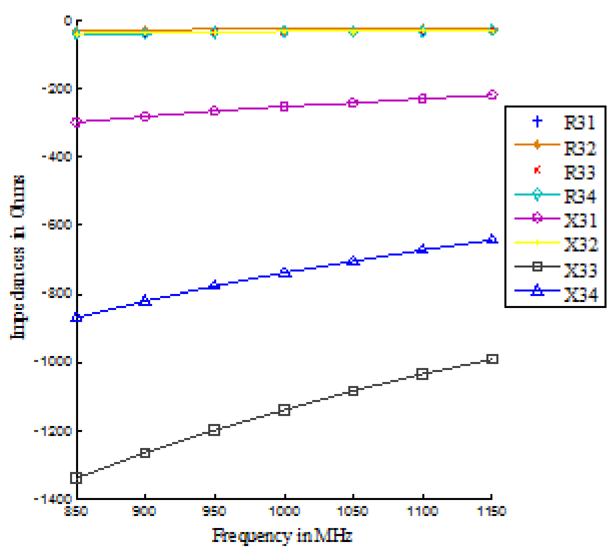
f(MHz)	I(μA)
850	0.944
860	0.767
870	0.767
880	1.717
890	0.684
900	0.724
910	6.09
920	6.09
930	6.09
940	6.09
950	6.09
960	6.09
970	6.09
980	6.09
990	6.09
1000	9.12
1010	6.09
1020	6.09
1030	6.09
1040	6.09
1050	6.09
1060	2.72
1070	2.72
1080	2.72
1090	2.72
1100	2.72
1110	6.09
1120	6.09
1130	6.84
1140	6.84
1150	9.12


Impedances in Ohms
Frequency in MHz
R11
R12
R13
R14
X11
X12
X13
X14

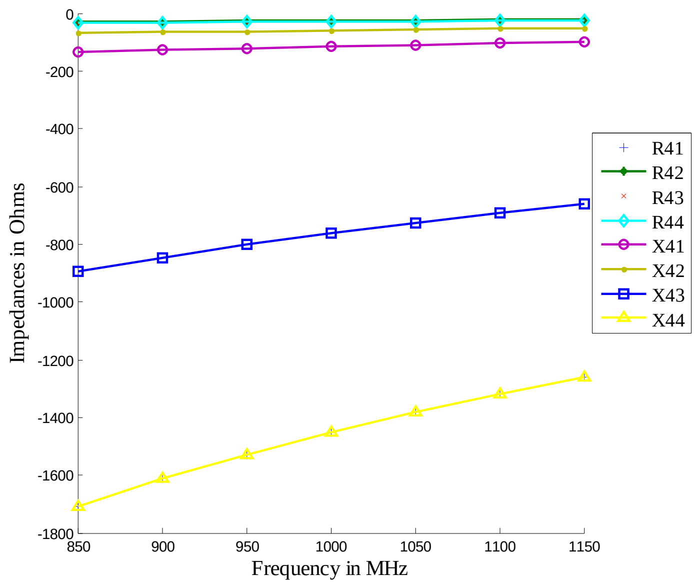
(a)


Impedances in Ohms
Frequency in MHz
R21
R22
R23
R24
X21
X22
X23
X24

(b)


Impedances in Ohms
Frequency in MHz
R31
R32
R33
R34
X31
X32
X33
X34

(c)



(d)

Figure 3a,b,c,d: Showing the impedances (resistive, R and reactive, X components)

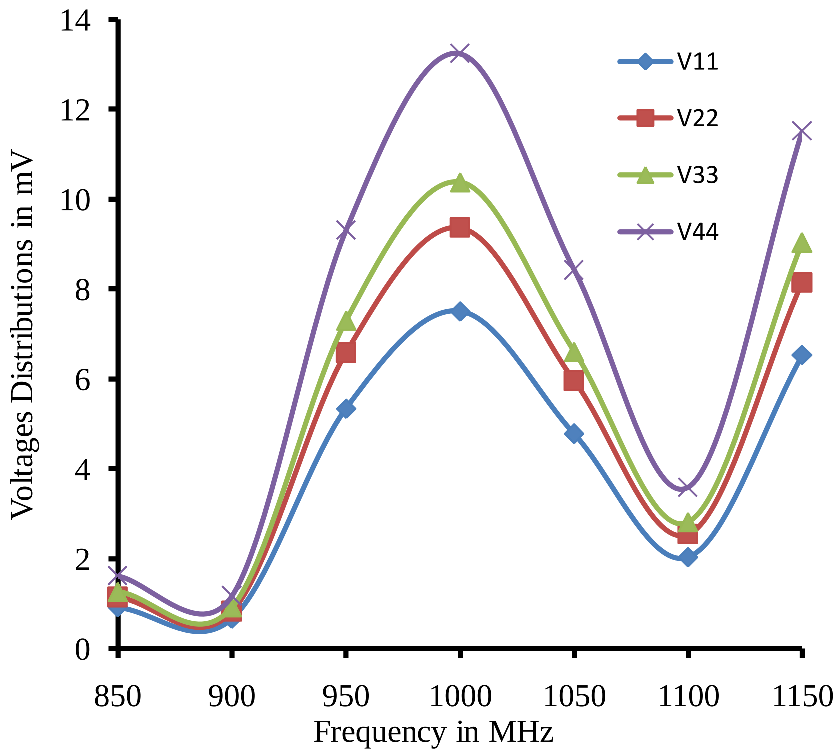


Figure 4: Showing the individual dipole element's voltages distributions of MDADA as a function of frequency.

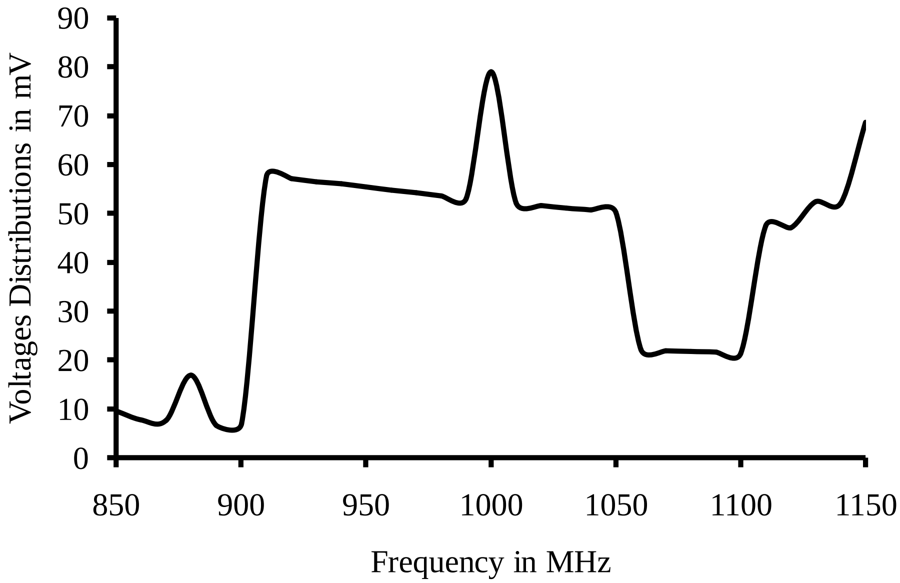


Figure 5: Showing the resultant voltages distributions of MDADA as a function of frequency.

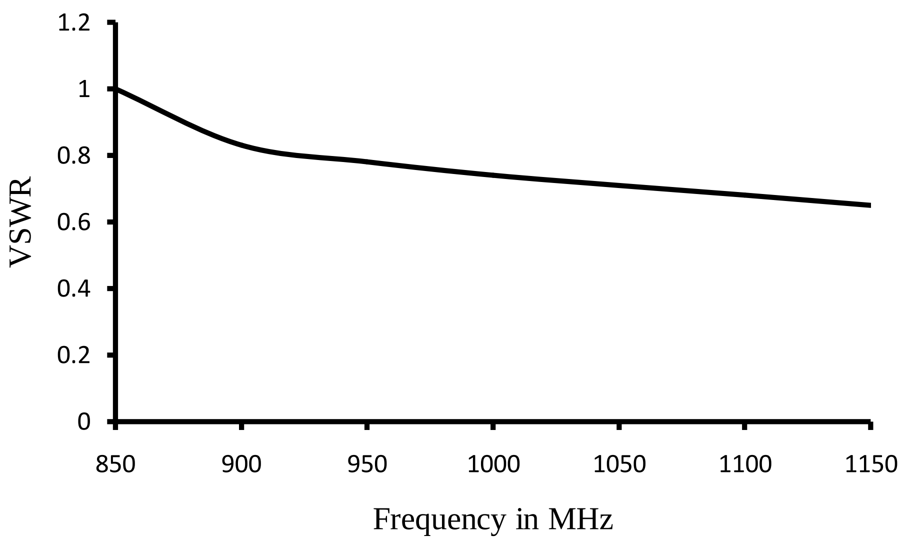


Figure 6: Showing a plot of the computed Voltage Standing Wave Ratio (VSWR) of MDADA as a function of frequency.

4. CONCLUSIONS

In this paper, the hybrid frequency domain moment method analyses of self/mutual impedances and voltage distributions of 8dBi Modified Driven Array of Dipoles Antenna at 850 – 1150MHz band, the antenna array previously proposed by Alade and Akande (2010), have been presented. The proposed antenna is a 4-dipole element of unequal length and unequal spacing linear array. The results of the analyses shown that the proposed antenna will expend almost all the energy received as radiation resistance. The proposed antenna resonates very well at the frequencies of 1000MHz and 1150MHz. VSWR of ~1.0 and Bandwidth of ±10% about the center resonant frequency are possible.

5. ACKNOWLEDGMENT

The authors would like to thank the Electronic Devices Research Group of Ladoke Akintola University of Technology, Ogbomoso, Nigeria for donating hp laptop6735s computer used for this work.

6. REFERENCES

[1]. Alade, M. O., and Akande, S. F. (2010): Design and Performance Analysis of 8dBi Modified Driven Array of Dipoles Antenna (MDADA) for GSM at UHF/L Band (850 - 1150MHz). Science Focus: - An International Journal of Biological and Physical Sciences, URL: http://www.sciencefocusngr.org, ISSN: 1598-7026, 15 (1), Pp 45 – 53.

[2]. Asoke, K. B. (2007): Mutual mpedance between two parallel thin linear antennas in chiral medium. Microwave and Optical Technology Letters, Wiley Periodicals Inc. Vol 4 (4), doi: 10.1002/mop.46500412, Pp 172 – 176.

[3]. Balanis C. A (2005): Antenna Theory. 3rd Edition, ISBN 0-471-66782-X, John Wiley & Sons Ltd. USA.

[4]. Chen Zhi Ning (2007): Antenna for portable Devices.15th Edition, ISBN: 0-87259-207-5, John Wiley & Sons, USA.

[5]. FEKO (2007): Mutual Impedance between Elements in Dipole Array. FEKO Comprehensive EM Solutions – Field computations involving objects of arbitrary shape. Retrieved on June 10, 2010 from http://www.feko.info/knowledge-base/application-notes/dipole_array, Pp 1 – 4.

[6]. Jackson, J. D. (1999): Classical Electrodynamics. 3rd Edition, ISBN: 0-471-30932-X, Hamilton Printing Company, USA.

[7]. Jiang Tie-hua, Su Dong-Lin, Yang zheng guang Xiao, and Hai-feng (2006): Calculation for the phase center of LPDA Based on Simulated Annealing Algorithms and MOM. Environmental Electromagnetic, the 2006 4th Asia – Pacific Conference. Vol. 2, Issue 4, ISBN: 1-4244-0183-6, doi: 10.1109/CEEM2006.258043, Pp 670 – 673.

[8]. Kraus, J. D (1988): Antennas. 2nd Edition, ISBN: 0-07-035422-7, McGraw-Hill Inc. USA.

[9]. Kraus, J. D., Marhefka, R. J., Muuk, B. A., Letho, A., Vainikainen, P., Newman, E. H., and Walker, C. (2002): Antennas for All Applications. 3rd Edition, ISBN: 0-07-232103-2, McGraw-Hill, USA.

[10]. Kun-Chou Lee, and Tah-Hsiung Chu (2005): Mutual Coupling Mechanisms within Arrays of Nonlinear Antennas. IEEE Transactions on Electromagnetic Compatibility, Vol. 47, No. 4, Retrieved on May 12, 2010 from http://www.google.com, doi: 10.1109/TEMC.2005.857892, Pp 963 – 970.

[11]. Loredo, S., Leon, G., Zapatero, S., and Las-Heras, F. (2009): Measurement of Low-Gain Antennas in Non-Anechoic Test Sites through Wideband Channel Characterization and Echo Cancellation. IEEE Antenna and Propagation Magazine, ISSN: 1045-9243, Vol. 51, No. 1, Pp 128 – 135.

[12]. Tian, Y., Zhang, Y. –H., and Fan, Y. (2007): The analysis of mutual coupling between paraboloid antennas. J. of Electromagn. Waves and Appl., Vol. 21, No. 9, Pp 1191 – 1203.

[13]. Todd, H. H. (1991): Survey of Numerical Electromagnetic Modeling Techniques. University of Missouri-Rolla, Electromagnetic Compatibility laboratory, TR91-1-001.3, Pp 1 – 19.

[14]. Vasylchenko, A., Schols, Y., De Raedt, W., and Vandenbosch, G. A. E. (2009): Quality Assessment of Computational Techniques and Software Tools for Planar-Antenna Analysis. IEEE Antenna and Propagation Magazine, ISSN: 1045-9243, Vol. 51, No. 1, Pp 23 – 38.

[15]. Vishal Bhavsar, Nicholas Blas, Huy Nguyen, and Alexander Balandin (2000): Measurement of Antenna Radiation Patterns Laboratory Manual. EE117 Laboratory Manual, UC-Riverside, Retrieved on April 20, 2010 from, http://www.google.com, Pp 1 – 42.

[16]. Yang, Y., Wang, Y., and Fathy, A. E. (2008): Design of compact VIVALDI antenna arrays for UWB see through wall applications. Progress In Electromagnetics Research, PIER 82, Retrieved on April 20, 2010 from http://www.ceta.mit.edu, doi: /26.08040601, Pp 401 – 418.