JIS Journal of Interdisciplinary Sciences
Volume 1, Issue 1; 20-31
November, 2017. © The Author(s)

Gain improvement of the Yagi-Uda Antenna Using Genetic Algorithm for Application in DVB-T2 Television Signal Reception in Tanzania

Twahir Kazema* and Kisangiri Michael
Department of Electronics and Telecommunication, Nelson Mandela Institution, Arusha, Tanzania
twahirkazema@gmail.com*

Abstract: *Region 2 UHF Frequency band is the frequency range which is used for transmitting Television signals in East Africa. Yagi-uda antenna is an array Antenna designed for various applications, in this paper a 5-element yagi-uda antenna is designed and optimized for operating on the frequency of 500 MHz for digital television signal reception. 4NEC2 and FEKO software's were used for simulation and optimization was done using genetic algorithm. A comparative analysis was done using the two software's with respect to the current used antenna in DVB-T2 digital television systems in Tanzania. The results shows that; the FEKO optimized antennas gives a better performance compared to the currently antenna used for digital television reception in homes.*

Keywords: VSWR, Gain, DVB-T2, antenna, signal reception, genetic algorithm, comparative analysis, television, simulation, optimization.

Introduction

A Yagi-Uda Antenna, commonly known simply as a Yagi antenna or Yagi, is a directional antenna system consisting of an array of dipole and additional closely coupled parasitic elements (usually a reflector and one or more directors) (Dubey and Zafar, 2014). The second dipole in the Yagi-Uda array is the only driven element with applied input/output source feed, all the others interact by mutual coupling since receive and radiate electromagnetic energy, they act as parasitic elements by the induced current Dubey and Zafar (2014). It is assumed that an antenna is a passive Reciprocal device, then may be used either for transmission or for reception of the electromagnetic energy this well applies to Yagi-Uda also (Dubey and Zafar, 2014). These antennas are directional along the axis perpendicular to the dipole in the plane of the elements, from the reflector toward the driven element and the director(s). A Yagi-Uda Antenna is a widely used Antenna design due to its high forward gain capability, low cost and ease to construction (Balanis, 2011).

It is commonly used as a roof top television receiver. Basically as antenna is a real system that matches or coupled the energy to the free space. One element is energized directly by a feed transmission line with the others act as parasitic radiators. The function of these elements is to enhance the radiation pattern in the source direction (Duchesneau, 2012). Generally the reflector will be 5% longer than the driven element (i.e. dipole) and the directors will be 5% Shorter (Bueno Díez, 2012). Parameter limits are: Driven Element, Directors and Separation between driven elements and parasitic.

Due to poor signal in DVB-T2 signals in Tanzania caused by either poor coverage or poor gain of the antenna, in this case Yagi-Uda Antenna is recommended for optimization. The yagi-uda Antenna which is to be optimized was taken from Murali et. al. (2011). The purpose of this experimental study is to optimize the same antenna and optimize it for UHF (DVB-T2) application.

Figure 1: The Antenna & decoder

The Yagi to be optimized is at a frequency band centered on 500 MHz using genetic Algorithm. Current Antenna used for DVB-T2 system Simulation results are also presented, the Antenna used is a dipole having a length of 15cm and a radius of 0.03cm as shown on the figure below. The following figure shows the simulation results which were done using commercial software FEKO.

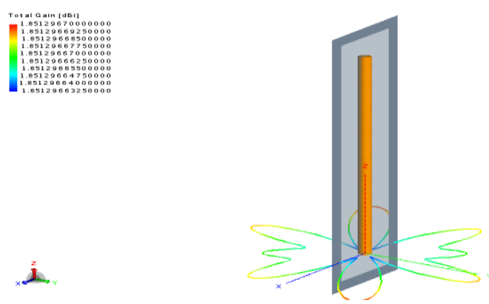

Figure 2: Current DVB-T2 Antenna

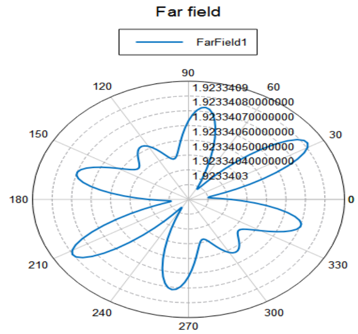

Figure 3: radiation pattern of DVB-T2

The antenna above produces a gain of 1.98 dBi with a poor radiation pattern as shown on the figure 2 above.

Yagi-Uda Theory

Yagi-Uda consist of three elements: the driven element, reflector and director, as shown in figure 1. The driven element is the active element; reflector and directors are passive elements, the length of the reflector should be greater than the driven element such that its impedance will be more and hence it can be acts as an inductive element. Similarly the length of the director is less than the driven element such that its impedance will be less and hence they acts as a capacitive elements Balanis (2016).

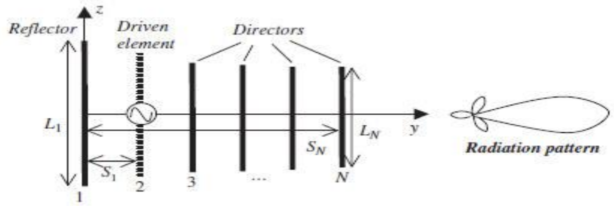

Figure 4: Source: Yagi Uda antenna structure Huang and Boyle (2008)

The maximum gain can be attained along the axis and on the side with the directors. The function of the reflector is to reflects power forwards and therefore it acts like a small ground plane. The Spacing between each element is not identical and it can be considered as a non-linear array. The number of directors in the antenna depends on the gain requirements Raju G.S.N (2006). The flow of current on the active element of the yagi-uda antenna is determined by its length, frequency and coupling with nearby elements, while the current distribution in passive elements is governed by the boundary condition. Radiation pattern for n-elements yagi-uda antenna is expressed as follow:

Equation 1

$$E(\theta)_n \approx j\eta \frac{I_n e^{j\beta r}}{2\pi r} \left(\frac{\cos(\beta l_n \cos\theta) - \cos(\beta l_n)}{\sin\theta} \right)$$

Where *In* is the maximum current and *ln* is half the length of the *n*th dipole. The total radiation pattern is the field superposition from all the elements is expressed as shown on equation 2 below

Equation 2

$$E(\theta)_n \approx j\eta \frac{I_{n\varepsilon^{j\beta r}}}{2\pi r}\left(\frac{\cos(\beta l_n \cos\theta) - \cos(\beta l_n)}{\sin\theta}\right) exp(j\beta S_{n-1}\cos(\theta))$$

Where *r* is the center of the reflector to the observation point and spacing *S*=0. It is apparent that each element length and spacing, weighted by its maximum current, affects the total. One important figure of merit in a Yagi–Uda antenna is the *front-to-back ratio* of the pattern. It has been found that this is very sensitive to the spacing of the director Huang and Boyle (2008). Directivity is the most important parameter of any antenna, a simpler estimation of the maximum directivity of a Yagi–Uda antenna is proposed by Huang and Boyle (2008) as shown below

Equation 3 : Directivity

$$D=3.28N$$

The coefficient 3.28 results from doubling the directivity (1.64) of a half-wave dipole and N is the total number of elements (Huang and Boyle, 2008). The gain of the antenna is expressed as

Equation 4: Gain

$$G = \frac{p_t}{p_{in}} * D$$

Where Pt and Pin are transmitted power and input power respectively.

Literature Survey

Yagi-Uda antennas gain is highly sensitive and depend upon numerous parameters and therefore it is difficult to optimize Simulated Annealing (SA) is a powerful stochastic global search and optimization method, using simulated annealing algorithms to optimize the element spacing and lengths of Yagi-Uda antennas was presented by Singh et al. (2007). Also a frequency reconfigurable printed Yagi-Uda antenna is presented for cognitive radio applications by Cai et al. (2012), a 46% continuous frequency tuning bandwidth is obtained by loading the driver dipole arms and four directors with varactor diodes. This configuration allows a high-gain and an almost constant end-fire pattern to be maintained while the antenna operating frequency is tuned. The introduction of an array of three-dimensional optical Yagi–Uda antennas, fabricated using top-down fabrication techniques combined with layer-by-layer processing was done by Dregely et al. (2011), this involve Future photonic circuits with the capability of high-speed data processing at optical frequencies. Towards this goal, bridging the size mismatch between optical radiation and sub wavelength emitters or detectors by optical Nano antennas is a subject of current research in the field of plasmonics.

An optimal design approach based on the popular realistic field simulator Numerical Electromagnetic Code (NEC) and the effective real coded Emperor-Selective genetic algorithm (EMS-GA) for automatic antenna design optimization was done by Lu et al. (2011), as an example and a real engineering application, a special corner reflector antenna driven by a Yagi-Uda array is designed by the NEC/EMS-GA approach. Compared to the traditional Yagi-Uda, the designed antenna has much lower side lobe level (SLL) with better immunity to interference and may find applications in wireless communication and TV reception.

A Yagi antenna system consisting of a low noise amplifier (LNA) and a reflector co-located on the same printed circuit board (PCB) as the radiators and directors is disclosed (Hegen doerfer, 2001), the balun cable was replaced by surface mount devices whose feed line is implemented in microstrip technology, all co-located on the same printed circuit board. The investigation of the use of a self-structuring antenna for television reception was done by Perry (2001), Information about the received signal strength is obtained from the automatic gain control circuit of the television and used to determine the appropriate antenna structure. For the purpose of comparison and benchmarking, equally spaced arrays, genetic algorithm optimized antenna design, and computational intelligence optimized antenna design are considered. The results clearly show that the CLPSO is a robust and useful optimization tool for designing Yagi antennas for the desired target specifications (Baskar, 2005).

Design of Yagi-Uda antennas is a challenging problem since antenna characteristics such as gain, input impedance, maximum side-lobe level etc., are known to be extremely sensitive to the design variables viz., element lengths and their spacing. Although, population-based, stochastic, zero-order methods like genetic algorithm (GA) and evolutionary algorithm (EA) are attractive choices for such classes of problems, their successful application requires a number of additional inputs (e.g. scaling and aggregating factors to deal with constraints and objectives) that is not easy for a designer to provide.

Venkatarayalu and Ray (2003) introduces a population-based, stochastic, zero-order optimization algorithm and use it to solve single and multiobjective Yagi Uda design optimization problems (Venkatarayalu and Ray, 2003). The advantage of the switched parasitic concept is that it is a relatively simple system, which can give the adaptive antenna performance of many branch selection or switched diversity was done by Vaughan (1999), Switched parasitic elements provide a useful implementation of antenna pattern diversity. The basic principle is presented with some examples of wire antennas computed using the method of moments. The modeled diversity gain available from selection combining of uncorrelated signals is used to quantify the expected improvement relative to non-diversity antennas (Vaughan, 1999).

Experiment Setup

The table below, present the value of the parameters before the antenna is optimized, the data are taken from Murali (2014). All the parameters were included for optimization as well as the radius of the wire.

Table 1: parameters before optimization

	Parameter	value	Constraints
Lf	Reflector length (L0)	0.165	
La	Active element (L1)	0.15	L0>L1
Ld1	Director 1 (L2)	0.135	L0>L2
Ld2	Director 2 (L3)	0.12	
Ld3	Director 3 (L4)	0.105	
S0	Spacing(S0) [L0-L1]	0.05	
S1	Spacing(S1) [L1-L2]	0.05	
S2	Spacing(S2) [L2-L3]	0.05	
S3	Spacing(S3) [L3-L4]	0.05	

4NEC2 Simulation Results

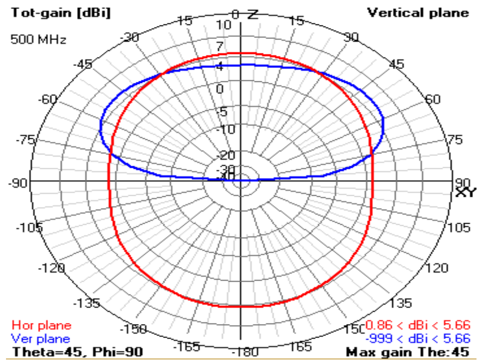

Figure 5: Radiation pattern before optimization

Before optimization: Gain = 5.66 dBi, VSWR= 123, Impedance = 13.4-j283

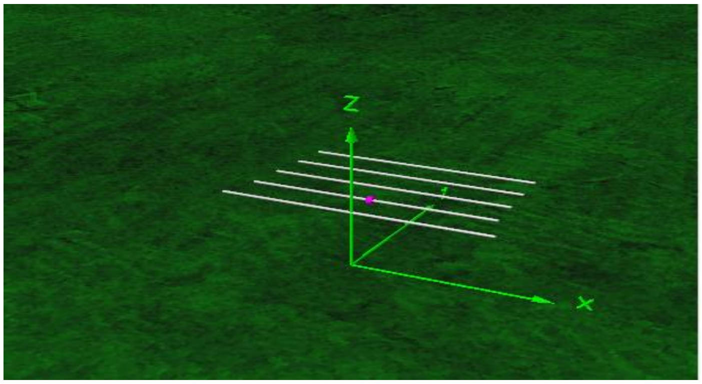

Figure 6 : the antenna structure

Optimization

The software used to model and simulates the Yagi-Uda antenna is 4NEC2X and FEKO. 4NEC2X Software based on Method of Moments has been used to carry out the first Yagi-Antenna simulations then followed by FEKO. The Antenna to be optimized has 5 elements as shown on table 1, it has three directors, one active element and a reflector. The Evolve (genetic algorithm) Available on 4NEC2 was used for optimizing the mentioned antenna. On the optimization a Uniform crossover was used with a probability value of 70% and then a Mutation was applied with a probability of 4%. All elements within a given individual were assigned the same radius value. Element lengths were constrained to be symmetric around the y-axis. Spacing between adjacent elements was set randomly for each, set at minimum and maximum values as shown on figure 5.

The 4NEC2 simulation program was used to evaluate and optimize the antenna design parameters. A revolver (genetic algorithm) with a population size of 3000 and maximum generation of 300 was used. Uniform crossover was applied at a rate of 70% and Mutation was uniform at a rate of 1%.

FEKO was also used for optimization with a goal of achieving a maximum gain possible as minimizing the side-lobes as well. The objective function used for the optimization is **FEKO Objective function (Mask)** Gain > 7 dB elang [15 60] MaxSLL< **-**10 dB elang [0 28; 122 180]**.**

The Method used by Feko is DGFM (Domain Green Function Method), the optimization far field goal was set to the following expression. Far-field Goal=log (total (gain (farfield (farfield1)))) and the impedance goal was expressed as impedancegoal=min (ex_VSWR:50 (impedance (voltagesource1))). The Algorithm used by Feko is Genetic Algorithm with the following parameters;
Maximum number of iterations: 50

Population size: 20
Creep mutation with probability: 0.5
Elitism, i.e. best individual replicated into next generation Enforce niching has the following parameters
Uniform crossover with probability: 0.5
Termination at standard deviation: 1.000000000e-04
Pseudorandom number generator seed: 1

Results

The following part present the simulation results after the optimization was done. All the element of the array dipoles of yagi-uda was optimized as well as the spacing between each.

4NEC2 Optimization Results

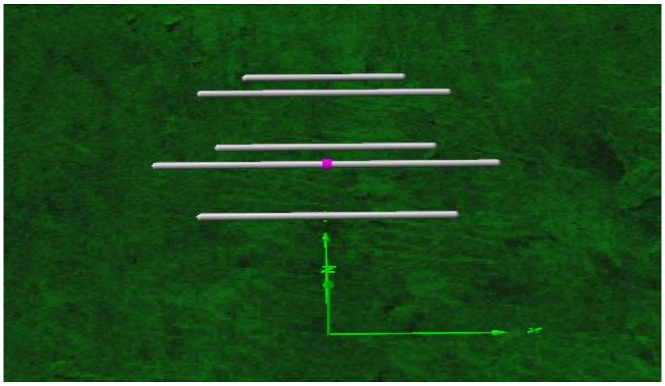

Figure 7: the gain & structure after optimization using 4NEC2

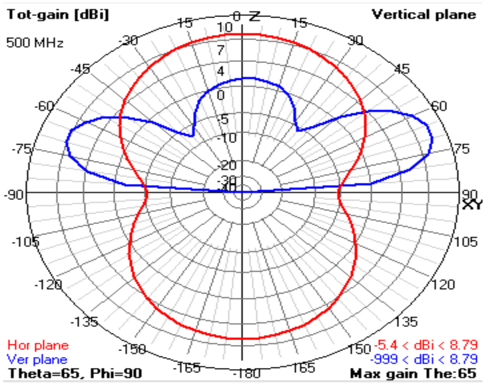

Figure 8: Radiation Pattern 4NEC2

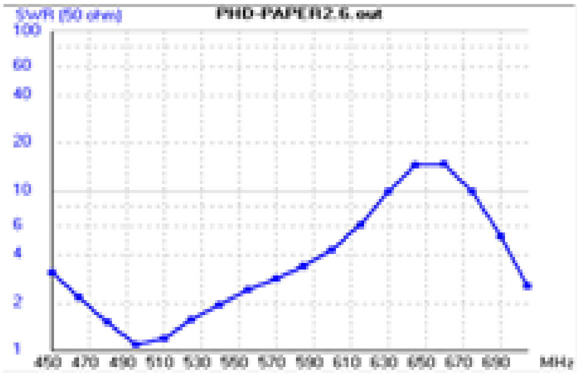

Figure 9: VSWR Results

FEKO Optimization Results

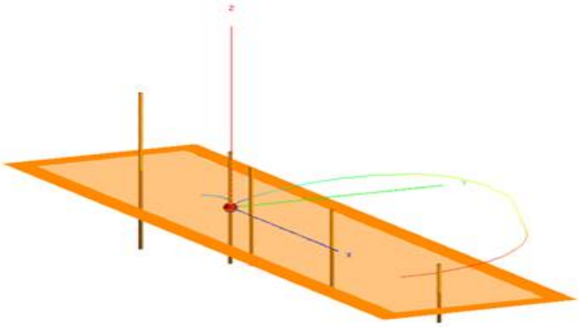

Figure 10: Optimized Yagi-Uda Antenna

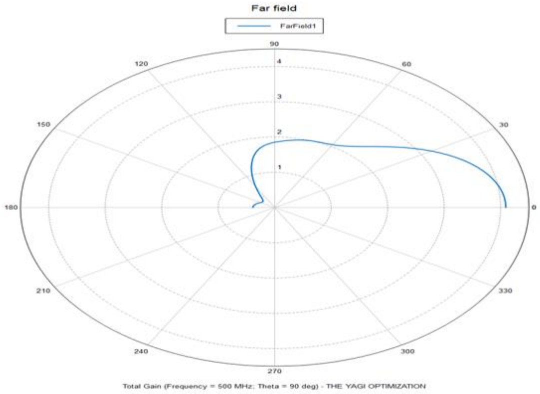

Figure 11: Optimized Radiation Pattern

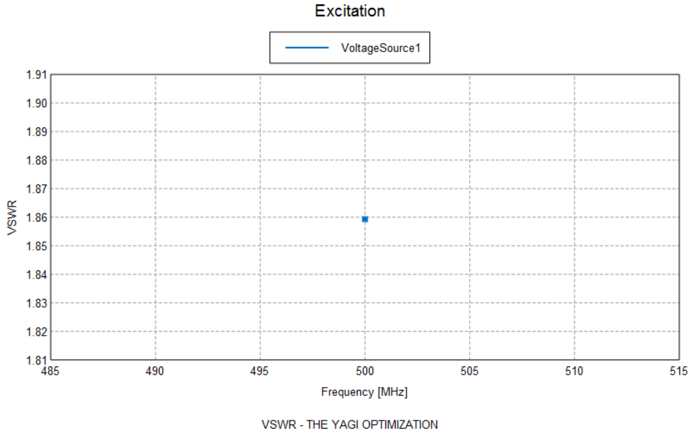

Figure 12: VSWR at center frequency

The table below, shows the summary of the physical parameters after the optimization process. However it also presents the performance parameters which are needed for the successful operation of the antenna as well.

Table 2: Optimal parameters summary

Variables	*4NEC2*	*FEKO*	
Lf	*0.2*	***0.65***	*Reflector Length*
L1	*0.28*	***0.46***	*Active element*
L2	*0.178*	***0.41***	*Director 1*
L3	*0.21*	***0.33***	*Director 2*
L4	*0.138*	***0.24***	*Director 3*

S1	*0.07565*	***0.64***	*Spacing [Lf – L1]*
S2	*0.10*	***0.14***	*Spacing [L1 – L2]*
S3	*0.19*	***0.57***	*Spacing [L2– L3]*
S4	*0.21*	***0.75***	*Spacing [L3 – L4]*
Wire diameter	*9.3e-3*	***7.8e-3***	
Gain	*8.79 dBi*	***6.25 dBi***	
VSWR	*1.14*	***1.48***	
Impedance	*46.7-j5.57*		
Rad.Efficiency	*71.66%*		

Conclusion

The yagi-uda antenna was designed and simulated for 5-elements. The proposed antenna was designed for operating at the frequency range of 450 MHz-550 MHz, centred at 500 MHz. The peak antenna gain is 8.79 dBi using 4NEC2 Software and 6.7 dBi using FEKO. 4NEC2 and FEKO Software's were used for designing the antenna and preliminary simulations were done for obtaining the characteristics of the Antenna. Optimization was done using Genetic Algorithm and the optimum parameters were simulated and they gives better results with respect to radiation efficiency and matching of impedance as well. The recommended antenna for using on the DVB-T2 digital system available in Tanzania is the antenna optimized using commercial software FEKO. The reason for selecting the parameters optimized using FEKO is that; Feko is a commercial software comparing it with 4NEC2 which is free software. When comparing the two software's, the commercial ones are the ones which gives minimum deviation from the true value when the antenna is fabricated and tested in labs.

References

Balanis, C.A. 2016. *Antenna theory: analysis and design*. John Wiley & Sons

Balanis, C.A. 2011. *Modern antenna handbook*. John Wiley & Sons.

Baskar, S., Alphones, A., Suganthan, P., & Liang, J. 2005. Design of Yagi-Uda antennas using comprehensive learning particle Swarm optimisation. IEE Proceedings-Microwaves. *Antennas and Propagation,* 2005. 152(5): p. 340-346.

Bueno Díez, M.Á. 2012. *Design of Yagi-Uda antennas based on high-permittivity dielectric bulk materials.*

Cai, Y., Y.J. Guo, & T. Bird. 2012. A frequency reconfigurable printed Yagi-Uda dipole antenna for cognitive radio applications. *IEEE Transactions on Antennas and Propagation*, 60(6):p. 2905-2912.

Lobanov, S., Weiss, T., Dregely, D., Giessen, H., Gippius, N., & Tikhodeev, S. 2012. Emission properties of an oscillating point dipole from a gold Yagi-Uda nanoantenna array. *Physical Review B*, 85(15), 155137.

Dubey, S. & S. Zafar. 2014. Broadband microstrip Yagi array antenna for SC Band application in Electrical, *Electronics and Computer Science (SCEECS*), 2014 IEEE Students' Conference on. IEEE.

Duchesneau, D. D. 2012. FRAME (Forced Recuperation, Aggregation and Movement of Exergy).2012, Google Patents.

Hegendoerfer, M. H. 2001. Yagi antenna coupled with a low noise amplifier on the same printed circuit board. 2001, Google Patents.

Huang, Y. & K. Boyle. 2008. *Antennas: from theory to practice*. 2008: John Wiley & Sons.

Lu, Y., X. Cai, & Z. Gao. 2000. *Optimal design of special corner reflector antennas by the real-coded genetic algorithm*. Microwave Conference, 2000 Asia-Pacific. 2000. IEEE.

Murali, S.D., Kavya, K. C. S., Kotamraju, S. K., Divya, R. S., Satish, Y., Chandra, K. P., & Sree, G. J. 2014. Size Reduction of Yagi-Uda Antenna by Altering the Diameter and Spacing between the Elements. *International Journal of Applied Engineering Research*, 2014. 9(22): p. 12011-12022

Perry, B., Coleman, C., Basch, B., Rothwell, E., & Ross, J. 2001. Self-structuring antenna for television reception. *Antennas and Propagation Society International Symposium*, 2001. IEEE. 2001. IEEE.

Raju, G. S. N. 2006. *Antennas and wave propagation*. Pearson Education India.

Singh, U., Rattan, M., Singh, N., & Patterh, M. S. 2007. Design of a Yagi-Uda antenna by simulated annealing for gain, impedance and FBR. *Information and Communication Technology in Electrical Sciences* (ICTES 2007), 2007. ICTES. IET-UK International Conference on. 2007. IET.

Vaughan, R. 1999. Switched parasitic elements for antenna diversity. *IEEE Transactions on Antennas and Propagation*, 1999. 47(2): p. 399-405.

Venkatarayalu, N.V. & T. Ray. 2003. *Single and multi-objective design of Yagi-Uda antennas using computational intelligence*. Evolutionary Computation, 2003. CEC'03. The 2003 Congress on. 2003. IEEE.

Paper Received August 18th, 2017, Accepted September 29th, Published 2nd November 2017