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Design & Development of a Model for Optimizing Non-identical Antenna Array Elements for DVB-T2 Broadcasting

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ABSTRACT

A Mathematical Model for Optimizing and simulating the effects of non-identical array element is developed. The analytical and numerical steps on which the Model is based are elaborated in detail in the paper. The observed results of the developed model and methodology used shows that it can be used effectively to Optimize the Linear Array Antenna having two elements. Based on the experiment conducted in this study; the array antenna is designed to transmitt waves in UHF and VHF frequency bands.

Keywords: *MoM, DVB-T2n, Gain*

1. INTRODUCTION

Television or TV is a telecommunication medium used for transmitting moving images in two or three dimensions and sound[1]. It can also refer to a television set, a television program ("TV show"), or the medium of television transmission. Television is a mass medium, for entertainment, education, news, and advertising in our societies. The television communication[2]. The television broadcasting system has moved from analog form of transmission to digital form of transmission. Currently the well known technique of television broadcasting is digital video broadcasting (DVB)[3]. DVB-T2 uses the Single Frequency Network (SFN) mode which is an attractive planning alternative to the well-known Multiple Frequency Network (MFN) mode[4]. SFN networks provide augmented spectrum efficiency as well as a quality of service improvement due to a more homogeneous distribution of the received signal strength over the coverage area. Nevertheless, some areas will also show degradation in practice[5]. Digital Video Broadcasting-Terrestrial second generation (DVB-T2) is developed from Digital Video Broadcasting - Terrestrial first generation (DVB-T) standard[6] ,in order to improve the performance of the SFN operation, the second generation broadcast system DVB-T2 standard incorporates Multiple Input Single Output (MISO) antenna diversity mechanisms. [4] conducted an empirical analysis and system level simulations analyzing the key factors affecting the Single Frequency network operation. A number of network architectures and network reference models are considered by [7] for different reception modes in order to study the effects of key planning factors on the maximum SFN size and minimum reuse distance. The results show that maximum bit rate, network size, and reuse distance are closely related. In addition, it has been found that the guard interval is not the only limiting parameter and that its impact strongly depends on the rest of DVB-T2 mode parameters as well as on the network characteristics (equivalent radiated power, effective height, and inter-transmitter distance). [8] presented the measurement process of DVB-T2 signal in an urban environment, and the simulations with a coverage calculation tool able to configure specific details of digital television signals and a detailed cartography. Empirical and simulations results were compared to determine additional settings and correction factors. A new positioning system using transmitter signature waveforms of DVB-T2 in Single Frequency Networks (SFNs) was proposed by [9]. Due to the wide coverage of the SFN and extremely high transmission power of digital television (DTV) transmitting stations, Array Antenna which has higher gain as well as multi-band operation characteristics can be considered as a promising complementary to remedy the poor coverage in dense multipath propagation environments.

The Model developed in this study is suitable to be used as a cost function in Genetic Algorithm so as to produce precise results. However, a lower and upper boundary of the parameter to be optimized must be set.

LITERATURE REVIEW

The next generation research on digital terrestrial broadcasting to enable large-volume content services such as 8K Super Hi-Vision was done by [10], the experimental station was installed for 8K transmissions in Hitoyoshi city, Kumamoto prefecture, Japan that uses dual-polarized multiple-input multiple-output (MIMO) technology and ultra-multilevel orthogonal frequency division multiplexing (OFDM) technology. Two 8K field experiments were conducted: a transmission test, and field measurements at 52 points in the Hitoyoshi area. In these experiments, achievement in carrying out the world's first terrestrial 8K transmission (91 Mbps) at a distance of over 27 km using only a single UHF (ultra-high frequency) channel (BW:6 MHz) was done. Also the study measured the required field strength for the 256QAM, 1024QAM, and 4096QAM carrier modulation schemes as well as the responses of dual-polarized MIMO transmission channels. In the advent of the conversion of analog to digital broadcasting, many of the countries including the Philippines have started adopting the standard for Digital Television (DTV) Broadcasting. Part of the set-up is a real-time in-campus digital TV broadcast facility which can be used for information dissemination for the school community. The broadcast facility operates at 479 MHz, ISDB-

T standard, 6 MHz BW, 13 segment 64 QAM with 1 W transmitting power. Optimum location for the four transmitting antenna in Mapua Intramuros Campus were identified by conducting indoor test measurements using signal level meter, signal level checker and one-segment mobile receiver. Three trial locations for the four proposed antenna positions were evaluated with a total of 2200 signal measurements. Field strength, delay profile, spectrum and constellations were measured and analyzed. Theoretical computations for field strength were compared to actual test results. A MATLAB program for contour mapping was provided for visual representations of signal spread. As expected, the experiment was able to prove the presence of interference, multipath and other factors like concrete and metal structures as well as human beings affecting the transmission and reach of each wall mounted antenna in a designated area. It is recommended to deploy additional Sky wallie antenna for campus wide coverage. Although, educational license allowed us to operate at 479 MHz with 1 W power, increasing transmitter power will improve signal coverage. In addition, increasing the number of test points will produce more accurate measurements[11]. The reviews of the main technical solutions adopted by the next-generation mobile broadcasting standard DVB-NGH, the handheld evolution of the second-generation digital terrestrial TV standard DVB-T2 was done by [12]. the study introduces main new technical elements with respect to DVB-T2 which are: layered video coding with multiple physical layer pipes, time-frequency slicing, full support of an IP transport layer with a dedicated protocol stack, header compression mechanisms for both IP and MPEG-2 TS packets, new low-density parity check coding rates for the data path (down to 1/5), non-uniform constellations for 64 Quadrature Amplitude Modulation (QAM) and 256QAM, 4-D rotated constellations for Quadrature Phase Shift Keying (QPSK), improved time interleaving in terms of zapping time, end-to-end latency and memory consumption, improved physical layer signaling in terms of robustness, capacity and overhead, a novel distributed multiple input-single output transmit diversity scheme for single-frequency networks (SFNs), and efficient provisioning of local content in SFNs. All these technological solutions, together with the high performance of DVB-T2, make DVB-NGH a real next-generation mobile multimedia broadcasting technology. In fact, DVB-NGH can be regarded the first third-generation broadcasting system because it allows for the possibility of using multiple input-multiple output antenna schemes to overcome the Shannon limit of single antenna wireless communications. DVB-NGH (Digital Video Broadcasting - Next Generation Handheld) is the next generation technology for mobile TV broadcasting, which has been developed by the DVB project with the most advanced transmission technologies. DVB-NGH is the first broadcasting standard to incorporate multiple-input multiple-output (MIMO) as the key technology to overcome the Shannon limit of single antenna communications. MIMO techniques can be used to improve the robustness of the transmitted signal by exploiting the spatial diversity of the MIMO channel, but also to achieve increased data rates through spatial multiplexing. [13] describes the benefits of MIMO that motivated its incorporation in DVB-NGH, reviews the MIMO schemes adopted, and discusses some aspects related to the deployment of MIMO networks in DVB-NGH. The study also provides a feature comparison with the multi-antenna techniques for 3GGP's LTE/LTE-Advanced for cellular networks. Finally, physical layer simulation results calibrated within the DVB-NGH standardization process are provided to illustrate the gain of MIMO for the next generation of mobile TV broadcasting. [14] did a review of the second generation of terrestrial digital video broadcasting standard (DVB-T2). DVB-T2 is the evolution of DVB-T and, together with DVB-S2 and DVB-C2, inaugurated a new transition from the first-generation digital broadcasting systems, similar to the transition from analog-to-digital systems. The study also presents a comprehensive review of the laboratory and field trial results available so far. Especial emphasis was placed in the results of the measurements carried out to test the mobile reception and the novel technologies as multiple input single output and time frequency slicing. To cope with increasing demands for spectral efficiency, multiple-input multiple-output (MIMO) technology is being considered for next generation terrestrial broadcasting television systems by [15]. The study propose a MIMO channel-precoder that utilizes channel statistical structure which is suitable for terrestrial broadcasting systems, while being potentially transparent to the receivers. The performance of the channel-precoder was evaluated in a wide set of channel scenarios and mismatched channel conditions. Capacity results show performance improvements in the case of strong line-of-sight scenarios with correlated antenna components and resilience against mismatched condition. [16] carried out the design of a digital transmitter infrastructure that utilizes new features DVB-T2 technology to provide Jabodebatek area TV digital broadcasting. To utilize the DVB-T2 features, three design options were proposed Option I use one transmitter, option II use two transmitters and option III use the four transmitters. All option was designed in order to meet the minimum operational parameters that have been set by the government. After designing all options is done, then compared the results technically and economically. Technical analysis was done by comparing the capacity and coverage of the population of each design, economic analysis is done by comparing the analysis of business each design using a calculation of payback period, NPV (Net Present Value) and IRR (Internal Rate of Return). It was concluded from the results that the design that use 4 transmitters is the most optimal to be implemented in the Jabodebatek area. The optimum design obtained 27.87 Mbps in capacity, 99.9% in population coverage (29,408,063 inhabitants) and IRR 9.64%. [17] studied a particular case which goes a step beyond the previous ones, as it aims at sharing the same frequency band in the same area between long term evolution-advance (LTE-A) and digital video broadcasting-terrestrial second generation (DVB-T2) technologies. Those geographical areas that are not covered because the useful DTT signal is obstructed by the environment or it has a limited coverage by the network design can be called “micro-TVWS.” [17] assumed that a DVB-T2 transmitter provides coverage for fixed rooftop reception as a primary service, to a building in our results provide the technical restrictions of the LTE-A femtocell, mainly on the maximum allowable effective isotropic radiated power that could transmit on the DTT band in terms of carrier separation, from co-channel

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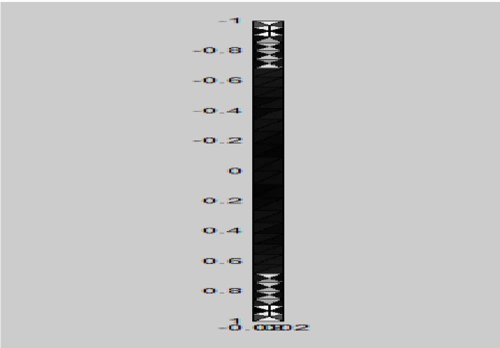
to adjacent band. These results meet the need of spectrum for IMT-Advanced technologies, so spectrum sharing was proposed as a new solution to make an efficient use of this resource

STRIP ANTENNA ANALYSIS USING MOM

The design of an antenna started with the observation using method of moments whereby we took a single strip and analyze it.

Figure 1: electric field density analysis



From the observation; we get the following parameters

Table 1: parameters observed

W	4.1760e-005	Radiation density
U	0.0010	Radiation intensity
Gain	2.1468	

The observation move to another step; the step which we identify the same parameters when the strip model is constructed as an array antenna with two elements as shown on the figure below.

Figure 2: Array element presentation

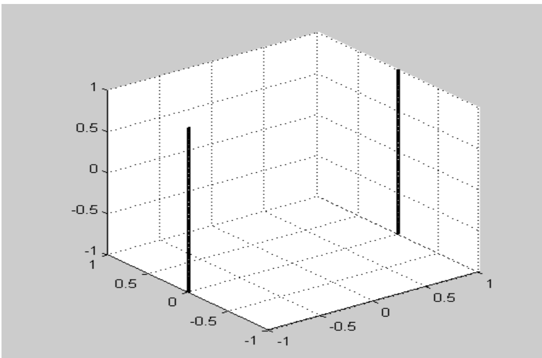
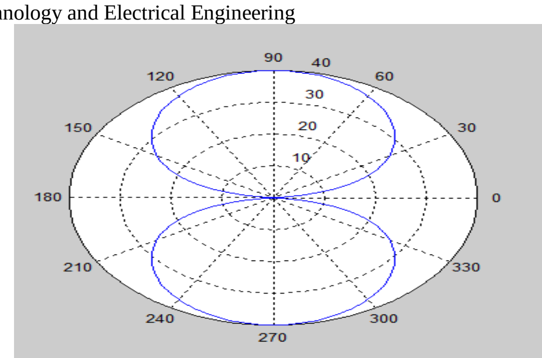


Table 2 : Array observed parameters

W	2.6640e-013	Radiation density (W/m^2)
U	2.6640e-009	Radiation intensity
Gain	5.9317	
Total Power	0.0145	

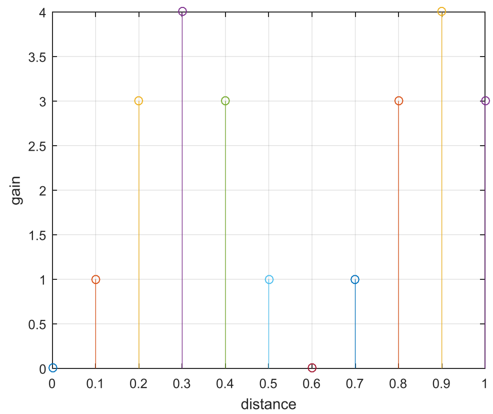
Figure 3:radiation pattern



EXPERIMENTAL STUDY BETWEEN ARRAY ELEMENT SPACING AND GAIN

The aim of this section is to conduct an experiment which will be able to compare the gain versus separation distance of the array elements. However, the pattern was also observed. The distance between the elements was taken from zero to one meter and the step size of the optimization was taken as 0.1 meter number of array elements was chosen to be two.

Figure 4: element spacing v/s gain optimization



Distance v/s Gain

from the figure above; it has been observed that, the maximum separation distance where the dipole antenna will produce a maximum gain is when the separation distance is 0.3 of a meter which is equivalent to 30 cm.

Model Development: Addressing Non-Identical Elements

From the model which was developed in this objective, we have the following equation to consider.

Length of the dipole $L = \frac{\lambda_g}{2}$

Also we have $\lambda = \frac{c}{f}$

Therefore we've; Length of the dipole equal to

$$L = 0.5 * \frac{c}{f}$$

The objective is to design an array antenna which will have non-identical elements which will enable it to produce resonance is two frequency bands. The first band is UHF-DVBT2 (500MHz) and VHF Band (230MHz).

For $f = 230MHz$

$$L = \frac{0.5 * 3 * 10^8}{230 * 10^6} = 0.652\ Meters \approx 65\ cm$$

for $f = 500MHz$

$$L = \frac{0.5 * 3 * 10^8}{500 * 10^6} = 0.3\ Meters \approx 30\ cm$$

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The next step is to find the electric field produced by a herzian dipole having a length of 65cm and 30cm. Since the array has only two-elements, then (N-1=1) and from the experiment conducted on the previous section; we've a value of d=0.3 (distance between array elements)

Then the array factor is expressed as;

$$AF(\theta,\vartheta)=\sum_{n=0}^{N-1}[B_n+C_n]e^{jn(kd\cos\theta+\beta)}$$

$$AF(\theta,\vartheta)=\sum_{n=0}^{1}[B_n+C_n]e^{jn(kd\cos\theta+\beta)}$$

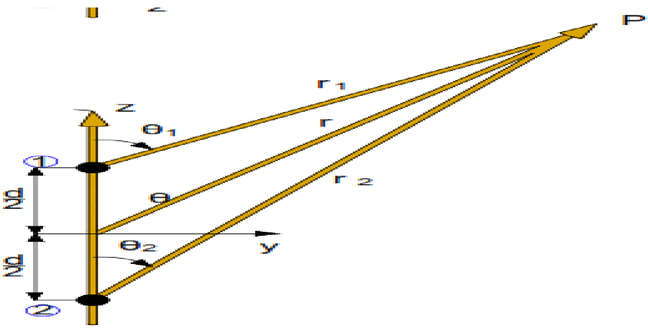
$AF(\vartheta,\theta)=$
$\sum_{n=0,d=0}B_n e^{jn(kd\cos\theta+\beta)}+\sum_{n=1,d=0.3}C_n e^{jn(kd\cos\theta+\beta)}$
$AF(\vartheta,\theta)=\sum\ B_0 e^{j*0(k*0*0*\cos\theta+\beta)}+\sum\ C_1 e^{jn(k*0.3*\cos\theta+\beta)}$
$AF(\vartheta,\theta)=\sum\ B_0+\sum\ C_1 e^{j(0.3k*\cos\theta+\beta)}$

from the above equation, we need to find the far zone of the two element array antenna in terms of electric field

$$B_0=E_1=M_1E_{n1}(\vartheta,\theta)\frac{e^{-j\left(kr1-\frac{\beta}{2}\right)}}{r1}\dot{\rho_1},$$

$$C_1=E_2=M_2E_{n2}(\vartheta,\theta)\frac{e^{-j\left(kr2-\frac{\beta}{2}\right)}}{r2}\dot{\rho_2},$$

Figure 5: observation figure at point P



where,

M field magnitudes

E_{n1} normalized patterns

$r1$ distance to the observation point

β phase difference between the two feeding points

ρ polarization vectors of the far-zone E fields

let us assume that:

1. The array elements are non-identical

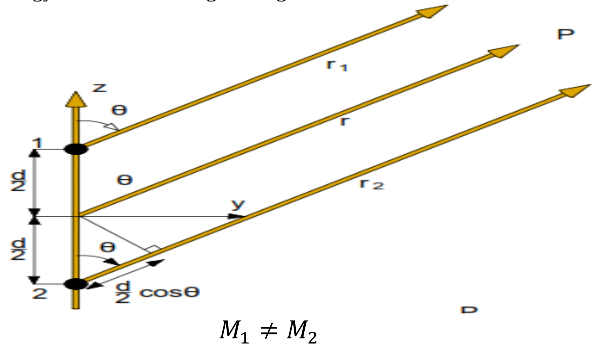
$$E_{n1}(\theta,\vartheta)\neq E_{n2}(\theta,\vartheta)$$

2. The elements are having identical polarization

$$\rho_1=\rho_2=\rho$$

3. The excitation amplitude isn't the same

Figure 6: array element observations



$$M_1\neq M_2$$

The total field is expressed as follow;

$$E\ =E_1+E_2$$

This leads to the following expression

$$E=M_1E_{n1}(\vartheta,\theta)\frac{e^{-j\left(kr1-\frac{\beta}{2}\right)}}{r1}\dot{\rho_1}+M_2E_{n2}(\vartheta,\theta)\frac{e^{-j\left(kr2-\frac{\beta}{2}\right)}}{r1}\dot{\rho_2}$$

$$r_1=r-{}^{d}/_{2}\cos\theta$$

$$r_2=r+{}^{d}/_{2}\cos\theta$$

substituting the values we get;

$$E=M_1E_{n1}(\vartheta,\theta)\frac{e^{-jk\left((r-{}^{d}/_{2}\cos\theta)-\frac{\beta}{2}\right)}}{r}\dot{\rho_1}+M_2E_{n2}(\vartheta,\theta)\frac{e^{-jk\left((r+{}^{d}/_{2}\cos\theta)-\frac{\beta}{2}\right)}}{r}$$

$$E=\frac{\hat{\rho}}{r}\left[M_1E_{n1}(\vartheta,\theta)\frac{e^{-jk\left((r-{}^{d}/_{2}\cos\theta)-\frac{\beta}{2}\right)}}{1}\dot{+}M_2E_{n2}(\vartheta,\theta)\frac{e^{-jk\left((r+{}^{d}/_{2}\cos\theta)-\frac{\beta}{2}\right)}}{1}\right]$$

$$E=\frac{\hat{\rho}}{r}e^{-jkr}\left[M_1E_{n1}(\vartheta,\theta)e^{-jk\left(r-{}^{d}/_{2}\cos\vartheta\right)+j{}^{\beta}/_{2}}+M_2E_{n2}(\vartheta,\theta)e^{-jk\left((r+{}^{d}/_{2}\cos\theta)-\frac{\beta}{2}\right)}\right]$$

$$E=\frac{\hat{\rho}}{r}e^{-jkr}\left[M_1E_{n1}(\vartheta,\theta)e^{j\left(\frac{kd}{2}\cos\vartheta+\frac{\beta}{2}\right)}+M_2E_{n2}(\vartheta,\theta)e^{-j\left(\frac{kd}{2}\cos\vartheta+\frac{\beta}{2}\right)}\right]$$

The array factor of the two element having the same excitation and identical element is expressed as follow;

$$AF=2\cos\left(\frac{kd\cos\vartheta+\beta}{2}\right)$$

$$\text{let } A=\frac{kd\cos\vartheta+\beta}{2}$$

$$AF=2\cos A$$

$$E=\frac{\hat{\rho}}{r}e^{-jkr}[M_1E_{n1}(\vartheta,\theta)e^{jA}+M_2E_{n2}(\vartheta,\theta)e^{-jA}]$$

From

$2\cos A=e^{jA}+e^{-jA}$
$2\cos A=e^{jA}+e^{-jA}$
$e^{jA}=2\cos A-e^{-jA}$
$e^{-jA}=2\cos A-e^{jA}$

$$E=\frac{\hat{\rho}}{r}e^{-jkr}[M_1E_{n1}(\vartheta,\theta)(2\cos A-e^{-jA})+M_2E_{n2}(\vartheta,\theta)(2\cos A-e^{jA})]$$

Assuming that;

$2\cos A-e^{jA}\approx 2\cos A=AF$

Hence, the final expression is as follow;

$$E=\frac{\hat{\rho}}{r}e^{-jkr}[M_1E_{n1}(\vartheta,\theta)(AF)+M_2E_{n2}(\vartheta,\theta)(AF)]$$

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$$E = (AF)\frac{\hat{\rho}}{r}e^{-jkr}[M_1E_{n1}(\vartheta,\theta) + M_2E_{n2}(\vartheta,\theta)]$$

$$E = (AF)\left[M_1E_{n1}(\vartheta,\theta)\frac{\hat{\rho}}{r}e^{-jkr} + M_2E_{n2}(\vartheta,\theta)\frac{\hat{\rho}}{r}e^{-jkr}\right]$$

$$E = \left[2\cos(\frac{kd\cos\vartheta + \beta}{2})\right]\left[M_1E_{n1}(\vartheta,\theta)\frac{\hat{\rho}}{r}e^{-jkr} + M_2E_{n2}(\vartheta,\theta)\frac{\hat{\rho}}{r}e^{-jkr}\right]$$

$$E = \left[2\cos(\frac{kd\cos\vartheta + \beta}{2})\right][EF1 + EF2]$$

$$M_1E_{n1}(\vartheta,\theta)\frac{\hat{\rho}}{r}e^{-jkr} = \text{Electric Field of Element } 1(EF1)$$

$$M_2E_{n2}(\vartheta,\theta)\frac{\hat{\rho}}{r}e^{-jkr} = \text{Electric Field of Element 2 } (EF2)$$

$$E = \left[2\cos(\frac{kd\cos\vartheta + \beta}{2})\right][EF1 + EF2]$$

$$E = (AF)[EF1 + EF2]$$

The above model shows that; the far field is the Product of Array Factor of two array element with the sum of electric fields of individual elements.

INVESTIGATION ON THE DEVELOPED MODEL

This part, entails to analyze the contribution of the non-identical elements on the developed model. A Matlab software will be used for programming the model and graphs will be used for analysis.

from the equation

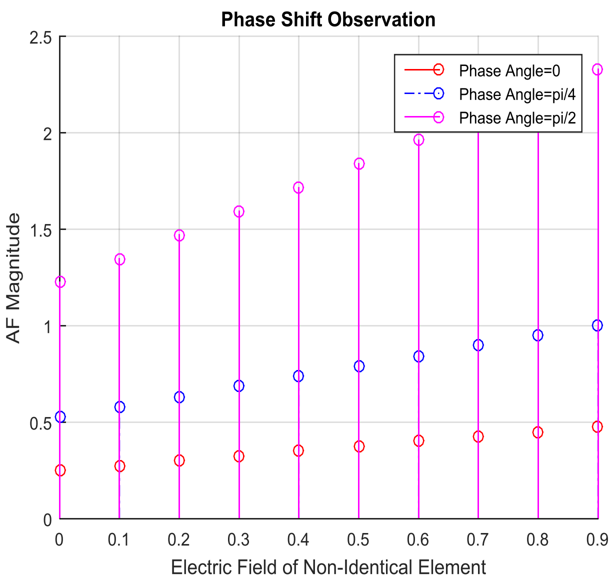
$$E = \left[2\cos(\frac{kd\cos\vartheta + \beta}{2})\right][EF1 + EF2]$$

since □ = $2□/□$ and □ = $□/□$

Assumption for β ranges from $0, □/4$ □□□ $□/2$

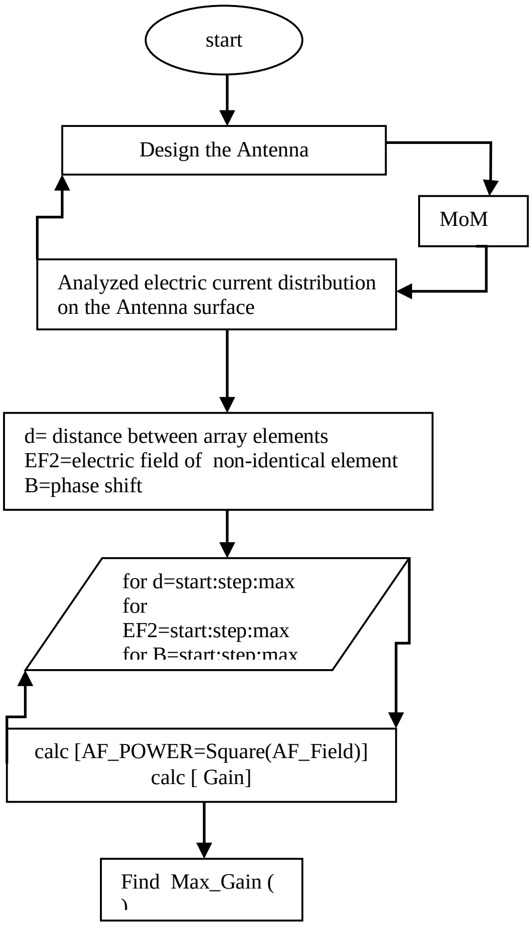
An optimization technique which uses iterative was developed and programmed using Matlab; purposely for observing the effect of the phase shift between the element on the magnitude of the Electric Field

Figure 7: Element Phase Shift Optimization



From the figure above, it is shown that; the phase shift $\frac{\pi}{2}$ produces higher magnitude compared to the other phase shift.
AF_power= AF_Field.^2
Gain =20*log10 (abs(AF_power))

Developed Optimization Algorithm/Model



The flow-chart above presents the algorithm which was designed and then developed in this study to optimize the antenna specifically with non-identical elements. The first step was to design the antenna and then use the method of moments to evaluate the electric current distribution on the antenna surface. After the required current distribution is obtain; the model developed in this study was optimized for array element spacing, phase shift between the elements and last the magnitude of the non-identical element.

RESULT PRESENTATION & DISCUSSION

The following table presents the results which are observed in this experimental study. The results presented are;

AF_field (avg)	Power Gain	Distance	Phase Shift
6.7600	8.2995	0.3	$\pi/2$
Model	$E = \left[2\cos(\frac{kd\cos\vartheta + \beta}{2})\right][EF1 + EF2]$		

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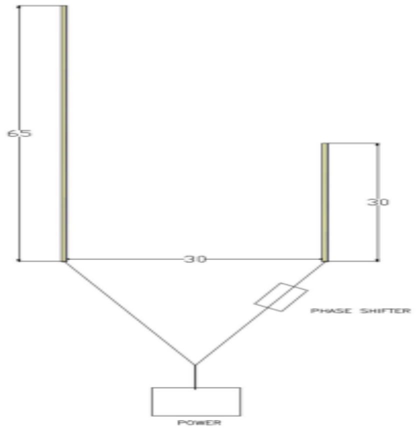
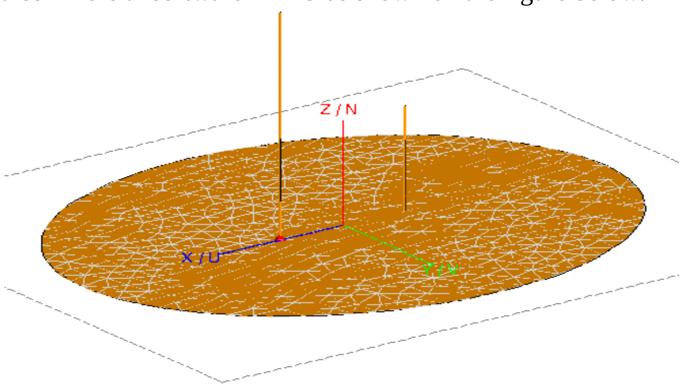
Figure 8: Antenna Mounting



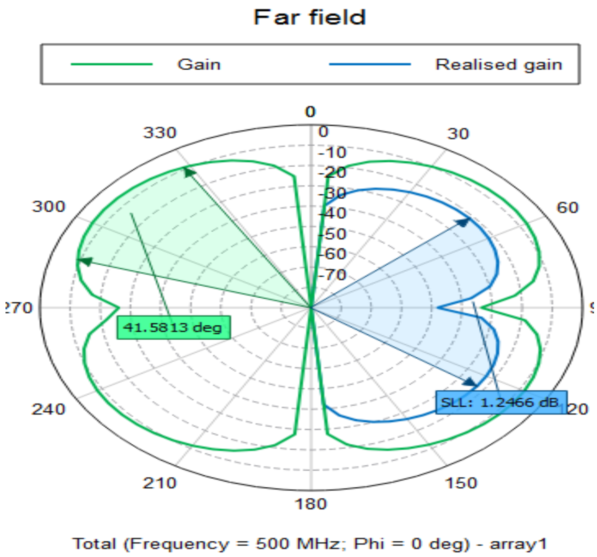
In this study; Optimization model was developed and presented. Taking into the assumption that; the element are non-identical and the excitation as well as the phase is different. In this study, an experimental procedure and a model for optimization of dipole array antenna is conducted. A two element dipole transmitting antenna for VHF Band was created and optimized using Method of moment. The first-step the dipole array was tested for eletric field density on its surface (taken as a strip antenna) and then optimized for maximum element spacing which will produce maximum gain. The result for the maximum gain was presented and then followed by the development of a model which will be used for optimizing array element having non-identical element. The developed model produces appreciable results for the needed antenna peformance parameters.

VERIFICATION OF THE MODEL USING COMMERCIAL SOFTWARE (FEKO)

The verification of the Proposed model was implemented using a commercial software FEKO as shown on the figure below.



The Simulation results shows that; A Gain of 6 dBi was achived with a minimum SLL of 1.2466 dB and a half power bandwidth of 45 degrees.



FUTURE WORK

Since this paper takes into consideration only on two elements of the array. The future work of this study is to develop a model which can be used to optimize Array antenna having more number of elements but also it will consider other array geometries such as rectangular and circular.

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