Request for Proposal (RFP) Telecommunications-Based Research Innovation from Academic in Nigeria Tertiary Institutions- August 2020

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1. Research Title

Design and Fabrication of Metamaterial Inspired UWB/MIMO Antenna for 5G sub 6GHz Applications.

2. Executive Summary of the Research

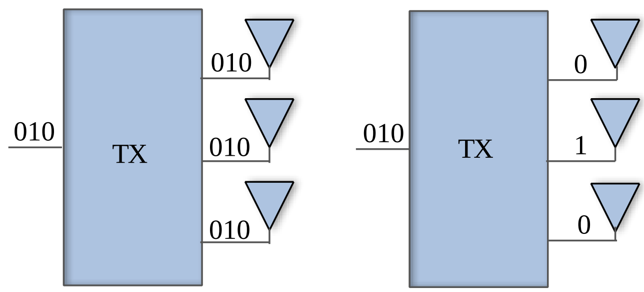
Wireless Communication and radar systems are among the leading technologies that have made a significant impact on the society. How to serve more number of users with better performance considering the fact that there is a limited available frequency bandwidth and transmission power, is these days' key points in wireless communication industry. To have a better performance some have sought to dynamically allocate the operable spectrum, called spectrum collaboration, or increase the operable spectrum by operating at millimeter frequency range which is proposed for fifth generation (5G). The above two techniques are cost effective but the option which almost has no cost attached to it, is to the technologies that make effective use of the useable spectrum. Example of this technologies are multiple-input-multiple-output (MIMO) methods and full duplex radio. MIMO system is a more popular choice because, without offering more frequency spectrum channel capacity and multiplexing efficiency can be vastly raised. Microstrip patch antennas compared with traditional microstrip antennas are small, ease, easy to produce and they are effectively coordinated in to versatile radio and wireless communication applications. The fundamental limitation of microstrip antennas are lower gain and low impedance width which can be improved by using metamaterial as part of several techniques. A miniaturized antenna for portability and cost reduction is needed. Therefore, this research work proposes the design of 2-element and four-element MIMO antenna array for wireless communication applications. Moreover, the proposed integration of a metamaterial structure with the MIMO antenna array have the advantage of multiple band operation, isolation enhancement, size reduction, high gain, and MIMO metric performance. The diversity analysis which includes envelope correlation coefficient (ECC), channel capacity loss (CCL), diversity gain (DG), total active reflection coefficient (TARC), mean effective gain (MEG), and total efficiency will be presented and discussed. The results are expected to provide good diversity performance. A computer simulation technology (CST) software with FR-4 substrate will be employed throughout the design. The transmission coefficient, radiation far-fields, current distribution and diversity parameters will be presented. Finally, a prototype will be constructed, tested and measured using vector network analyzer (VNA) for S_{11} and anechoic chamber for radiation far-fields and gain. The estimated cost of this research work is eleven million, eight hundred and ninety-four thousand, one hundred and seventy-three naira, seventy-kobo only (#11,894,173.70).

3. Literature Review

Any microstrip structure is finite in dimensions; i.e. its ground level and its dielectric substrate are bounded in the transverse directions. The edges may however, be located at a very large distance, in which case this third inhomogeneity may be neglected (the structure is then assumed mathematically broaden to infinity). Models used to study microstrip patch antenna range from very simplified ones, such as the transmission-line, through cavity models, planar circuit analysis, segmentation techniques and up to quite sophisticated approaches based on integral equation formulation [1].

In communication, the diversity pattern is the technique for enhancing the accuracy of message signal [2]. There are many different kind of diversity schemes: time diversity separates the transmit signal by different time, frequency diversity uses several frequency spectrums to transmit and receive. In MIMO structure, there are two type of methods used to improve the performance. Spatial diversity transmits same data to the beneficiary. Different transmitted antenna has different location. At receiver, various duplicate of a similar signal is received through independent channels. Due to different channel paths, each gotten signal will have experienced distinctive fading. These received signals are then correlated to determine the signal that was transmitted. At receiver, various duplicate of a similar signal is received through independent channels. Due to different channel paths, each gotten signal will have experienced distinctive fading. These received signals are then correlated to determine the signal that was transmitted. This procedure can improve the reliability of the communication system. It likewise improves the signal-to-interference-noise ratio and bit-error-rate [3], [4].

The other method is spatial multiplexing, the raw signal separates into small portion and transmits to the receiver. The different portion signal is communicated by different propagation avenue. The MIMO orthogonal frequency division multiplexing (OFDM), uses this technique to cut signal to small pieces and do modulation and demodulation in sub-channel. If the environment provides enough scattering surroundings, small portion of independent sub-channels can transmit in the same allocated bandwidth. Then, the multiplexing gain can transmit without additional cost for filters and power amplifiers. Spatial multiplexing can revamp the information proportion of the correspondence system. Degree of freedom means the quantity of autonomous channel that can be utilized by the transmitter. In spatial multiplexing, degree of freedom is determined as the quantity of autonomous channels which transmit different bits in the communication system [5], [6]. Figure 3.1 shows the example of different antenna diversity in MIMO system. Figure 3.1(a) shows the spatial diversity that same signal is transmitted to embellish the reliability and accuracy. Figure 3.1(b) shows the spatial multiplexing that signal is cut into small portion to increase data rate.



(a) Spatial diversity (b) Spatial multiplexing

Figure 3.1 Antenna diversity

There are varied kind of wireless correspondence which is pictured in Figure 3.2 [7]. First, Single input single output (SISO) is the straightforward and most basic communication which is presented in Figure 1.3(a). The pair of transmitter (Tx) and receiver (Rx) can transmit signal. The advantage of this technique is its simplicity. It doesn't need extra post-processing. The disadvantage is it has less efficiency since one antenna can only transmit to one receiver. If there are many users, it needs to have many transmit and receive antennas, which is costly. Second, Single input multiple output has a single transmit antenna and multiple receiving antennas which is shown in Figure 1.3(b). The advantage is that; it can receive independent signal. It is noticed that it needs to have post-processing component. If the receiver is mounted in mobile phone, the size is limited and battery capacity will be the other issue. We have two architectures to be used in single input multiple output: one is to detect the direction of strongest signal and switch to that antenna. The other is combine two signals into one to have stronger signal. The fading effect also needs to take into concern to avoid distortion signal. If fading effect is solved, it could have better signal-to-noise ratio to get more accurate signal.

Third, Multiple input single output means by transmitting same data through various receiving wires but only be received by one antenna, which is shown in Figure 1.3(c). The benefit of this technique is that, the transmitter has the duty of signal processing. Generally speaking, the transmitter has the larger structure which can offer more complicated and heavy task, so the processing can be done by transmit part. It can curtail the power utilization for the receive part such as cell phone. Finally, MIMO uses more than one reception apparatus at the transmit port and receive port to increase the throughput capacity, which is shown in Figure 1.3(d).

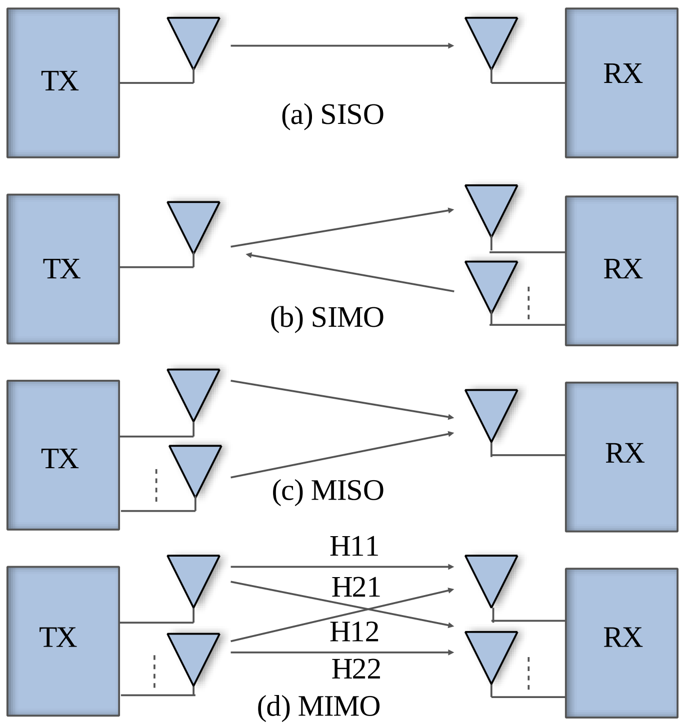


Figure 3.2 Various types of wireless communication.

3.1 Multiple-Input-Multiple-Output (MIMO) Antenna

The present 4G, 5G and sub 6GHz wireless communication systems, require antenna components with multifunction for better performance and cost reduction. For that, it is necessary to have antenna with enhanced bandwidth, channel capacity, gain and diversity performance. Before keying in to these parameters, lets explain briefly the concept of MIMO system using figure 3.3. Deployment of multiple antennas at both links gives the capability to gest other advantages than MIMO/diversity gains. MIMO techniques can be characterized when multiple antennas are used at both transmitting and receiving end [8], [9]. The main idea on the use of MIMO system is that sampled signals in the spatial terrain at both terminals are integrate to elevate the data rate, enhance the quality of the communication and create concrete multiple parallel spatial information. Geometric area is the advantages of using multiple antenna because the spatial geometric occur as a complement to time.

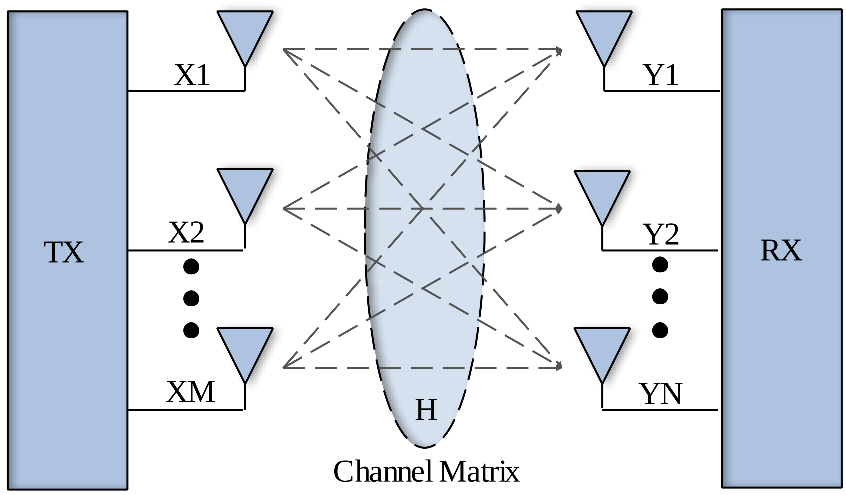


Figure 3.3 Annotative illustration of a MIMO system

The technique to increase wireless system capacity was first investigated in 1990's and since then, it has been under research worldwide [10] – [15]. Until the 1990's utilizing multiple antennas at one end of the terminal was mainly for the diversity and estimation of directions of arrival, which leads to spatial MIMO/diversity and beamforming. Concentrating the energy to a desired direction increases the signal-to-noise ratio (SNR) which is termed as beamforming in the existence of random fading caused by multipath propagation, the signal to noise ratio, will be enhanced by adding the output non correlated antenna element, this is the main idea of space diversity.

To verify the capability of MIMO antenna systems, some important parameters need to be considered. These parameters are calculated from S-parameter results, far-field among others. Matlab is used for this purposed after extracting the S-parameters from computer simulation technology.

3.2 Shanon-Hartley Theorem

In 1948, Shannon raised an equation that it can calculate the upper boundary of wireless link which is defined as capacity of a discrete channel and its unit is bits over second [16]. The mathematical expression is written as

$$C = B\log_2\left(1+\frac{S}{N}\right) \tag{3.1}$$

where B is the data transfer capacity of channel with unit Hertz, *S* is the received signal control at receiver with unit Watts, and *N* stands for noise power. The thought of *S/N* can be figure out as SNR. It's difficult to have the exact value of noise in reality, so additive white gaussian noise is commonly used to simulate the random noise. This equation can clearly explain that bandwidth is dominating the maximum capacity of channel. With the SNR become larger, it can provide exponential increase; however, in the real world, it is hard to provide such a high gain. One reason is the control source from handset cannot provide high gain. The other reason is if the device provides high gain, it will increase the unnecessary interference between each link and might be harmful to human body. Federal communication commission (FCC) has a clear definition about the bandwidth of different telecommunications carriers and signal absorption rate for measuring the power absorbed by human tissue.

In SISO, the greatest channel limit is restricted because only one antenna supports the signal strength. MIMO can improve power density since the signal strength is supported by multiple antennas. It needs to mull over that noise power increases if MIMO receive the interference of other antenna. Assume the power received by the *kth* antenna, the equation can be rewritten as [17].

$$R_K = H_K T_K + \sum_{i=1, i\neq k}^{m} H_i T_i + W \tag{3.2}$$

where $H_K T_K$ is desired signal, $H_i T_i$ are interference signal from antennas which are transmit to different receiver, and w is additive white Gaussian noise. The carrier symmetrical frequency OFDM isolates signal to different sub-signal, does modulation and demodulation at different frequencies, and combines sub-signal together. Through this method, it can not only increase the SNR, but also have wider bandwidth to increase the channel capacity.

3.3 Envelope Correlation Coefficient

It's hard not to mention about envelope correlation coefficient (ECC), when the parameter of MIMO is discussed. ECC becomes the standard parameter for MIMO structure. The interference signals which transmit to other receiver are regarded as noise for specific antenna. ECC is the correlation between two antennas. It is defined as [18].

$$\rho_{ECC} = \frac{\iint_{4\pi} E_1(\theta,\phi)\cdot E_2^*(\theta,\phi)d\Omega}{\sqrt{\iint_{4\pi} E_1(\theta,\phi)\cdot E_1^*(\theta,\phi)d\Omega \iint_{4\pi} E_2(\theta,\phi)\cdot E_2^*(\theta,\phi)d\Omega}} \tag{3.3}$$

E_1 and E_2 stand as the far-field behaviors from antenna 1 and antenna 2, respectively. The target is to have lower ECC to provide appropriate S_{21} so that it can have better SINR. The lower ECC, the higher data throughout can be provided in MIMO structure. There is another calculation for ECC. It can be easier calculated by knowing the S-parameter of S_{11}, S_{12}, S_{21}, and S_{22} and efficiency η1 and η2.

$$\rho_{ECC} = \frac{S_{11}S_{12}^* + S_{21}S_{22}^*}{\sqrt{\left(1-|S_{11}|^2-|S_{21}|^2\right)\left(1-|S_{22}|^2-|S_{12}|^2\right)\eta_1\eta_2}} \tag{3.4}$$

(3.4) is well-founded if the losses between two receiving wires are either autonomous or have low loss correlation that can be ignored. Equation (3.4) has less calculation than (3.3) and easy to measure the S-parameter through vector network analyzer, less accuracy and difficulty to have antenna efficiency will become the challenge for (3.4).

3.4 Diversity Gain

The diversity gain is another criterion that can be utilized to verify the capability of the MIMO framework. The diversity gain is related to ECC through the following equation

$$G_{app} = 10 * \sqrt{1-|ECC|} \tag{3.5}$$

In practical MIMO applications diversity gain tends to be 10dB. In later chapter we will present more examples of various diversity gain of some MIMO antennas.

3.5 Mean Effective Gain

For a multiport receiving wire framework, the mean effective gain can be characterized as the proportion of mean received power from the reception apparatus along some arbitrary course to the mean incident power to the antenna along the same route and can be represented as [19], [20].

$$MEG_n = \frac{P_{rec}}{P_{inc}} = \oint \left[\frac{XPD.G_{\theta n}.P_{\theta n} + (1+XPD).G_{\varphi n}.P_{\varphi n}}{1+XPD} \right] d\Omega \tag{3.6}$$

Where XPD is the cross-polarization discrimination of the incident signals, G_θ and G_φ are the gain polarized components, P_θ and P_φ represent the channel model, and Ω is the solid angle. Like ECC, mean effective gain of the receiving wire can likewise be acquired by utilizing commercial EM simulation apparatus. To establish a good diversity performance, the MEG ratio $\left| MEG_i / MEG_j \right|$ of the multiple antennas should be approximately unity and should not exceed ± 3dB.

3.6 Total Active Reflection Coefficient

Total active reflection coefficient (TARC) is characterized mathematically as square root of the accessible power created by all excitations minus transmitted power, divided by the available power as equation [21], [22].

$$\Gamma_a^t = \sqrt{\frac{availablepower - radiatedpower}{availablepower}} = \sqrt{\frac{P_a - P_r}{P_a}} \tag{3.7}$$

For example, N array antennas have active impedance at the X^{th} port, the TARC can be calculated by

$$\Gamma_a^t = \sqrt{\frac{1-P_{rx}}{1}} = \sqrt{\sum_{j=1}^{N} \left| S_{ij} \right|^2}, i = 1,2,....., N \tag{3.8}$$

For a lossless reception apparatus, the TARC can be resolved by utilizing $S_{p.}$ For a given excitation [a] the Γ_a^t, as a part of frequency is

$$\Gamma_a^t = \frac{\sqrt{\sum_{i=1}^{N} \left| b_i \right|^2}}{\sqrt{\sum_{i=1}^{N} \left| a_i \right|^2}} \tag{3.9}$$

where

$$[b] = \lfloor S_p \rfloor [a] \tag{3.10}$$

The TARC is a real number somewhere in the range of 0 and 1. The estimation of the TARC equivalent to zero implies all the conveyed power is emanated and is equivalent to one methods all power is either reflected back or advance to different feeding port.

3.7 Channel Capacity Loss

Channel capacity loss (CCL) can be defined as a data rate that can be supported in a particular channel and that channel is a fading environment. Considering a high SNR value, CCL can be evaluated from either measured or simulated S-parameters using the equation below

$$CCL = -\log_2 \det\left(\varphi^R\right) \tag{3.11}$$

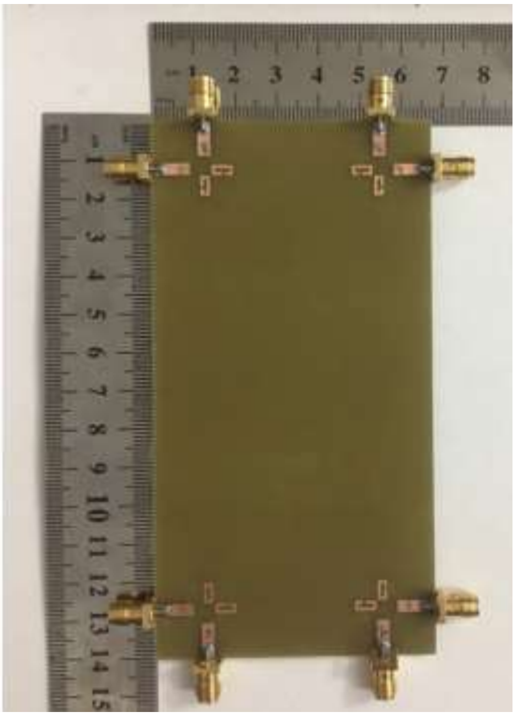
3.8 Multiplexing Efficiency

Multiplexing efficiency is a criterion that represents a power related measure of a MIMO array antenna in a high signal to noise ratio environment SNR at the receiver sides. This is used in spatial multiplexing as presented in the later chapter where we will see how decoupling structure improved the multiplexing efficiency of the proposed MIMO antenna.

3.9 Limitations of MIMO Antenna System

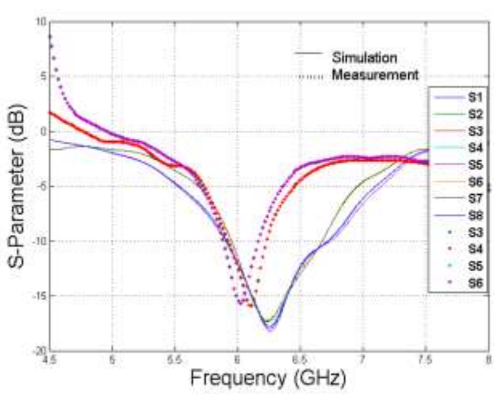
As mentioned earlier that MIMO systems promises an increase in channel capacity without offering additional spectrum of frequency and transmitted power, as we will see, many factors could undermine the system performance, this is especially true in compact devices, because of many constraints imposed on MIMO antenna design due to some limitation in terms of area and electromagnetic interaction between the MIMO elements called mutual coupling and antenna physical limit. Several literatures are available on the methods for improving the performance of MIMO. For the purpose of reduction in electromagnetic interactions and larger space between the radiating elements some researchers used various innovative techniques known as defected ground structure [23] – [25], parasitic elements [26], neutralization line [27], [28] and electromagnetic band gap (EBG) configurations [29], [30].

The design of [31] presented a wide impedance width MIMO antenna for 5.8GHz WLAN application. The author used a unit cell metamaterial structure to obtain the high isolation, but the design is 2 x 2 MIMO antenna. However, in [32] split rectangular loop resonator inspired MIMO monopoles for GSM/LTE/WLAN applications is presented with high isolation of -20dB, but the design is not compact. A single band MIMO antenna is presented in [33], the method employed for enhancing the isolation between the antenna elements was mesh type resonator and this kind of resonators, better controllability of the gap capacitance will not be unveil. A dual polarized four port MIMO antenna was investigated in [34]. However, the design is not compact and does not support the lower band of WLAN application. The structure is depicted in Figure 3.4. The comparison summary of some existing literature in MIMO antenna design is shown in table 3.1, it can be seen that most of the work reported are not compact as compared to our proposed design. Our work will cover UWB frequency range from 2.6 – 12GHz with a miniaturized radiating element size and compactness.

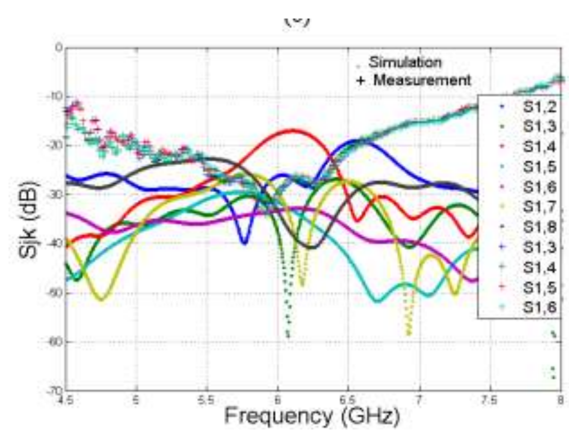


(a)

(b)



(c)



(d)

Figure 3.2 (a), (b) Fabricated prototype, (c) (d) Simulated and measured S-parameters

3.10 Statement of the Problem

The planar monopole antenna has acquired significant attention in communication system [35] - [36]. Many features are offered by these types of an antenna including the compactness, ease of consolidation with microwave circuits, small size, the capability to support multiband/wideband and UWB operation. The antenna consists of a planar metallic radiator printed on a dielectric substrate and fed by either transmission line, coaxial cable or coplanar waveguide. Different forms of MIMO monopole antennas have been proposed to enhance the performance in terms of bandwidth and isolation [37]. The low power requirements of the UWB system has earned important attention in wireless high data rate usage [38]. In view of that, the federal communication commission has dispensed an unlicensed frequency spectrum of 3.1-10.6 GHz for UWB frameworks [39]. One of the factor that affect the output of UWB system is the limited channel capacity. MIMO techniques presents a solution to overcome this challenges [40], Deployment of multiple antennas increases channel capacity and transmission range [41] - [42]. 5G will operate in the millimeter-wave spectrum although there is a significant path loss in that frequency as compared to the sub 6GHz spectrum [43]. Why MIMO? It is all about the channel capacity of the system whereby the channel capacity depends on bandwidth and signal to noise ratio. How do we increase the channel capacity of the system, is either we increase the bandwidth of the system which sometimes is not easy due to resource limitations or we can work on the signal to noise ratio, these two options are amendable to increase the channel capacity of the system. Metamaterials are used as a protective measure between two radiating elements to control and limit propagation among antenna elements and minimize the electromagnetic interaction among them [44], [45]. A letter was presented in the use of compact dual band 2x1 metamaterial inspired MIMO antenna system with high port isolation for LTE and WIMAX applications in [46], in which each element has a square-ring slot radiator surrounding a complementary split ring resonator. The use of complementary split ring resonator (CSRR) has been researched in [47] and [48], where the CSRR used to lower the resonant frequency of the radiating element as well as to achieve multiple resonance. Antenna arrays have more advantages in terms of high gain and pattern synthesis over single element radiators due to its simplicity in design and high performance. However, the distance covered by antenna array is far more than the single element as lower gain radiators are less efficient in radio frequency communication.

4. Proposed Solution

To develop a novel miniaturized UWB/MIMO antenna which can cover a wider range of frequencies is proposed.

Table 3.1 Comparison of the proposed 4x4 MIMO antenna with other planar MIMO antennas

Preference	No. of Elements	Size (mm^2)	Isolation	Method
[31]	2	40 x 80	-20	RLR
[32]	2	70 x 120	-20	Stub
[33]	2	30 x 52	-48	EBG
[34]	4	67 x 139	-15	Mesh Resonator
This work	**4**	**30 x 80**	**-30**	**RLR**

- **Research Objectives**

As discussed in the previous sections, the challenges faced by the MIMO wireless systems are hereby identified and proper objectives are defined to carry out the research. Figure 4.1 highlights the problems, solutions and steps to be taken in the proposed metamaterial inspired MIMO antenna design.

To achieve a high isolation and UWB/MIMO antenna, a stub loading technique and metamaterial structure in form of rectangular loop resonator is here by proposed. Thus, the main objectives of this research work are as follows.

1. To design a compact UWB/MIMO antenna consisting of metamaterial unit cell

2. To design a single UWB/MIMO antenna

3. To design a 4 x 4 UWB/MIMO antenna with high gain and isolation

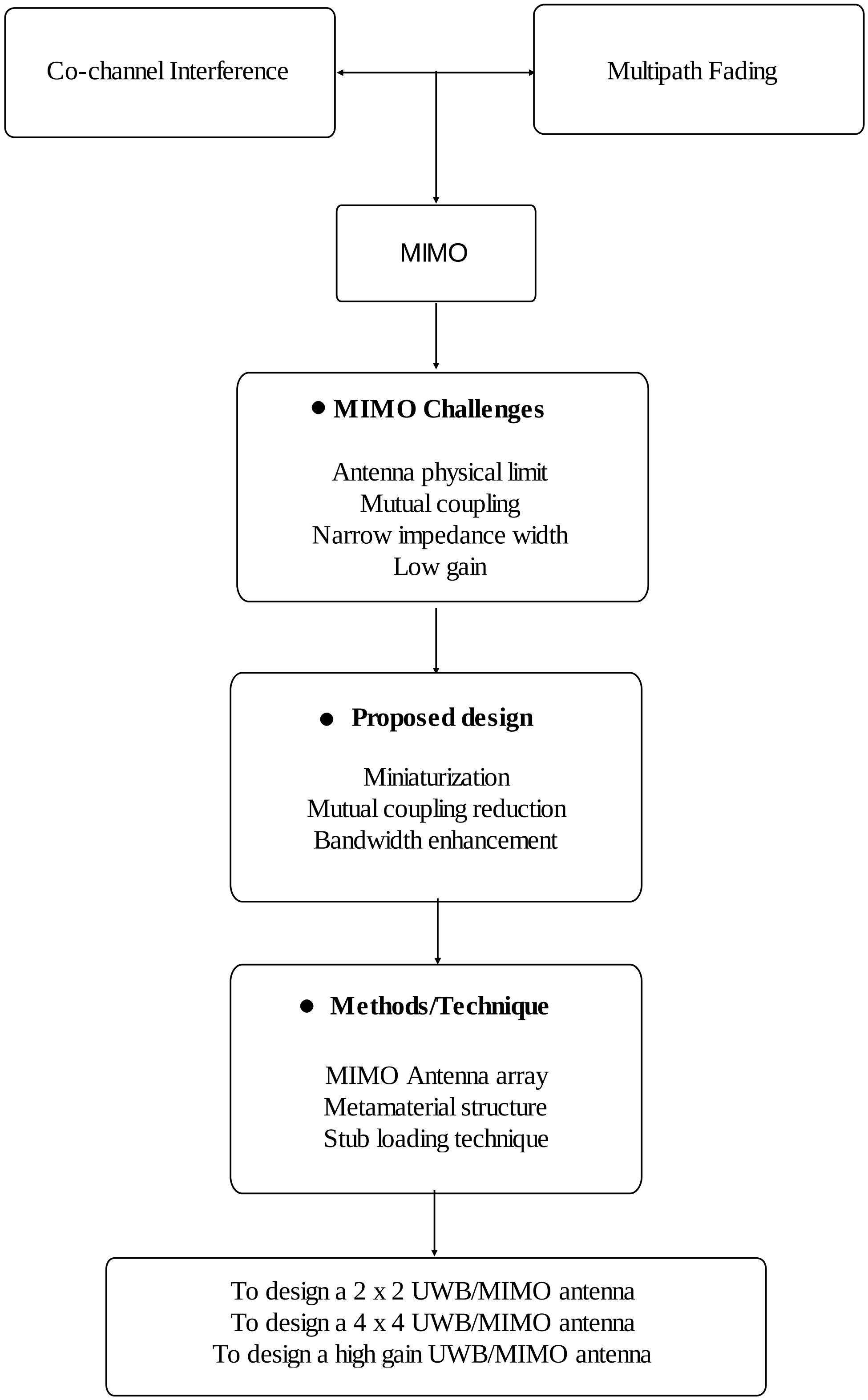


Figure 4.1 Formulation of problem statement.

5. Novelty of the research

The novelty of the research is to deal with how to reduce the mutual coupling effect of 2 x 2 UWB/MIMO antenna and 4 x 4 UWB/MIMO antenna using metamaterial structure in form of rectangular loop resonator. A few attentions were given to improve the gain of the MIMO antenna systems with low mutual coupling between the MIMO elements. The reason why we will use metamaterial is because, they provide a negative permittivity which will lead to enhancement of inter-element isolation of MIMO elements.

6. Methodology, proposed approach

The design of UWB/ MIMO antenna for 5G sub 6GHz application involves several stages with which one stage depends on the other. Various stages including the design is hereby suggested. Parametric analysis using optimization tools is required for parameter optimization. After the design and simulations, fabrication and measurements are the key parameters in validating the simulated results. Thus, fabrication process requires the use of materials, UV machine, chemicals and etching machine. In this design, all appropriate measures and procedures will be taken and outlined to undertake the fabrication. Furthermore, measurements of the fabricated antenna are another step to validate the simulated results and designs. There are number of equipment for measuring the performance of the fabricated antenna. With the invention of latest, accurate and efficient VNA network analyzer. However, the availability of such devices is another setback for the research. It is expected to use such for better results and presentation. The outline below presents the necessary steps in the suggested research.

❖ Characterization of high gain UWB/MIMO antenna

- Literature review
- Research concept
- Design and simulation
- Fabrication and measurements
- Analysis and implementation
- Comparison summary
- Conclusion

7. Proof of concept (Feasibility of idea with diagram, algorithm etc.)

The design methodology has been elaborated in the previous section. Various section in the design process is presented and discussed, with the successful completion and deployment of the antenna the proposed prototype can be feasibly applied in many areas of wireless communication. This can be proved by deploying the proposed design in the areas where high data transfer is required such as high transfer of information for upload and download security surveillance system, instant messaging etc. Although, these services are provided by the service providers (internet, GSM, GPS etc.). But, the need to enhance the services as a result of the signals been affected by high buildings, trees, geographical nature of the land or terrain. Thus, the efficiency of the services in the important places such as schools, libraries, administrative blocks, offices and banks are greatly affected. To mention but few, low output productivity, user and customer frustration and low revenue generation are among the negative effects caused by the multipath effects.

8. Relevance to the telecommunication industry

With the rapid growth in the wireless communication technology, portable devices such as handheld computers and smart phones are becoming smaller for portability and cost reduction. Antenna as transmitting and receiving component in these devices is expected to meet the current trends and needs for the industrial and end user application such as the low cost, compact size, light weight, easy fabrication and improved performance. Conventional antennas have limitations of high cost, and inflexibility to wireless communications systems, thus, in addition cannot meet these requirements due to its huge size. To overcome this issue, one plausible solution is to use printed patch antenna with miniaturized antennas.

Thus, commercialization of microstrip printed MIMO antenna systems is set to reduce the industrial production cost, enhances the wireless system performances and ultimately mitigate the challenging issue of multipath fading. By deploying the printed MIMO antenna to rural, sparsely and isolated areas, low speed or no data available problems will be solved. Furthermore, adopting the single antenna element into an array of multiple antenna with orthogonal diversity increases the system performance.

9. Expected outcomes

The prototype metamaterial inspired UWB/MIMO antenna is set to have the following advantages.

Cost Minimization: By obtaining the reduced antenna size using metamaterial unit cell, and multiband antenna, cost is expected to be minimized since cost is proportional to size and number of antennas used. Thus, if a single is used to cover various number of bands saves a lot of space and cost of antennas that must have used. Our proposed research is aimed at reducing size, minimizing the cost of antenna production industrially and commercially.

UWB operation and size reduction: As the wireless communication devices are getting smaller, miniaturizing antenna is very important. Antenna element serve as the transmitting as receiving component in wireless devices. The need to reduce the antenna size greatly reduces the size of these devices. As it is known that ordinary antenna is efficient and have good performance, however some limitations associated with these antennas limits its uses in most area of applications. These include limited space environment. Similarly, inflexibility of conventional antenna is another limitation that hinders its application in the wireless communication. Antenna with flexibility in terms of its multiband operation are very important. More importantly, multiband is the ultimate target for adaptability to numerous situations in covering large number of bands in a limited space with a MIMO antenna. Many of the literatures adopt single method to apply for each, i.e. size reduction and multiband operations. This creates additional cost and complexity if both techniques are applied to achieve optimum size and wide bandwidth. Thus, this research proposes single method to achieve simultaneously size reduction and multiband operation. Various techniques exist for size reduction and multiband operation such as using high permittivity substrate, slot loading, shorting PIN, subsequent folding, meandering and metamaterial structure. Metamaterial structures are well known for size reduction due to the characteristics it processed that are not readily available in nature. Compared to other conventional antennas, metamaterial antennas have reduced size, and better performances.

Performance improvement: Using metamaterial structure, bandwidth and gain are improved. Conventional patch antenna suffers the problem of narrow bandwidth and low gain. This makes less commercially productive and applicable. To improve its performance, this research will investigate and development of cheaper, small and improved performances.

Multipath mitigation: With the adoption of the MIMO system, multipath fading is greatly mitigated, which results in improving the link reliability and signal to noise ratio. This has to set the MIMO to become more popular in wireless communication systems.

10. Evidence of local realization up to prototype level

The proposed research is set to be carried out locally in the prestigious academic universities in Nigeria. Firstly, Taraba State University Jalingo is a well-known academic institution of engineering and technology. The institution is well equipped with high caliber of technological facilities and intellectual researchers to carry out this important research. In addition, the location is environmentally free to carry out the research from its beginning to the end. On the other hand, a need might arise to seek additional hand in undergoing the research from other institution such as Ahmadu Bello University Zaria and University of Ilorin which the co-researcher 2 and 3 is set to carry out such.

11. Cost reasonableness (cost of actualizing the idea including hardware and software requirements but excluding purchase of Vehicles, Furniture or Internet.

S/N	Items Description	Unit	Justification	Price
1	Equipment (a) Lenovo Ideapad, Core i7 805DU, 1.8GHz up to 4GB, 16GB DDR4, ITB HDD	1	Workstation for simulation and analysis	₦237, 700
2	Softwares (a) Computer Simulation Tech. (CST) License (b) Software purchase license for 2 years (c) Autocad (d) Matlab (e) Origin plot (f) E-draw max	 1 1 1 1 1 1	 Prototype design	 ₦2,528,000

3	Fabrication Equipment (a) Sodium persulfate (b) FR-4, $\varepsilon = 4.4$, thickness 1.6mm substrate (c) Photo positive developer-NaoH (d) Laminating Machine (e) SMA ports, leads, soldering iron (f) portable etching machine 	1	Reagent /materials required for antenna fabrication	₦73,117.37 ₦92,701.32 ₦131,905.90 ₦114, 990.00
4	Measurement of reflection coefficient N5244A PNA-X Network Analyzer  	1	Antenna testing and signal measurement	₦1,473,691.60 $3,915,81
5	Power source • Standby solar inverter set • Inverter 1000w • Solar panel (18V/150w) • Charge controller 12V/60A • Battery (12V/200Ah	1 1 1 1 1	The provision of constant power as required for effective simulation	₦130,219.20 ₦19,910.00 ₦53,576.00 ₦200,000.00
6	Radiation pattern measurement and analysis Anachoic chamber	1	Measurement of radiation parameters such as radiation pattern, gain, axial ratio etc.	₦1,730,000

				
7	Publications (a) International Conference Registration and transportation (b) International Journal publication	1	Peer review and interaction with professional in the field SCI/ISI Journal publication	₦1,400,000 Including flight ticket, conference registration etc. ₦496,000
8	Miscelleneous		Unbudgeted events	₦1,200,0000
9	**Total**			**₦9,911,811.39**

12. Schedule of project organization

This section presents the flow chart of the research work. Detail steps are shown in Figure 12.1. With the formulation of the coherent flow chart, the proposed design is set to address the critical of multipath fading. Bandwidth enhancement is achieved through various methods as presented the review. With the adoption of metamaterial structure, not only improving the bandwidth but other key parameters are enhanced and introduced. Thus, the proposed technique presents a single, simple and low-cost method to provide high quality service for wireless communications systems through high gain MIMO technology.

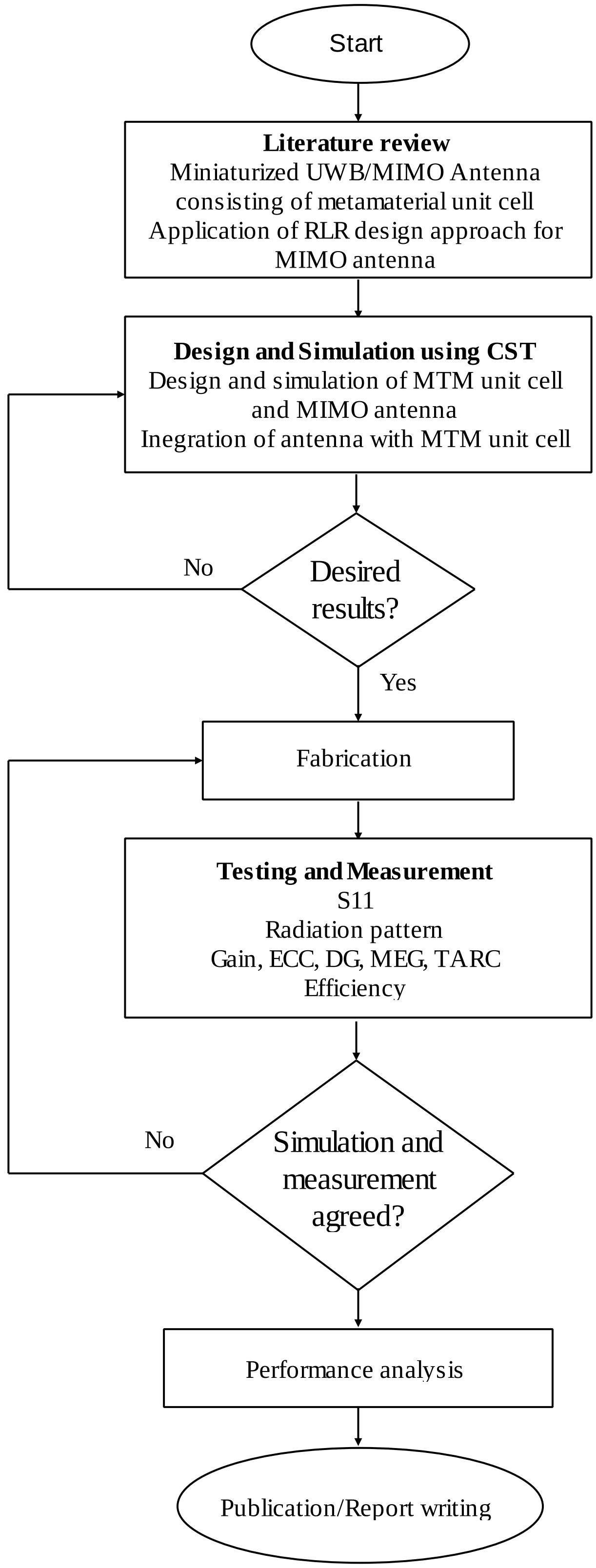


Figure 12.1 Research flowchart

13. Schedule Gantt chart

	2021							2022												2023				
Activities	J	J	M	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
Literature review	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Familiarization of the software (CST-microwave studio)	■	■	■	■	■	■	■	■	■	■	■	■												
Parametric study of different antenna types	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Parametric study of rectangular loop resonator metamaterial structure	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Simulation: Antenna with RLR and antenna array	■	■	■	■	■	■	■	■	■	■	■	■												
Fabrication: validation of preliminary results										■	■	■	■	■	■	■	■	■	■	■				
1st year evaluation										■	■	■												
Validate the simulation results with the measurements results and analysis									■	■	■	■	■	■	■	■	■	■	■	■	■			
Conclusions										■	■	■										■	■	■
Prepare documents for publications and reports	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

14. Coherent presentation

Since the research is to be carried in the university, a number of presentations, workshops, symposiums and lectures will be carried along to students, interested lecturers and researchers. This will help in disseminating latest research findings and technological equipment adopted.

15 Allowances for researchers should not exceed 20% of cost of actually the research

S/N	Items Description	Justification	Unit
	Personal cost/Allowances (a) Principal researcher 1 (b) Co-researcher 1 & 2	Monthly Honorarium	20% of research cost
	Total ₦9,911,811.39 x 20%		**₦1,982,362.28**
	Grand Research Total =		**₦9,911,811.39** **₦1,982,362.28** **₦11,894,173.7**

16. Evidence of competence

As attached in the CVs

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