FABRICATION AND OPTIMIZATION OF BI-QUAD ANTENNA AND ENERGY-EFFICIENT BALANCED RF POWER AMPLIFIER FOR 5G-LTE MULTI-CARRIER APPLICATIONS

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Abstract *– Wireless technology is presently one of the most actively researched fields of digital communication systems. Wireless communication technologies are insufficient without an understanding of antenna design and operation. A wide range of radio frequency equipment, including microwave antennas, microwave ovens, cordless telephones, and medical devices, utilize the 2.4 GHz band. In this article, a parabolic mesh dish was used to build and improve a bi-quad antenna with a central working frequency of 2.445 GHz. The bi-quad antenna was put in a parabolic mesh dish to optimize wave propagation. The findings show that the antenna obtained a signal strength range of 70% to 80%, increasing the directivity of WLAN coverage. The bi-quad antenna feed was placed in the center of a mesh dish, which assists in focusing radio waves onto the antenna. The bi-quad antenna outperformed the omnidirectional antenna, which had a signal strength of 56%. The results of each antenna test were separately simulated in MATLAB. The combined impact of bi-quad and parabolic was then duplicated using mathematical models, resulting in a unique waveform propagation pattern known as para-quad, which improved performance. A balanced RF power amplifier was conceived and built in this study. A 2.620 – 2.690GHz frequency range on a large signal Si-LDMOS transistor model achieves 53% PAE, 41dBm power output, and 14 dB gain at the P1dB saturation point.*

Keywords *– Bi-quad antenna, fabrication, fifth generation, optimization radio frequency*

1. INTRODUCTION

An antenna is a collection of conductors or an electrical wire that may function as both a transmitter and a receiver, delivering electromagnetic energy into space and receiving electromagnetic energy from space. An antenna is defined as "that part of a transmitting or receiving system designed to broadcast or receive electromagnetic waves" by the IEEE [1]. According to [2,] a broadband antenna is a bi-quad antenna that is fairly directional, affordable, and simple to build. A bi-quad antenna is made up of two single-turn loop antennas. A bi-quad antenna produces the same radiation pattern as a dipole antenna, but with more directivity and bandwidth [3]. Furthermore, by definition, a bi-quad antenna is a modified variation of a folded dipole antenna. [2] emphasizes that the bi-quad antenna, which consists of two 14-wavelength squares as a radiating element and a metallic plate or grid as a reflector, is simple to construct and provides high directivity and gain for point-to-point communications. The bi-quad antenna was also stated to have a beam width of 70 degrees and a gain of 10–12 dB, as well as the ability to be utilized as a solo antenna or as a feeder for a parabolic dish [3].

The folded dipole antenna has the same radiation pattern as the normal Hertz antenna but has an input impedance of 288Ω, approximately about 4×73Ω and operates very wideband [4]. The folded dipole is a good reception antenna for FM and VHF TV broadcasts. Its input impedance correlates nicely with the 300Ω input impedance terminals used in receivers [4]. A loop antenna is a single turn of wire with dimensions much smaller than a wavelength, and the current in it may all be regarded in phase. As a result, a magnetic field exists everywhere perpendicular to the loop. The resulting radiation pattern is strongly bidirectional and effective across an extraordinarily wide frequency range for individuals with a diameter of roughly $\lambda/16$ or less [3]. The antenna is commonly circular due to its highly defined pattern, small size, and broadband properties, as well as the direction-finding applications, although any shape is useful.

A parabolic antenna's capacity to concentrate light beams or sound waves at a precise area is widely known [3]. Common uses include, among others, dentist's lights, flashlights, and automobile headlights. As long as the paraboloid's mouth width is at least 10m wavelengths, the same ability applies to electromagnetic waves of lower frequency than light. As a result, they cannot be used at low radio frequencies. Cassegrain feed is utilized in emergency situations to decrease the length of the feed mechanism [3]. They produce enormous power gain, with a decent estimate provided by the equation $Ap = 6(D/\lambda)^2$, where Ap is the power gain with respect to a half wave length dipole, D is the mouth diameter of the main reflector, and λ the free space wavelength of the carrier frequency. As expected by antenna reciprocity, a dish antenna functions equally well in transmitting and receiving [3]. The router utilized is a wireless – N broadband router branded Tenda model W307R with a frequency range of 2412 – 2472 MHz. It has a transmit power of 19.32 dBm EIRP max – 802.11b/g and employs the modulation type OFDM. The router features a power adapter and the model number ILA4IV – 0901200. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier digital communication method that combines a large number of low data rate carriers to create a composite high data rate. Orthogonality gives the carriers a solid cause to be tightly spaced, even overlapped, without inter–carrier long symbol interference.

In 5G-LTE multicarrier systems, greater proportional radio wave amplification and higher efficiency are required. A balanced power amplifier produces a multicarrier signal while accounting for linearity, efficiency, and output power. The IEEE 802.11a standard for information technology and wireless communication systems does not establish a minimum requirement for power amplifier intermodulation distortion at the system level. The Adjacent Channel Power Ratio (ACPR), Error Vector Magnitude (EVM), and Envelope Spectral Mask (ESM) are examples. The ACPR is the ratio of total power given to the main channel to signal power delivered to the adjacent channel. The multicarrier transmitter signal as it goes through the power amplifier is described by a convoluted RF band. The RF band is being drowned by spectral regrowth. This type of power amplifier nonlinearity is measured using the neighboring channel power ratio. This paper discusses the design of a balanced RF power amplifier. The amplitude-to-amplitude and amplitude-to-phase characteristics (AM-AM/AM-PM) of the amplifier are used in the nonlinearity simulation of an IEEE 802.11a. An OFDM transceiver utilizing Simulink version R2018b setup was also used. The purpose of this study is to design and construct a 5G power amplifier for a bi-quad antenna that can increase power added efficiency while also reacting to high linearity. This is due to the need to reduce power amplifier energy usage while also extending battery life. The goal of this research was to determine the radiation pattern's direction and coverage, as well as to optimize the bi-quad antenna.

2. RELATED WORK

The University of York partnered with other institutions in 1994 to create a hybrid biconical and log periodical antenna for broadband emissions testing. Below 100 MHz, the antenna worked badly, however this was easily remedied by amplifying the antenna signal using a low power amplifier. An in-line attenuator was employed to compensate for the poor match into 50 ohms at low frequencies. This antenna was never meant to be used for RF immunity testing. In order to create RF immunity fields below 100 MHz, a very costly high-power amplifier would be necessary [5].

In their work, the aim was to create Yagi antenna with a bi-quad inside the director, which used a working frequency of 2100 MHz – 2400 MHz. The designed system parts consisted of a Printed Circuit Board (PCB), copper wire and RP-SMA connector. The designed antenna was first simulated by using WIPL-D software and after the expected result were obtained; it was fabricated by using part of the designing system. The antenna worked by connecting the modem with the antenna as an external antenna of an 4G LTE modem. The simulation results for working frequency 2100 MHz to 2400 MHz which was slightly different from actual measurement of 2364 MHz to 2464 MHz [6].

[7] designed, simulated and realized a triple bi-quad antenna for WiMAX applications in the 3.3 to 3.4 GHz frequency. The designed triple bi-quad antenna worked with a bandwidth of 100 MHz at a frequency of 3300-3400 MHz with a VSWR limit ≤ 1.5. The radiation pattern of this antenna was omnidirectional with linear polarization. The gain of this antenna was ≥ 16dBi [7]. According to another study, the triple bi-quad dual band antenna was at a frequency of 2.3 to 2.4 GHz and 3.3 to 3.4 GHz for fixed WiMAX applications and Wi-Fi. The antenna works on two frequencies and these were 2300-2400 MHz and 3300 to 3400 MHz [8].

Furthermore, the corresponding simulation results were used to determine the effect of the reflector antenna parameters. The flat reflector on antennas affects the antenna characteristics and especially on the gain and radiation patterns. The VSWR obtained was 1,104, with an impedance of 53.234 Ω - j3,384 and maximum gain of 10.42 dBi. This resulted in shaped radiation pattern unidirectional and elliptical polarization. Hence, this reach paper used the same approach [8].

3. *FABRICATION AND TESTING OF THE ANTENNA*

A blank Printed Circuit Board (PCB) measuring 123 x 123mm square was sliced off. A 50mm copper tube piece was removed and smoothed on both ends. Sandpaper was used to polish the copper pipe, including the inside of the copper pipe. This was done to ensure that the coax braid was securely attached. Following that, a notch was cut into one end of the copper pipe, removing approximately 2mm off half of the circumference, as seen in Fig. 1 below.

Fig. 1 – 50mm copper pipe with 2mm notch cut off

To fit the copper tubing, a hole was bored in the center of the blank PCB. Fig. 2 illustrates how a small hole was bored and then expanded using a file to accommodate the copper pipe appropriately.

Fig. 2 – Rectangular reflector plate

The notched end of the copper pipe was put into the hole on the copper side of the blank PCB. To improve electrical connection, the copper tubing was attached to the PCB [3]. Now that the element had been connected to the reflector, just the two ends of the copper wire were needed to be connected to the copper pipe. To guarantee that the center of the copper wire were not exposed to the copper pipe, the notch was removed from the end of the copper pipe. After putting everything together as instructed, the antenna looks like that in Fig. 3.

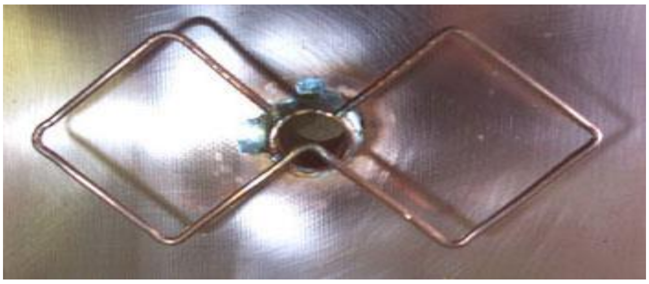

Fig. 3 – The complete bi-quad antenna with its reflectors

A 30mm section of the coaxial cable's outer coating was peeled for feeding the antenna. As indicated in Fig. 4, the braid was wrapped back over the outer sheath, and the 4mm protruded.

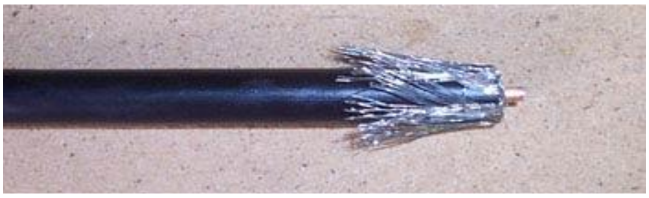

Fig. 4 – Copper cable with the braided shield exposed

The braiding was placed into the copper pipe such that the end of the center conductor corresponded to the extreme end of the copper pipe, and the element's center was soldered to the bi-quad antenna while avoiding contact with the copper pipe. The bi-quad antenna, as illustrated in Fig. 5, is completed at this point.

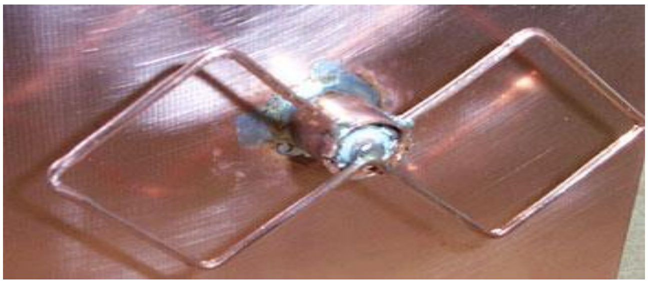

Fig. 5 – The complete bi-quad antenna with coaxial cable connected

Fig. 6 – The copper pipe crimped onto the coax

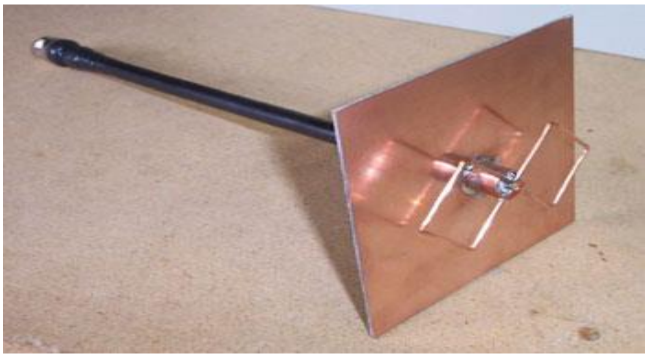

Fig. 7 – The view of a completed bi-quad

4. *BALANCED RF POWER AMPLIFIER CIRCUIT DESIGN ARCHITECTURE*

The equitable power amplifier is a cumulated system comprised of two opposing transistors. The two amplifiers have the same source and target. They can provide parallel output power; however, the biasing circuit is different. The two amplifiers operate in class-AB, with the first in the first carrier stage and the second in the second. At this point, the first carrier stage refers to the first amplifier, whereas the second carrier stage refers to the second amplifier. A band pass filter signal divider splits the input signal evenly. The divider has a 90-degree phase difference and the same amplitude to drive the two cascaded class-AB amplifiers. The outputs of both amplifiers are connected to a combiner, which gathers the signals for the last phase of amplification [5, 6]. Due to power back-off, the balanced RF power amplifier is more efficient than the standard single stage amplifier. As a result, despite increased efficiency and linearization attempts, nonlinear distortion induced by Peak to Average Power Ratio (PAPR) has an influence on multicarrier systems.

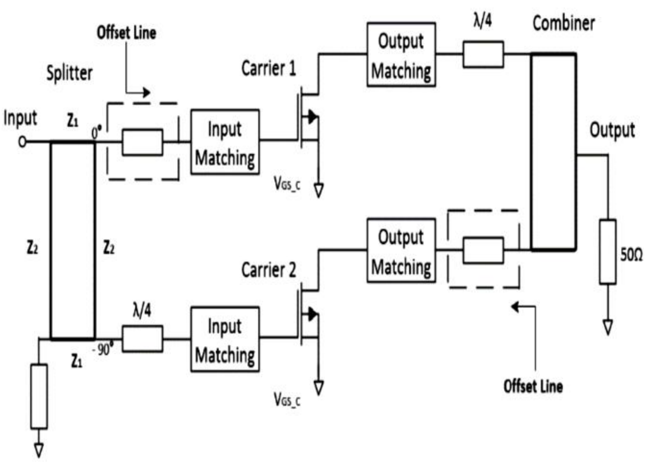

Fig. 8 - Proposed balanced RF power amplifier schematic design with offset lines.

Fig. 8 shows the proposed RF power amplifier schematic design with offset lines, consisting of two concurrent amplifiers with equal output power capability. Both amplifiers are carrier amplifiers working in class AB mode since they have the same bias point. There is a 90-degree phase shift between the two amplifiers. A separate signal splitter was created for the input. A coupler was also created for the output. Both the splitter and the output coupler were evaluated individually for operational bandwidth and frequency responsiveness. The design does not specify the carrier amplifier mode. The fact that all category modes were operational at the same time offered the potential to increase efficiency. Resonator circuits are linked to the input of the first carrier and the output of the second carrier. These result in the summing circuits for the phase difference signal compensator. The circuits amplify the signal from the two amplifiers and send it to the output load. The quarter-wave transmission line was similarly applied to the input and output of the second carrier. The proposed balanced RF power amplifier design grows in complexity while boosting efficiency and linearity across a wide frequency range. MATLAB was used to linearize the balanced RF power amplifier by creating polynomials with the AM-AM and AM-PM transfer functions. In the context of the normalized input voltage, the extracted AM-AM and AM-PM values are measured as a function of the output voltage.

5. EQUATIONS

The antenna radiation pattern depicts the distribution of powerflowing out from the antenna as a function of direction angles from the antenna. The following are the primary distinctions between a parabolic cylinder and a paraboloid in terms of aperture amplitude, phase, and polarization. The amplitude taper variations are proportional to $1/\rho$ in a cylinder compared to $1/r^2$ in a paraboloid owing to changes in distance from the feed to the surface of the reflector. The focus region is a line source for a cylinder and a point source for a paraboloid, where incident plane waves converge. When the feed fields are linearly polarized parallel to the axis of the cylinder, the parabolic cylinder produces no cross-polarized components. The surface of a paraboloid reflector is created by rotating a parabola about its axis. In order for rays emanating from the reflector's focus to be converted into plane waves, its surface must be a paraboloid of revolution.

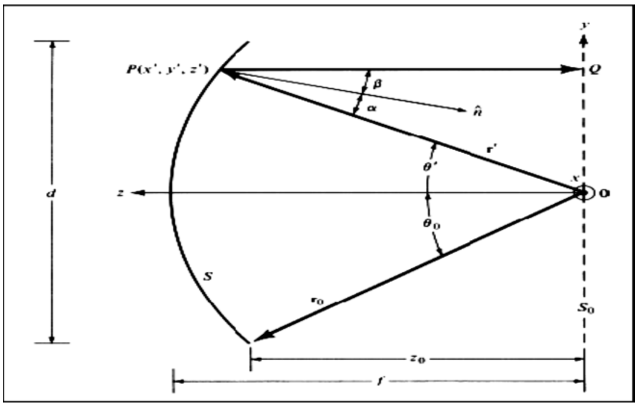

Fig. 9 – Two-dimensional configuration of a paraboloid reflector.

The design is optical in nature and does not take into account any distortion from the reflector's rim through the focus. As seen in Fig. 9, it implies that:

$$OP + PQ = cons\tan t = 2f \quad (1)$$

$$OP = r' \quad (2)$$

$$PQ = r'\cos\theta' \quad (3)$$

$$r'(1+\cos\theta') = 2f \quad (4)$$

$$r' = \frac{2f}{(1+\cos\theta')} = f\sec^2(\frac{\theta'}{2})\theta \le \theta_0 \quad (5)$$

$$r' + r'\cos\theta' = \sqrt{(x')^2 + (y')^2 + (z')^2 + z'} = 2f \quad (6)$$

$$f - r'\cos^2(\frac{\theta'}{2}) = s = 0 \quad (7)$$

$$U(\theta',\phi') = \frac{P_t}{4\pi} G_f(\theta',\phi') \quad (8)$$

$$\left[E^0(\theta',\phi')\right] = \left[2\eta U(\theta',\phi)\right]^{\frac{1}{2}} = \left[\eta \frac{P_t}{2\pi} G_f(\theta',\phi')\right]^{\frac{1}{2}}$$
(9)

$$E'(\theta',\phi') = \bar{e}_i \left[\eta \frac{P_e}{2\pi} G_f(\theta',\phi')\right]^{\frac{1}{2}} = \bar{e}_i C_i \sqrt{G_f(\theta',\phi')} \frac{e^{-jkr'}}{r'} \quad (10)$$

$$C_i = (\frac{\mu}{\varepsilon})^{\frac{1}{4}} (\frac{P_i}{2\pi})^{\frac{1}{2}} \quad (11)$$

$$y(t) = a_5u^5 + a_4u^4 + a_3u^3 + a_2u^2 + a_1u + a_0 \quad (12)$$

$$z(t) = b_5u^5 + b_4u^4 + b_3u^3 + b_2u^2 + b_1u + ab_0 \quad (13)$$

6. MATHEMATICAL MODELING

Adding equations (2) and (3) to (1) yields equation (4) and making r' the subject of Equation (4) yields the expression in Equation (5). A paraboloid is a parabola of rotation about its axis, the equation of a paraboloid in terms of the spherical coordinates r', θ', and Ø' is itself a paraboloid. Equation (5) can alternatively be stated in terms of the rectangular coordinates x', y', and z', as illustrated in equation (6). It is preferable to select a unit vector that is normal to the local tangent at the surface reflection point when analyzing parabolic reflectors. To do this, Equation (5) is first written as Equation (7). Fig. 10 shows a bi-quad antenna with a gain function of G_f (‘θ, Ø’) set at the focal point of a paraboloid reflector.

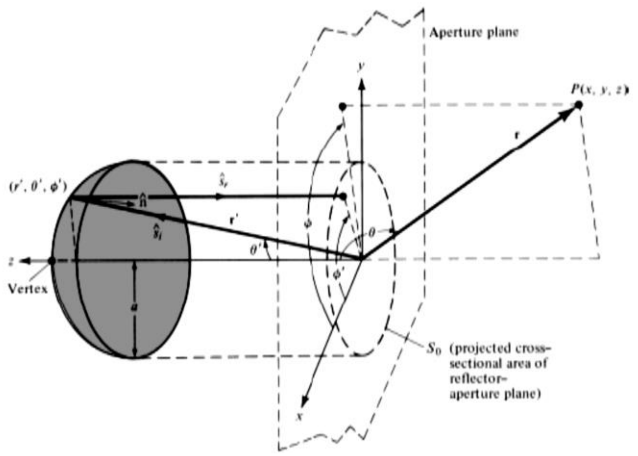

Fig. 10 – Three-dimensional geometry of a paraboloid reflector system.

The radiation intensity of this source is expressed by Equation (8), where P_t is the total radiated power at a point r' in the source's far-zone. The incidence field is given in equations (9) and (10), where I represent a unit vector perpendicular to r' and parallel to the plane formed by r' and y, as illustrated in Fig. 11.

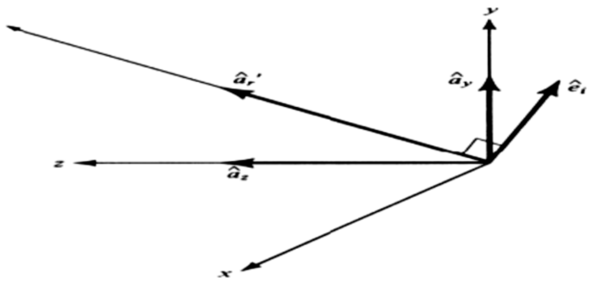

Fig. 11 – Unit vector alignment for a paraboloid reflector system.

The values for the coefficients in Equation (12) which was used for MATLAB simulation are a_6 = 33.06, a_5 = -85.52, a_4 = 82.06, a_3 = -34.052, a_2 = 2.85, a_1 = 3.21, and a_0 = -0.01 are the MATLAB curve fitting AM-AM polynomials. The gadget reaching saturation causes the AM-AM distortion. The balanced amplifier's normalized input voltage as a function of output phase is also evaluated, using the following AM-PM MATLAB fitted coefficients to yield polynomials represented as: b_6 = 3.5485, b_5 = -5.7836, b_4 = 3.0384, b_3 = -0.8434, b_2 = 0.1826, b_1 = -0.0225 and b_0 = 0.1001. The AM-PM distortion is caused by the device approaching saturation. This information will be used in a Simulink transceiver system based on the IEEE 802.11a OFDM Hipper LAN/2 standard Device Under Test (DUT). Equations (12) and (13) show AM-AM and AM-PM variations, respectively. Where y(t) and z(t) are the AM-AM and AM-PM responses of the balanced RF power amplifier, respectively [6].

7. MATLAB SIMULATION RESULTS

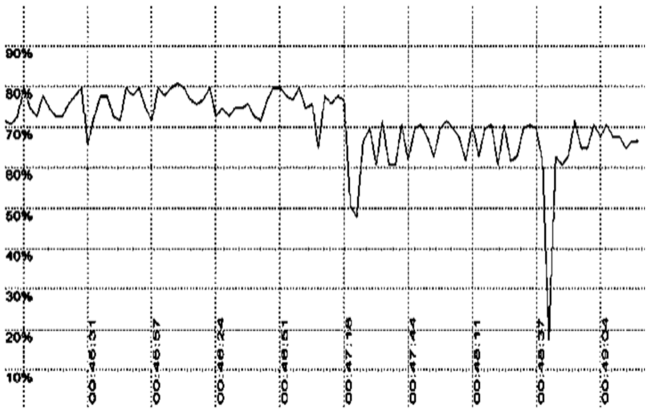

Fig. 12 – Receiver sensitivity percentage versus time for bi-quad.

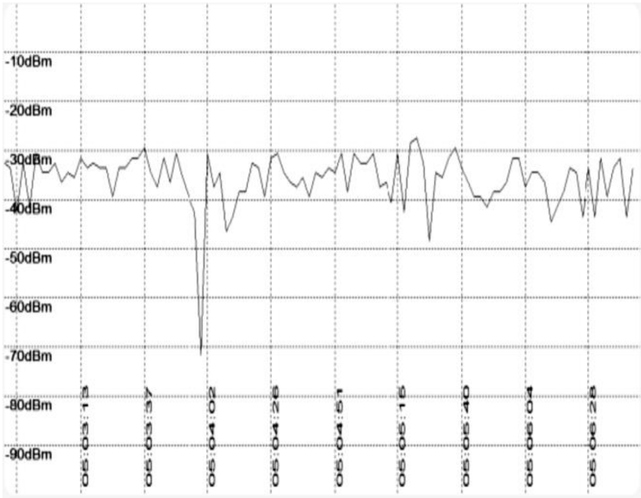

Fig. 13 – Receiver sensitivity (dBm) versus time for bi-quad.

Table 1 - Performance comparison of bi-quad and omnidirectional antenna.

Antenna	Biquad	Omni directional
Signal Strength (dBm)	-33	-45
Signal Strength (%)	71	56
Speed (Mbits)	11	5

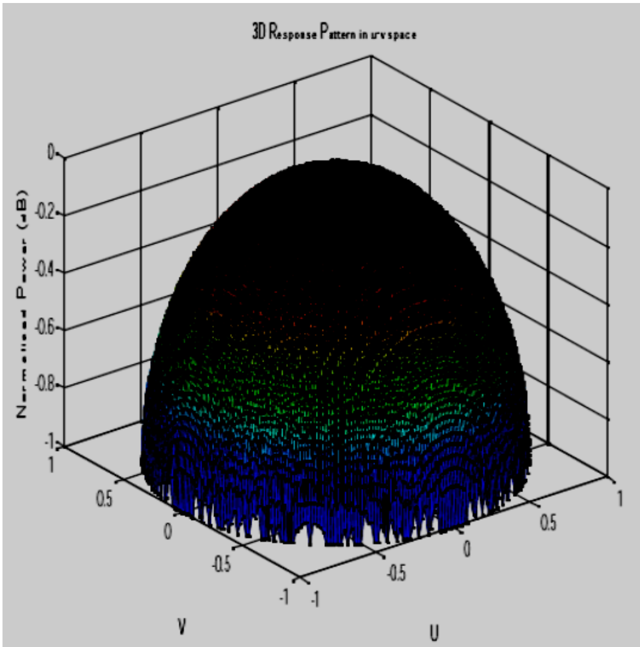

Fig. 14 – Radiation pattern for parabolic mesh without bi-quad antenna.

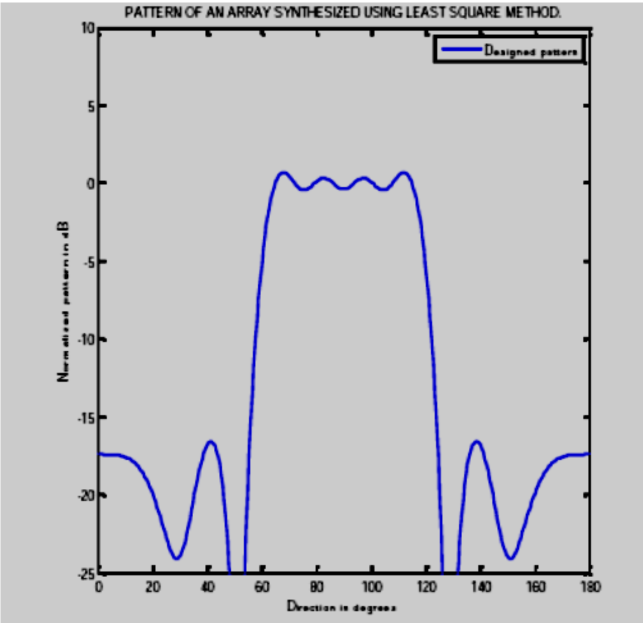

Fig. 15 – Rectangular radiation pattern for bi-quad antenna.

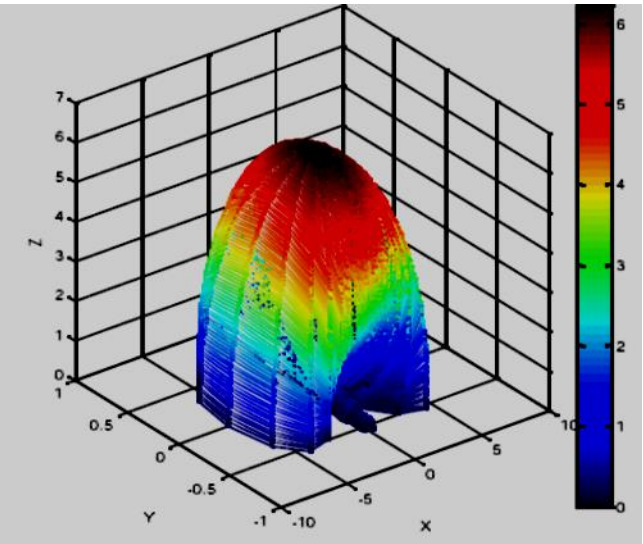

Fig. 16 – Radiation pattern for combination of bi-quad and parabolic mesh.

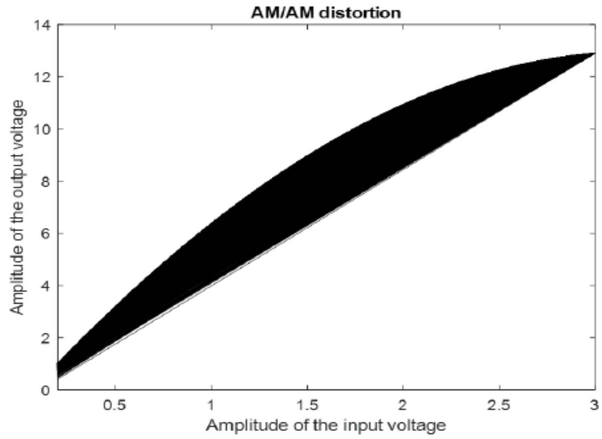

Fig. 17 – AM/AM distortion of proposed balanced RF power amplifier.

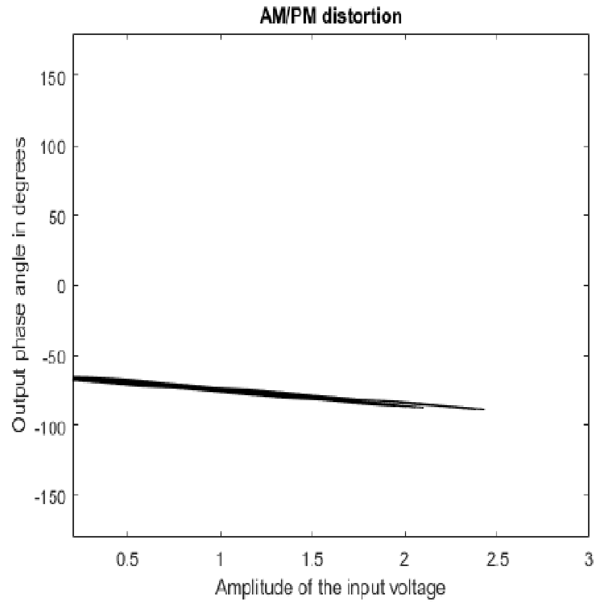

Fig. 18 – AM/PM distortion of proposed balanced RF power amplifier.

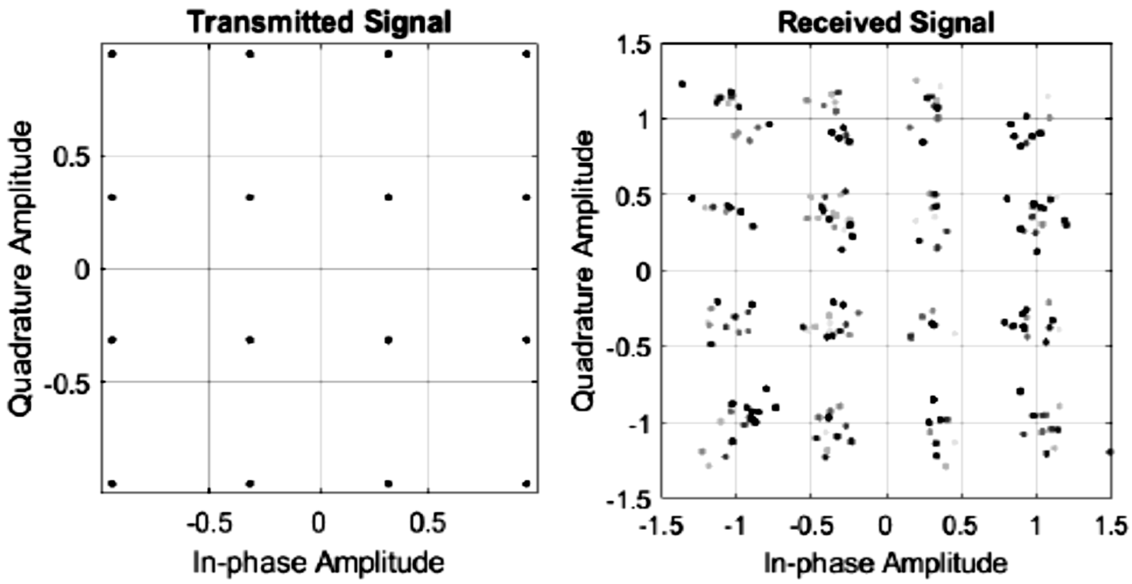

Fig. 19 – OFDM transmitted and received signal constellations without linearization.

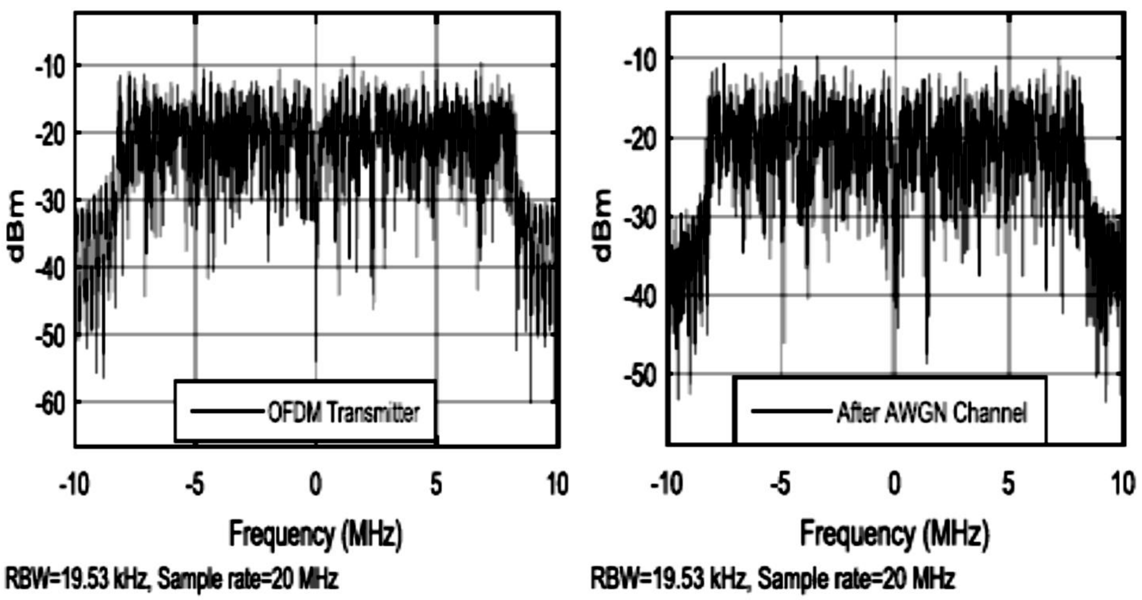

Fig. 20 – Spectrum signal illustrating the bandwidth.

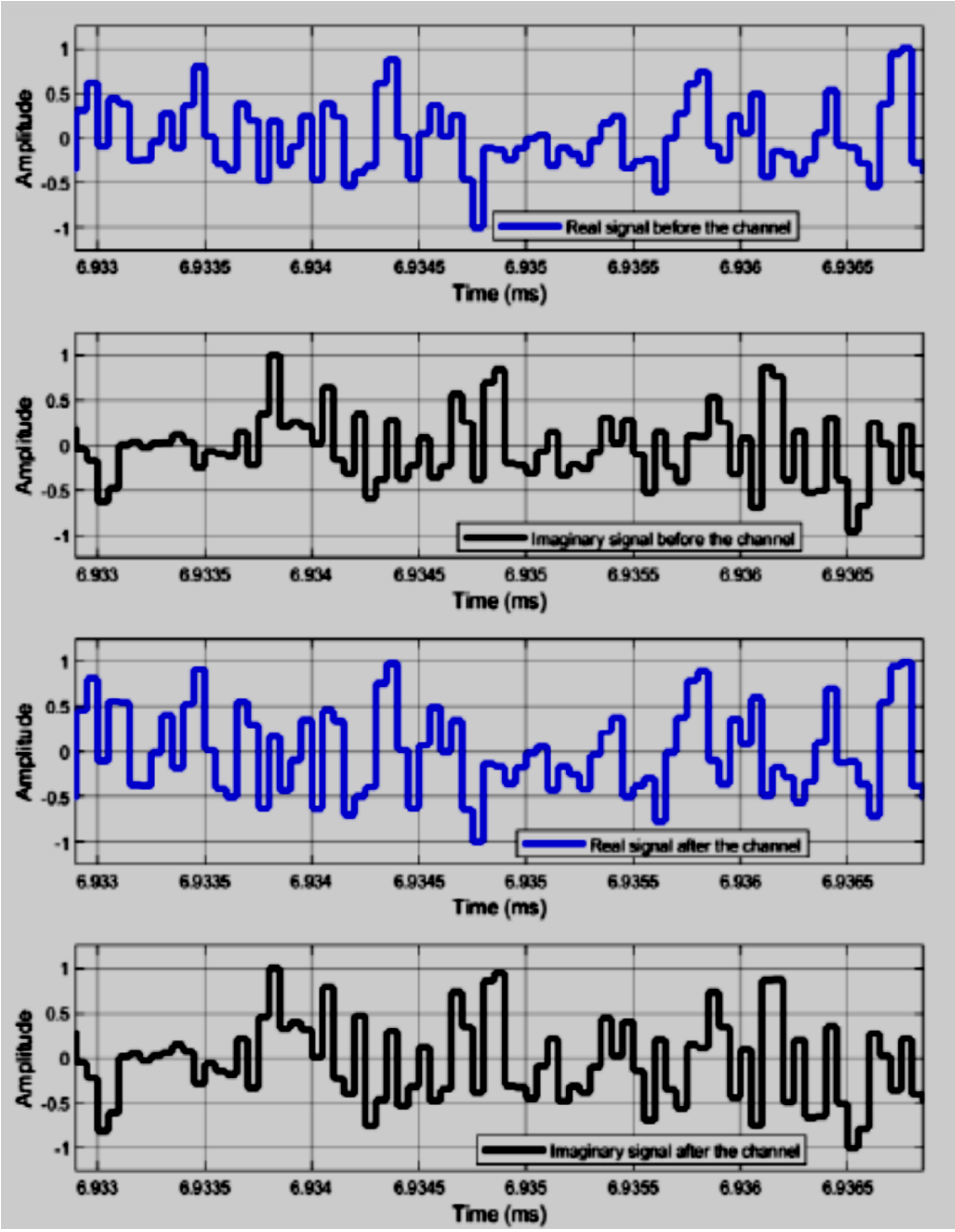

Fig. 21 – OFDM complex signal on time scope frame before linearization.

8. SELECTING ANTENNA AND POWER AMPLIFIER COMBINATIONS.

The fundamental requirements are that the antenna and amplifier combination generates the necessary RF field strength over the specified frequency range. These include dissipative heat loss in the cable feed to the antenna, dissipative loss in the antenna and any power reflected back by the antenna. These losses affect the net power utilized by the antenna to generate the RF field. An amplifier converts a low voltage or power into a higher voltage or power signal. Different types of amplifiers and different formats are available depending on the applications required. The high voltage amplifiers, with a bandwidth from DC to a few MHz, allow getting at the output stage, voltages of several hundreds of volts. Power amplifiers, low frequency, and a few MHz maxima are generally used to stimulate inductive loads and are driven in voltages or current as required. These amplifiers deliver a few hundred watts to several kilowatts in loads often with very low impedance. RF power amplifiers are amplifiers that convert a low power RF signal into a higher power signal. Hence, the antenna at 2.445GHz and power amplifier at 2.620GHz were designed not at some frequencies.

9. DISCUSSIONS

The objective of this research was attended by creating a bi-quad antenna that was improved by putting it into a parabolic mesh. The frequency and power levels at which the intended and tested bi-quad antenna functioned are shown in Table 1. A balanced RF power amplifier was devised and built in this study. A 2.620 – 2.690GHz frequency range on a large signal Si-LDMOS transistor model achieves 53 per cent PAE, 41dBm Pout, and 14dB gain at the P1dB saturation point. Using the MATLAB fitting tool, the AM-AM and AM-PM measured data of the balanced RF power amplifier were utilized to generate polynomials. The polynomials were employed in the suggested pre-distortion technique to account for the nonlinearities of the balanced power amplifier. A simple linear model was constructed for the memory-less baseband digital pre-distorter model development. The suggested mathematical model was validated using a Simulink IEEE 802.11a. OFDM transceiver system. The results of the revised bi-quad antennas were compared; the improved bi-quad antenna provided better coverage throughout the tests. The new wave radiation pattern formed by combining a bi-quad antenna provided better coverage throughout the tests. The new wave radiation pattern formed by combining a bi-quad antenna and a parabolic mesh was shown in Fig. 16. A predistortion system that employed Simulink to compensate for the nonlinearity of a balanced RF power amplifier also worked well in this investigation.

10. CONCLUSION

The new balanced radio frequency power amplifier worked very well at a frequency range of 2.620 – 2.690 GHz. The new wave radiation pattern, which was formed with the combining effect of a parabolic mesh, resulted in 2.445 GHz higher power radio frequency signal propagation. Hence, the main aim of the research was achieved and this will effectively help with signal optimization and propagations in Fifth-Generation (5G) Long Term Evolution (LTE) technology.

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