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Smart Antenna at 300 MHz for Wireless Communications

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ABSTRACT

As Radio Frequency spectrum is increasingly choked, there is need for the extension of communications system with higher capacity and higher bandwidth. Signal transmission over the radio frequency are mitigated by the transmission impairments. Antennas play a prominent role in the transmission of signal over the radio frequency. This work examines how a smart antenna with its dynamic physical antenna arrays can mitigate the bandwidth limitation and expand wireless communications coverage. At higher radio frequencies wave, the effects of interference cannot be overemphasized as the quality of signal is reduced drastically. To overcome this drawback on the propagation of signal, smart antenna offers the mitigation of interference on signal transmission and reception as it combines its different elements and digital signal processing capacity. To avoid interference at these frequencies, beamforming plays a prominent role in the smart antenna system. The beamforming varies the radiation beam pattern of an antenna in a particular direction. This research work presents an innovative approach of designing smart antenna using a waveguide-fed pyramidal horn antenna for wireless communication systems.

Keywords—Azimuth, Beamforming, Digital Signal Processor, Interference, Smart Antenna, Radio frequency, Wireless communication

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1. INTRODUCTION

The radio frequency spectrum has been jam-packed with the coalition of personal and commercial communications, thereby causing signal interference. In the past two decades, wireless communications industry have witnessed tremendous growth in the numbers of subscribers globally and demand for high speed data transmission. In addition to these, high bandwidth, mobility, and on-line connectivity have become the requirements for the wireless communications networks [1, 2]. A Signal transmitted at radio frequency range always faces interference which reduces the quality of signals at the receiving end. Starting from radio frequency (RF) and above, wireless communications systems require innovation of smart antennas for the transmission of signals that will mitigate interference at the electromagnetic spectrum range.

Radio frequency is a portion (range) of an electromagnetic (EM) radiation spectrum that has a frequency between 3 KHz and 300 GHz which is equivalent to the frequency of radio waves and correlates to the frequency of alternating current electrical signals used to produce and identify radio waves. A radio frequency system includes; a point of supply of electromagnetic (EM) wave; a designated destination for that message; and the frequency at which the message is being transmitted [3, 4]. The radio source is the transmitter, while the radio destination is the receiver.

In the contemporary communication industry, antennas play a prominent role in the creation of communication link. For effective performance application of wireless communication such as mobile, radio, aircraft, satellite, and missile application at higher frequencies, a smart antenna has being a succor to their expansion in bandwidth, data rate, and quality of wireless transmission, which has been confined by interference, local scattering, and multipath propagation [5, 6]. Furthermore, for the effective transmission of radio frequency signals, antenna that can mitigate transmission impairments is required. To overcome this drawback on the propagation of signal, smart antenna offers the mitigation of interference on signal transmission and reception as it combines its different elements and digital signal processing capacity.

Smart antennas is an array of antennas that incorporate various elements of an antenna array together with the signal processing efficiency with a view to enhance its radiation beam arrangement dynamically in response to the signal environment [7, 8]. Smart antenna amalgamates signal processing and antenna array for its optimization in order to automatically change the direction of the radiation of beam pattern in response to the received pattern. The fundamental principle of the smart antenna is shown in Figure 1 [9].

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When smart antenna received a signal, beamforming weight can be decided by an adaptive process by making use of reference signal (temporal information) or user's direction (spatial information). In modern wireless communications, Smart antennas gain more space by using the property of spatial filtering [10, 11]. Das [12], through the techniques of adaptive beamforming approach stated that using beamforming algorithms, adjusted the antenna array's weight to form typical amount of adaptive beam to track corresponding subscribers automatically. This can be simultaneously minimized interference coming from another users by the introduction of nulls in their respective directions.

Zalawadia et al. [13] formulated a basic approach for evaluating the realization of a beamformer as the feedback for a given N-by-1 weight vector W(n) as objective, known as the beam response and computed for all possible angles from $-90^0 \leq \theta \leq +90^0$ that is the angular response:

$$R(\theta) = w^H(n)s(\theta) \quad (1)$$

Where s(θ) is the N-by-1 steering vector. The steering vector on θ is defined as:

$$s(\theta) = [1\ell^{-j\theta}\ell^{-2j\theta}\ldots\ell^{-j(N-1)\theta}]^T \quad (2)$$

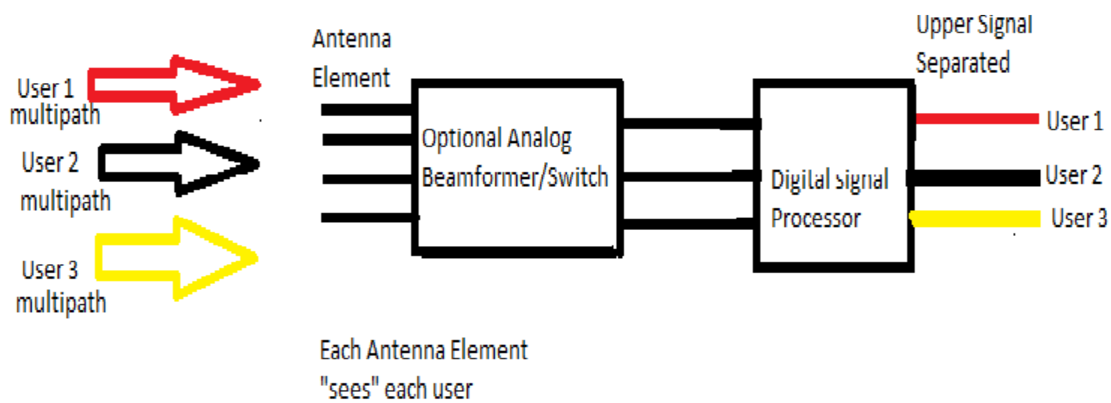

Fig. 1. Smart Antenna System

Assuming the actual angle of incidence of a plane wave, measured with consideration to the normal and to the linear array,

$$\theta = \frac{2\pi d}{\lambda}\sin\phi, \qquad -\frac{\lambda}{2} \leq \theta \leq \frac{\pi}{2}$$

(3)

Where d is the array configuration between sensors and λ is the wavelength of the incident wave. The array factor used does not depend on the nature of antenna used for N-element linear arrays. The smart antenna system as shown in figure 1, tries to shape and locate the beam of the radiating antenna element and the desired user or the target through the upper signal separated. With the combination of beamformer and digital signal processor (used to identify spatial signal), the users 1 to 3 can clearly receive their desired signals without any interference [14]. Smart antennas incorporate various elements of an antenna array together with the signal processing efficiency with a view to increase its radiation beam pattern dynamically in feedback to the signal environment [7]. One of the fundamental elements of smart antenna is the waveguide-fed pyramidal horn antenna, as it has a wide gain.

Due to its good electrical distinctive, the horn can be used as feed for antenna reflectors [15]. As a result of these peculiar features of waveguide-fed pyramidal horn antenna, this technique is used in this work.

The organization of the paper is as follows. The brief description of physical antenna waveguide-fed pyramidal horn antenna array for smart has been described in section II. In section III, the physical antenna has been designed using the estimated parameters. Section IV describes the estimated performance of the modelled antenna at various frequencies. Finally, the section V concludes the work and recommends the future works.

2. DESCRIPTION OF THE PROPOSED ANTENNA

The smart antenna systems consist of four assemblages: the physical antenna, radio unit, beamforming, and the signal processor. These are shown in Figure 2. The physical antenna consists of the array of antenna system. Smart antenna is a combination of multiple antenna arrays spatial signal processing algorithms used to analyze the spatial signal parameters like direction of arrival of signal; adopt it to estimate beamforming vectors track and spot antenna beam on the target [16]. One of the smart antenna arrays chosen for this work is waveguide-fed pyramidal horn antenna.

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Wave-guide pyramidal horn antenna is a microwave horn antenna that has a flickering metal waveguide configured to optimize radio waves in a beam. The horn antenna is designed to transmit radio waves from a waveguide and feed it into space. Mostly, it consists of short length of the waveguide, closed at one end, flaring into an open-ended pyramidal shaped horn on the other end [17]. The waves then radiate out the horn end in a narrow beam. Wave-guide pyramidal horn antenna was chosen as our physical antenna for this work because its popularity at UHF (300 MHz – 3 GHz) and higher frequencies it is somewhat intuitive and relatively simple to manufacture. Some horn antennas do operate as high as 140 GHz. For the design of antenna, some of the factors to be considered are frequency to be used either ISM and other bands, one-way or two-way systems, modulation, range, power supply, cost, protocols, and antenna. This type of Antennas have a controlled radiation pattern with a high gain, which can range up to 25 dB [18]. Horn antennas have a wide impedance bandwidth since there is no resonant elements, implying that the input impedance is slowly varying over a wide frequency range.

The bandwidth for practical horn antennas can be on the order of 20:1. Some of the antenna's properties such as type, size, shape, and direction can have a considerable influence on the design and performance of a system. Since form factor can be an extensively driving in any ISM application, antenna characteristics may determine what frequency range is chosen and basically, which radio is available. Antennas take many patterns, from simple ¼λ monopoles and ½λ dipoles, to loop, F, and others. They can also be classified as E-field or H-field, depending on which arrangement of current classic they employ. The first step in choosing an antenna is to take the largest dimensional length allowed within limits of the application and peradventure to use a trace or a physically connected antenna. During the design, we observed that the gain of horn antennas often increases as the frequency of operation is increased. Hence, the gain is directly proportional to the frequency. This is because the size of the horn aperture is always measured in wavelengths (0.5λ); as the operation frequency is increasing, the horn antenna is "electrically larger"; this is because at higher frequency the wavelength of antennas are small. Since the horn antenna has a fixed physical size, the aperture is has additional wavelengths across at higher frequencies. In antenna design, larger antennas are referred to as antenna with large wavelength. If any antenna with large wavelength, such antenna will have higher directivities. The directivity of a horn antenna is approximately equal to its gain because it has little loss [19].

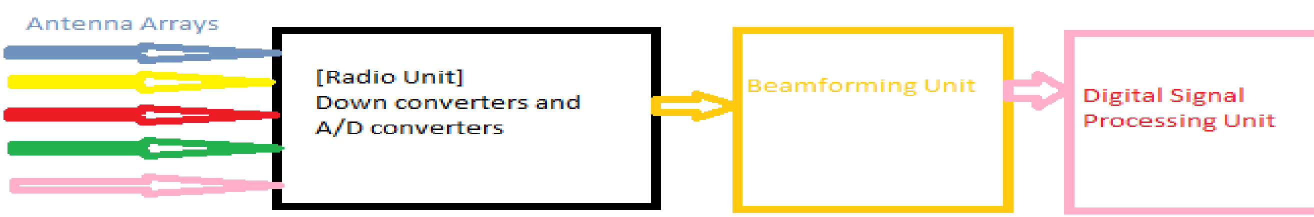

Fig. 2. The Proposed Smart Antenna System.

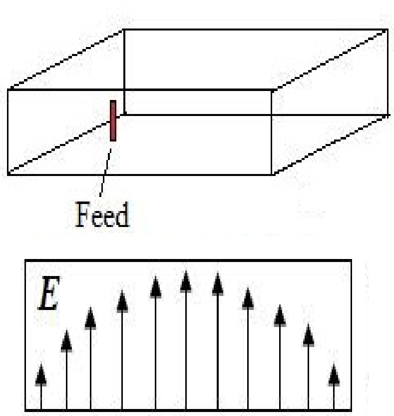

Fig. 3. Waveguide-fed Horn Antennas

Horn antennas are generally fed by a portion of a waveguide as shown in Fig. 3. The waveguides are used to guide the electromagnetic energy from one place to another.

3. DESIGN OF THE PHYSICAL ANTENNA

Radio frequency coverage from any base station is determined by three factors (a) the height of the antenna, (b) the type of antenna used, (c) and the radio frequency power level emitted. The type of antenna is crucial to an antenna designers. The type of antenna chosen for this work is smart antenna using a waveguide-fed pyramidal horn antenna as its physical antenna. The frequency of operation of the designed antenna is 300 MHz. The modelled antenna synthesizes a linear array that has a broadside null that mitigates interfering signals and having a specified directivity on both sides of the null and excitation taper. With the specification of the excitation paper for the ultra-wideband and tightly coupled antenna arrays [20], this allows the sidelobes of the antenna to be controlled. The array was designed with the arrangement of the parameters through any of the three capital axes in conjunction with the producing pattern. The resulting beam pattern is being rotated in symmetric manner around the axis being chosen while the null which in the plane is being held normal to the axis of the plane.

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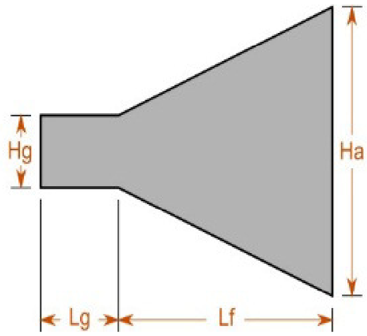
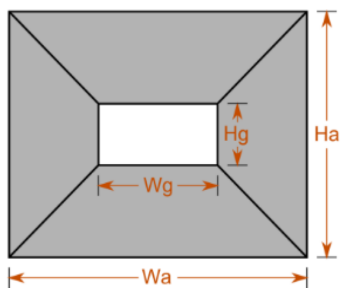
The optimum designed inter-element spacing in the array is 0.5λ. Fig. 4 shows the proposed modelled antenna design's side view and end view.



(a) Side view



(b) End view

Fig. 4 Proposed Modelled Antenna design (a) side view and (b) end view

4. DESIGN PARAMETERS

W_g is width of waveguide section (23.53 mm), H_g is height of the waveguide section (11.77 mm), L_g is length of waveguide section (44.97 mm), W_a is aperture width (69.24 mm), H_a is aperture height (50.71 mm), L_f is Length of flare section (26.66 mm).

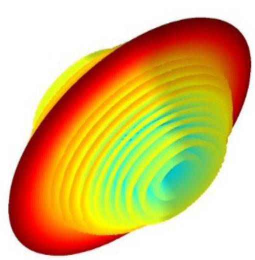
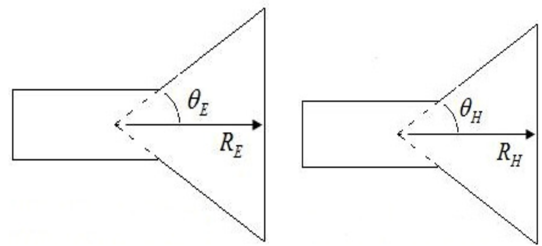


Fig. 5. Synthesized array phased pattern of the proposed antenna

The selected frequency of operation is 300 MHz. To obtain maximum gain and minimum reflection, the flare angle between 0^0 and 90^0 must be maintained. The chosen dimensions for the design optimum horn is obtained using the following equation [19].

$$a_E = \sqrt{2\lambda L_E} \text{ and } a_H = \sqrt{3\lambda L_H} \quad (4)$$

Where a_E and a_H are the aperture width in the direction of E-field and H-field respectively, and L_E and L_H are the slant length side in the E-field and H-field direction respectively. λ is the wavelength of operation. The distribution of the E-field across the horn antenna aperture takes the responsibility for the radiation.



(a) E-Plane (b) H-Plane

Fig. 6. Waveguide Cross section cut (a) E-Plane (b) H-Plane

The critical observation in Fig. 6 is that the flare angles [θ_E and θ_H] and the radiation pattern depends on the measured parameters (waveguide size, horn length which affects the flare angle, horn size at the opening) of the horn antenna. The optimization of these parameters can be used to control the performance of the horn antenna.

5. ESTIMATED PERFORMANCE OF THE MODELLED

The designed antenna has simulated in antenna software using the specifications stated in the Section III, and its performances are shown as below. Fig. 7 shows the plot of the far-field radiation effects of the antenna as a transformation of spatial co-ordinates indicated by azimuth and elevation angle (Φ, ϴ). The azimuth angle is the compass direction from which the signal is coming. The azimuth angle varies from 90^0 to 270^0 as shown in Fig. 7.

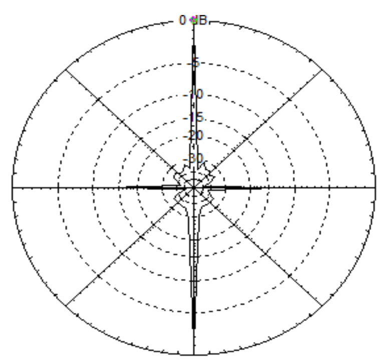


Fig. 7. Radiation pattern for the Far-field plot of the antenna

It can be observed that the angle of elevation which is the altitude angle of the signal observed remains constant at an angle of 60^0 throughout the operating band of frequencies. At an elevation angle of 60^0, the step size is 10^0 intervals at a dipole reference level of 1dBi swr $z_o = 50\ \Omega$.

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The far field pattern specified the angular dependence of the radio waves from the antenna. As shown in Fig. 7, the directional dependence are 0^0, 5^0, 10^0, 15^0, and 30^0.

Fig. 8 shows the frequency of operation at 300 MHz. At this frequency, the beamwidth cannot be calculated for elevation angle of 60^0. The outer ring is 2.57 dB having a slice maximum gain of 2.13 dBref at azimuth angle of 90^0. The front/back (F/B) for the plotted azimuth antenna array at an angle of 260^0 is 0.07 dB with sidelobe gain of 2.06 dB.

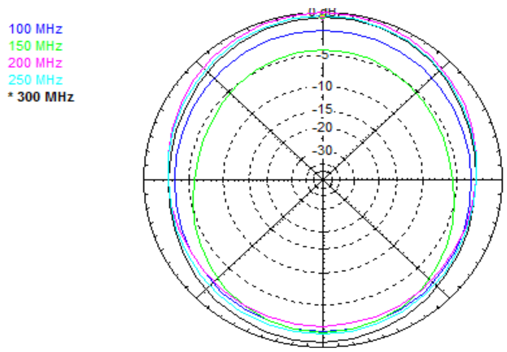

Fig. 8. Frequency array pattern at 300 MHz

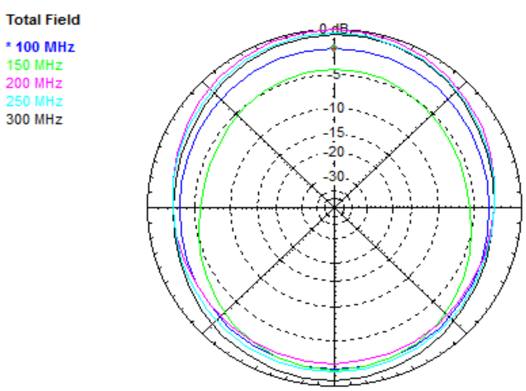

Fig. 9. Frequency array pattern at 100 MHz

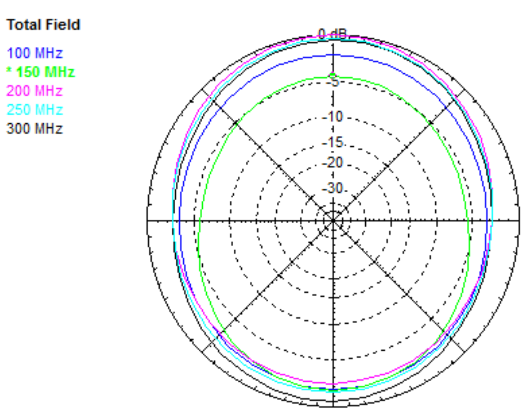

Fig. 10. Frequency array pattern at 150 MHz

Fig. 9 shows the array radiation frequency at 100 MHz. The beamwidth cannot be calculated at an elevation angle of 60^0, having an outer ring of 2.57 dB and slice maximum gain of 0.88dBref at an azimuth angle of 270^0. The front/sidelobe is 0.24 dB with sidelobe gain of 0.64 dBref at azimuth angle of 90^0. Figure 10 shows the frequency radiation pattern at 150 MHz, the beamwidth is 139.5^0, the front/back lobe gain has increased by 2.47dB, and the front/sidelobe has also increased by 2.47 dB the sidelobe gain has decreased to -1.7 dB at azimuth angle of 90^0.

Figure 11 shows that the beamwidth at a frequency of 200 MHz is out of range. The sidelobe gain has increased to 0.3 dB at an angle of 270^0. This means that as the frequency is increasing, the sidelobe will be increasing, while the front/sidelobe will be decreasing.

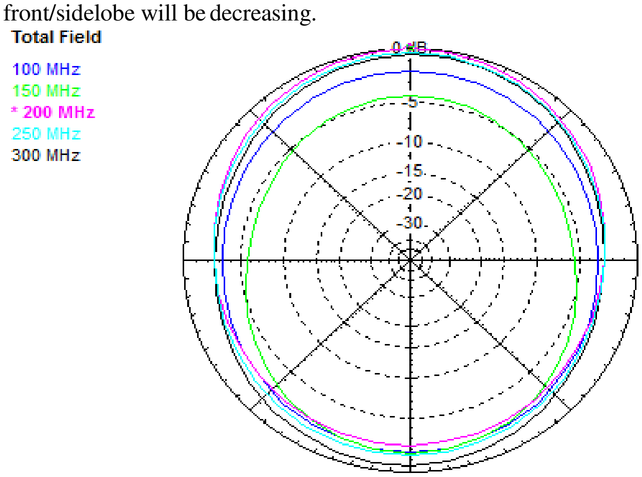

Fig. 11. Frequency array pattern at 200 MHz

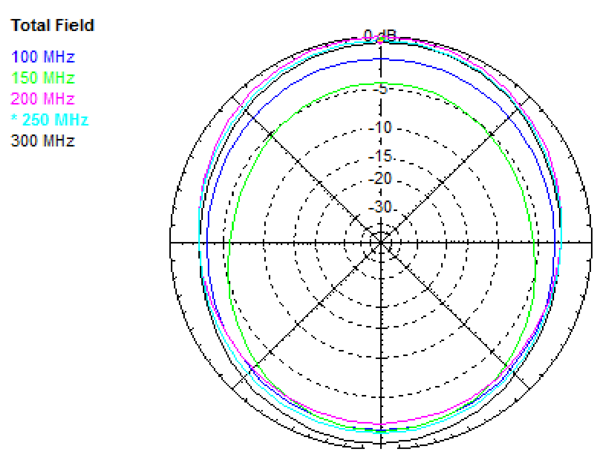

Fig. 12. Frequency array pattern at 200 MHz

Figure 12 shows that the beamwidth at a frequency of 250 MHz is out of range. The sidelobe gain has increased to 1.24 dB at an angle of 270^0.

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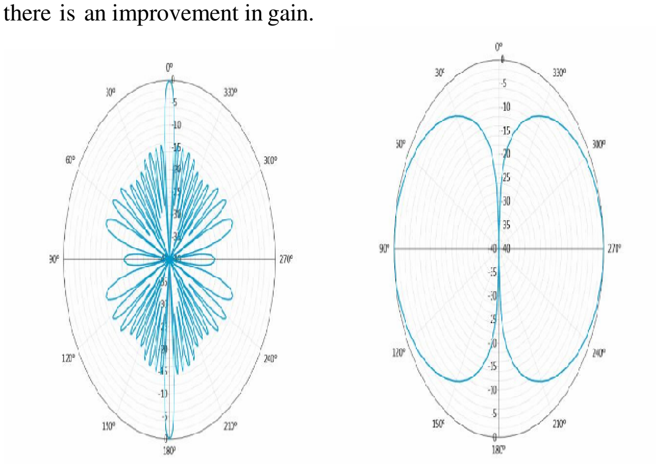
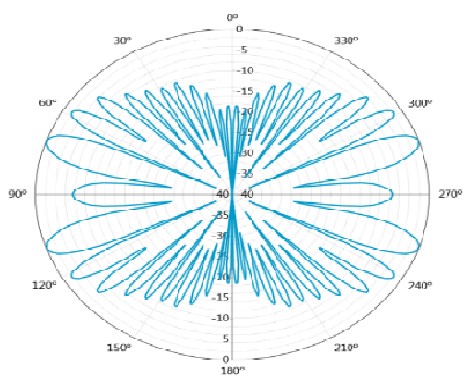
This means that as the frequency is increasing, the sidelobe will be increasing, while the front/sidelobe will be decreasing. In conclusion, as the frequency is increasing there is an improvement in gain.

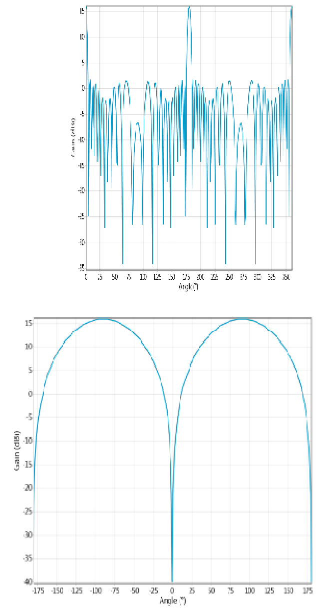


(a) XY-Plane cut (b) (XZ-Plane cut

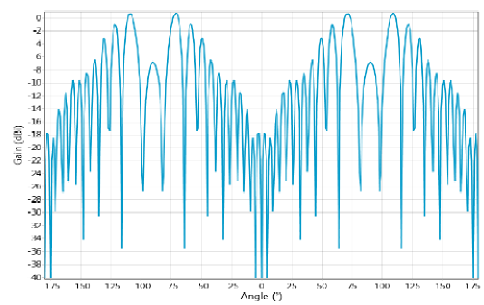


(c) YZ-Plane cut

Fig. 13. The polar plane cut axes (a) XY-Plane cut, (b) (XZ-Plane cut, and (c) YZ-Plane cut at 300 MHz



(a) XY-Plane cut (b) XZ-Plane cut



(c) YZ-Plane cut

Fig. 14. The cartesian plane cut axes of the antenna at 300 MHz

From figure 13, the XY-plane cut at an angle of 187.5^0 at 15 dBi and at an angle of 62.5^0, 112.5^0, 240^0, and 290^0 the gain is -34 dBi. In the XZ-plane cut, the highest 15 dBi gain occurs at -87.5^0 and 87.5^0 respectively. The lowest gain at -40 dBi occurs at -175^0 and 175^0 respectively. The ZY-plane cut gives its lowest gain of -40 dBi at -175^0, -5^0, 0^0, 5^0, and 175^0. At -112.5^0, -70^0, 112.5^0, and 70^0 the gain is 0 dBi which is the highest gain for the frequency. Figure 14 shows the Cartesian plane cut axes of the antenna at 300 MHz.

$$E(\phi) = 2E_o \left| \cos\left[\frac{\alpha}{2} - \frac{\pi d \sin\phi}{\lambda} \right] \right| \quad (5)$$

Equation 5 characterizes the array pattern in the xy-plane, in which the angle θ of a three-dimensional coordinate system is constant $(\theta = \pi/2)$. Angle θ is constant, that is why it doesn't come out in equation 4.Three-dimensional pattern can obtained by revolving the xy-pattern about the y-axis, that is the line of the array.

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This can be made possible since the xy-pattern is identical in shape and size at any value of rotation in the yz-plane. The pattern in the yz-plane can be expressed as a function of the angle θ instead of the angleϕ. Using the other planes, all the angles are included. The expression for the complete three-dimensional pattern is given by [17],

$$E(\theta,\phi) = 2E_o \left| \cos\left[\frac{\alpha}{2} - \frac{\pi d \sin\theta \sin\phi}{\lambda} \right] \right| \qquad (6)$$

Using the waveguide-fed pyramidal horn antenna designed in this work as one of the several antenna elements, the signal received from this antenna and the other antennas will be combined [21]. The combination will be processed adaptively in order to exploit the spatial domain of the mobile radio channel. Signals from the individual elements are down-converted and A/D-converted in the radio unit to baseband signals. Then after digitization of signals at the radio unit, it will be fed into a digital signal processing (DSP) where the direction of arrival of signals calculation algorithm will be carried out. Smart antennas itself are not smart. The system that combines the array of antenna with a digital signal processing capability to transmit and receive signals dynamically, change the direction of its radiation pattern and then optimize it automatically in response to the signal [6]. This system is called a smart antenna system. The system depends on the capability of a good antenna elements being received from the arrays of the antenna for the transmission of signal. When the antenna arrays configurations are used correctly, it increases range coverage and reduces multipath fading [7]. The basic block diagram of the conceived smart antenna system is shown in Figure 2. The antenna array is the physical antenna designed in section III.

The formation of the radiation beam pattern towards the desired user and nulling out interfering signals depends on the premises of direction of arrival of desired signal and interfering signals are known to the smart antenna system [22]. Smart antenna system estimates the direction of arrival (DOA) of the signal using various finding algorithms techniques [23]. Some of the techniques used are multiple signal classification (MUSIC), Eigen structure methods, estimation of signal parameters via rotational invariance techniques (ESPIRIT).

Direction of arrival and beamforming are the two main task need to be met by smart antenna system along with main function of propagation and reception of radio signals. Beamforming is technique used to establish the radiation beam pattern of the antenna arrays [24, 25].

6. CONCLUSION AND FUTURE RECOMMENDATION

This work examines how a smart antenna with its physical antenna can be used for data transmission at various frequencies of operation, the beam radiation pattern at various levels of frequencies and adaptive beamformed for smart antenna at their respective frequencies of operation. As most of the current research is on high data transmission [26-30], smart antenna can be as one of the chosen antennas for transmission and reception of signals due to its ability to mitigate interference and multipath signals at higher frequencies with the aid of antenna arrays. The future work recommends that array of antenna should be a half-wavelength dipole antenna. The dipole antenna exhibits an exceptional radiation pattern. In free space, the radiation pattern of a dipole antenna is highly active at right angles to the wire.

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