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Analysis Techniques on Yagi-Uda Antenna Configured for Wireless Terrestrial Communication Applications

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Abstract
The paper focuses on analysis and operation of Yagi-Uda antenna which is usually excited at frequencies between 30MHz and 3GHz with coverage of 40 to 60km. The length of the reflector is selected approximately equal to 0.55wavelength of the radiated signal. The optimum spacing between the reflector and the driven element is chosen between 0.15wavelength and 0.25wavelength. The length of the reflector has a large effect on the front-to-back ratio and antenna input impedance. For the dipole driven element, a length of 0.47wavelength was chosen to ensure good input impedance to a 50 ohms feed line. In this paper both empirical and measured data were collated to ensure a solid and efficient analysis of the parameters of this antenna. However, the paper has successfully presented a comprehensive analysis of the design, implementation and operation of the end-fire antenna configured for wireless terrestrial communication services.

Keywords: Yagi-Uda antenna, Coverage, Reflector, Dipole driven element, end-fire, Wireless terrestrial communication services

1.0 Introduction

Antenna is the backbone of every communication system. With the advent of wireless technology, a lot of innovation happens to develop the antennas. It is a device which helps to transform an RF signal travelling in a conductor into an electromagnetic wave in free space (transmit mode), and to transform an electromagnetic wave into an electrical signal (receive mode). The Yagi-Uda antenna has become very important in modern wireless communication antennas and is the most common kind of terrestrial TV Antenna found on the rooftops of houses. It is usually used at frequencies between 30MHz and 3GHz with coverage from 40 to 60km because of its simplicity, low cost and relatively high gain.

Antennas constitute a decisive component of all communication abilities described by [1]. Most fundamentally, an antenna is a way of converting the guided waves present in a waveguide, feeder cable or transmission line into radiating waves travelling in free space, or vice versa in [2]. The choice of antenna is very important for a transmitting - receiving communication system. The antenna must be able to radiate or receive efficiently so the power supplied is not wasted as shown in fig.1 below. Bandwidth, gain and radiation efficiency as well as low cost and simple integration are requirements that need to be met. The different types of antennas include; the dipole antennas, log periodic antennas, helical antenna, horn antenna, rhombic antennas, the Yagi-Uda antenna.

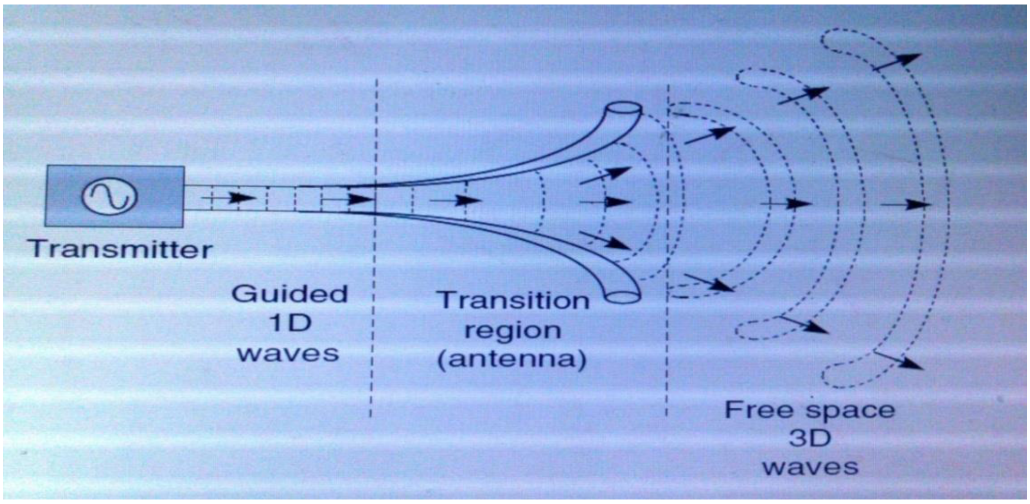


Fig. 1: The antenna as a transition region between guided and propagating waves

Section 2.0 of this paper briefly discussed some the concept of radiation mechanism necessary in Yagi-Uda antenna. The evaluation of antenna parameters from analytical and measurement approach was explained in section 3.0. Section 4.0 narrates the Yagi-Uda antenna performance and results obtained. Finally, the conclusions were enumerated in section 5.0.

2.0 Necessary Conditions for Radiation in Yagi-Uda Antenna

As Figure 2(a) shows, and as a direct consequence of Maxwell's equations, a group of charges in uniform motion (or stationary charges) do not produce radiation. In Figure 2(b)–(d), however, radiation does occur, because the velocity of the charges is changing in time. In Figure 2(b) the charges are reaching the end of the wire and reversing direction, producing radiation. In Figure 2(c) the speed of the charges remains constant, but their direction is changing, thereby creating radiation. Finally, in Figure 2(d), the charges are oscillating in periodic motion, causing a continuous stream of radiation. This is the usual practical case, where the periodic motion is excited by a sinusoidal transmitter. Antennas can therefore be seen as devices which cause charges to be accelerated in ways which produce radiation with desired characteristics. Similarly, rapid changes of direction in structures which are designed to guide waves may produce undesired radiation, as is the case when a printed circuit tracks carrying high-frequency currents changes direction over a short distance as enumerated by [2].

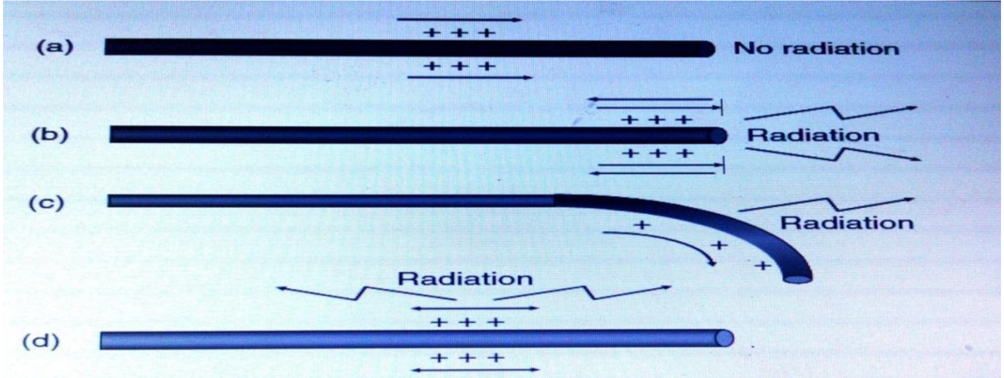
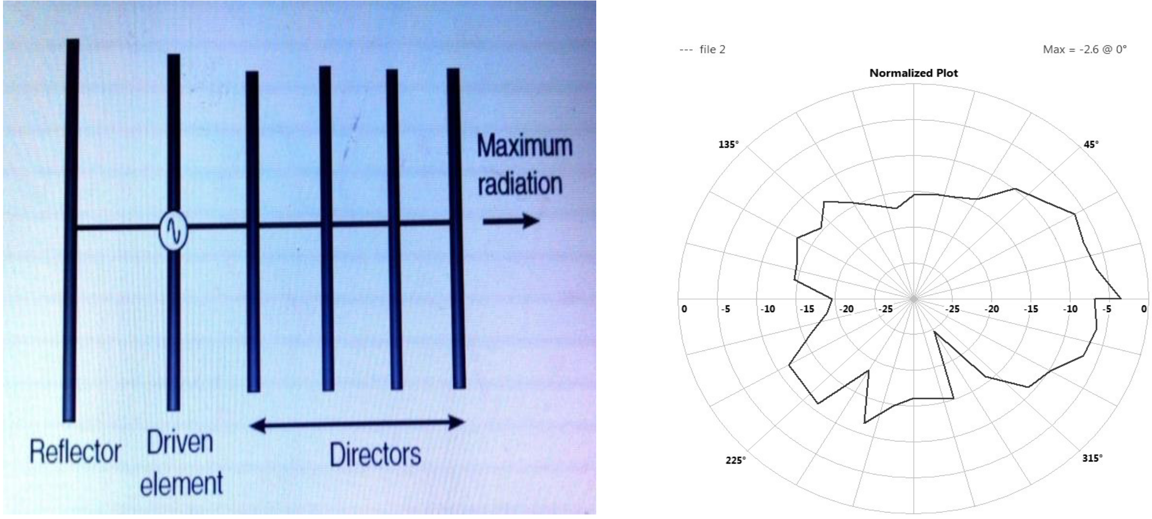


Fig. 2: Radiation Charges Distribution in Antenna

2.1 Literature Review: During the early 1920s professors Yagi and Uda, based in a university in Japan, set about researching and developing a directional antenna for the HF, VHF, UHF, SHF and microwave band. S. Uda made the first Yagi-Uda antenna and published the result in Japanese in 1926 and 1927 and the design was further developed and published in English by the colleague Professor Yagi a year later. Since then, a significant of amount of work has been done theoretically and experimentally. A lot of data and results are available in public domain. A Yagi-Uda antenna consists of a driven element and one or more parasitic elements. They are arranged collinearly and close together in [3].

2.2 Theoretical Framework: The Yagi-Uda antenna is another array-based approach to enhancing the directivity of a dipole antenna. Parasitic elements are mounted close to the driven dipole and are connected directly to the source. Instead, the radiation field of the driven element induces currents in the parasitic elements causing them to radiate in turn. It consists of a driven element and one or more parasitic element as shown in figure 3. If the length and position of the parasitic elements are chosen approximately, then the radiation from the elements and the driven element add constructively in one direction, producing an increase in directivity. The classic form of such an antenna is the Yagi-Uda.



(a)Yagi-Uda Antenna (b) Radiation Pattern

Fig. 3: Yagi-Uda Antenna and its Radiation pattern

The parasitic elements are mounted close to the driven dipole and are not connected directly to the source. Instead, the radiation field of the driven element induces currents in the parasitic elements causing them to radiate in turn. If the length and the position of the parasitic elements are chosen appropriately, then the radiation from the parasitic and driven element add constructively in one direction, producing an increase in the directivity. Typical driven element is less than λ/2 and typical director length 0.4-0.45λ. If multiple directors are used, they are not necessarily the same length or diameter and typical separation between directors is 0.3-0.4λ. Typical separation between driven element and reflector is 0.25λ as stated in [1].

The key element to the Yagi-Uda theory is the phases of the currents flowing in the additional elements of the antenna. The parasitic elements of Yagi-Uda antenna operate by re-radiating their signals in a slightly different phase to that of the driven element. In this way the signal is reinforced in some directions and cancelled out in others. As a result these addition elements are referred to as parasitic elements. In view of the fact that power in these additional elements is not directly driven, the amplitude and phase of the induced current cannot be completely controlled. It is dependent upon their length and the spacing between them and the dipole or driven element. As a result it is not possible to obtain complete cancellation in one direction. Nevertheless, it is still possible to obtain a high degree of reinforcement in one direction and have a high level of gain, and also have a high degree of cancellation in another to provide a good front to back ratio. The Yagi-Uda antenna is able to provide very useful levels of gain and front to back ratios. To obtain the required phase shift an element can be made either inductive or capacitive as described by [1].

Inductive*:* If the parasitic element is made inductive it is found that the induced currents are in such a phase that they reflect the power away from the parasitic element. This causes the RF antenna to radiate more power away from it. An element that does this is called a **reflector.** It can be made inductive by tuning it below resonance. This can be done by physically adding some inductance to the element in the form of a coil, or more commonly by making it longer than the resonant length. Generally it is made about 5% longer than the driven element.

Capacitive: If the parasitic element is made capacitive it will be found that the induced currents are in such a phase that they direct the power radiated by the whole antenna in the direction of the parasitic element. An element which does this is called a **director**. It can be made capacitive tuning it above resonance. This can be done by physically adding some capacitance to the element in the form of a capacitor, or more commonly by making it about 5% shorter than the driven element. It is found that the addition of further directors increases the directivity of the antenna, increasing the gain and reducing the beamwidth. The addition of further reflectors makes no noticeable difference above a certain number for a Yagi-Uda antenna designed for a particular radio-frequency (RF) or super high frequency (SHF) sub-band as described in [3].

2.3 Yagi-Uda Antenna Feed Impedance: As with any other type of antenna, ensuring that a good match between the feeder and the antenna itself are crucial to ensure the performance of the antenna can be optimized. The impedance of the driven element is greatly affected by the parasitic elements and therefore, arrangement needed to be incorporated into the basic design to ensure that a good match is obtained. It is possible to vary the feed impedance of a Yagi-Uda antenna over a wide range. Although the impedance of the dipole itself would be 73 ohms in free space, this is altered considerably by the proximity of the parasitic elements. The spacing their length and a variety of other factors all affect the feed impedance presented by the dipole to the feeder. In fact altering the element spacing has a greater effect on the impedance than it does the gain, and accordingly setting the required spacing can be used as one design technique to fine tune the required feed impedance. Nevertheless the proximity of the parasitic elements usually reduces the impedance below the 50 ohms level normally required. It is found that for element spacing distances less than 0.2 wavelengths the impedance falls rapidly away.

2.4 Yagi-Uda Matching Techniques: To overcome the impedance mis-match problem, a variety of techniques can be used. Each technique has its own advantages and disadvantages, both in terms of performance and mechanical suitability. No one solution is suitable for all applications. They include:

2.4.1. Balun: It is a straightforward method of providing impedance matching; a balun is an impedance matching transformer and can be used to match a great variety of impedance ratios, provided the impedance is known when the balun is designed. 4:1 baluns are widely available for applications including matching folded dipoles to 75Ω coax. Baluns like these are just RF transformers. They should have as wide a frequency range as possible, but like any wound components they have a limited bandwidth. However, if designed for use with a specific Yagi-Uda antenna, this should not be a problem. One of the problems with a balun is the cost- they tend to be more costly than some other forms of Yagi-Uda impedance matching. They may also be power limited for a given size.

2.4.2. Folded dipole**:** A folded dipole can effectively be implemented to increase the feed impedance. In its basic form it raises the impedance four fold, although by changing various parameters it is possible to raise the impedance by different factors. The folded dipole is a standard approach to increasing the Yagi-Uda impedance.

It is widely used on Yagi-Uda antennas including the television and broadcast FM antennas. Under free space conditions, the dipole impedance on its own is raised from 75Ω for a standard dipole to 300Ω for the folded dipole.

The folded dipole is a form of dipole that has higher impedance than the standard half-wave dipole. In the standard version, it has four times the impedance of the simple half-wave. However, different ratios can be obtained by changing the mechanical attributes in the boom of the antenna.

Another advantage of using a folded dipole for Yagi-Uda impedance matching is that the folded dipole has flatter impedance versus frequency characteristics than the simple dipole. This enables it and hence the Yagi-Uda to operate over a wider frequency range. While a standard folded dipole using the same thickness conductor for the top and bottom conductors within the folded dipole will give a fourfold increase in impedance, by varying the thickness of both, it is possible to change the impedance multiplication factor to considerably different values.

2.4.3. Delta match: This method of Yagi-Uda impedance matching is one of the straightforward solutions as it involves fanning out the ends of the balanced feeder to join the continuous radiating antenna driven element at a point to provide the required match. Both the side length and point of connection need to be adjusted to optimise the match. One of the drawbacks for using the Delta match for providing Yagi-Uda impedance matching is that it is unable to provide any removal of reactive impedance elements. As a result a stub may be used.

2.4.4. Gamma match: The gamma match is often used for providing Yagi-Uda impedance matching. It is relatively simple to implement. The coax braid feeder is connected to the centre of the driven element of the Yagi-Uda antenna where the voltage is zero. As a result of the fact that the voltage is zero, the driven element may also be connected directly to a metal boom at this point without any loss of performance. The inner conductor of the coax is then taken to a point further out on the driven element – it is taken to a tap point to provide the correct match. Any inductance is tuned out using the series capacitor. When adjusting the RF antenna design, both the variable capacitor and the point at which the arm contacts the driven element are adjusted. Once a value has been ascertained for the variable capacitor, its value can be measured and fixed component inserted if required in [4].

3.0 Evaluation of Antenna Parameters from Analytical and Measurement Approach

3.1.1. Current Distribution

The current distribution on the driven element is determined by its length, frequency and interaction or coupling with nearly elements (mainly the reflector and first director), while the current distribution in parasitic elements is governed by the boundary condition (i.e. the total tangential electric field must be zero on the conducting surface. This results in induced currents and they may be viewed as the second sources of the radiation.

Analytical and numerical methods have been employed to obtain the current distribution along each element. The results show that the current distribution on each element is similar to that of a dipole. As expected, the dominant current is on the driven element, the reflector and the first director carry less current, and the currents on other directors are further reduced and they appear to be of similar amplitude, which is typically less than 40% of that of the driven element. Consider a Yagi-Uda antenna as shown in Fig. 4 for our mathematical analysis which is enumerated in [5], [6], [7] & [8].

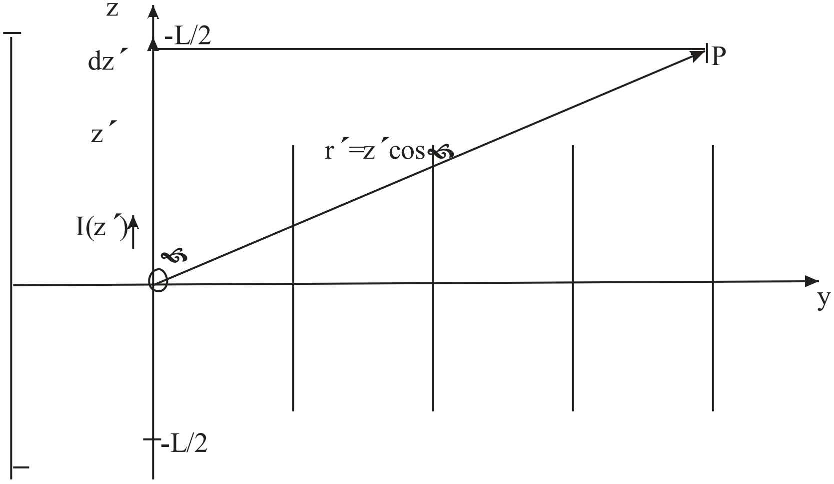


Fig. 4: The current distribution in Yagi-Uda antenna.

From Figure 4, given that $\left|\bar{r} + \bar{r}'\right| = r - z' \cos\theta$

And the current I(z') = $I_m sin\left(k\frac{L}{2} - k|z'|\right)$

The magnetic vector potential of the driven element at point, P is:

$$A_z = \frac{\mu}{4\pi}\int \frac{I(z\prime)e^{-jkR}}{R}\, dz'$$

But the amplitude approximation, R = r and the phase approximation, $|\bar{r} + \bar{r'}| = R = r - z'$. Therefore,

$$A_z = \frac{\mu}{4\pi}\int_{-L/2}^{L/2} \frac{I(z\prime)}{r}\, e^{-jk(r - z\prime\cos\theta)}\, dz' \quad \text{……………………...........1.1}$$

But I(z') =$I_m sin\left(k\frac{L}{2} - k|z'|\right)$ ……………………………..........1.2

Substituting the value of I(z') into equation 1.1 we have;

$$A_z = \frac{\mu}{4\pi}\int_{-L/2}^{L/2} \frac{I_m\left(k\frac{L}{2} - k|z\prime|\right)}{r}\, e^{-jk(r - z\prime\cos\theta)}\, dz'$$

$$= \frac{I_m\mu e^{-jkr}}{4\pi r}\int_{-L/2}^{L/2} sin\left(k\frac{L}{2} - k|z'|\right)\, e^{-jk(r - z\prime\cos\theta)}\, dz' \quad \text{.........1.3}$$

Taking the positive value of z'; $|-z'| = z'$ and the modulus of $|z'| = z'$. The magnetic vector potential can be further evaluated as

$$A_z = \frac{I_m\mu e^{-jkr}}{4\pi r}\left[\int_0^{L/2} sin\left(k\frac{L}{2} - kz'\right)\, e^{jkz\prime\cos\theta}\, .dz + \int_0^{L/2} sin\left(k\frac{L}{2} + kz'\right)\, e^{jkz\prime\cos\theta}\, .dz'\right]$$

Let $A_1 = \int_0^{L/2} sin\left(k\frac{L}{2} - kz'\right) e^{jkz\prime\cos\theta}\, .dz'$ 1.4

But $\int e^{ax}\sin(bx + c)\, dx = \frac{e^{ax}[a\sin(bx+c) + b\cos(bx+c)]}{a^2 + b^2}$.......1.5

Let $ax = jkz'\cos\theta\,;\ x = z'; c = \frac{KL}{2}\ a = jk\cos\theta\ and\ b = -k$

$$A_1 = \left[\frac{e^{jkz'\cos\theta}\left[jk\cos\theta sin\left(\frac{KL}{2} - kz'\right) + (-k)cos\left(\frac{KL}{2} - kz'\right)\right]}{k^2 sin^2\theta}\right]$$

$$= \left[\frac{e^{jkz' \cos\theta . z'} \left[jk \cos\theta \sin\left(\frac{KL}{2} - kz'\right) + -k\cos\left(\frac{KL}{2} - kz'\right) \right]}{k^2 \cos^2\theta + k^2} \right]$$

But $k^2 - k^2\cos^2\theta = k^2(1 - \cos^2\theta) = k^2\sin^2\theta$

$$A_1 = \left[\frac{e^{jk\cos\theta z'} \left[jk\cos\theta \sin\left(\frac{KL}{2} - kz'\right) - k\cos\left(\frac{KL}{2} - kz'\right) \right]}{k^2\sin^2\theta} \right]$$

$$= e^{jk\frac{L}{2}\cos\theta} \left[jk\cos\theta \sin\left(\frac{KL}{2} - \frac{KL}{2}\right) - k\cos\left(\frac{KL}{2} - \frac{KL}{2}\right) \right] \div k^2\sin^2\theta - e^0 \left[jk\cos\theta \sin\frac{KL}{2} - k\cos\frac{KL}{2} \right] \div k^2\sin^2\theta$$

$$A_1 = \frac{e^{jk\frac{L}{2}\cos\theta} \left[(-k) - jk\cos\theta \sin\frac{KL}{2} + k\cos\frac{KL}{2} \right]}{k^2\sin^2\theta} \qquad \text{.................................1.7}$$

Also,

$$A_2 = \int_{-\frac{L}{2}}^{0} \sin\left(\frac{KL}{2} + kz'\right) e^{jkz'\cos\theta} . dz' \qquad \text{...1.8}$$

$$A_2 = \int_{-\frac{L}{2}}^{0} e^{jk\cos\theta . z'} \sin\left(\frac{KL}{2} + kz'\right) . dz'$$

But $\int e^{ax} \sin(bx + c) dx = \dfrac{e^{ax}[a\sin(bx+c) + b\cos(bx+c)]}{a^2 + b^2}$

Let $ax = jk\cos\theta . z'; \ x = z'; c = \frac{KL}{2} \ a = jk\cos\theta \ \ and \ b = -k$

$$A_2 = \left[\frac{e^{jk\cos z'} \left[jk\cos\theta \sin\left(\frac{KL}{2} + kz'\right) + k\cos\left(\frac{KL}{2} + kz'\right) \right]}{(jk\cos\theta)^2 + k^2} \right]_{-L/2}^{0}$$

But, (jkCos$\theta)^2 + k^2 = -k^2\cos^2\theta + k^2 = k^2\sin^2\theta$

$$A_2 = \frac{e^0 \left[jk\cos\theta \sin\frac{KL}{2} + k\cos\frac{KL}{2} \right] - e^{-j\frac{KL}{2}\cos\theta} [jk\cos\theta \sin(0) + k\cos(0)]}{k^2\sin^2\theta}$$

But $A_z = A_z = \frac{I_m \mu e^{-jkr}}{4\pi r}\left[A_1 + A_2\right]$ 1.9

$$A_z = \frac{I_m \mu e^{-jkr}}{4\pi r}\left[\left(\frac{-ke^{jk\frac{L}{2}} - jk\cos\theta\sin\frac{KL}{2} + k\cos\frac{KL}{2}}{k^2\sin^2\theta}\right) + \left(\frac{jk\cos\theta\sin\frac{KL}{2} + k\cos\frac{KL}{2} - ke^{-j\frac{KL}{2}\cos\theta}}{k^2\sin^2\theta}\right)\right]$$

$$= \frac{I_m \mu e^{-jkr}}{4\pi r}\left[\frac{-k\left[e^{j\frac{KL}{2}\cos\theta} + e^{-j\frac{KL}{2}\cos\theta}\right] + 2k\cos\left(\frac{KL}{2}\right)}{k^2\sin^2\theta}\right]$$

$$A_z = \frac{I_m \mu e^{-jkr}}{4\pi r}\left[\frac{-\left[e^{j\frac{KL}{2}\cos\theta} + e^{-j\frac{KL}{2}\cos\theta}\right] + 2\cos\left(\frac{KL}{2}\right)}{k\sin^2\theta}\right]$$

Multiplying A_z by -1 normalizes the magnetic vector potential of the current distribution. Also, the modulus of A_z is $|-A_z| = A_z$. Therefore,

$$A_z = \frac{I_m \mu e^{-jkr}}{4\pi r}\left[\frac{\left[e^{j\frac{KL}{2}\cos\theta} + e^{-j\frac{KL}{2}\cos\theta}\right] - 2\cos\left(\frac{KL}{2}\right)}{k\sin^2\theta}\right] \quad \text{...........................1.10}$$

From Euler's Identity, $e^{j\theta} = \cos\theta + j\sin\theta$ and $e^{-j\theta} = \cos\theta + j\sin\theta$

Therefore, $2\cos\theta = e^{j\theta} + e^{-j\theta}$. Therefore, we have this relation:

$$A_z = \frac{I_m \mu e^{-jkr}}{4\pi r}\left[\frac{2\cos\left(\frac{KL}{2}\cos\theta\right) - 2\cos\left(\frac{KL}{2}\right)}{k\sin^2\theta}\right] \quad \text{……….............................1.11}$$

Equation 1.11 reveals the overall magnetic vector potential from the current distribution of the driven element of the Yagi-Uda antenna.

3.1.2. Radiation Pattern

The radiation pattern of an antenna is a plot of the far-field radiation from the antenna. Once the current is known, the magnetic vector potential, A_z is also known, the total radiated field can be obtained using equation 2.4. For a dipole Yagi-Uda antenna, the radiation from element, n is derived as follows.

We know that, $A_r = A_z\cos\theta$ and $A_r = -A_z\sin\theta$

Also $Er = j\omega A_r = j\omega A_z \cos\theta$

And $E_\theta = -j\omega A_\theta = -j\omega A_\theta(-A_z \sin\theta) = j\omega A_z \sin\theta$ 1.12

Substituting equation 1.11 into 1.12, we have

$$E_\theta = \frac{j\omega\mu I_m e^{-jkr}}{4\pi r}\left[\frac{2\left(\frac{KL}{2}cos\theta\right) - cos\left(\frac{KL}{2}\right)}{k sin^2\theta}\right]\sin\theta \quad ....1.13$$

$$= \frac{j\omega\mu I_m e^{-jkr}}{4\pi r.k}\left[\frac{cos\left(\frac{KL}{2}cos\theta\right) - cos\left(\frac{KL}{2}\right)}{sin\theta}\right]$$

But $k = \omega\sqrt{\mu\epsilon}$

Substituting the value of k into the relation of E_θ in equation 1.13

$$E_\theta = \frac{j\omega\mu I_m e^{-jkr}}{\omega\sqrt{\mu\epsilon}.2\pi r}\left[\frac{cos\left(\frac{KL}{2}cos\theta\right) - cos\left(\frac{KL}{2}\right)}{sin\theta}\right]$$

$$= \frac{j\sqrt{\frac{\mu}{\epsilon}}I_m e^{-jkr}}{2\pi r}\left[\frac{cos\left(\frac{KL}{2}cos\theta\right) - cos\left(\frac{KL}{2}\right)}{sin\theta}\right]$$

$$E_\theta = \frac{j\eta I_m e^{-jkr}}{2\pi r}\left[\frac{cos\left(\frac{KL}{2}cos\theta\right) - cos\left(\frac{KL}{2}\right)}{sin\theta}\right] \quad ....1.14$$

Also $H_\emptyset = \frac{E_\theta}{\eta} = \frac{jI_m e^{-jkr}}{2\pi r}\left[\frac{cos\left(\frac{KL}{2}cos\theta\right) - cos\left(\frac{KL}{2}\right)}{sin\theta}\right]$...........................1.15

The radiation from element n is given as:

$$E(\theta)n = \frac{j\eta I_m e^{-jkr}}{2\pi r}\left(\frac{cos(KL_n cos\theta) - cos(KL_n)}{sin\theta}\right) \quad …..........................1.16$$

Where: I_m is the maximum current and L_n is half the length of the nth dipole. Thus, the total radiation pattern is the field super position from the entire element and may be expressed as:

$$E(\theta)n = \frac{j\eta e^{-jkr}}{2\pi r}\sum_{n=1}^{N} I_m\left(\frac{cos(KL_n cos\theta) - cos(KL_n)}{sin\theta}\right)exp(jks_{n-1}\cos\theta)$$

$$E(\theta) = \frac{j\eta e^{-jkr}}{2\pi r} \sum_{n=1}^{N} I_m \left(\frac{cos(KL_n cos\theta) - cos(KL_n)}{sin\theta} \right) e^{jks_{n-1} \cos\theta} \quad .1.17$$

Where r is the center of the reflector to the observation point, the spacing is given as $S_0 = 0$ *and* it is apparent that each element length and spacing, weighted by its maximum current, affects the total radiation. This approach is the same as the one we are using for analysing antenna array.

More specifically, it is a plot of the power radiated from an antenna per unit solid angle, or its radiation intensity U measured in watts per unit solid angle. This is arrived at by simply multiplying the power density at a given distance by the square of the distance r, where the power density S measured in watts per square metre.

$U = r^2S$ 1.18

This has the effect of removing the effect of distance and of ensuring that the radiation pattern is the same at all distances from the antenna, provided that r is within the far field in [9]. The simplest example is an idealised antenna which radiates equally in all directions, an isotropic antenna.

3.1.3 Beamwidth

The half-power beamwidth (HPBW) or commonly the beamwidth is the angle subtended by the half-power points of the main lobe.

3.1.4 The front-back ratio

One important figure of merit in a Yagi-Uda antenna is the front-to-back ratio. This is the ratio between the peak amplitudes of the main and back lobes, usually expressed in decibels as in [2]. It has been found that this is very sensitive to the spacing of the direction. It varies from trough to peak and from peak to trough repetitively as a function of the spacing.

3.1.5 The side-lobe level

It is the amplitude of the biggest side-lobe, usually expressed in decibels relative to the peak of the main lobe as shown in Fig. 5 expressed by [10].

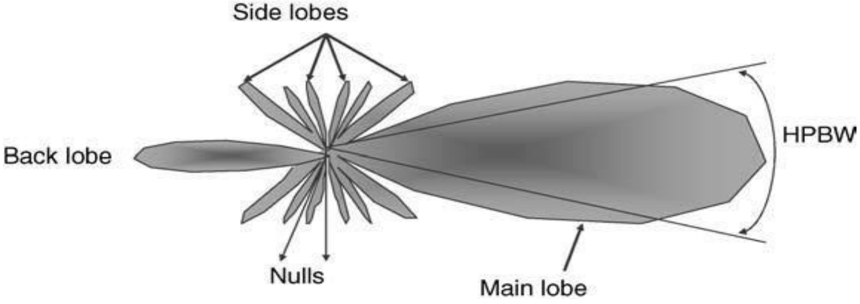


Fig. 5: The Radiation Pattern of an Antenna

4.0 Yagi-Uda Antenna Performance and Results

It is one of the most brilliant designs and easy to construct. The Yagi-Uda antenna typically operate in the HF to UHF bands (about 3MHz to 3GHz), although their bandwidth is typically small, on the order of a few percent of the centre frequency.

4.1 Yagi-Uda Antenna Gain and Directivity: One of the reasons for using a Yagi-Uda antenna is the gain it provides. The Yagi- Uda antenna gain is of great importance, because it enables all the transmitted power to be directed into the area where it is required, or when used for reception, it enables the maximum signal to be received from the same area. The geometry of the radiation of the Yagi-Uda antenna is shown in figure 6.

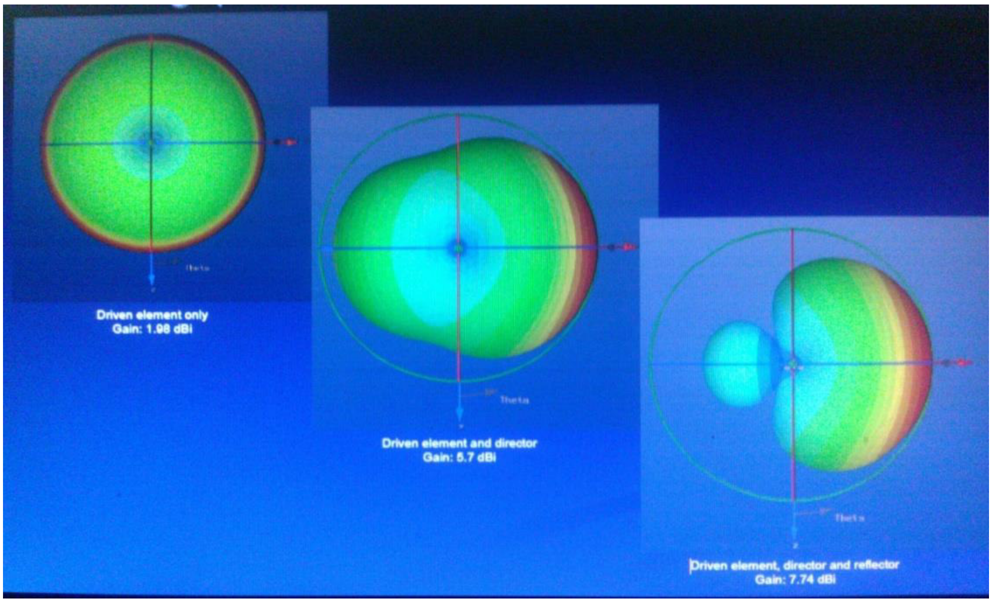


Fig. 6: Yagi-Uda antenna viewable Radiation Patterns

4.2 Yagi-Uda Directive Gain and Beamwidth considerations: It is found that as the Yagi-Uda gain increases so also the beam-width decreases as shown in fig. 7 below.

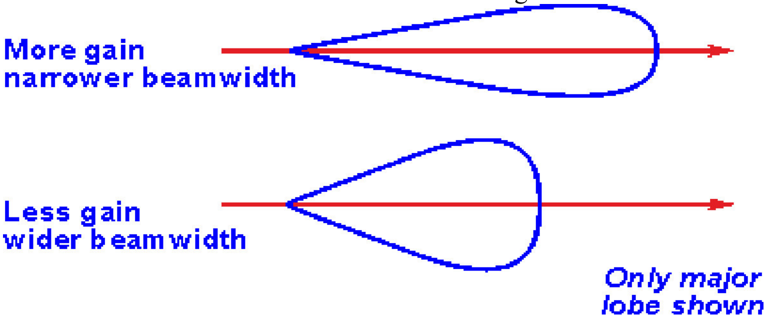


Fig. 7: Yagi-Uda Directive gain and Beamwidth

Antennas with a very high level of gain are very directive. Therefore high gain and narrow beam-width sometimes have to be balanced to provide the optimum performance for a given application. Features that affect the overall gain of a Yagi-Uda antenna include the followings:

4.2.1. Number of element in the Yagi-Uda: One of the main factors affecting the gain of Yagi-Uda antenna is the number of element in the design. Typically a reflector is the first element added in any yagi-Uda design as this gives the most additional gain. Directors are then added to it boom.

4.2.2. Element spacing: The spacing can have an impact on the Yagi-Uda gain, although not as much as the number of elements. Typically a wide-space beam (i.e. one with a wide spacing between the elements) gives more gain than one that is more compact. The most critical element positions are the reflector and first director, as their spacing governs that of any other elements that maybe added.

4.2.3. Antenna length: When computing the optimal positions for the various elements it has been shown that in a multi-element Yagi-Uda array, the gain is proportional to the length of latitude in the element positions.

The gain of a Yagi-Uda antenna is governed mainly by the number of elements in the particular RF antenna. However the spacing between the elements also has an effect. As the overall performance of the RF antenna has so many inter-related variables, many early designs were not able to realise their full performance. Today computer programmes are used to optimise RF antenna designs before they are even manufactured and as a result the performance of antennas has been improved.

4.2.4. Yagi-Uda Directive Gain Using the Number of Elements**:** The directivity can be obtained as we did for simple dipole. Although there is a variation between different designs and the way Yagi-Uda antennas are constructed, it is possible to place some very approximate figures for anticipated gain against the number of elements in the design. The approximate Yag-Uda antenna gain level is paramount to its characterization. A simple estimation of the maximum directivity of a Yagi-Uda antenna is proposed as follows:

$D = 10\mathrm{Log}3.28N$ (dB), Where N is number of elements in its boom [11].

The coefficient 3.28 results from doubling the directivity (1.64) of a half-wave dipole. Since there are N elements, the maximum is obtained when they are combined constructively as 3.28N. The reason for introducing the factor of 2 is that the radiation pattern is now unidirectional end-fire. The radiation is redirected to just half of the space by the reflector and directors, which is somewhat similar to the effect of conducting ground plane. For simplest three-element Yagi-Uda antenna, N=3. Therefore, D=3.28(3) and D=9.93dB. When the number is doubled to N=6, additional gain can be obtained as D=12.94dB in [12] & [13].

The directive gain level of the antenna with different number of parasitic elements is clearly shown in table 1 below.

Table 1: Antenna Approximate Directive Gain with Number of Elements

Number of elements	Approximate Anticipated gain(D) dB over Dipole
2	8.17
3	9.93
4	11.18
5	12.15
6	12.94
7	13.61
8	14.19
12	15.95
15	16.92
18	17.71

As an additional rule of thumb, once there are around four or five directors, each additional director adds around an extra 1dB to the directive gain of the antenna. This is clearly seen in the gain for directors up to about 14 or more. It is interesting to know that with 25 numbers of elements, the achievable gain is just 19.14dB. The gain increases with the increasing number of directors as shown in Fig. 8 below. Since there is no appreciable increment in the gain, it is therefore economical to keep the number of directors to the allowable minimum as postulated in [12].

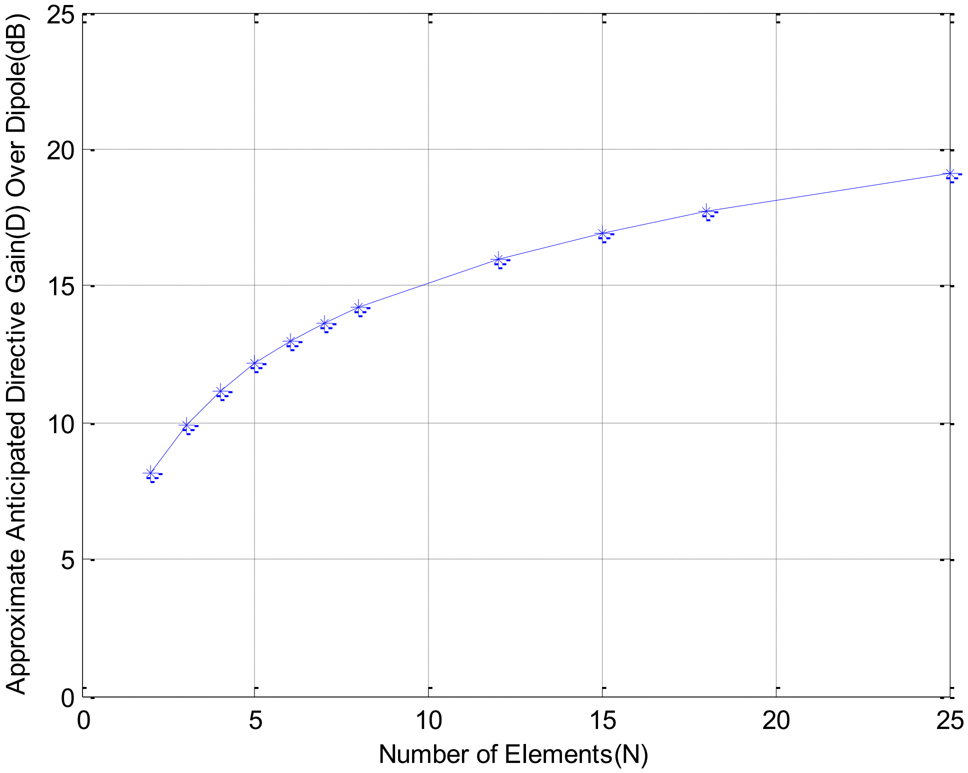


Fig. 8: Graph of Directive Gain versus Number of Elements

4.3 Yagi-Uda Side-lobes and Front to back ratio: The diagram of Yagi-Uda Main lobe, Side-lobes from front to back is shown in figure 9.

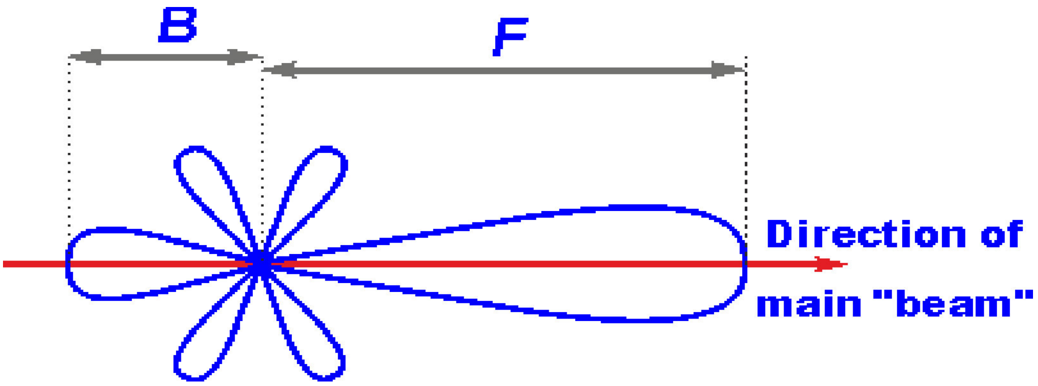


Fig. 9: The Yagi-Uda Radiation main lobe and Side-lobes

Depending on the spacing of the reflector and director elements, a Yagi-Uda antenna will display lobes to a greater or lesser extent in its radiation pattern. The spacing will therefore determine the size and number of rear-lobes present in the entire radiation pattern. One of the figures associated with the Yagi-Uda antenna gain is what is termed the front to back ratio, F/B. This is a ratio of the signal level in the forward direction to the reverse direction and normally expressed in dB.

$$\text{Front to back ratio} = \frac{\text{Signal in forward direction}}{\text{Signal in reverse direction}} = \frac{F}{B}$$

The front to back ratio is important in circumstances where interference or coverage in reverse direction needs to be minimised. Unfortunately the conditions within the antenna mean that optimisation has to be undertaken for either front to back ratio or maximum forward gain. Conditions for both features do not coincide, but the front to back ratio can normally be maximised for a small degradation of the forward gain in [12].

Advantages of a Yagi-Uda antenna include the followings:

- It has a moderate gain of about 7dB.
- It is a directional antenna.
- It can be used at high frequency.

Disadvantages of a Yagi-Uda Antenna

- The gain is not very high using a few numbers of elements.
- Needs a large number of elements to be used in its boom.

Applications of a Yagi-Uda antenna include the followings:

- HF terrestrial transmission and reception
- VHF television receiving antenna
- VHF and UHF radio frequency bands (30MHz to 3GHz)

5.0 Conclusion

The Yagi-Uda antenna is an array-based approach to enhancing the directivity of dipole antennas. It consists of a driven element and one or more parasitic element. The different elements (i.e. reflector and directors) of the Yagi-Uda antenna react in a complex and interrelated way to provide the overall high performance directive gain necessary for its efficiency. Elements with varying lengths and element spacing determine the antenna radiation behaviour. From the analytical and measured data, the input impedance of the antenna measured is small (about 50Ω) and Gamma match technique was used. The Yagi-Uda antenna incorporated with folded dipole produces better efficiency and finds its application in modern digital satellite television aerial operating in the UHF band.

6.0 References

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