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Design and construction of array dipole antenna adaptable to VHF and UHF bands

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Abstract

In this paper, an array dipole antenna adaptable to VHF and UHF bands was designed and constructed. The dimension (length and spacing) of the parasitic elements (directors) were determined: the longest length being 17.0cm and the shortest 5.3cm. The widest spacing was 3.58cm and the shortest 1.27cm. The characteristics of the antenna were determined at a frequency of 189.5MHz. It has an input impedance of 96.72Ω and a gain of 2.15dBi. It performs optimally in frequency range of 60MHz- 300MHz as attested using TV (receive only) monitor. It adapts favourably well to the VHF and lower UHF bands.

Keywords: Dipole antenna, design

Introduction

An array dipole antenna is an arrangement of metallic conductors in a predefined form to facilitate the reception and transmission of electromagnetic (EM) waves which is a priori to electronic communication (Wikipedia, 2009; www.http.wikipedia). The successful design of any radio system depends on a crucial element called an *antenna* which is the part through which radio frequency energy is coupled from the transmitter to the outside world and in reverse to the receiver from the outside world. Antenna systems rely on EM radiation with an antenna at both transmitting and receiving ends. Signal is radiated into a substantial angular region of space by the transmitting antenna and only a fraction is intercepted by the receiving antenna.

This implies that there is a significant coupling loss between the receiving and transmitting antennas. However, unlike transmission lines, this loss is algebraic and not exponential due to the fact that the radiated power incident on the receiving antenna decrease as the inverse square of the distance between the transmitting and receiving antennas and as a result, beyond a certain distance, the loss in the antenna system will increasingly become less than that of transmission lines (Balanis, 1982; Burkholder & Lundin, 2006). In addition to this, antennas are usually needed to optimize or accentuate the radiation energy of the em wave in some direction and minimize it in others (a property referred to as its directivity). Hence, an antenna can serve not only as a probing device but as a directional device (Balanis, 1982). A few types of antennas include wire antenna (Helix and loop), aperture antenna (Pyramidal Horn, Conical Horn), array antenna (Yagi-Uda array, Apperture array and slotted waveguide), reflector antenna (parabolic reflector), lens antenna etc. Considering the advantages of reduced size, robustness, improved antenna performance and others, choice was made of developing a computational model to aid antenna engineers.

Development of array gained wide acceptance after the researches of Hidestu Yagi and Shinatevro Uda (1926). During this period broadband antennas were also produced. The Yagi-uda Antenna remained in active use till date. These have a performance that is periodic logarithmic in fashion hence the name log-periodic antenna.

Antenna radiation theory

Theory classifies antennas into two fundamental types with reference to a specific three dimensional (usually horizontal or vertical) plane. These two types are: (i) Omni-directional (radiates equally in all directions) and (ii) Directional (radiates more in one direction than in the other).

By adding more conducting rods or coils (called Parasitic elements) and varying their length, spacing, and orientation (or changing the direction of the antenna beam), an antenna with specific desired properties can be created. The term active element is intended to describe an element whose energy output is modified due to the presence of a source of energy in the element (other than the mere signal energy which passes through the circuit) or an element in which the energy output from a source of energy is controlled by the signal input. Parasitic elements are metallic conductive structures which re-radiate into free space impinging electromagnetic radiation coming from or going to the active antenna. The velocity of the waves radiated from or going to the active antenna has a component which is in the same direction (director) or in the opposite direction (reflector) to that of the velocity of the impinging wave. An electromagnetic wave refractor is positioned to delay or accelerate transmitted wave passing through it. The refractor alters the direction of propagation of the waves emitted from the structure with respect to the waves impinging on the structure.

The energy stored by an electromagnetic wave in a unit volume of space is (Gonca, 2005; Burkholder & Lundin, 2006)

$$E = \frac{1}{2}\left(\varepsilon \bar{E}^2 + \mu \bar{H}^2\right).j \qquad (1)$$

ε is the permittivity while μ is the permeability. E and H are the electric and magnetic fields respectively. The total energy is (Gonca, 2005; Burkholder & Lundin, 2006;):

$$E_{total} = \frac{1}{2}\int\left(\varepsilon\bar{E}^2 + \mu\bar{H}^2\right)\cdot dv \qquad (2)$$

From Gauss theorem, the power flow out of a volume is (Burkholder and Lundin, 2006; Gonca, 2005):

$$P_{out} = \int_v \nabla\left(\bar{E}\times\bar{H}\right)dv = \int_s \nabla\left(\bar{E}\times\bar{H}\right)n\cdot da = \int \bar{p}\cdot nda \qquad (3)$$

Equation (3) gives the volume (v), as well as the surface (a) integral of the power flow out of a given space. The bracket term is called the *Poynting vector*. Due to the time varying electric and magnetic fields, electromagnetic waves are created and these travel between the conductors. As these waves approach open space, free space waves are formed by connecting the open ends of the electric lines. Since the sinusoidal source continuously creates the electric disturbance, electromagnetic waves are created continuously and these travel through the transmission line, and are radiated into free space through the antenna. The power flow out of the space implies that EM waves can be propagated through space (by an antenna) by the interaction of the electric and magnetic field intensities. Typically, antennas are designed to operate in a relatively narrow frequency band. The design criteria for receiving and transmitting antennas differ only slightly, but generally an antenna can receive and transmit equally well. This property is called reciprocity.

Antenna specifications

With a frequency range of 880MHz to 3000MHz

Maximum frequency = 3000MHz = f_H ; Minimum frequency = 880MHz = $f_{\min}$

The centre frequency was computed as 1940MHz using the expression

$$f_c = \frac{f_H + f_{\min}}{2} \qquad (4)$$

$$\text{Bandwidth ratio} = B = \frac{f_H}{f_{\min}} = 3.40 \qquad (5)$$

$$\text{Longest wavelength} = \lambda_{\max} = \frac{c}{f_{\min}} = 0.34 \qquad (6)$$

$$\text{Longest dipole length} = L_H = \frac{\lambda_{\max}}{2} = 17.0cm \qquad (7)$$

$$\text{Shortest wavelength} = \lambda_{\min} = \frac{c}{f_H} = 0.10m \qquad (8)$$

$$\text{Shortest dipole element length} = L_1 = \frac{\lambda_{\min}}{2} = 5.0cm \qquad (9)$$

The number n of elements required for the design is given as (Purdie, 2008; Putman, 2002):

$$n = \frac{\ln B}{\ln\tau} = 15 \qquad (10)$$

To check if the number of elements (n) will be adequate for the design ratio, the following relation is used (Purdie, 2008; Putman, 2002):

$$\frac{L_H}{\tau^n} \le L_1$$

$$\text{Proof: } \frac{L_H}{\tau^n} = \frac{17}{(1.08)^{14}} = 6.1cm \quad \{(> L_1) = (> 6.1)\} \qquad (11)$$

Adding an element i.e. 14+1 =15

$$\frac{L_n}{\tau^n} = \frac{17}{(1.08)^{15}} = 5.6cm \qquad (12)$$

n =15

The remaining elements lengths were estimated using the same expression.

$$L_{n-1} = \frac{L_n}{\tau} = \frac{L_{12}}{\tau}$$

The directive gain of a dipole antenna with surface area A and source resistance R_s is (Gonca, 2005):

$$G = \frac{\frac{1}{2Z_0}\frac{A^2I^2}{r^2}}{\frac{\frac{1}{2}R_sI^2}{4\pi r^2}} = \frac{A^2}{30R_s} \qquad (13)$$

If the antenna is a half wave dipole $A=60$ and $R_s=73\,\Omega$. The gain is $G=1.64$. Often the gain is given in dBi (decibels over isotropic radiator):

$$G = 1.64 = 10\log_{10}G \text{ dBi} = 2.15 \text{ dBi}$$

Computation of length

The computation of the length is determined as follows:

$$L_{14} = \frac{L_{15}}{\tau} = \frac{17.0}{1.08} = 15.7cm$$

$$L_{13} = \frac{L_{14}}{\tau} = \frac{15.7}{1.08} = 14.5cm$$

A similar approach was used to compute for lengths L_{11} to L_1. The results are presented on Table 1.

The element spacing are estimated using the following expression (Purdie, 2008; Putman, 2002):

$$d_{n\to(n-1)} = \frac{1}{2}\left(L_n - L_{n-1}\right)\cot\alpha \qquad (14)$$

$\alpha = 10^0$

$$d_{n\to n-1} = d_{15-14}$$

$$L_n = L_{15} = 17.0cm$$

$$L_{n-1} = L_{14} = 16.2cm \qquad (15)$$

$$d_{15-14}=\frac{1}{2}\left(L_{15}-L_{14}\right)\cot 10^0$$

$$=\frac{1}{2}(17.0-16.2)\frac{1}{\tan 10^0}$$

$$d_{15-14}=\frac{1}{2}(1.30)(5.672)=3.58cm$$

(16)

The remaining element spacings are estimated using the expression (Purdie, 2008; Putman, 2002)

$$\tau=\frac{d_{n,n-1}}{d_{n-2,n-1}} \tag{17}$$

$$d_{n-1,n-2}=\frac{d_{n,n-1}}{\tau}$$

Computation of spacing

$$d_{14-13}=\frac{d_{15-14}}{\tau}\frac{3.58}{1.08}=3.31cm$$

$$d_{13-12}=\frac{d_{14-13}}{\tau}\frac{3.31}{1.08}=3.06cm$$

Similarly, the spacing of the other parasitic elements were computed and presented on Table 2.

Impedance Matching

This is a technique used in matching the resistance of the antenna to the resistance of the coaxial cable. It is an important part of antenna performance because it helps in obtaining a standing wave ratio (SWR) of 1 and maximum power transfer, hence minimizing signal loss. The resistance of the antenna is calculated using (Jaleel, 2008):

$$R_a=120\left(\ln\frac{h}{a}-2.25\right)=96.72\Omega \tag{18}$$

Where h is the longest dipole length and a the diameter of the dipole

Design model, test and result of array dipole antenna

As shown in Fig.1. the director parasitic elements are sloppy and shorter than the driving element and a little shorter than a half wavelength. The reflector present is a driving element and spaced closer than the directors. As the directors are <λ/2 they are capacitive and therefore reinforce the field. The length and the spacing of the reflector have strong influence on the residual backward radiation from the array dipole. Typically the reflector will be spaced by 1\8 +1\4 of a wavelength the directors by 1\3 wavelength each.

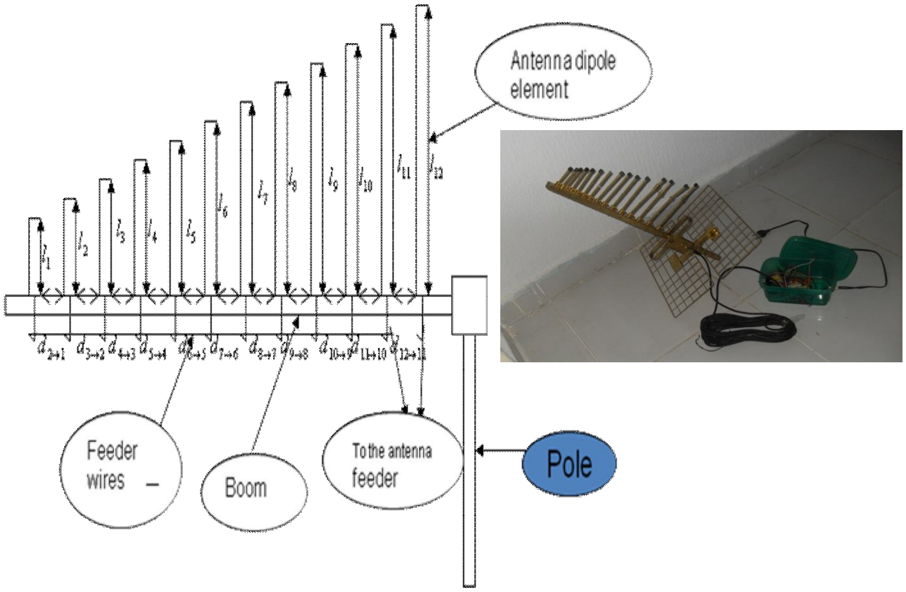
Testing and results

A multimeter was used in testing the connectivity between: (i) The antenna elements, (ii) The antenna elements and the feeder. Computed results of parameters of the design are presented in Tables 1 and 2.

Discussion

In communication and information processing a “transmitter” sends information to an observer (receiver) via an antenna. Antenna being an arrangement of electrical conductors designed to transmit or receive radio waves in the form of electromagnetic (EM) waves, a good antenna is able to convert radio frequency electrical current into EM and *vice versa* by generating a radiating electromagnetic field. Poynting vector has shown that signal is transmitted by the interaction of the electric and magnetic fields generated. Antenna parameters for transmission are identical to reception as well due to reciprocity. The theory and parameters analyzed apply in the same way except for impedance because the impedance at the load (where the power is consumed) is most critical. For a receiving antenna, this is at the (radio) receiver rather than at the antenna. Tuning is done by adjusting the length of an electrically long linear antenna to alter the electrical resonance of the antenna. Antenna tuning is done by adjusting an inductance or capacitance combined with the active antenna (but distance and separate from the active antenna). The inductance or capacitance provides the reactance which combines with the inherent reactance of the active antenna to establish a resonance in a circuit including the active antenna. The established resonance here is at a

Fig. 1. Designed Model of Array Dipole Antenna (Inset is the picture of the designed antenna)



frequency other than the natural electrical resonant frequency of the active antenna. It was observed that: The signal strength increases with favourable weather condition; at low noise environment, the signal strengths received are higher; at favourable heigth the antenna are able to receive and transmit better signals which shows interference from trees and high building are reduced; the signal strength of the antenna in the active mode is higher than that of passive mode.

Table 1. Computed lengths of parasitic elements

N	Length (cm)
15	17.00
14	15.70
13	14.50
12	13.40
11	12.40
10	11.40
9	10.50
8	9.72
7	8.90
6	8.20
5	7.50
4	6.90
3	6.30
2	5.80
	5.30
Total	153.52

Table 2. Computed spacing of parasitic elements (cm)

d_{15-14}	3.58
d_{14-13}	3.31
d_{13-12}	3.06
d_{12-11}	2.83
d_{11-10}	2.62
d_{10-9}	2.42
d_{9-8}	2.24
d_{8-7}	2.07
d_{7-6}	1.91
d_{8-5}	1.76
d_{5-4}	1.62
d_{4-3}	1.50
d_{3-2}	1.38
d_{2-1}	1.27
Total	31.57

Antennas are typically responsive to one of these ranges although most of the antennas reviewed actually capture signals in both frequencies. Since UHF antenna captures high frequency VHF signals (Channels 7-13), VHF antennas are marginalized except when there is need to capture the low end of the VHF band (Channels 2-6). And since more than 90% of all HDTV broadcast are transmitted in UHF which is why they are more popular than VHF. A good knowledge of antenna theory and types equip one to face the challenge of choice in view of optimum performance in present day advanced digital broadcasting technology.

In view of this, we can conclude that the array antenna designed and constructed is more useful in frequency range of 60MHz to 300MHz. This was confirmed practically where a strong signal was received at the test frequencies of 189.5MHz and over a range of frequencies in the short wave radio band.

The antenna designed though quite good, can be improved upon. Properties of the antenna such as the radiation pattern could not be measured and this property is useful in characterizing the antenna. If and when possible a computer plot of the radiation pattern can be obtained. The antenna could also be tested at various ranges and areas to measure the signal strength.

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