International Journal of Advanced Materials Research
Vol. 5, No. 3, 2019, pp. 46-52
http://www.aiscience.org/journal/ijamr
ISSN: 2381-6805 (Print); ISSN: 2381-6813 (Online)

Design and Construction of a Cost-effective Parabolic Satellite Dish Using Available Local Materials

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Abstract

Communication through satellite is very important at this information age. It can provide complete global coverage. It can be used to send and receive information in remote area where other technology may fail. Communication signals are sent in form of electromagnetic signal which are intercepted by the parabolic dish. The offered high-efficiency and high-gain by the parabolic dish makes it appropriate for direct broadcast satellite reception. However, parabolic dish procurement in developing countries is very expensive. This makes it to be unaffordable to majority of the masses. This paper focuses on design and construction of cheap parabolic satellite dish using local readily available materials. An indigenous technology is exploited to achieve the goal of this work. The paper describes from the scratch, how to design and construct a parabolic dish that can be used to intercept electromagnetic signals from the satellite stationed in the space. The proposed design approach offers a number of advantages such as cost-effectiveness and high simplicity. These are due to the fact that; it can be effectively developed with the easily available materials. Besides, it development demands neither special/long time training nor skill. Thus, both technical and non-technical personnel with minimal training can construct it either for commercial and/or personal use. The conducted measurement results show that the apart from being a cost-effective solution, the constructed parabolic dish offers high-efficiency and high-gain benefits.

Keywords

Dish, Frame, Concave Lens, Antenna

Received: July 7, 2019 / Accepted: November 12, 2019 / Published online: November 28, 2019

1. Introduction

A communication satellite is an artificial satellite that relays and amplifies radio telecommunication signals via a transponder; it creates a communication channel between a source transmitter and a receiver at different locations on Earth. Communications satellites are used for television, telephone, radio, internet, and military applications. There are 2,134 communications satellites in Earth's orbit, used by both private and government organizations [1].

Satellite communication is one of the most popular next generation communication technologies for global communication networks in parallel to terrestrial communication networks. In modern age military intelligence, navigation and positioning, weather forecasting, digital video Broadcasting (DVB), and broadband internet services, are the few demanding applications of Satellite communication [2]. The purpose of communications satellites is to relay the signal around the curve of the Earth allowing communication between widely separated geographical points [3]. The advent of satellite has revolutionized the communication industries. Satellite has turned the world into a global village. The advantages

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offer by the satellite communication has made it desirable by many households. Its unlimited reception has brought new dimension in signal transmission and signal receiver. The satellite is immune to both political and geographical barriers. Satellite communication has become a flexible and cost-effective solution for domestic and international networks, irrespective of the user's geographic location. Satellite technology has become a solution for some of the most complicated access problems, connecting cities across a large landmass. Communications satellites use a wide range of radio and microwave frequencies [4]. However, the signal being in microwave form cannot be received except with aid of parabolic antenna also called satellite dish.

Furthermore, a parabolic antenna is an antenna that uses a parabolic reflector. It has a curved surface with the cross-sectional shape of a parabola that is mainly for directing the radio waves. The most common form of it is shaped like a dish and is popularly called a dish antenna or parabolic dish. The parabolic dish operation is similar to the concave lens which reflects all signals parallel to it to the focus. In general, satellite dish performs two major functions in the satellite communication. It doubles as transmitter and receiver; consequently, it is a transceiver. As a transmitter, radio frequency current from satellite company or service provider is coupled through a transmission cable to the feed horn antenna, which is a transducer that converts the electrical signals into radio wave suitable for propagation through space. The radio waves are emitted back toward the dish by the feed and reflect off the dish. Moreover, as a receiver, the satellite dish acts as a concave lens that has a certain point "focus" where all the reflected signals meet. The dish of appropriate size will intercept the incoming electromagnetic waves and reflected them onto the focal point where there is a low-noise block converter (LNB). The radio waves, on getting to the LNB, are converted to a signal which is sent through a cable to the receiver inside the building.

It is remarkable that, the parabolic antenna was invented by the German physicist, Heinrich Hertz, during his discovery of radio waves in 1887. He used cylindrical parabolic reflectors with spark-excited dipole antennas at their focus, for both transmitting and receiving during his historic experiments. Conceptually, the satellite dish is designed to intercept specific type of signals. Large sized dish like 2.0 m 3.0 m and higher are used for C-band signal reception, while smaller ones are for KU band signals. Historically, the parabolic antennas referred to as "dish" antennas had been in use long before satellite television. The term "satellite dish" was coined in 1978 during the beginning of the satellite television industry, and came to refer to dish antennas that send and/or receive signals from communications satellites. Taylor Howard of San Andreas, California adapted an ex-military dish in 1976 and became the first person to receive satellite television signals using it [5]. A typical parabolic antenna consists of a metallic parabolic reflector with a small feed antenna suspended in front of the reflector at its focus pointed back toward the reflector. The reflector is a metallic surface formed into a parabolic or revolution and usually truncated in a circular rim that forms the diameter of the antenna [6].

The German physicist, Heinrich Hertz, constructed the world's first parabolic reflector antenna in 1888 [6]. The first satellite television dishes were built to receive signals on the C-band analog was used, and were very large. The front covers of the 1979 Neiman-Marcus Christmas catalog featured the first home satellite TV stations on sale [7]. The early satellite dishes were of wide diameter. The satellite dishes of the early 1980s were 10 to 16 feet (3.0 to 4.9 m) in diameter [8] and made of fiberglass with an embedded layer of wire mesh or aluminum foil, or solid aluminum or steel [9].

Satellite dishes made of wire mesh first came out in the early 1980s, and were at first 10 feet (3.0 m) in diameter. As the front-end technology improved and the noise figure of the LNBs fell, the size shrank to 8 feet (2.4 m) a few years later, and continued to get smaller reducing to 6 feet (1.8 m) feet by the late 1980s and 4 feet (1.2 m) by the early 1990s [10]. Larger dishes continued to be used, however, in December 1988 Luxembourg's Astra 1A satellite began transmitting analog television signals on the K_u band for the European market. This allowed small dishes (90 cm) to be used reliably for the first time [11].

In the early 1990s, four large American cable companies founded Prime Star, a direct broadcasting company using medium power satellites. The relatively strong K_u band transmissions allowed the use of dishes as small as 90 cm for the first time [12]. On 4 March 1996 EchoStar introduced Digital Sky Highway (Dish Network) [13]. This was the first widely used direct-broadcast satellite television system and allowed dishes as small as 20 inches to be used. This great decrease of dish size also allowed satellite dishes to be installed on vehicles [14]. Dishes this size is still in use today. Television stations, however, still prefer to transmit their signals on the C-band analog with large dishes due to the fact that C-band signals are less prone to rain fade than K_u band signals [15].

It is noteworthy that a number of studies have been conducted on various applications and uses of parabolic dish. For instance, a technical report on step by step configuration of free to air satellite in west Africa in K_u band was presented in [16]. Also, design, construction and testing of parabolic solar oven was considered in [17]. In [18] design and development of a parabolic dish solar water heater shed light on application of satellite dish without considering its construction. Furthermore, [19] and [20] report ways of employing a dual reflector antenna for measurement system that was based on dielectric lens horn antennas. Besides, design of feed antenna for parabolic dish was presented in [21] without considering construction of the parabolic dish itself. Consequently, all the aforementioned extant studies have not considered the construction of a satellite dish. In the light of this, this study tends to give a detail insight into the design and construction of satellite dish using both local materials and indigenous technology.

2. Methodology

In this section, the materials and methods employed in this work are presented.

2.1. Materials and Methods

The four major factors that are considered in selecting the materials used in this paper are the:

i. Availability and accessibility of the material;

ii. Durability of the materials;

iii. The price of material; and

iv. The materials properties

Based on the factors above, the following materials are used to construct the parabolic dish

i. Resin

ii. Fiber matte

iii. Catalyst

iv. Accelerator

v. Aluminum foil

vi. Paint

vii. Steel

viii. Cement

ix. Sand

2.2. Design and Analysis

The design procedures used for various parameters of the dish and their explanations are presented in this subsection. Since the satellite dish is parabolic in nature, the relationship between the diameter and depth of parabolic equation is employed in determining the focal length of the dish. A parabola is the locus of a point, which moves such that its distance from a fixed point (focus) is equal to its distance from a fixed line (directrix), thus a parabola is the locus of points that are equidistant from the focus (a fixed point) and the directrix (a fixed line). It should be noted that a parabola is a mathematical expression that is a quadratic function in nature.

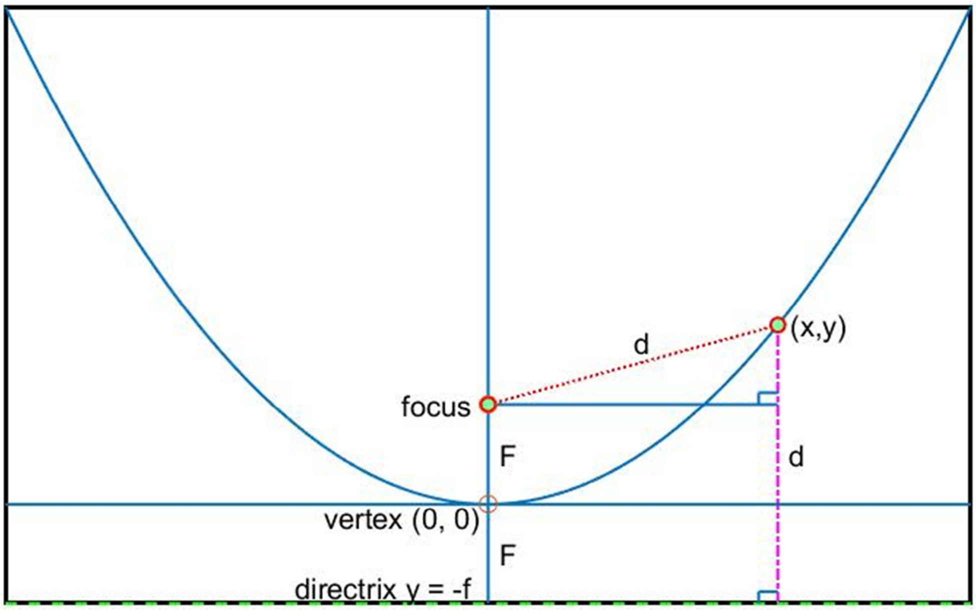

Figure 1. Parabolic antennas analysis.

The parabolic dish antenna focus can be estimated by considering the dish diameter, as well as its depth. With reference to Figure 1, the origin of the parabola is (0,0). Then, since the parabola starts from the origin, the coordinates of the parabola's vertex will also be (0,0). Furthermore, focus of the parabola is at $(0, f)$ and the directrix at $y = -f$ as well. So, for any points (x, y) on the parabola, distance (d) is of the same length. From the rectangle formed by the parabola coordinates, applying Pythagoras theorem implies:

$$(x-0)^2 + (y-f)^2 = d^2 \quad (1)$$

Where x denotes the radius of the diameter, D, and y represents the depth of the dish.

Squaring both sides of eqn. (1) gives:

$$\sqrt{(x-0)^2 + (y-f)^2} = d \quad (2)$$

From the vertical line, d can be defined as

$$\mathrm{d} = \mathrm{y} + \mathrm{f} \quad (3)$$

In order to achieve the parabolic equation that entails the focal distance f, we substitute eqn. (3) into (2) and then simplify as

$$y + f = \sqrt{(x-0)^2 + (y-f)^2}$$

$$(y+f)^2 = (x-0)^2 + (y-f)^2$$

$$(y+f)^2 = (x)^2 + (y-f)^2$$

$$y^2 + 2fy + f^2 = x^2 + y^2 - 2fy + f^2$$

$$2fy = x^2 - 2fy$$

$$4fy = x^2 \quad (4)$$

In addition, since D is the diameter of the dish, it relates to the radius as:

$$x = \frac{D}{2} \quad (5)$$

Then, substitute for x in eqn. (4) gives:

$$x = \left(\frac{D}{2}\right)^2 = 4fy$$

$$\frac{D^2}{4} = 4fy$$

$$f = {D^2}/{16y} \quad (6)$$

This formula is used for design of a particular mold. The ratio of the focal distance to the dish diameter, denoted by f/D is a standard component parameter used by the system installers [d]. f/D ratio is a factor of geographical area. The value ranges between $0.35 - 0.45$ is good for African terrain especially west Africa.

For this design, 0.4 is selected.

$$f/D = 0.4, \text{therefore}, f = 0.4\, D$$

Assuming that a dish of 300 cm is to be constructed, $f = 0.4 \times 300$

$$f = 120$$

From eqn. (6), $d = y = {D^2}/{16f}$

For instance, to estimate the depth of the dish with diameter D = 300 focal length f = 120, we have:

$$d = {300^2}/{(16 \times 120)} = 46.875$$

Using the relationship between the diameter, focal length and the depth of the parabolic dish with f/D = 0.4, Table 1was estimated for different parameters.

Table 1. Relationship between diameter, focal length and depth of the dish.

Diameter (cm)	Focal length (cm) $f = 0.4\, D$	Depth (cm)
60	24	9.3750
90	36	14.0625
180	72	28.1250
200	80	31.2500
250	100	39.0625
300	120	46.8750
400	160	62.5000

2.2. Construction and Assembly of the Components

This subsection describes the detailed construction procedure of the parabolic dish. It consists of three sections; Construction of the mold, construction of frame and making of the dish. The mold construction is based on the initial design formulas.

2.2.1. Construction of Mold

A well-constructed mold can be used to design millions of dish with identical parameters. Mold fabrication starts with calculating relationship between the focal length and the size of the dish. Since the satellite dish is a parabola, the parabolic equation is applied in the making of the mold. Trenches were then cut out of the steel based on the parameter for the desired size. A stand is made of steel to keep the trenches firm. Then sand is used to shape the mold. The cement mixed with the sand is applied and then allowed to dry.

2.2.2. Construction of Frame

A mild steel iron was procured locally for the frame construction. It was measured and cut using devices such as tape rule, bench vice and hack saw. The parameter for the desired dish was used to cut the steel into the desired shape and size. Welding machine is then used to weld the frame components together to form a skeleton that will hold the casting dish. Figure 2 illustrates the constructed frame which was placed on the constructed mold as shown in Figure 3.

Figure 2. Constructed frame.

Figure 3. Constructed frame and the mold.

2.2.3. Dish Making

This subsection presents a detail description of dish making process. Resin is used to coat the mold to serve as the base for holding layer of aluminum foil that serves as reflector to the mold. This first layer of resin serves as the separator of the dish from the mold. It allows the dish being removed without sticking after curing. Then, layer of fiber matte is spread on it. Resin mixed with catalyst and accelerator are applied on the laid matte and evenly spread with brush and given time for curing. The resulting dish on the mold is shown in Figure 4. Furthermore, as depicted in Figure 5, the steel frame is then placed on it to provide the structure and strength for the dish. The strips of matte that cover the frames was then cut. Afterwards, a mixture of resin, catalyst and accelerator was applied on the matte strips to hold the stream and left for curing. Figure 6 depicts the casted dish be ready for usage.

Figure 4. Resulting dish on the mold.

Figure 5. The steel frame and mold.

Figure 6. Casted dish.

3. Result

The strength of the signal received by a dish is important parameters in determining the efficiency of the dish. The designed 4.0m dish, alongside the imported ones, are used to track six different cable television signals using Strong SRT4369x. The received signal strengths for the constructed local dish, imported mesh dish, and imported metal dish, based on different parameters such as direction, frequency, polarity, symbol rate, and the maximum signal strength are shown in the Table 2, Table 3 and Table 4, respectively. Also, Table 5 presents the current prices of the local dish and imported dishes in the Southern Nigeria.

Table 2. Received signal strengths using the constructed local dish.

Satellite name	Direction	Frequency	Polarity	Symbol rate	Signal quality (%)
Hispasat	30°West	11510	Vertical	10000	91
Hotbird	13°East	10719	Vertical	27500	75
Nilesat	22°West	10986	Vertical	30000	97
Amos	16°East	10804	Horizontal	30000	91
Eutelsat	10°East	3650	Horizontal	20161	93

Table 3. Received signal strengths using the (mesh) imported dish.

Satellite name	Direction	Frequency	Polarity	Symbol rate	Signal strength (%)
Hispasat	30°West	11510	Vertical	10000	84
Hotbird	13°East	10719	Vertical	27500	71
Nilesat	22°West	10986	Vertical	30000	87
Amos	16°East	10804	Horizontal	30000	82
Eutelsat	10°East	3650	Horizontal	20161	80

Table 4. Received signal strengths using the (metal) imported dish.

Satellite name	Direction	Frequency	Polarity	Symbol rate	Signal strength (%)
Hispasat	30°West	11510	Vertical	10000	86
Hotbird	13°East	10719	Vertical	27500	72
Nilesat	22°West	10986	Vertical	30000	90
Amos	16°East	10804	Horizontal	30000	85
Eutelsat	10°East	3650	Horizontal	20161	82

Table 5. Current prices of the local dish and imported dishes in the Akure Nigeria

Size of dish (cm)	Local dish ($)	Metal dish ($)	Mesh dish ($)
60	100	180	150
90	120	200	170
180	150	230	210
200	200	300	280
250	254	360	320
300	300	430	420
400	320	440	425

4. Discussion

With reference to tables 2, 3, and 4, it can be deduced that the locally manufactured dish pulls more signals compared with the imported ones of the same sizes and at the same locations. Also, from Table 5, regarding the current prices of both local and imported dishes, it can be inferred that it is more economical to procure the local ones. Moreover, the high-efficiency and high-gain of the locally made dish presented in this work made it suitable for tracking any form of signals. Another notable advantage of the presented dish is that it is has high-immunity to deformation. It is noteworthy that, dish deformation is one of the main challenges that technicians normally face during installation and this always hinders the quality of the received signal during tracking. This associated deformation of imported dish usually occurs during the course of transportation form one place to the other.

5. Conclusion

Based on the result obtained when tracking signal with the locally constructed dish and the imported ones, the locally made parabolic dish is effective in tracking satellite signals. Also, the locally made dish is cheaper than the imported counterparts. This paper has been able to meet its purpose of constructing not only cheap but also high-efficiency and high-gain parabolic dish. Implementation of the presented design and construction procedures in this work will enable technical and non-technical personnel to produce their own dish not only for private use but also for commercial purposes.

6. Recommendation

It is recommended that further research work should be carried out on the design and construction of locally made dish using both readily available raw materials and local technology. This will really help in giving the masses considerable access to different applications of satellite communications.

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