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EVALUATION OF PARABOLIC ANTENNAS IN SATELLITE TVRO SYSTEMS

Raied A. R. Ibrahim, Khalid A. S. al-Khateeb, and Rafiqul Islam
raiedibr@hotmail.com, khalid@iiu.edu.my
Electrical and Computer Engineering Department,
Kulliyyah of Engineering,
International Islamic University Malaysia
Jalan Gombak, Kuala Lumpur 53100, Malaysia

Abstract

Considerations relating to the parabolic dish reflector antennas are discussed. The characteristics, efficiency and construction for a variety of dish antennas are analyzed. Actual measurements and tests were made and a comparative study of the performance of screen mesh and solid antennas is presented. TVRO signal reception levels from a number of geo-stationary satellites were used as criteria for the assessment.

Key words: antenna, parabolic, dish, reflector, TVRO, satellite.

1. Introduction

The antenna, commonly called the dish, owing to its shape, is the most visible outdoor component of a satellite television receiver system. Invariably it is seen aiming at a distant satellite in space. The parabolic dish is the most common type of antennas for satellite communications. The parabolic shape has an important property of directing parallel rays of signals to the focus. Hence, a proper design is essential.

1.1 The Parabolic Reflector

Since a parabola is defined as 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), the standard equation [1] can be easily employed to facilitate the design and manufacturing process.

1.2 Mathematical Analysis

With reference to Fig.1, the point S (a, 0) denotes the reflector focal point and KK' the fixed line or directrix. Let Q (x, y) be any point of the parabola, then

$$QS = QM \qquad (1)$$

or

$$(a-x)^2 + y^2 = (a+x)^2 \qquad (2)$$

Hence, the standard equation of the parabola:

$$y^2 = 4ax \qquad (3)$$

and by considering a line T_1T_3 , the tangent touching the parabola at R (x_1, y_1):

$$RS = T_1S \qquad (4)$$

and from:

$$\begin{aligned} y^2 &= 4ax \\ 2ydy &= 4adx \\ \left(\frac{dy}{dx}\right)_R &= \frac{2a}{y_1} \end{aligned} \qquad (5)$$

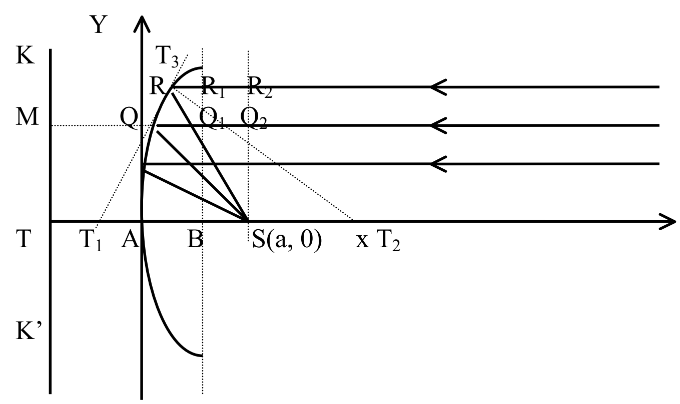


Fig. 1: Analysis of a parabola reflector

The equation of the tangent becomes:

$$y = mx + c = \frac{2a}{y_1}x + c \qquad (6)$$

If it passes through the point R (x_1, y_1), then:

$$y_1 = \frac{2a}{y_1}x_1 + c$$
$$c = \frac{y_1^2 - 2ax_1}{y_1} = \frac{2ax_1}{y_1} \tag{7}$$
$$y = \frac{2a}{y_1}x + \frac{2ax_1}{y_1}$$

at T_1 where $y = 0$ and $x = -x_1$, hence

$$T_1S = a + x_1 \tag{8}$$

(10)

If $RT_2 \perp T_1T_3$, it is easy to show that

$$\angle SRT_2 = \angle R_2RT_2 = \angle ST_2R \tag{11}$$

and thus

$$RS = ST_2 = T_1S \tag{12}$$

T_1ST_2 is the diameter of a circle passing through R (x, y) and S (a, 0) is the center of the circle. This shows the useful property of the parabolic reflector, to direct the incoming signals in the form of rays parallel with the main axis to the focal point at S. On the other hand, any signal entering the dish not ideally parallel to the main axis is reflected in such a way as to miss the focal point.

1.3 Illumination, Aperture (*f/D* ratio) and Noise

A parabolic dish may be specified by its diameter D, depth d, and focal length f, as illustrated in Fig. 2. Given a parabolic dish it is important to locate the precise position of its focal point. The choice of the ratio of the focal length to the diameter f/D is also important. It influences the noise levels via the antenna side-lobes and the illumination.

Here again, the application of the basic equation of the parabola is useful:

$$y^2 = 4ax = 4fx \tag{13}$$

to find the focal length:

$$f = \frac{y^2}{4x} = \frac{(D/2)^2}{4d} = \frac{D^2}{16d} \tag{14}$$

Since both d and D can be measured, it is possible to determine the precise position of its focal point.

and likewise:

$$RS = \sqrt{(a-x_1)^2 + y^2} = \sqrt{(a-x_1)^2 + 4ax_1} = a + x_1 \tag{9}$$

Hence, for a ray RR_2 parallel to the x-axis, get

$$\angle T_1RS = \angle RT_1S = \angle T_3RR_2$$

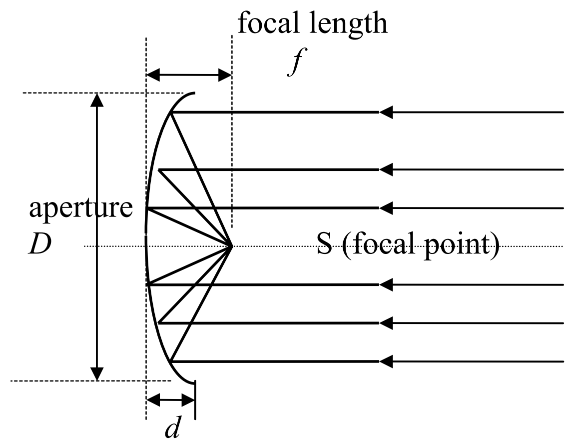
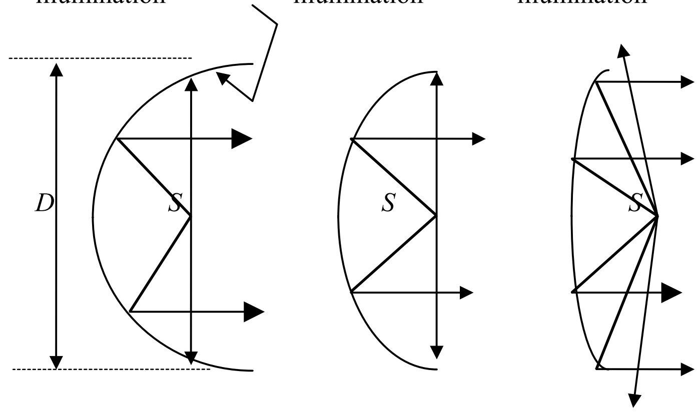


Fig. 2: Aperture, depth, and focal length of a parabolic reflector

The depth d of the dish plays an important role in the illumination performance, namely under illumination, uniform illumination, and over illumination as shown in Fig. 3 [2]:

under illumination | uniform illumination | over illumination



a) $f/D < 0.25$ focus inside aperture plane | b) $f/D = 0.25$ focus in aperture plane | c) $f/D > 0.25$ focus outside aperture plane

Fig.3: Types of dish illumination

For uniform illumination, the focus lies in the aperture plane, namely $f = d$, the dish depth

$$f = \frac{D^2}{16d} = \frac{D^2}{16f} \tag{15}$$

$$f = \frac{D}{4} = 0.25D$$

TV satellite wavelengths are usually small compared to the aperture; therefore a fixed focal point is not truly practical. This gives rise to a slightly divergent main beam and some undesirable collection of "off axis" signals. The resulting polar radiation diagram consists of a thin pencil beam or main lobe and a series of lower amplitude side lobes. Polar diagrams are often difficult to interpret; hence the Cartesian co-ordinates are often used instead. Ground noise enters the antenna system mainly through side lobes, which are arranged to be as low as possible in relation to the main lobe amplitude.

Theoretically, a uniformly illuminated antenna produces the first and largest of the side lobes at about -17.6dB with reference to the main lobe. Under illuminating deep dishes with f/D < 0.25 have the sidelobes reduced to less than –20 dB and hence provide better shield from ground noise. This seems ideal, but there is a number of drawbacks, one being a reduction in antenna gain and another is a corresponding increase in beamwidth.

In practice, $0.3 < f/D < 0.6$ for *prime focus* dishes is normal. A prime focus dish has the head unit positioned at the focal point at the center of the dish. Perhaps worth noting that C-band antennas have the advantage of being larger and often are prime focus dishes, which provide better mechanical support.

1.4 Antenna Efficiency

There are a number of factors that may affect the performance of a parabolic reflector, resulting in antenna efficiency η less than unity. Some of the major factors are:

- Wave scattering at the rim
- Surface irregularities causing reflected waves to miss the focal point.
- Blocking of incoming waves by the head unit and the support structure.
- Electromagnetic wave absorption by the reflector surface.

Antenna efficiency may also be viewed as a ratio of antenna effective area to its actual area. It is therefore a measure of the percentage of the incoming waves finally collected by the head unit at the focal point. In practice, η is in the range of 0.5 to 0.8.

1.5 Gain and Beam-width

The aperture area of the reflector is given [3] by:

$$A = \frac{\pi D^2}{4} \tag{16}$$

and the effective area of the aperture is:

$$A_e = \eta A \tag{17}$$

The antenna gain is given by:

$$G = \frac{4\pi A_e}{\lambda^2} = \eta\left(\frac{\pi D}{\lambda}\right)^2 = 10\ \log_{10} \eta\left(\frac{\pi D}{\lambda}\right)^2 dB \tag{18}$$

Calculation of the beam-width θ_{3dB} from the theoretical equation may be quite complex and is often based on the uniform illumination maximum gain condition[4]. As an approximation, the beam-width may be given as:

$$\theta_{3dB} \cong 70\left(\frac{\lambda}{D}\right) \text{ degrees} \tag{19}$$

2. Experimental Parabolic Reflectors

Various types of parabolic reflectors were tested for a comprehensive comparative investigation. Some of the dishes were hydro-formed solid parabolic reflectors and others were screen mesh structures. The structure, assembly, and properties [5] of the two categories were compared, and presented as part of the study.

2.1 Screen Mesh Parabolic Reflectors

Screen mesh dishes have the advantages of lightweight, easy packing and transportation, less wind resistance, and better drainage during heavy rain. If the holes of the mesh are less than 1/10 of the operating wavelength λ, the losses due to the holes are generally negligible. The screen mesh dishes were carefully selected for the current design. They are of a brand name well known for mesh dishes in the market, ORBITRON SX-7 and ORBITRON S-10 e, they are 2m and 2.89m in diameter respectively, which are suitable for both C-band and Ku-band applications. Each of the dishes consists of 12 panels, 12 ribs, 6 perimeter arms and a steel quick hub, to be assembled on site into a parabolic shape. They were assembled and constructed, as shown in Fig. 4.

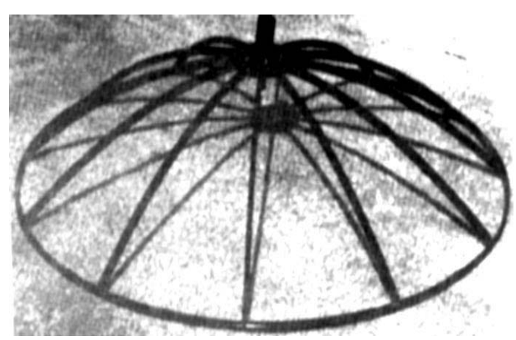


Fig 4: Assembly of the screen mesh antenna

The assembly or construction of the screen mesh dish is a skillful job. It requires making sure that there are no irregularities or bumps on the surface. It begins by making a perimeter ring, joining the 6 perimeter arms

together. The panels, with pre-cut meshes, have a baked-on black powder coat finish for better protection from rust, corrosion, and severe weather conditions. The ribs are curved rods of aluminum with internal grooves, which play an important role in the reflector assembly. They hold the 12 mesh panels, together with the steel quick hub at the center piece and the outer perimeter ring to form the parabolic reflector. Another important reason for the black powder coat is to reduce noise and solar radiation damage.
The sun is a major source of noise and radiation, and a gloss finish will cause over heating to the low noise block (LNB), which can be a serious cause of the signal distortion.

2.2 Specifications of the Mesh Dishes under Test

The specifications related to the mesh reflectors as given by the manufacturer's data sheet for SX-7 are as follows:

i) Diameter:	2.0 m
ii) Focal length:	0.732 m
iii) Gain at 4.2 GHz (C-Band):	37.3 dBi
iv) Gain at 12.2 GHz (Ku-Band):	44.0 dBi

It can be deduced that its *f/D* ratio is 0.366, which is within the normal recommended range for uniform reflector illumination.

Similarly, the specifications for the S10 e as given by the manufacturer's data sheet are as follows:

i) Diameter:	2.89 m
ii) Focal length:	1.04 m
iii) Gain at 4.2 GHz (C-Band):	39.6 dBi
iv) Gain at 12.2 GHz (Ku-Band):	49.0 dBi

The *f/D* ratio is 0.36, which is again within the normal recommended range for uniform reflector illumination.

2.3 Hydro-formed Solid Parabolic Reflectors

The solid parabolic dish is manufactured directly as one solid piece, ensuring a smooth reflecting surface. Unlike the screen mesh dishes, they do not need to be assembled at the site, making the installation task easier. However, the dish being one solid piece, it is rather heavy and not easy to transport and lift onto the antenna mount. The models used in the tests are PARACLIPSE 7.5' VP and PARACLIPSE 6.0' VP.

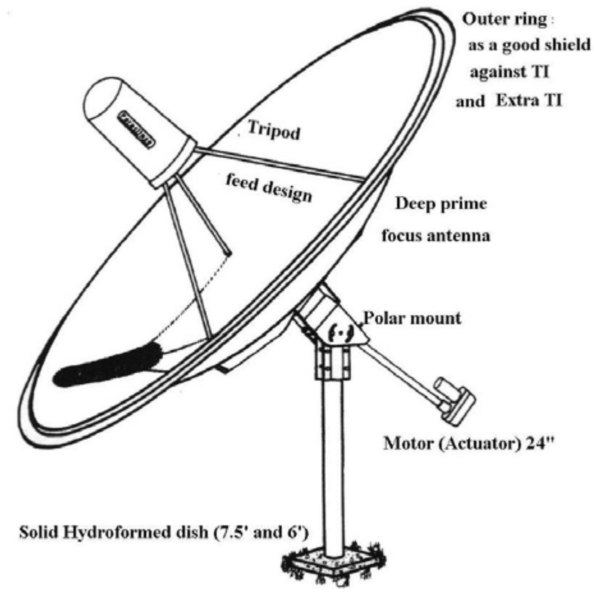


Fig.5: Solid dish 7.5 with VP polar mount

2.4 Specifications of the Hydro-formed Dishes

The specifications of the 7.5' VP according to the data sheet are as follows:

i) C-band antenna Gain:	37.8 dB
ii) Ku-Band antenna Gain:	47.2
iii) C-Band efficiency:	60%
iv) Ku-Band efficiency:	62%
v) 2° Spacing approved (C & Ku): (with opposite polarization)	Yes
vi) C-Band beamwidth:	2.2°
vii) C-Band first side Lobe:	-25.3dB
viii) Ku Band Antenna Noise Temperature:	28°K@ 30° elevation
ix) C-Band Antenna Noise Temperature:	41°K @ 45° elevation
x) *f*/D ratio:	0.312
xi) Focal point:	0.714 m

The specifications for the 6.0' VP are as follows:

i) C-Band antenna gain:	35.9dB
ii) Ku Band antenna Gain:	44.9dB
iii) C-Band efficiency:	68%
iv) Ku-Band efficiency:	64%
f/D ratio:	0.335
Focal point:	0.587 m

3. Prime and Offset focus Feed Support

The antenna may be a centrally symmetric paraboloid, for which the focus is located at the axis of symmetry, referred to as the prime focus. And if it were a non-centro symmetric segment it will have an offset focus. The experimental dishes used in this work are of the prime focus type. In a TVRO system, the antenna is large and is

required to rotate from extreme east to extreme west for satellite tracking. Prime focus antenna has its feed at the center focus to avoid the problem of mechanical instability for offset antennas over 1.5 m, where the feed support structure has to be stable especially in strong wind.
Therefore, it will be easier to design a sturdy feed support for a prime focus antenna. Solid dishes normally have tripod supports, while the screened mesh use sturdy button-hook feed support and others use a quad leg feed support. Actually prime focus antennas are preferred in TVRO systems.
The offset type are useful for receiving moderate to high power DBS satellite TV transmissions such as the 60 cm off-set dish used in Ku-band ASTRO TV in Malaysia.

4. Comparative Analysis of Parabolic Reflectors

The comparison is based on two types of parabolic reflectors. The parameters that have been considered are; terrestrial microwave interference rejection, installation assembly errors, antenna gain, efficiency, beamwidth, wind and rain resistance, and signal strength reception.

4.1 Terrestrial Microwave Interference Rejection

The solid dishes have the advantage of rejecting C-band interference from terrestrial microwave transmission as well as ground noise. One of the reasons that these dishes out perform the screened mesh dishes is because they are deeper. Another reason for the better inference rejection is the presence of an outer ring, which acts as a shield against terrestrial interference signals. The general observation is that TV picture quality using the solid dishes was better.

4.2 Installation Assembly Errors

From the installation point of view the solid dishes are better. When they arrive intact to the site they suffer no errors due to assembly inaccuracies, as they come from the manufacturers in one piece. The finish of the screened mesh dishes, however, depends on the skill of the installer. In general, the reflector surface of the screened mesh dish is less perfectly parabolic than that of the factory finished product.

Channel	Freq. in	Received Signal Strength In dBμV		
		1.8 m Solid Dish	2 m Screen Mesh	2.89 m Screen Mesh
TPI	4180	58	58.8	61
CNN	3980	55	55.3	57.1
TV3	3900	54.5	54.6	57
MTV	4120	57	56.8	58.9
HBO	4000	52.5	52.5	55
MRT	4180	52	52.7	54.7
INDOSIAR	3961	54	55	58.3
BRUNEI	3740	53	53.3	56

Table 1: Signals strength measured from 8 different channels using dish antennas

The installation assembly errors may cause misfocusing of the incident signals, which may affect the signal strength at the head-unit.

4.3 Antenna Gain, Beam-width and Efficiency

The antenna gain and beam-width are directly dependent on the dish diameter regardless of whether it is solid or screened mesh. Smaller dishes have smaller antenna gain but wider beam-width. Wider antenna beamwidth may have an advantage in that it is less critical to antenna mispointing errors. In general, due to installation assembly errors the solid dishes should have higher antenna efficiency. However, being solid and heavy, the weight of the solid dish may cause distortion and hence deviation from the ideal parabolic shape, especially in high wind conditions.

4.4 Wind and Rain Resistance

The performance of the screened mesh dishes in windy and rainy conditions is better than the solid dishes. However, in the case of high wind in excess of 80 km/h, the advantage of the screened mesh dishes disappears. It had been found through practical experience that under high wind conditions, the screened mesh dishes behave like solid dishes.

4.5 Signal Strength

The strength of the received signals is one of the most important parameters. The signal strength was measured for each of the dishes using a spectrum analyzer. The CCTV-4 program from ASIASAT2 satellite at 3960 MHz had been monitored. The measured average signal strength for the 2 m screened mesh, 2.89 m screened mesh, 1.8 m solid and 2.4 m solid dishes was 59-60, 59-60, 58-59 and 60-61 dBμV respectively. Obviously, the bigger the dish, the bigger is signal strength. It can be noticed however that the received signal strength by the 2.4m solid dish is 2 dB higher than the 2.89 m screen mesh dish. This indicates that the performance of the solid dish is better than the screen mesh. From the various observations it can be concluded that for this satellite and this TV channel, the smallest dish 1.8m, is quite sufficient for good quality reception. Another investigation has actually recommended a dish size of about 2m [1]. Obviously, larger dishes are advantageous in the case of weak transponder signals. The selection process however, should be based on the lowest that can fulfill the objectives.

5. Conclusion

The paper presented the merits and demerits of some of the most visible outdoor components of a TVRO system, namely the antenna dish reflector. The parabolic reflector efficiency, its ability to collect satellite signals under various conditions has been highlighted. Different features including installation of screened meshed dishes and solid dishes are compared. The received signal strength from 8 geostationary satellites by different types of parabolic dishes were presented and compared. It shows that solid dish is more efficient than the screen mesh with satellites of low elevation, due to better stability with wind caused vibration.

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