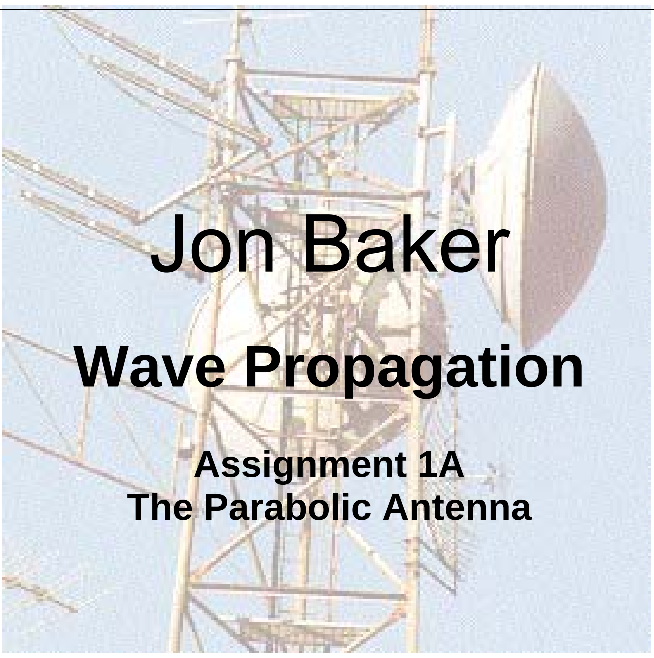


Jon Baker

Wave Propagation

Assignment 1A
The Parabolic Antenna

Introduction

"Write a report covering the design of different types of parabolic antennas."

In this report I will be looking into parabolic antennas, attempting to explain how they work, how they are made, and why they are used.

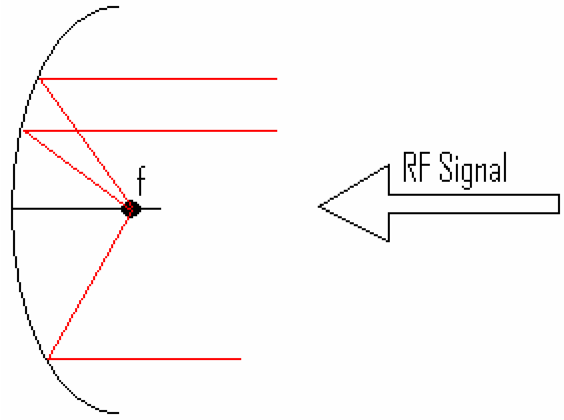
To aid in simplifying matters I will start with an introduction of the basics of parabolic antennas then follow this up with the theory and maths behind their design before going into the more complex matter of their feeds and other details.

Why We Use Parabolic Antennas

Parabolic antennas, or ‘microwave dishes’ are one of many types of antenna (yagi, dipole, monopole to name just three) but each one of the types of aerial/antenna have their best use. Here I will explain what the parabolic antennas use is.

“*The basic property of a perfect parabolic reflector is that it converts a spherical wave emanating from a point source placed as the focus into a plane wave, ie the image of the source is focused at an infinite distance from the dish. Conversely, all the energy received by the dish from a distant source is reflected to a single point at the focus of the dish.*”

The main points of parabolic antennas are that they can have high gain and be highly directional. This is easily recognised as the basis for a point-to-point antenna. Below you can see the basic outline of a parabolic antenna:



Above you can see a very basic 2D image of a parabola showing several concepts. You can see the direction of signals coming in. The diagram highlights the concept that all incoming signals to a parabolic antenna are focused into the focal point (f).

It can be proved that all signals that come toward the dish in the direction indicated by the arrow, in other words parallel to the dish to point ‘f’ line, that the signals will converge at ‘f’ and all travel the same distance, thus all arrive in phase and increase the signal strength. Also, since only those signals on the correct path will converge that means that signals not coming from the correct direction will not arrive at the focus point, and thus not interfere too badly.

This focusing is the basic design concept of the antenna.

Also it is worth noting the ‘principle of reciprocity’ which says that no matter whether an antenna is used for transmitting or receiving it will show the same characteristics. In essence this makes the parabolic antenna not only an excellent receiving antenna but an excellent transmitting antenna as all the rays leave the antenna in parallel with each other making the signal well focused, so, with high gain.

This completes the basic introduction, it should now be understood just how useful this antenna can be if point-to-point links want to be created.

Practical Design

So, this antenna is a dish, parabolic in shape.

How big is it?
How deep?
What's this 'beamwidth' thing?

These are all excellent and valid questions, time to take a look and see if we can answer some of them.

Well, to start with we're going to have to go into some maths. Parabolic antennas are designed to work for microwave signals really, waves that are going to have quite small wavelengths, this is for two reasons primarily:

1. Any lower in frequency than microwave and the wavelength becomes so big (more than 50cm) that the dish is too large for practical use.
2. As always, cost.

They do exist, but are not often seen.

Microwave signals are in the 1GHz to 100GHz frequency range and are part of the three highlighted bands below:

- UHF – 300MHz to 3GHz
- SHF – 3GHz to 30GHz
- EHF – 30GHz to 300GHz

In UHF the wavelength is 1m to 10cm, 10cm to 1cm in SHF and 1cm to 1mm in EHF.

These wavelengths, from mid-band UHF are acceptable for reasonably sized dishes. With this in mind, I'll get to the maths.

To start with, the formula for a simple parabola:

$$y = \frac{x^2}{4\pi}$$

Where x is the radius and y is the distance from the plane. It is possible (though I will not be proving) to rearrange this formula to:

$$f = \frac{D^2}{16c}$$

Where D is the aperture of the antenna (diameter in essence), c is the depth of the dish at centre point, and f is the focal point.

Now Gain, G, is proportional to the antennas effective area, A.

$$G = \frac{4\pi A}{\lambda^2} \times n$$

The gain here is relative to what is known as an isotropic antenna. This antenna is purely theoretical, it radiates equally in all directions and as such makes a good basis for comparison.

The n factor is the antennas efficiency as no antenna can be perfect with the exception of our reference. The efficiency is based mainly on the effectiveness of illumination of the dish by the feed, this will be dealt with later.

The formulas here help to start us on the maths side of the construction of an antenna.

Each time you double the diameter of a dish, the gain increases by a factor of 4, or 6dB however you prefer to look at it.

Beamwidth is defined by EutelSat as “usually expressed as the angle between the directions of radiation as which the beam strength falls to half its maximum value.” A very easy to understand definition stating simply that beamwidth is a measurement of the width of the corridor in which the signal is being transmitted with more than half the maximum power.

This is a very important value and it can be shown that beamwidth is inversely proportional to the diameter of the reflector.

$$\Phi = \frac{1}{D}$$

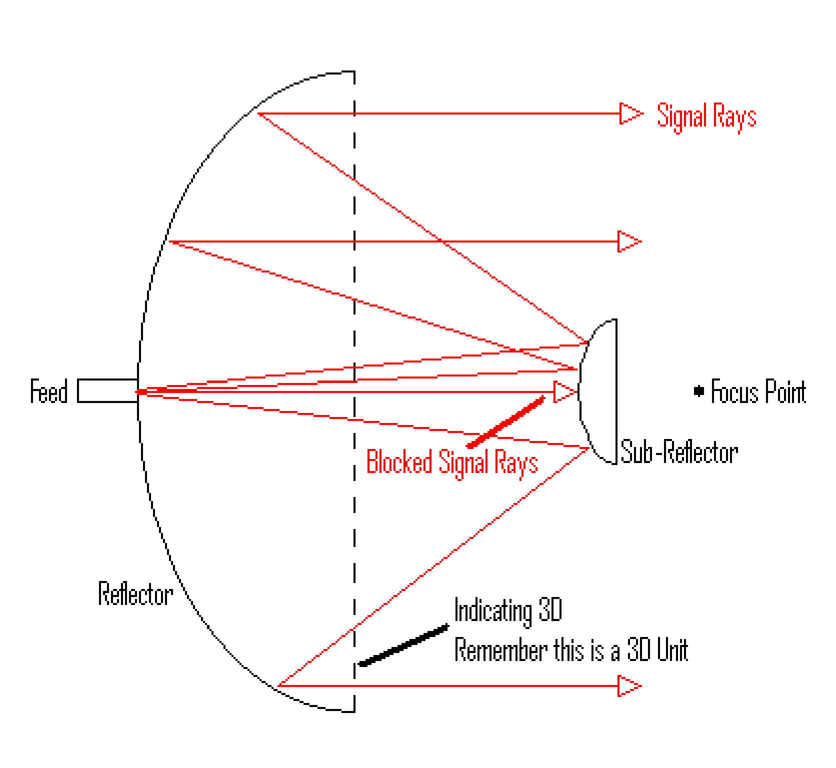
Where Φ is beamwidth in degrees and D is the reflector diameter in metres.

The beamwidth, operating frequency, gain and dish size are the main factors when constructing the antenna as their values control the physical size and the sort of operation you need. For example, a very large antenna will have a very large gain, but a very small beamwidth, a “pencil beam” this means that although you have a very strong signal your receiving antenna will need precise alignment otherwise the signal will not *hit* your receiver.

In contrast a small receiver will have a small gain but a wider beam, not a strong signal but at least your antenna depend less precision in aiming.

Examples:
6 metre antenna, beamwidth of approx. 0.25° @ 14GHz
60 cm antenna, beamwidth of approx. 2.5° @ 14GHz

Diagram of Parabolic Antenna and Description



Feed
There will be more on this later. This is the connection for the antenna to the rest of the system, either the receiving or transmitting electronics.

Reflector
The actual dish, the focusing element of the system, the focal point of the signal rays is highlighted as *focal point*.

Indicating 3D
I believe this is worth including, all the diagrams here are in 2D, it is worth keeping in mind that these are 3D units, dishes, and should be thought of as such.

Sub-Reflector
Again, there will be more on these later, I will not attempt a description here.

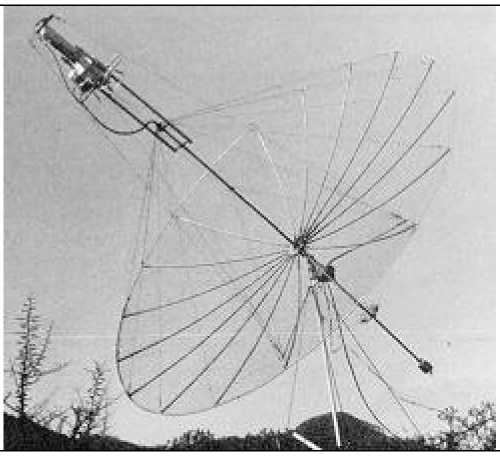
Signal Rays
You can see here how the signals, whether incoming or outgoing do so in parallel and focus with the reflector (and sub-reflector if in use).

Blocked Signal Rays
These are rays which do not get transmitted and cause problems for the system, more on these later.

It is worth noting at this point that parabolic antenna don't only come in the *traditional* dish form, below are some examples.

Here is a typical grid antenna. This is something I will not be mentioning anywhere else in this report, it is a parabolic reflector that is girded. In other words it is not a complete reflector, there are gaps. This has its uses and downfalls. On the plus side the construction is lighter and windage is reduced (wind effect on a large parabolic antenna can be a problem) but interference is increased. The gaps can only be 1/10λ in size.

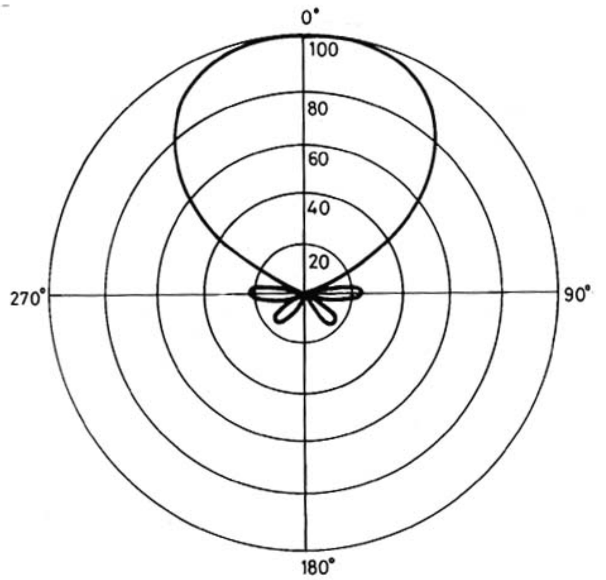
A common amateur design is shown here



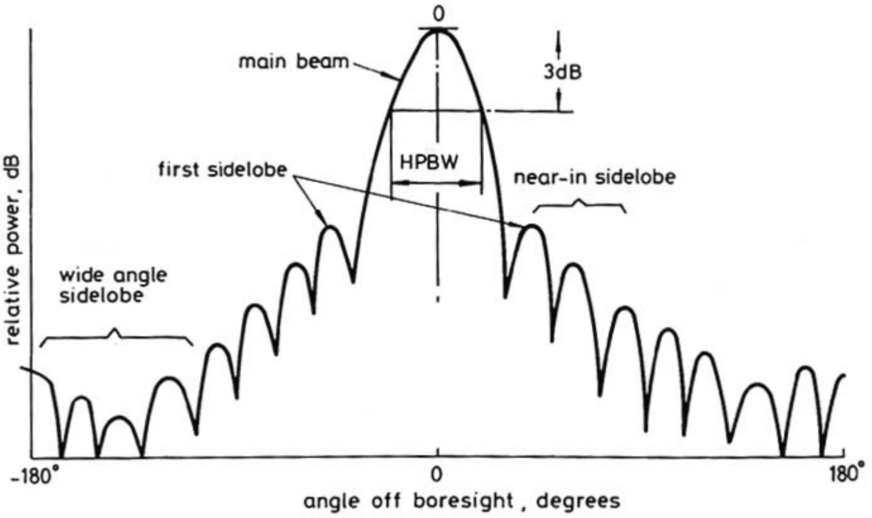
This is AFC Sat's 3.7 metre diameter pipe mount antenna, something more expectant when dishes are mentioned.

Beam Patterns

Below are the beam patterns of a typical parabolic antenna, first is the **Polar** plot then the **Cartesian** plot. Each has a specific use.



a



b

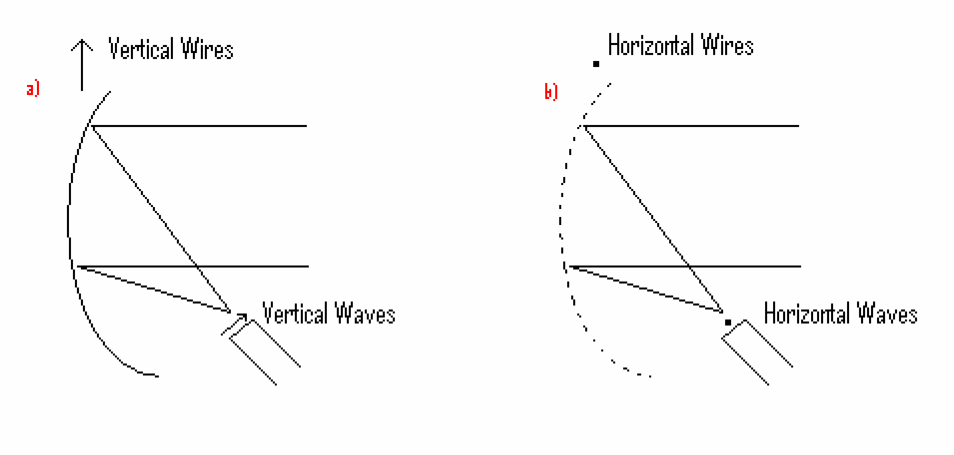
These diagrams were taken from “Satellite Communications Systems” as listed in my bibliography.

Here you can diagrammatically see the transmission direction. Both show the high directivity common to parabolic antenna and the unwanted sidebands, lobes, which are still produced. However this level of directivity is still very high in comparison to other antenna.

Polarisation

Polarisation describes the ‘direction’ of the travelling wave, either horizontal or vertical. These terms are relative to a plane of course and always to the waves’ electrical component, not the magnetic field.

Polarisation can be utilised as either selective, reflective or both in a parabolic antenna system.

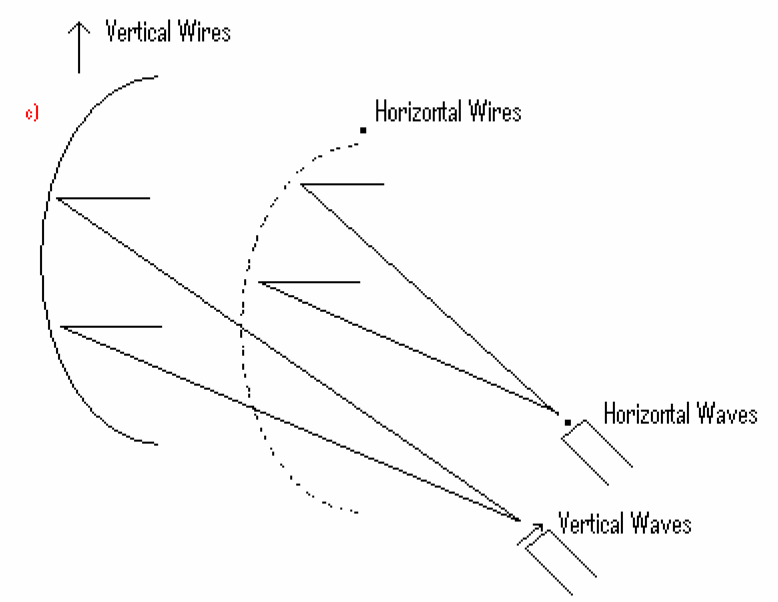


Above we can see two diagrams to highlight the reflective point of polarisation. Both the vertical (a) and horizontal (b) waves reflect off wires polarised the same way as the waves which as approaching them.

If we were to swap the wires over in the above diagrams and they were polarised perfectly in their direction, the waves would pass through the reflectors, indicating the selective usage.

The condition of perfectly polarised waves is very important, incorrectly polarised waves can cause very serious interference.

Below both the reflective and selective components are shown, this diagram allows us to see how both usages can be utilised to give a parabolic system able to transmit two separate signals through the same antenna (again presuming both the polarisation of the wires and waves are perfect otherwise interference occurs).



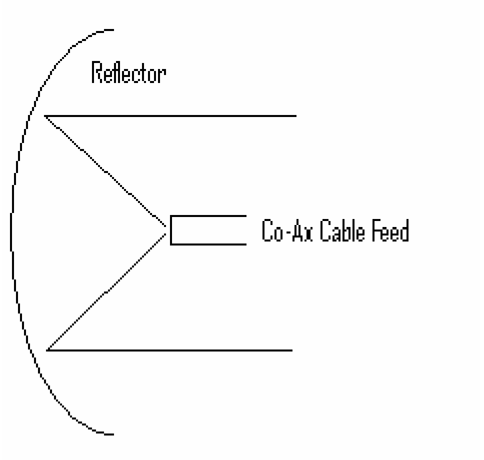
Antenna Feeding

Basic Definition: The feed of an antenna is the connection from the parabolic antenna to the transmitting or receiving circuitry.

This is not as simple as connecting a horn at the dish and plugging it into the appropriate box, the cable is specific, there are many ways and places to attach the feed and cabling is not the only way to connect the system up. Feeds have to match their antenna otherwise you will not get a satisfactory performance and the feed has its own beamwidth too!

Lets' take a look at what I mean and start with a simple horn (a horn is an antenna in its own right, but it often used as a feed on a parabolic dish as it has a large bandwidth).

The *Prime Focus Paraboloid Reflector Antenna* or *Axisymmetrical Paraboloid*.



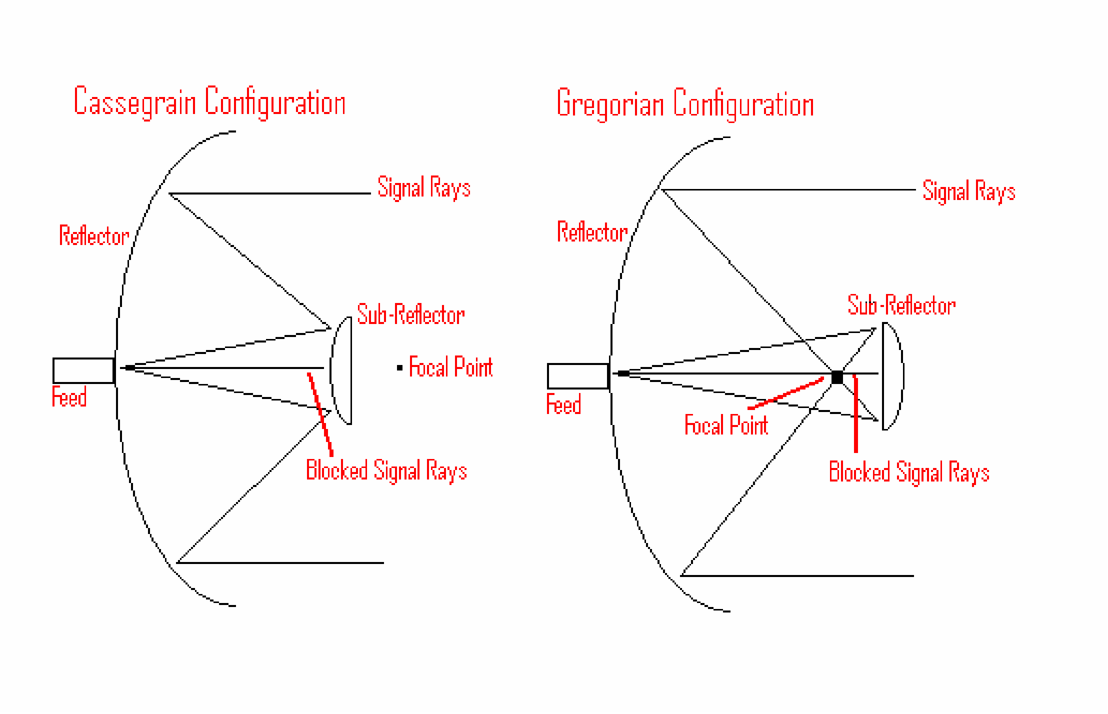
Ridiculously simple yes, the feed from the cable is fed to the dish from the focal point at the correct angle so the signal radiates out as it is meant to.

Simplicity has its drawbacks I'm afraid:

- **Attenuation**
  Attenuation will always be a problem, no matter what feed mechanism is used, but co-axial cable at the frequencies we would be using can cause from 2 to 20dBs of attenuation per 100m dependant on the cable.
  Waveguides have much less attenuation on these systems.
- **Position**
  The position shown above is not a good place to place electronics, especially low noise equipment, receivers, amplifiers etc. as the focal point has a lot of signal interference obviously, and along with power requirements and cooling requirements this is obviously not a good choice.
  Out of the way of the signals is a much better solution.

- **Frequency**
  As has been said attenuation occurs on co-axial cabling, the maximum usable frequency of co-axial is less than 20GHz, waveguides can take above 300GHz.

The next step up is the *Dual Reflector* Antenna. These solve the three problems above by re-positioning the main feed and using a waveguide.

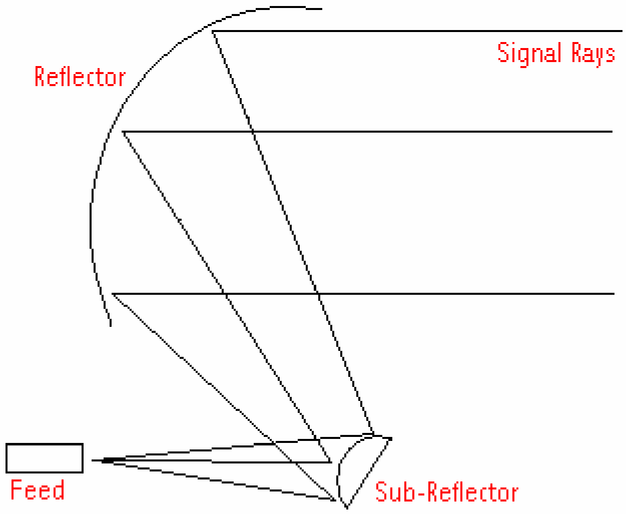


As you can see two setups are given. Both utilise a second *sub-reflector* which is positioned in the signal path. This has the advantage of the feed being located behind the main dish, thus extra cabling is not required and this eliminates one of our problems above, the waveguide eliminates the second and third.

The first of these two setups is the Cassegrain configuration where the sub-reflector is positioned inside the focal range, the second is the Gregorian configuration where the sub-reflector is positioned outside of the focal range.

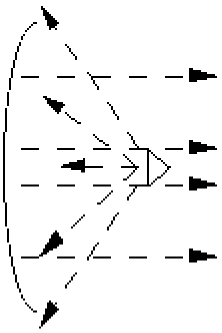
The use of these sub-reflectors does do a lot to improve on the previous configuration but this way does incur a problem of its own, Blocked Rays. As is pointed out on the diagrams there are some rays which do not get through the system.

The next step is to use an offset antenna, these again come in the two configurations using both styles of sub-reflector, the basic premise is illustrated below:

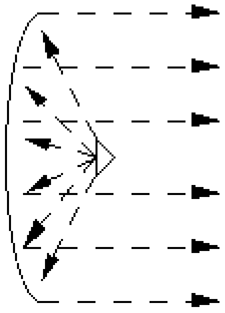


This setup has the added ability of having no blocked rays.

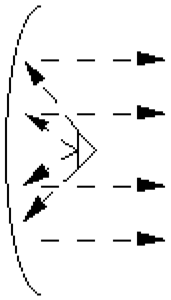
So, now should see the wide variety of feeding available and this is just the start! There is one further topic I'll touch on which is illumination, as I mentioned earlier these feeds have their own beamwidth, I will now explain this.



Over Illumination



Correct Illumination



Under Illumination

Illumination can be thought of as a comparison of the beamwidth of the feed against the diameter of the dish. As is clear from above under and over illumination is where the beamwidth of the signal does not match the antennas size.

Advantages and Disadvantages of Parabolic Antennas

Parabolic antennas have their advantages:
- Controllable beamwidth
- Being large or small dependant on design
- High gain
- Very much configurable dependant on usage

But their main downfalls can be discouraging:
- Difficult to balance variables
- Difficult to design accurately
- Costly

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