AVN Training HartRAO 2017

Radio Antennas

Introduction and overview

- Radio antennas come in a great variety of forms
- We will only consider a small number that are relevant to radio telescopes and radio astronomy in general.
- Starting from the simplest, we will deal with commonly used antennas and end with the antenna that is widely used in radio astronomy, the parabolic reflector.
- My approach will be to convey the basic concepts so that they will be clearly understood. I will therefore concentrate on basic physical principals without going into detailed mathematical derivations based on Maxwell's equations. These are available in standard text books, or on the internet for those who are interested.
- I acknowledge the value of the internet, where many of the diagrams used in my talk were sourced.

Important concepts

- A basic, and important concept used when studying antennas is that of ***reciprocity.***

- What this means is that the properties of an antenna are the same whether it receives or transmits radio waves.

- Sometimes it is convenient to consider the antenna as a radiator – emitting or transmitting radio waves. When it receives, it then has the identical properties as when it transmits, and vice versa.

Transfer of power

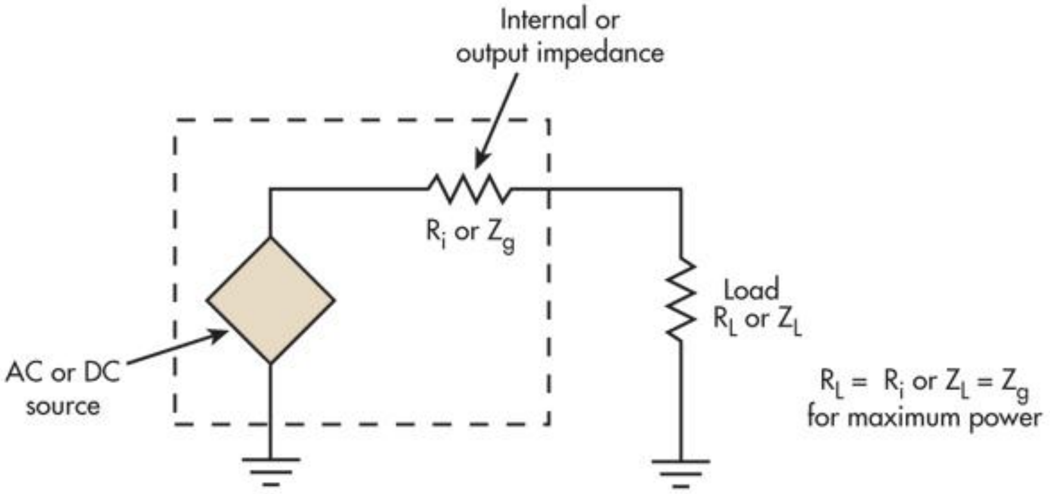
Another important concept is that of maximum power transfer in any circuit.

If one has a source of voltage, it always has an associated ***internal resistance or impedance***.

In order to transfer the ***maximum*** amount of power from the source, the resistance, or impedance, of the ***load*** must equal the ***internal resistance or impedance*** of the voltage source.

This is known as ***impedance matching.***

This implies equally to an antenna – which has its own ***characteristic impedance***.



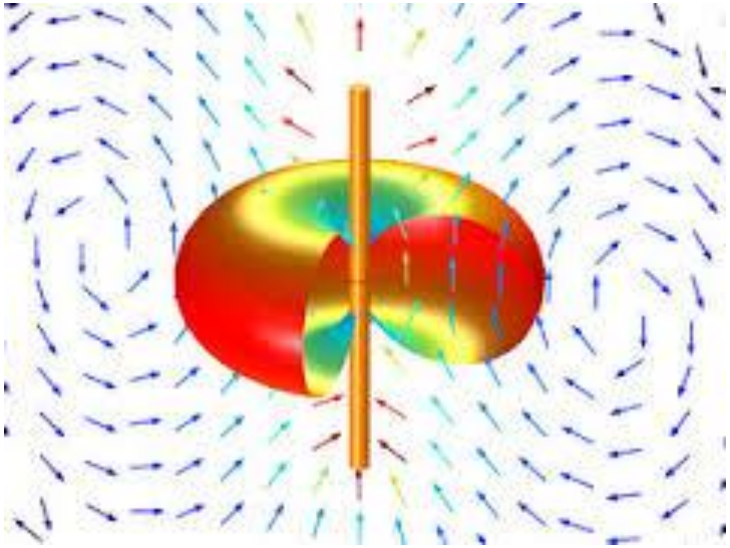
The Dipole antenna

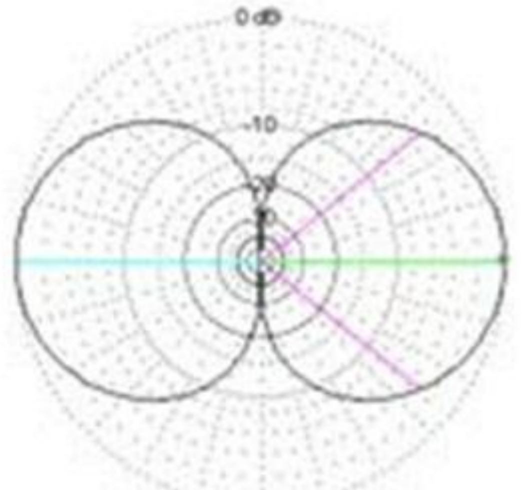
The dipole antenna is the basic antenna element.

It is half a wavelength long and is fed from the centre.

When it transmits, it radiates energy in in the form of a torus or doughnut, referred to as the ***Radiation Pattern .***

In a two dimensional plane it projects as a double-lobed pattern





Other types of antennas

Multi element antennas:

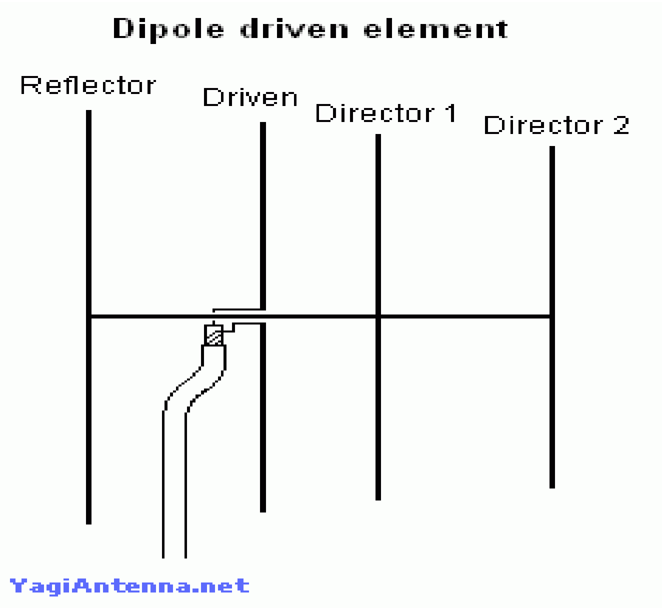
1. **Yagi antennas**

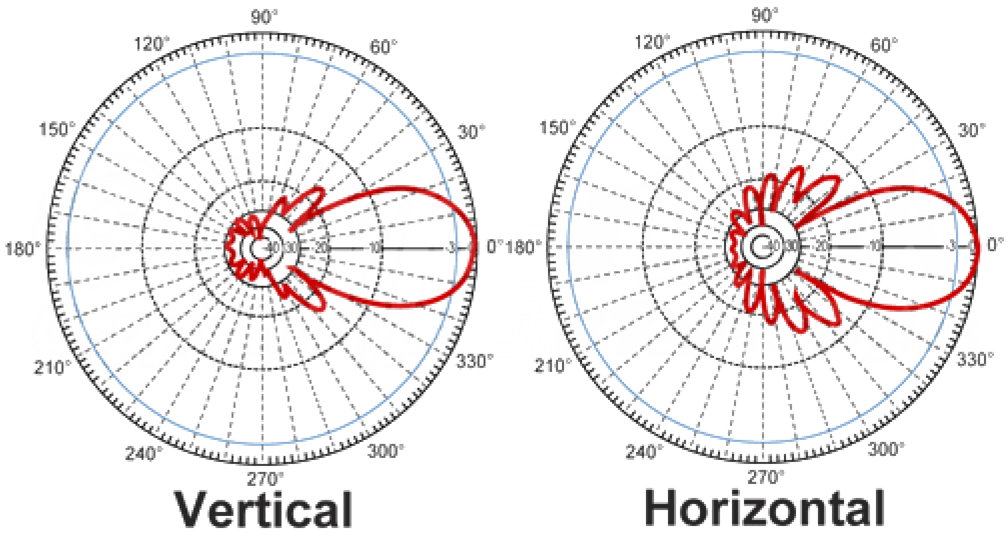
   If one places a second slightly longer rod behind the dipole it acts as a reflector.

   Increasingly smaller rods at appropriate distances in front of the dipole act as directors.

   The net effect is to direct the radiation in the forward direction, making the antenna ***directional.***

   The ***principal, or main lobe*** points forward, with radiation in subsidiary directions via ***side lobes***





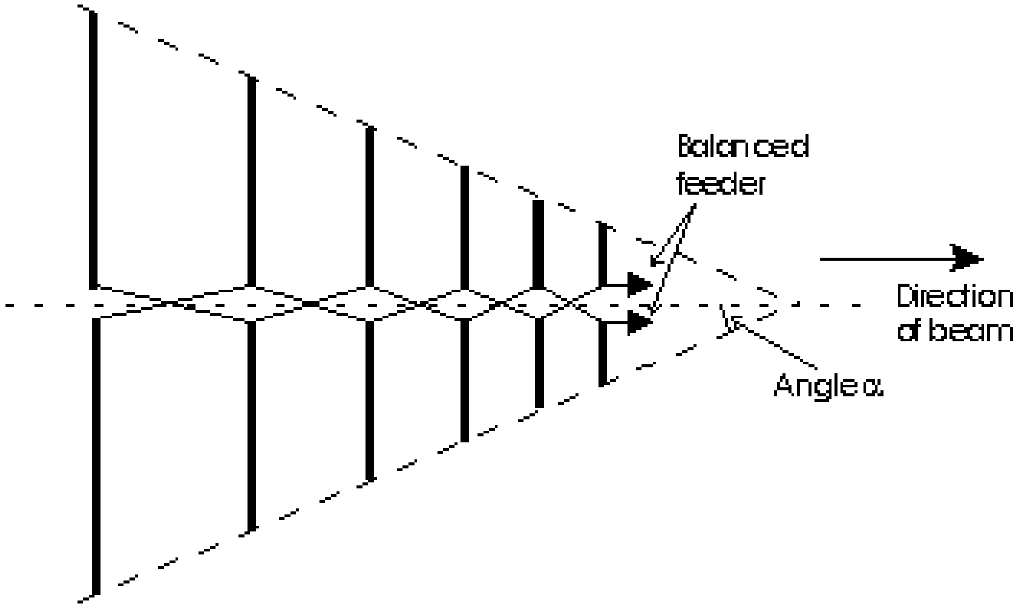
Some further definitions

- Another important consideration is the range of frequencies over which an antenna radiates or receives.
- This is called the ***bandwidth*** of the antenna and is denoted by the symbol **B**.
- This is defined as **B = f2 – f1** where

  f1 is the lower operating frequency and

  f2 is the upper operating frequency
- Dipoles and Yagis have a small fractional bandwidth **B/fo** (where fo is the centre frequency) of about a few percent, although there are methods of increasing this.

Log periodic antenna



Logarithmic periodic antennas are a variation of the dipole and Yagi antennas.

They consist of a series of dipole elements of increasing size, with a logarithmic progression of spacing.

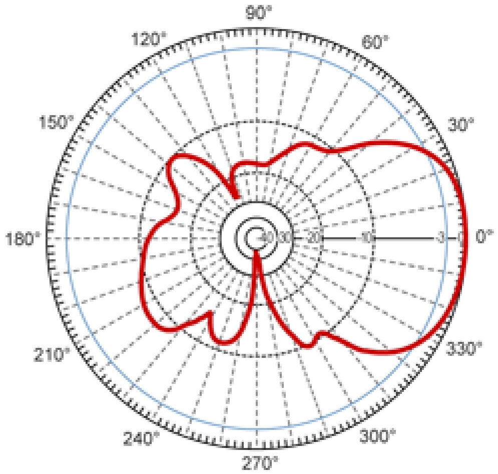
This gives the log periodic antenna a far greater ***bandwith***, which enables if to operate over a wide range of frequencies.

For these antennas,

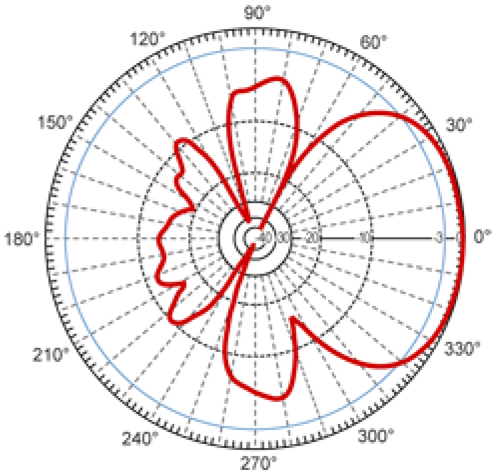
f2/f1 can be as large as 20,

e.g. 1 GHz – 20 GHz. A common use for log periodic antennas in radio astronomy is for locating ***radio frequency interference, or RFI.***

Typical radiation patterns for a log periodic antenna are show on right and are roughly independent of frequency.



Vertical



Horizontal

Antenna Gain

- At this point it is convenient to introduce the concept of ***antenna gain***.
- We define an ideal ***isotropic antenna*** as one that radiates or receives equally in all directions.
- The ***gain*** of a given antenna is then the ***ratio*** of the power received by an antenna from a transmitter, to the power received by an ideal isotropic antenna.
- Gain is measured in decibels, or ***dB*** defined as the ***dB ratio = 10 x log (P2/P1)*** where ***P2*** is the power received by the given antenna and ***P1*** is the power received by the isotropic antenna.

Beamwidth of an antenna

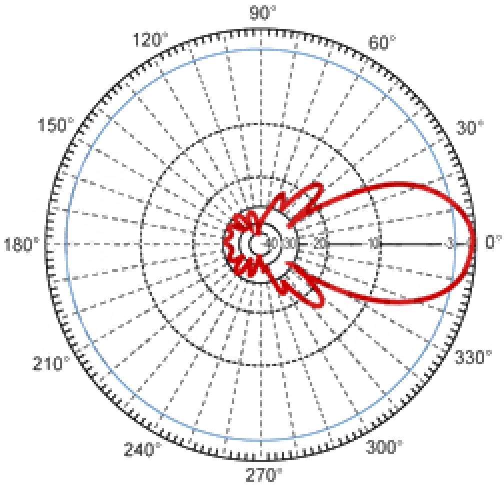
The main lobe of the antenna pattern is also balled the ***main beam.***

The angular distance between the directions at which the power falls to one half its value in the centre defines the ***half power beamwidth***, contracted to ***HPBW.***

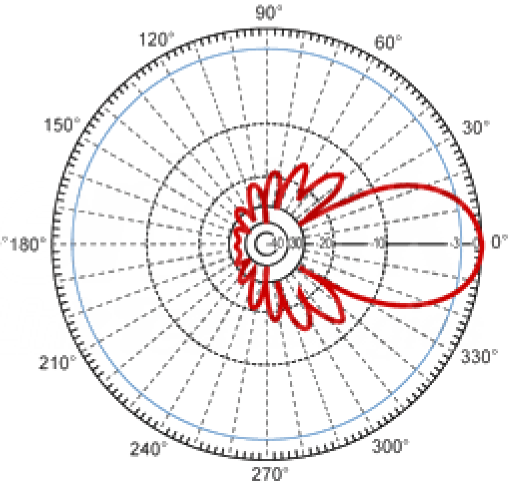
For the radiation patterns shown , the radial scale is in decibels, shown in circles at 3 dB, 10 dB, 20 dB, 30 dB and 40 dB.

On a dB scale, the HPBW is measured at the 3 dB point on the beam, shown by the blue circle.

The minimum between the main lobe and the first side lobe is known as the first null, and those between successive sidelobes as the 2nd, 3rd, 4th .... nulls.

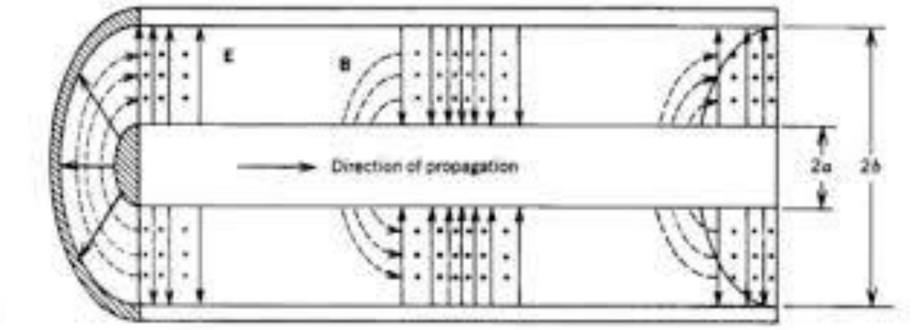


Vertical



Horizontal

Digression:
Feeding power to, or received from these antennas.



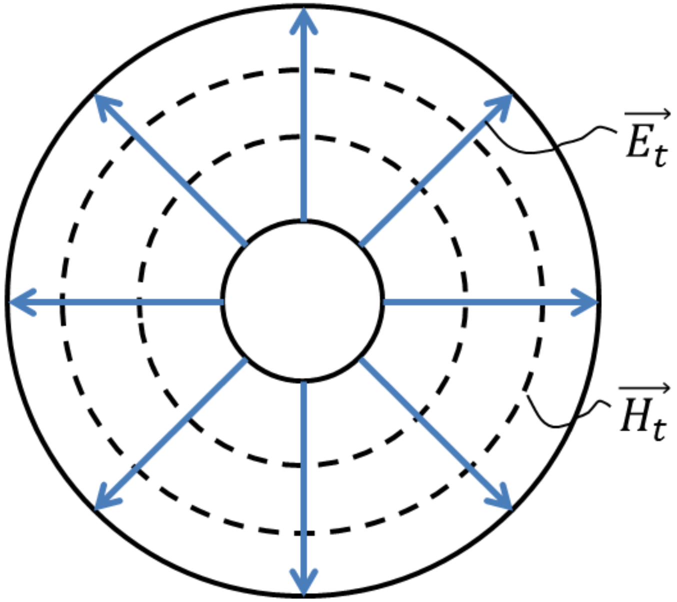
- In order to feed power to, or receive a signal from the above antennas it is necessary to use an appropriate cable, generally a coaxial cable.

- These comprise an outer conducting cylinder with a central conductor. The field distribution is shown on the right.

- The ***electric (E)*** and magnetic (***H***) fields are orthogonal to each other, ***E*** being radial, and ***H*** circular.

- The mode of propagation is known as the ***transverse –electromagnetic mode, or TEM mode***.

- Coaxial cables are versatile, and have low loss - i.e., very little power is absorbed by resistive losses in the cable.



More on coax cables .....

Coaxial cables have a characteristic impedance, measured in Ohms, which must match the impedance of the antenna and the impedances of the transmitter or receiver, to ensure maximum power transfer.

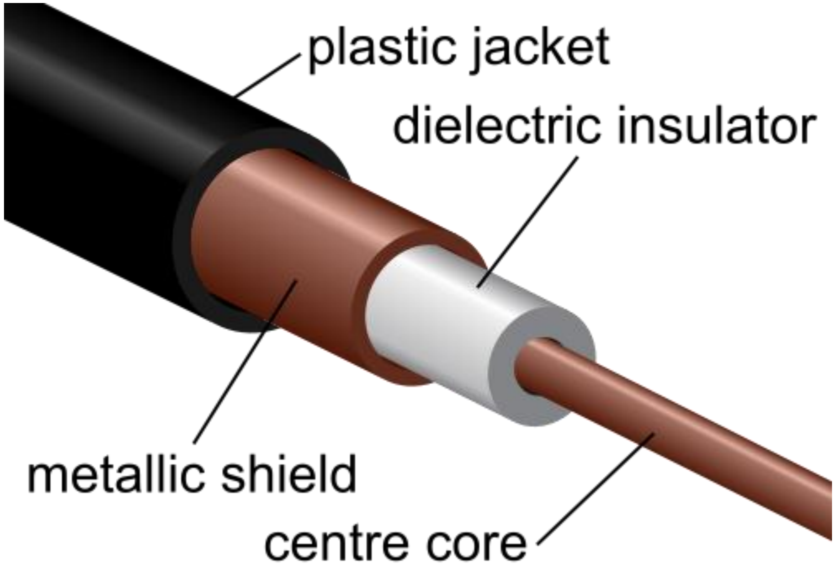
The characteristic impedance of coax depends on the ration of the of the diameters of the inner and outer conductors given by the formula:

$$Z = 24.1 \times \varepsilon / \log(D/d),$$

where ε is the dielectric constant of the insulating material.

Standard values commonly used coaxial cables are 50 Ohms (lower loss), or 75 Ohms (lower weight).

Coax cables come in various sizes , can be flexible or semi rigid, depending on the application.



Antennas used as radio telescopes

- The most common antenna used as a radio telescope is the parabolic reflector, examples of which you see outside.

- The main reason for using these is that they are frequency independent, and within certain constraints can be used at any frequency.

- This makes them very versatile, but they generally require separate receivers for each frequency band at which they operate.

The parabolic reflector antenna

The basic parameters of a parabolic reflector are:

Diameter: D

Focal length: f

The ratio f/D, called the focal ratio is a measure of the depth of the paraboloid.

For F/d = 0.25, the focus lies in the aperture plane of the paraboloid.

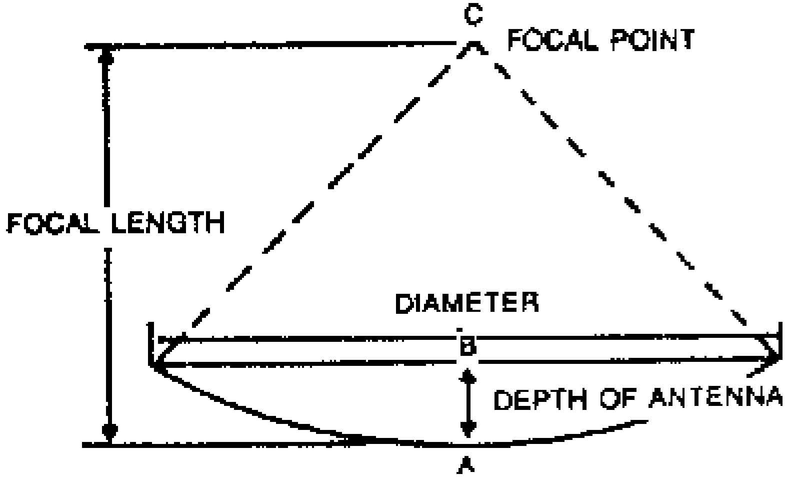
Equation: $y = x^2 / 4f$

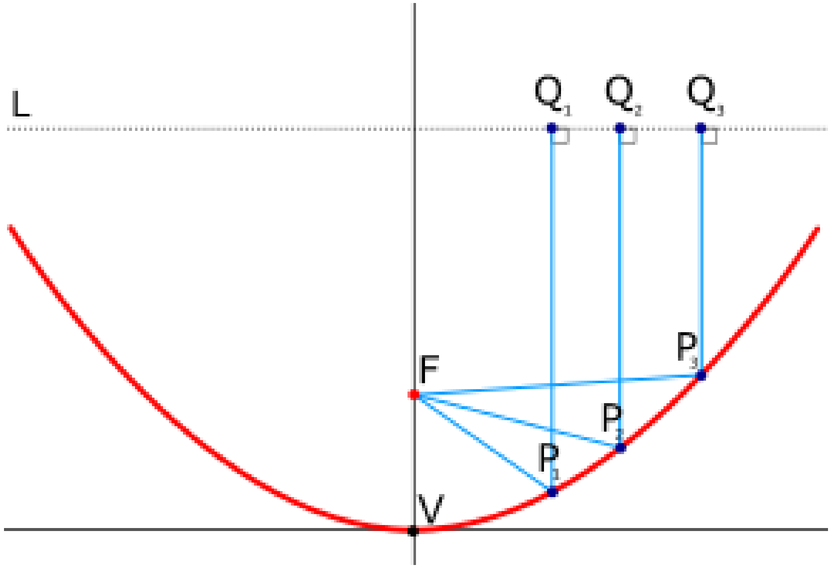
Important properties:

Rays radiating from the focus are reflected as parallel rays.

The distance travelled by any ray from the focus to a fixed line, L, parallel to the aperture of the parabola, is always constant.

Therefore, the wavefront normal to the exiting rays always has a constant phase.





The limitations of parabolic reflectors

The first limitation is the diameter measured in wavelengths, i.e. D/λ, which must be > 15

This is not a problem for radio telescopes where D is very much greater than λ, e.g.,
λ 1.3 - 13 cm, d=26 m $D/\lambda = 200 – 2000$.

The second limitation is the deviation from true paraboloidal shape, including distortions in individual panels as well as mis-alignment of individual panels.

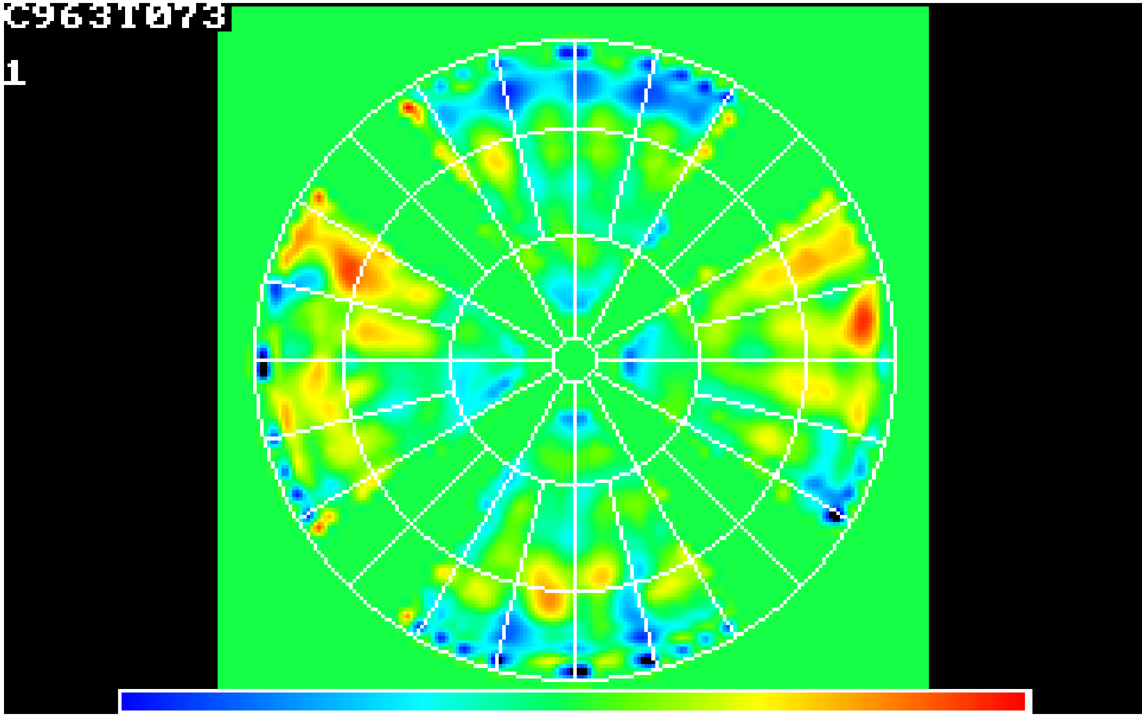
This is shown in the diagram, which maps errors in a dish surface measured with a technique known as radio holography.

Ruze has shown that if the root mean square (rms) deviations ε are known, then the gain is reduced by a factor given by:

$$G/Go = \exp(-4\pi\varepsilon/\lambda)^2$$

This limit is typically stated as $\varepsilon \leq \lambda/20$

For the HartRAO 26m antenna
$\lambda_{min} = 1.3$ cm, or 22 GHz frequency.



Feeding signals to and from a Paraboloidal antenna

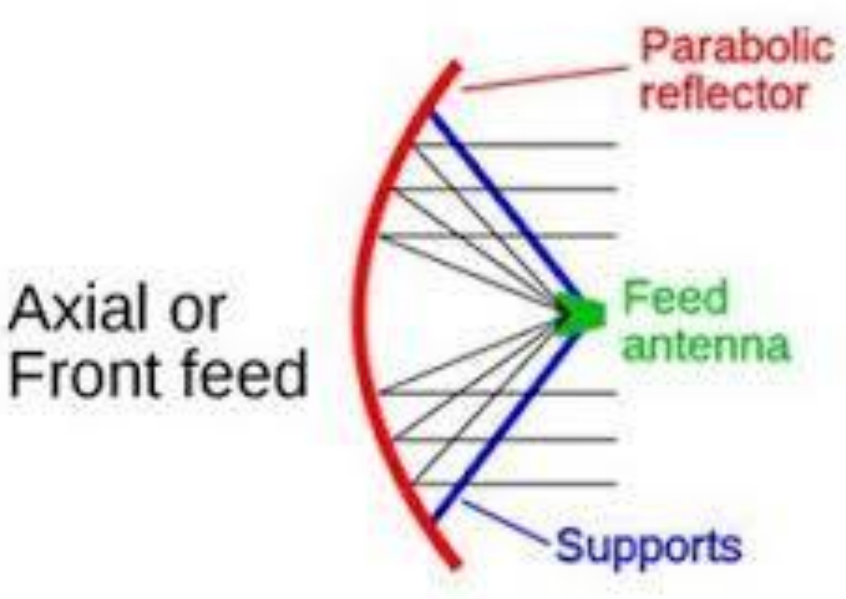
The feed antenna, often contracted to "***the feed"*** must have a radiation pattern that correctly illuminates the paraboloid, without spilling over the edges – lost energy is known as known as "***spillover" .***

A deep paraboloid with f/d = 0.25 can be illuminated with a dipole feed, with a back plane but this is not the most efficient method.

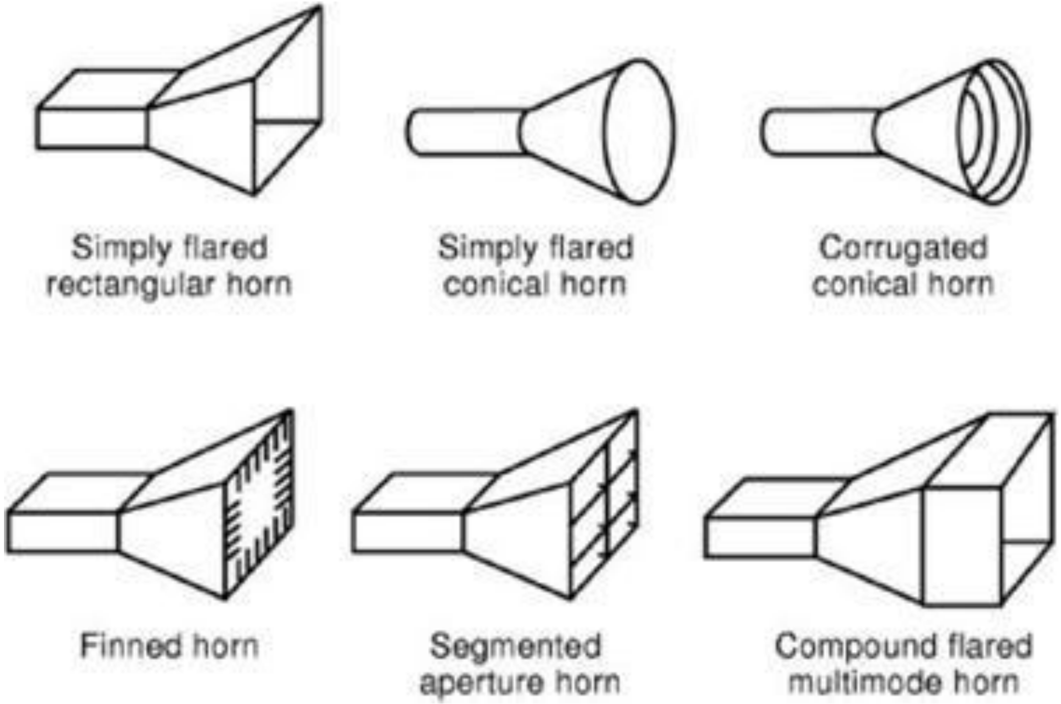
For a front fed prime focus feed, a horn feed is most commonly used.

Because the wavelength is not that small, the energy received at the focus is not confined to a point, but fills a small circle at the focus, known as the ***Airey disc***, with a diameter proportional to the wavelgth.

The aperture of the horn must then be matched to the Airey disc in order for it to intercept the maximum amount of energy.



Horn antennas



Horn antennas can come in a variety of forms, e.g. rectangular or square pyramidal horns, or conical horns.

Because the paraboloid is circularly symmetric one would imaging that the conical horn would best match the field in the Airey disc and this is true.

The corrugated conical feed is generally the most efficient feed and has the widest bandwidth.

There are conical feeds which combine several modes to generate a beam with suppressed side lobes. Invented by Phil Potter, and known as ***"Potter feeds"*** these horns are the ideal for modest bandwidths of ≤ 5%.

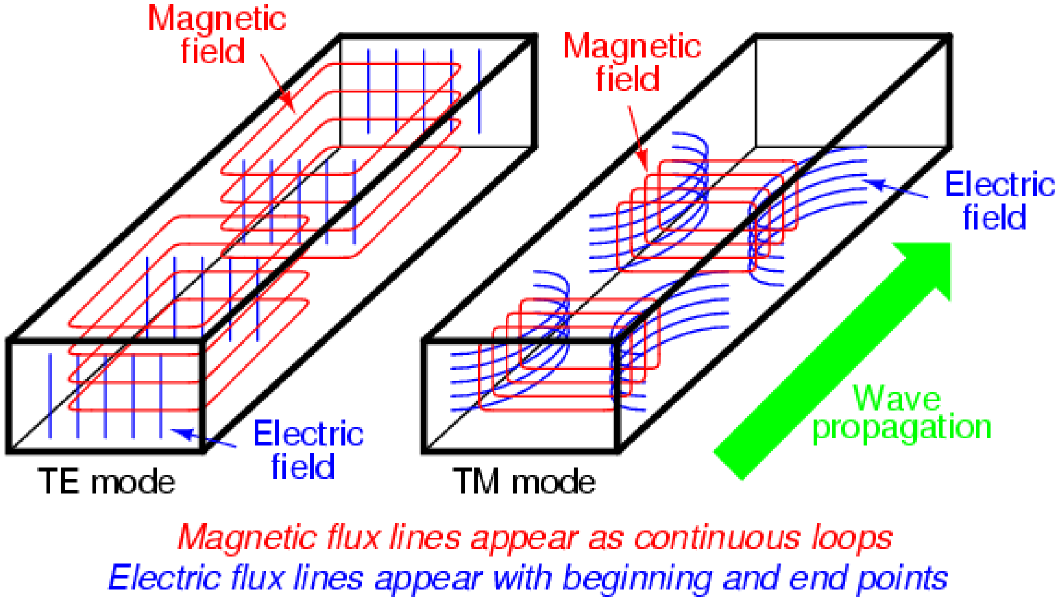
Feeding signals to or from the horn antenna

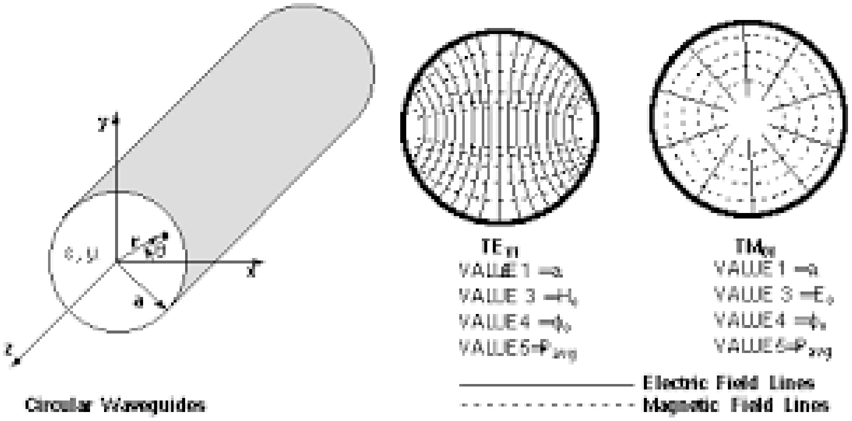
While the feed receives signals focussed by the paraboloid, these signals still need to be fed to a receiver.

This is normally done by means of a waveguide, either square or round in cross section. These structures allow electromagnetic waves to propagate through the waveguide, with minimal loss of signal.

Each guide has a dominant mode, which the desired mode for optimal propogation. Most commonly used is the TE10 mode in rectangular guide.

For circular guide the TE11 mode is the dominant mode that needs to be excited.



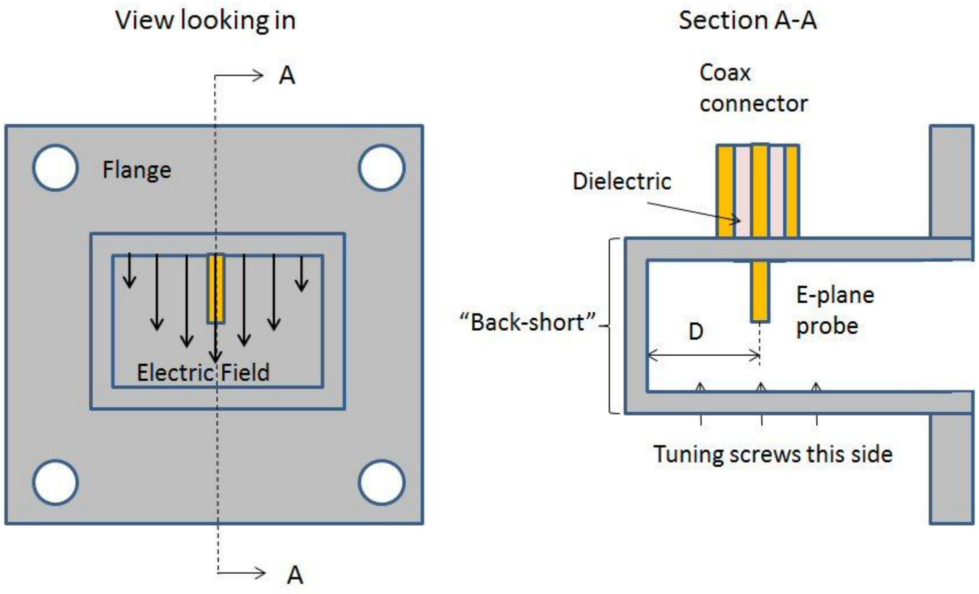


Connecting a receiver or transmitter to a waveguide

To connect a receiver (or transmitter) to a waveguide we require a waveguide to coaxial converter, because most receiver components are designed for a coaxial input.

This device uses a coaxial input connector to excite the E field in a short section of rectangular guide.

This establishes the TE10 mode, which then propogates into the rectangular waveguide to which it is connected.



Connecting to circular waveguide

The ideal way to connect to a circular waveguide is to use an orthogonal mode transducer, or ***OMT*** or alternatively a ***hybrid polariser.***

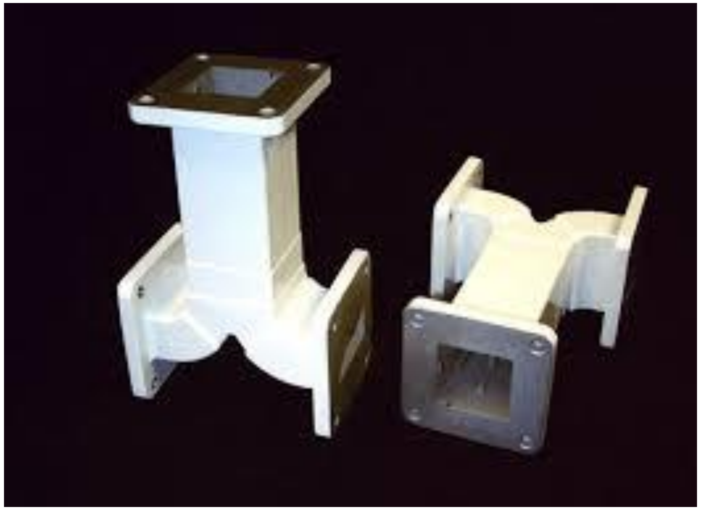
The advantage of the OMT is that itreceive two orthogonal linear ly polarised signals simultaneously.

The hybrid polariser, which is widely used in HartRAO feed assemblies***,*** generates orsthogonal circularly polarised signals, left and right hand circular polarisations (***LCP and RCP).***

Although the output guide is square, circular cross sections, or square to circular adaptors are available.

The two output flanges can then be connected to rectangular waveguide to coax converters.

Model PR40C and CP-1214C
Seavey Engineering Associates, Inc
28 Riverside Drive Pembroke, MA 02359



Waveguide sizes

Waveguides come in standard sizes. A tyical wave guide operates over a frequency range of about 1:1.5, e.g.

WR90 operates over 8.2-12.4 GHz.

The height and width of a rectangular guide define it frequency range.

In the case of circular guide the diameter is the determinant factor.

Radiation pattern of paraboloidal dishes

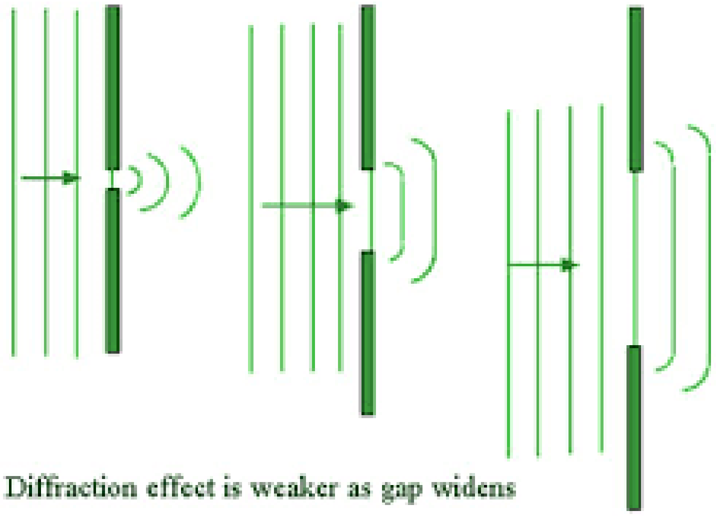
The radiation pattern of of paraboloidal dishes can be derived using Huygen’s principle.

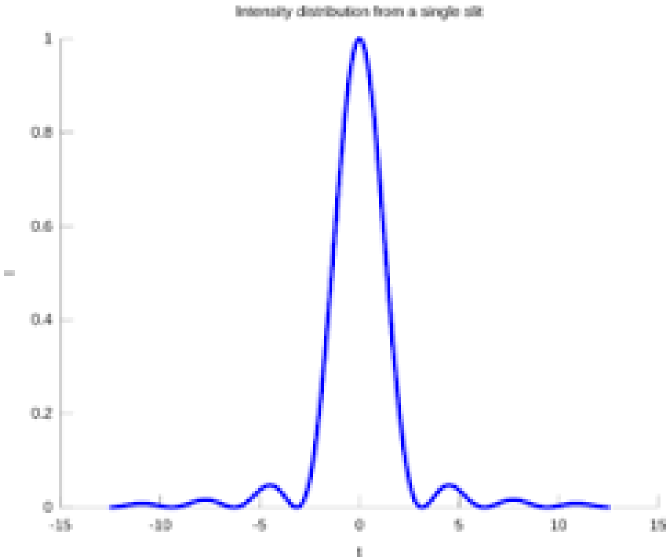
The dish aperture can be replaced by a hole in an infinite plane, with a plane wave propagating parallel to the plane from behind. The waves then diffract through the hole , as shown in the upper figure.

As the hole becomes larger (i.e. larger values of D/λ) diffraction takes place at the edges.

For large D/λ the radiation propagates as a column for a distance≈ D^2/λ. This is known as the near field and extends for >10 km at the higher frequency for the HartRAO 26 m dish. It is also known as the Freznel zone.

Beyond this lies the far field, or Fraunhofer diffraction zone. It is in this zone that we measure the radiation pattern of the antenna. The half power width is of order λ/D radians.


Diffraction effect is weaker as gap widens



Various form of parabolic reflectors

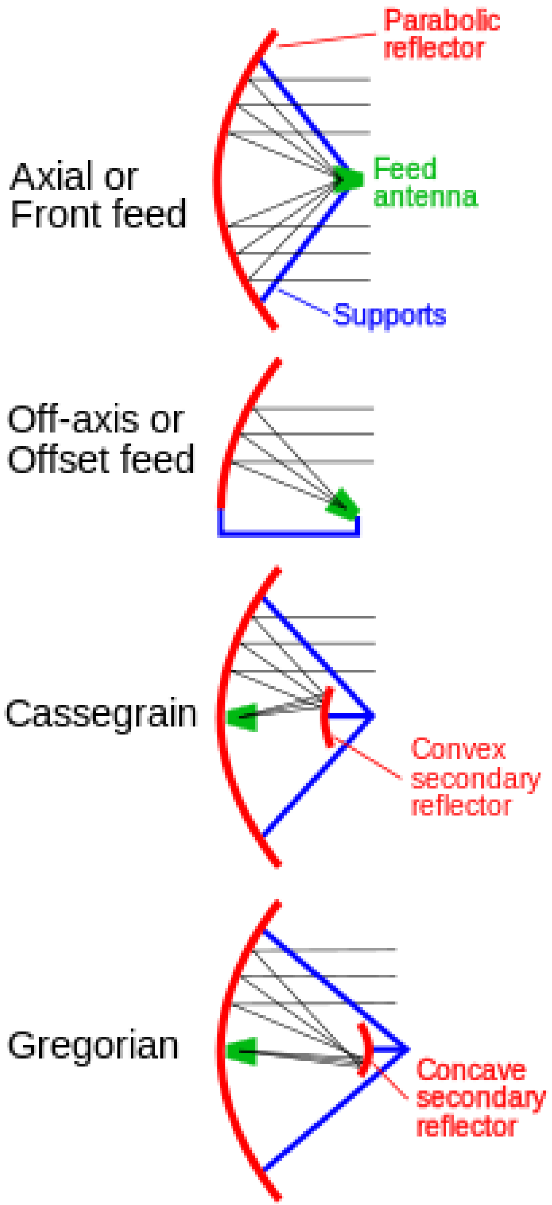
The axial or front fed feed is the mosst basic, and is known as a ***prime focus feed.***

The most common use of the off-axis feed is for DSTV saellite reception. It has a clear aperture with no blockage loss .

The ***Cassegrain feed*** is widely used for radio telescopes and large satellite communication antennas. The secondary reflector is ***hyperboloidal*** in shape, and is below the primary focus. It generally has high efficiency, and low spillover towards the ground.

The ***Gregorian feed*** is similar to the Cassegrain, but the secondary, which is ***ellipsoidal*** in shape, lies above the prime focus. Similar advantages to the Cassegrain, but additiional one is that prime focus is accesible without removing the secondary reflector.

Both have the advantage that there is far more space available at the secondary focus than there is at the prime focus. This allows for multiple receivers to be permenently mounted.



The HartRAO 27m radio telescope

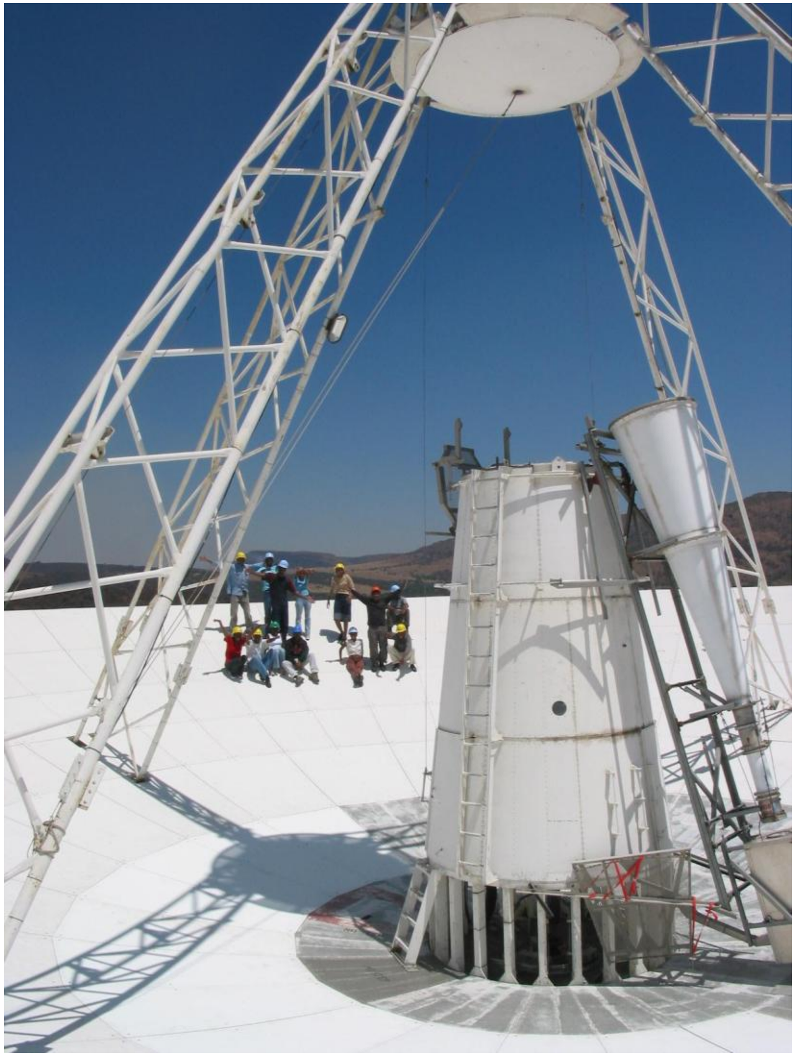
The HartRAO 26m telescope is an example of a Cassegrain focus.

The central truncated cone contains most of the feed and receivers.

The cone to the right is the largest feed for 18cm wavelength.

The Airey disc that we discussed earlier has a diameter of 5λ for this antenna.

The beam widths range from 30 arc minutes at 18cm, to 2 arc minutes at 1.3 cm.



The MeerKAT and SKA Antennas

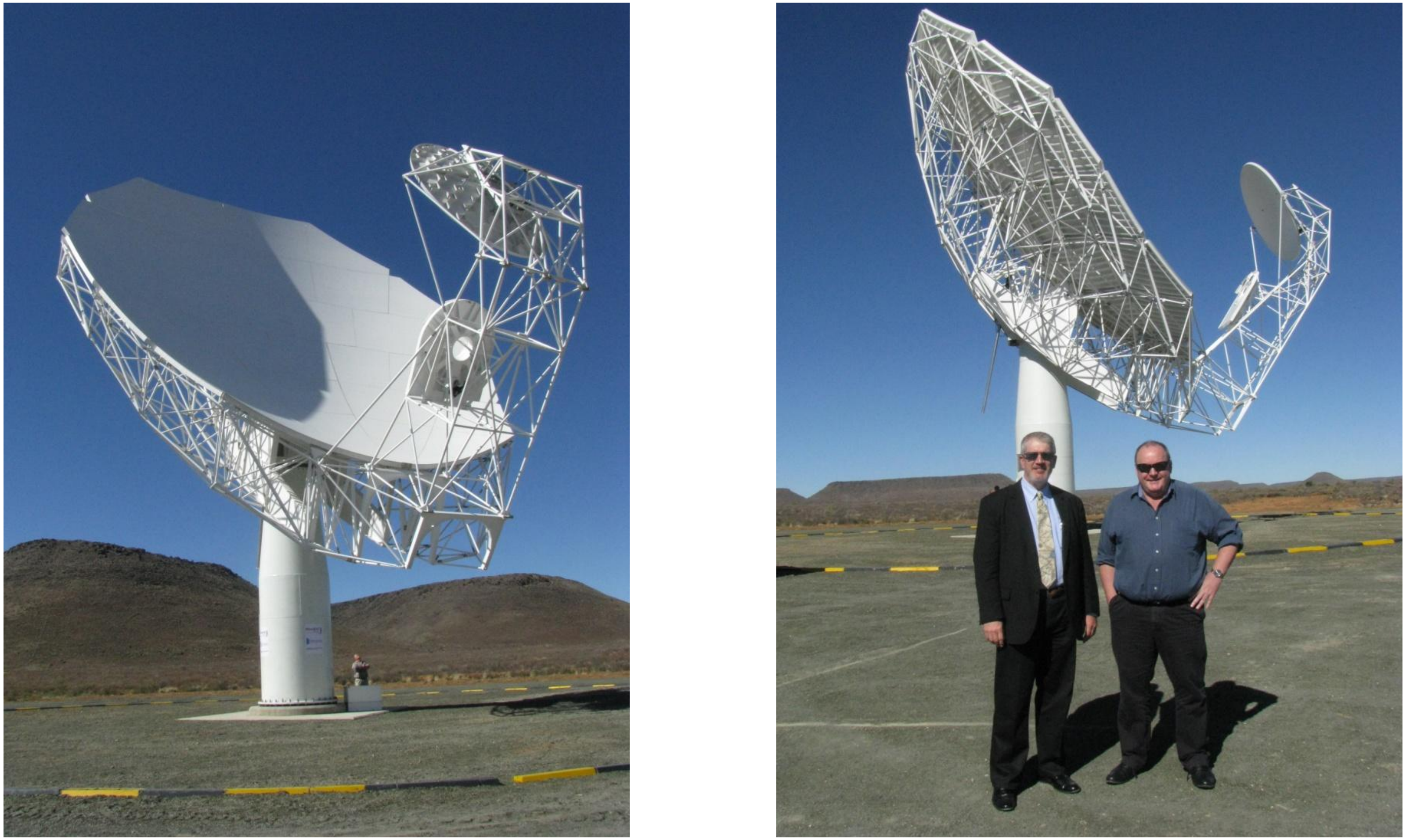
- An important new antenna design is the South African MeerKAT antenna which is currently being built in the dry Karoo region at the future SKA site as a precursor to the SKA.

- This antenna is a combination of the offset feed and the Gregorian secondary mirror.

- This combination gives excellent performance, and despite being half the diameter of the 26m antenna, is almost equivalent in overall performance, which combines the antenna gain, or aperture efficiency, together with the receiver performance.

- Antennas of this type, either the MeerKAT or the SKA design, which is slightly larger than the MeerKAT (15m vs 13.5m) is now the proposed design for AVN stations in Botswana and Namibia.

First MeerKAT Antenna



MeerKAT antennas being assembled on site in the Karoo

MeerKAT Antennas

Photo by Justin Jonas