Aperture antennas

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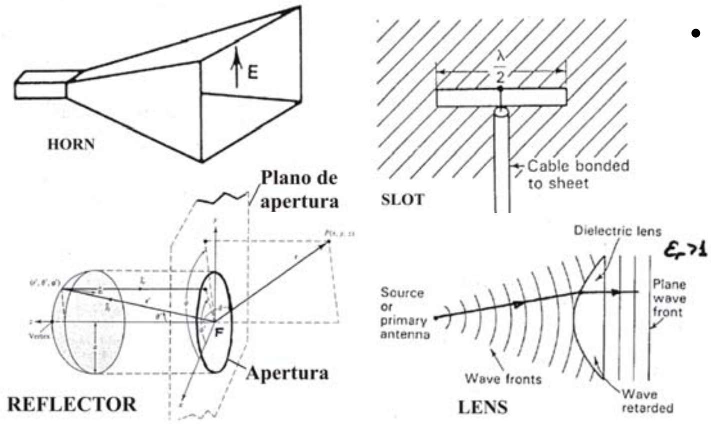
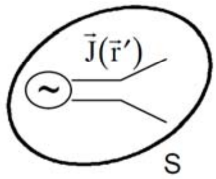
Outline

Apertures antennas

- Aperture antennas radiates the energy toward the space that surrounds them through an aperture.
  - In some cases the aperture is perfectly limited by metallic conducting walls: horns or slots over metallic plane or cylindrical plates, open waveguides.
  - In other cases the aperture is defined as the portion of a frontal plane surface where fields of the collimated wave by the aperture takes subtantial values.

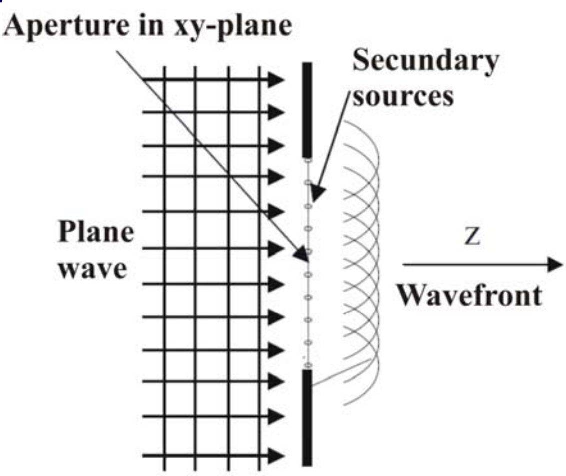


- The analysis of this kind of antennas is based on the Equivalence Principles:



Data: $\vec{E}\big|_S\,,\ \vec{H}\big|_S$

Aperture antennas



Huygens Principle:

Each point on a primary wavefront can be considered to be a new source of a secondary spherical wave and that a secondary wavefront ca be constructed as the envelope of these secondary spherical waves.

Fields in the aperture:

$$\vec{E}_a = \hat{x}E_{ax}(x',y') + \hat{y}E_{ay}(x',y')$$

Radiated fields:

$$\vec{E}_\theta(r,\theta,\phi) = jk\frac{e^{-jkr}}{2\pi r}(P_x\cos\phi + P_y\sin\phi)$$

$$\vec{E}_\phi(r,\theta,\phi) = -jk\frac{e^{-jkr}}{2\pi r}\cos\theta(P_x\sin\phi - P_y\cos\phi)$$

$$P_{x,y}(u,v) = \iint_{Sa} E_{ax,ay}(x',y')e^{jk_0(ux'+vy')}dx'dy'$$

where: $u = \sin\theta\cos\phi$

$v = \sin\theta\sin\phi$

Horn antennas

Horn Antennas

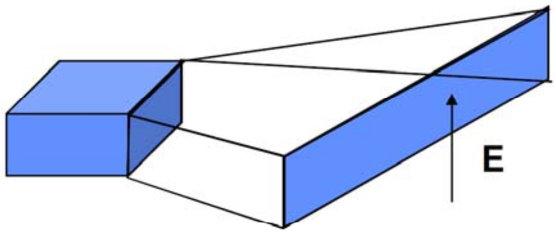
- A horn antenna is a hollow pipe of different cross sections which has been tapered to a larger opening.
- The hollow pipe which feeds the horn is a sort of transmission line: waveguide.

- Horn is the simplest and probably the most used microwave antenna, because they provide a high gain, a good matching to the feeding waveguide (low VSWR), a relative large bandwidth and they are easy to design and to manufacture.

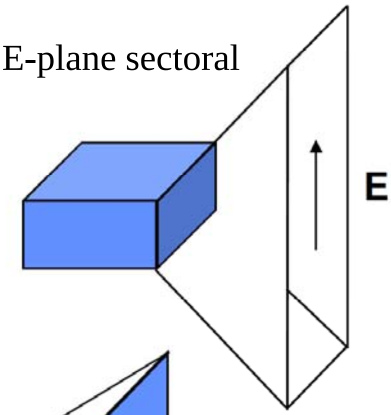
- Horn antennas divide mainly in:
  - *Rectangular horn*, which is generated from a rectangular waveguide.
  - *Conical horn*, which is feed by a circular waveguide.

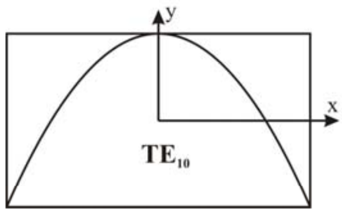
Rectangular horn

H-plane sectoral

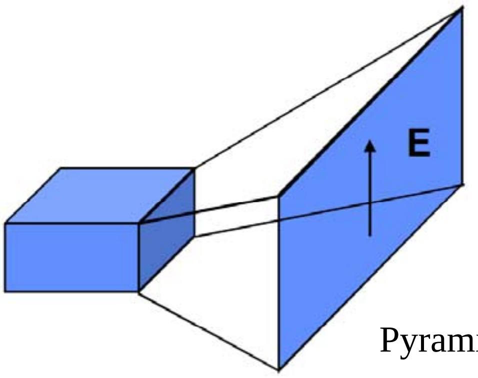


E-plane sectoral



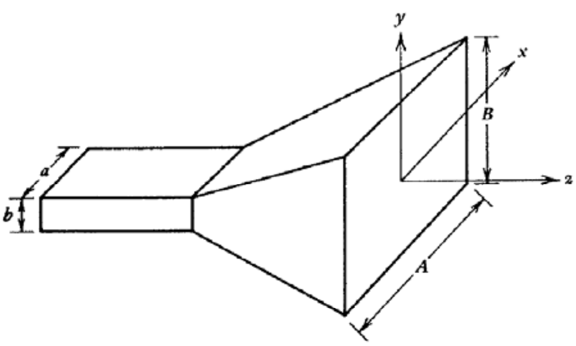


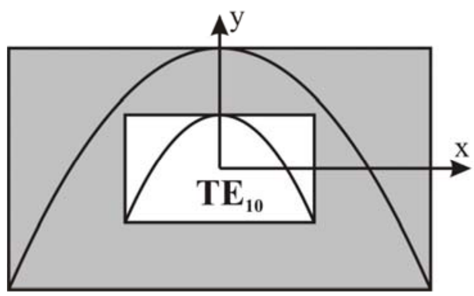
Electrical field of the TE_{10} mode in a rectangular waveguide



Pyramidal

Pyramidal horn



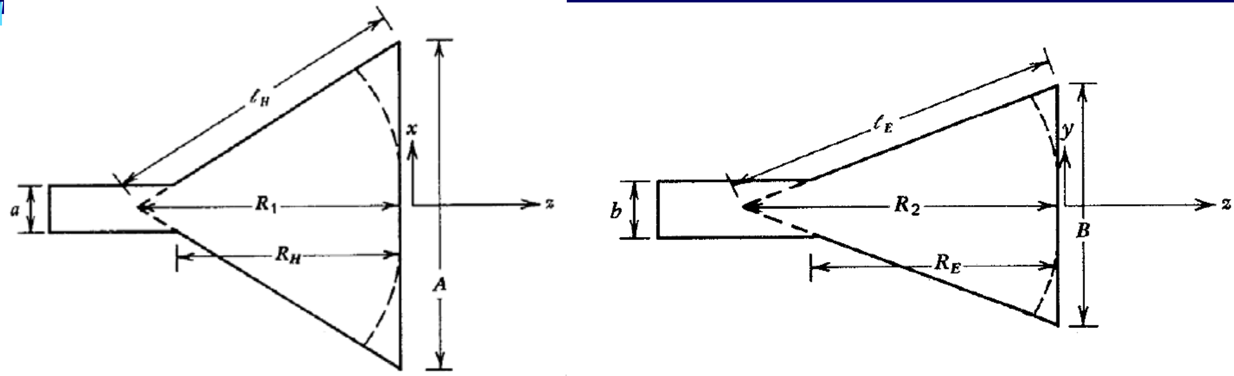


- Pyramidal horn a x b dimensions where id propagated the fundamental mode TE_{10}. Aperture A x B, with A>a and B>b.
- Fields in the aperture are an expanded version from the fields within waveguide:

$$\vec{E}_{ay} = \hat{y} E_0 \cos\left(\frac{\pi x}{A}\right) e^{-j\cdot\beta\cdot\Delta R}$$

- The electrical field amplitude in the horn aperture changes as a cosine in the x direction and keeps uniform along y direction.

Pyramidal horn



- In the phase of the electrical field in the aperture has to be included a cuadratic phase error, which is related with the path difference of the cylindrical phase front in the different points of the aperture.
- The difference in path in the two main planes:

$$\Delta R_1(x) = \sqrt{R_1^2 + x^2} - R_1 \approx \frac{x^2}{2R_1} \qquad \Delta R_2(y) = \sqrt{R_2^2 + y^2} - R_2 \approx \frac{y^2}{2R_2}$$

Pyramidal horn

- Finally the electrical field in the aperture can be written as:

$$\vec{E}_{ay} = \hat{y} E_0 \cos\left(\frac{\pi x}{A}\right) e^{-j\cdot\beta\cdot\left[\left(x^2/2R_1\right)+\left(y^2/2R_2\right)\right]}$$

- Where E_0 is amplitude of the electrical field, and β is the phase constant which in the aperture is equal to the propagation constant in the free space if A>>λ:

$$\beta = k_0\sqrt{1-\left(\frac{\lambda}{2A}\right)^2} \approx k_0 = \frac{2\pi}{\lambda}$$

With λ the wavelength.

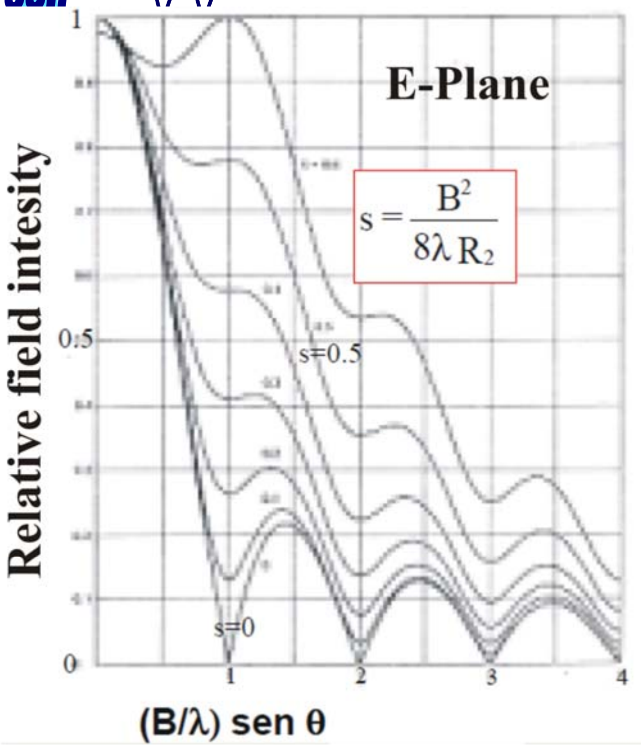
Pyramidal horn

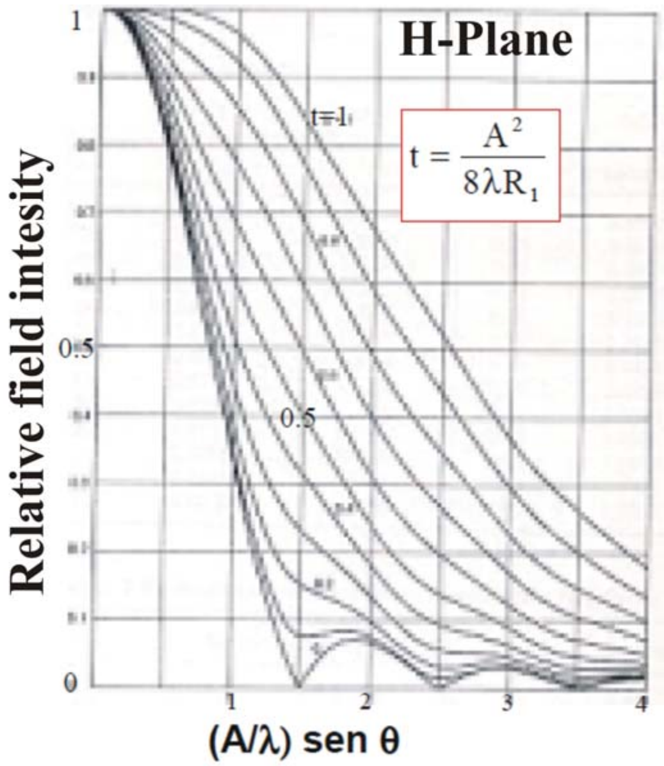
- Radiation pattern of the horn antennas are called universal radiation patterns, because they can be used for any A and B.
- They are function of the maximum phase errors that exist in the aperture.
- These maximum phase errors are ***t*** for the H-plane and ***s*** for the E-plane, they are expressed as a multiple of 2π radians, and they are calculated from the maximum phase error δ_{max} in the aperture:

$$\delta_{\mathbf{max}} = \frac{k_0}{2R_1}\left(\frac{A}{2}\right)^2 = \frac{2\pi}{\lambda}\frac{A^2}{8R_1} = 2\pi t \Rightarrow t = \frac{A^2}{8\lambda R_1}$$

$$\delta_{\mathbf{max}} = \frac{k_0}{2R_1}\left(\frac{B}{2}\right)^2 = \frac{2\pi}{\lambda}\frac{B^2}{8R_2} = 2\pi s \Rightarrow s = \frac{B^2}{8\lambda R_2}$$

Pyramidal horn

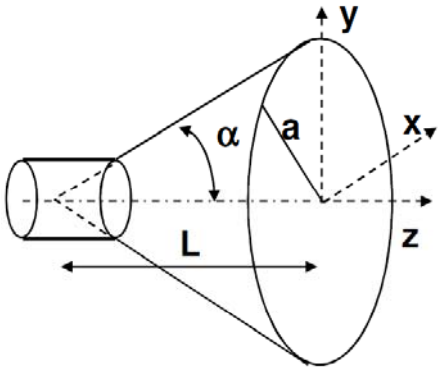


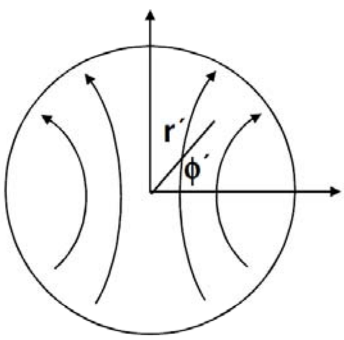


Pyramidal horn

- When there is not phase errors, t=s=0:
  - Side lobe level in the H-plane radiation pattern SLL=-23dB.
  - Side lobe level in the E-plane radiation pattern SLL=-13.5dB.
  - Aperture efficiency ε_a is 0.81, which corresponds with the aperture efficiency of an open rectangular waveguide with the same size that the aperture.
- Phase errors enhance the side lobes level and fill the nulls between these and the main lobe.
- If a high efficiency is required it is needed low phase errors (s,t<0.15) which means very large horns.
- If a compact structure is required it is made an optimum design, with s=1/4 and t =3/8, which defines the shorter horn that is achieved with a fixed gain. In this case the ε_a =0.5.
- Feasibility condition has to be fullfilled: $R_E=R_H$.

Conical horn

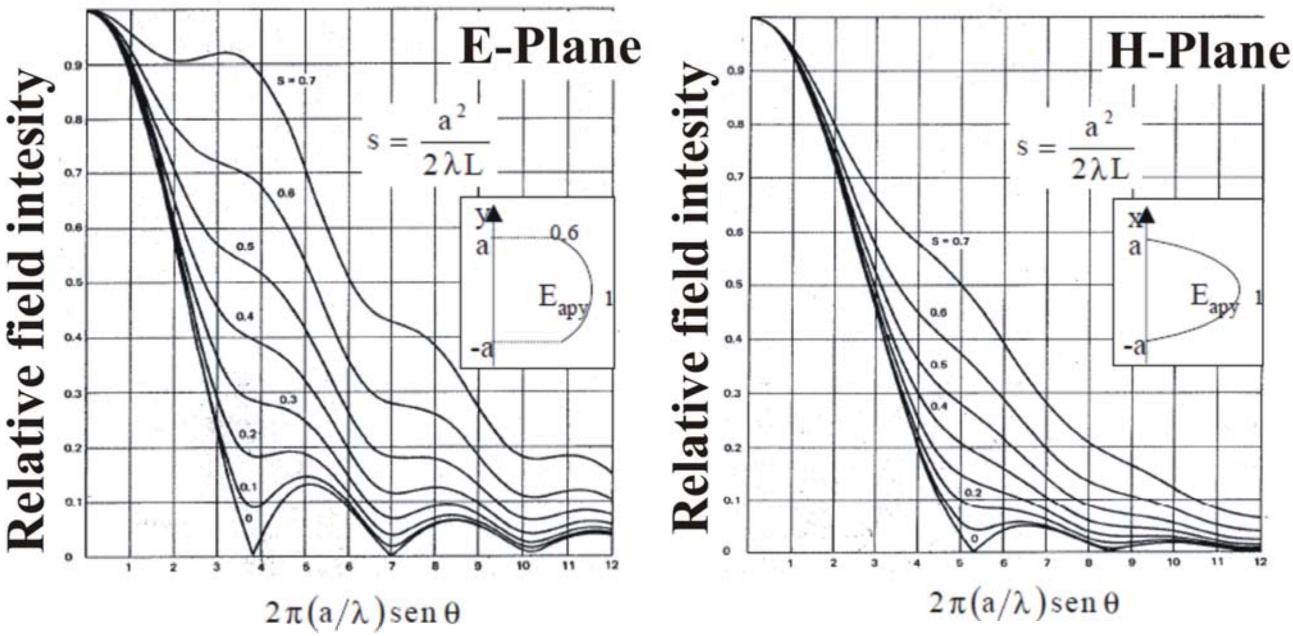




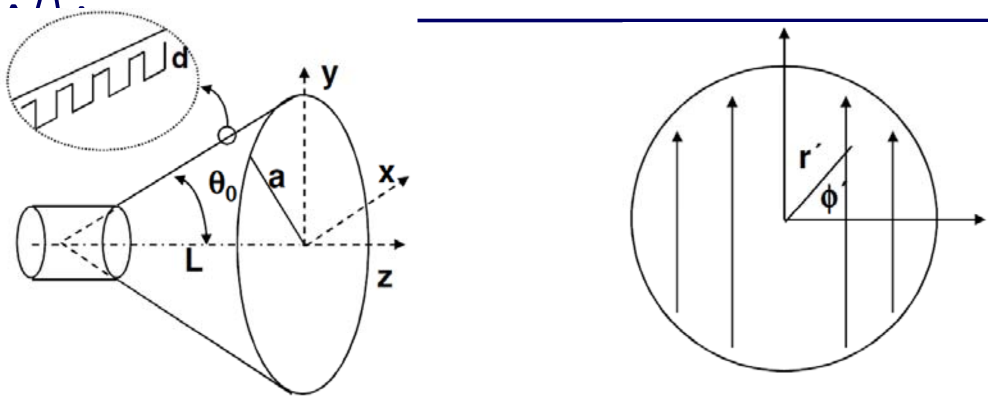
- Conical horn is fed by circular waveguides, where the fundamental mode TE_{11} is propagated.
- Crosspolar radiation in the bisectors planes: at ϕ=45º and ϕ=135º. With lobes at very high levels when aperture is large (about -19dB).
- The radiation pattern are calculated from the universal radiation patterns, which depend on the maximum phase error in the aperture ***s***:

$$s = \frac{a^2}{2\lambda L}$$

Conical horn



Corrugated conical horn

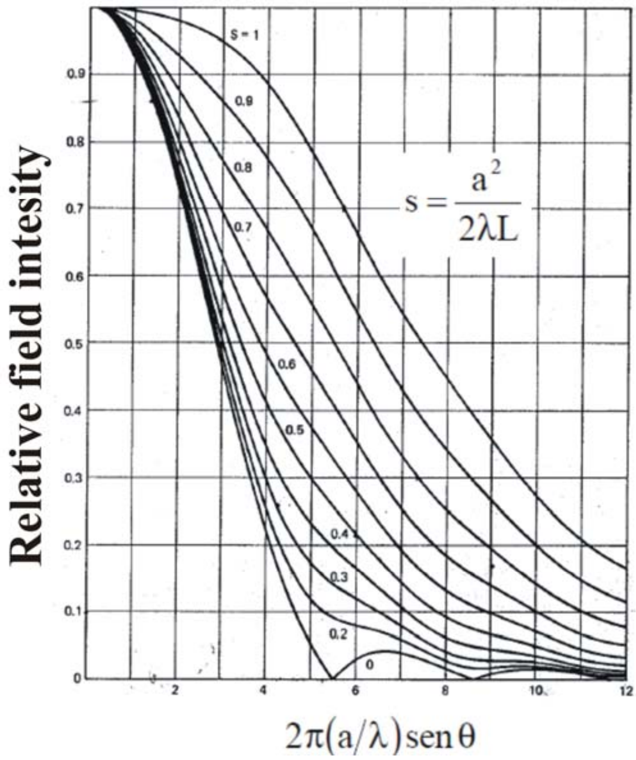


- Corrugations of about $\lambda/4$ of depth in the inner face of a conical horn achieve an hybrid mode HE_{11} as the field in the aperture:
  - Electrical field lines straights and parallels.
  - Elecrical field amplitude with rotational symmetry, decreasing from the center toward the edge and being null on it.
  - Electrical field phase in the aperture as a wave with spherical phase front.

Corrugated conical horn

- Radiation pattern with rotational symmetry, independent from the ϕ– plane considered.
- They are calculated from the universal radiation patterns which depend on the maximum error phase ***s***:

$$s = \frac{a^2}{2\lambda L}$$



Horn antennas applications

- Some horn antennas applications are:
  - They serves as a universal standard for calibration and gain measurements of other high gain antennas.
  - They can be used in satellites to achieved global coverage of the Earth.
  - It is a common element in phased arrays.
  - They are widely used as a feed element of reflectors antennas and lenses, for large radio astronomy, satellite tracking and communication dishes (for instance, satellite TV).

Reflector antennas

Introduction (I)

• Reflector antennas are characterized by the use of a metallic reflector to concentrate the low directive radiation of a small feeder in a beam very directive.

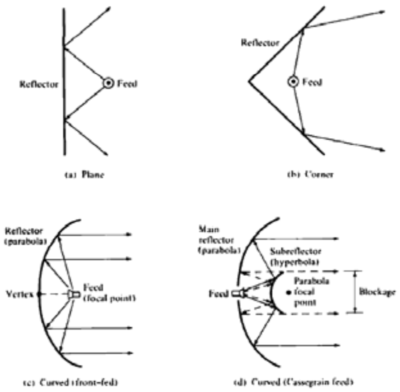
• It is possible to reduce the antenna dimensions, without change the directivity.

Introduction (II)

• Have been in use since the Second War World for radar applications.

• Nowadays, they are used in radio astronomy, microwave communications, satellite tracking and communication, deep space communications, radar…

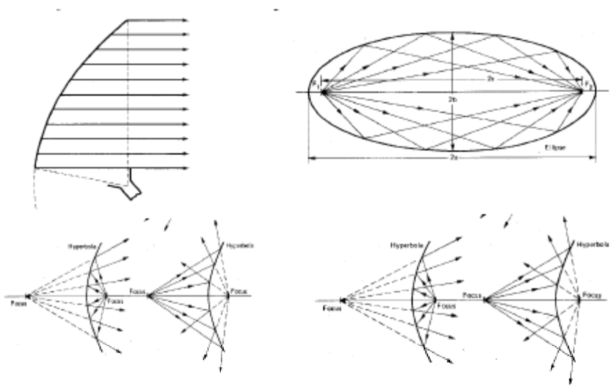
• In all cases, they are employed two elements: feeder and metallic reflector.



Analysis techniques (I)

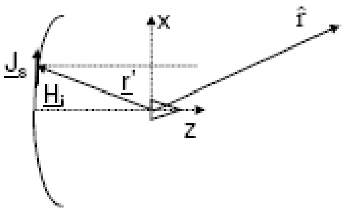
Reflector antennas can be analysed using different methods which provide similiar results:

• **Geometrical Optics (GO):** It allows to calculate the fields over the aperture and then the radiated fields using the equivalent principles. It is based on the Fermat principle and the Snell's laws.



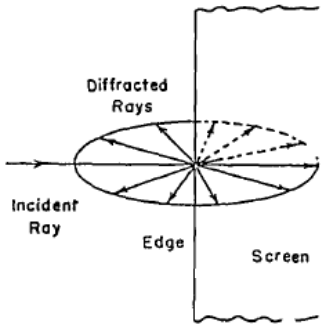
Analysis techniques (II)

Physical Optics (PO): It calculates the radiated fields with the induced currents over the metallic reflector.



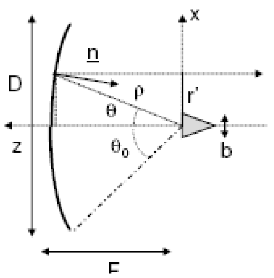
$$\vec{E}(\vec{r}) = \frac{-j\omega\mu}{4\pi}\frac{e^{-jkr}}{r}\iint_S\left[\vec{J}_s(\vec{r}') - \left(\vec{J}_s(\vec{r}')\cdot\hat{r}\right)\hat{r}\right]e^{jk\hat{r}\cdot\vec{r}'}dS'$$

Geometrical theory diffraction (GTD): It provides us the best results for the radiated fields, overall for the secondary far lobes. They are analysed the direct rays and the diffracted rays in the edges.



Reflector types (I)

Parabolic reflector: the metallic surface is parabolic and the feeder is over the spotlight.

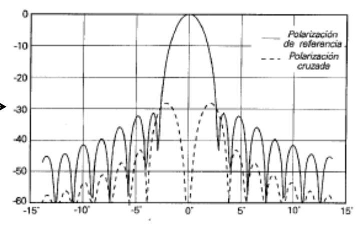


GO →

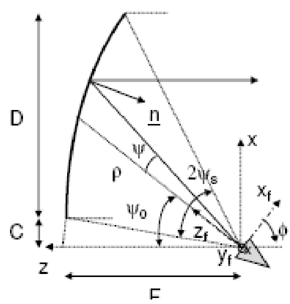
$$\vec{E}_{ap} = \hat{e}_r\sqrt{\frac{Z_0 P}{2\pi}}\frac{\sqrt{G(\theta,\phi)}}{\rho}e^{-jk2F}$$

$$\hat{e}_r = 2(\hat{n}\cdot\hat{e}_i)\hat{n} - \hat{e}_i$$

FFT →

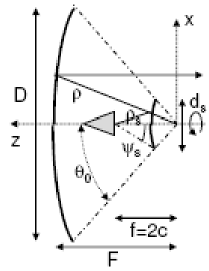


Offset-fed parabolic reflector: It has a reflector which is a section of a normal parabolic reflector. If this section does not include the center of the dish, then none of the radiated beam is blocked by the feed antenna and support structure.

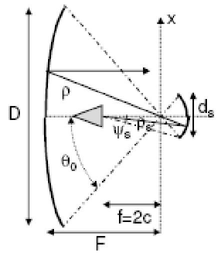


Reflector types (II)

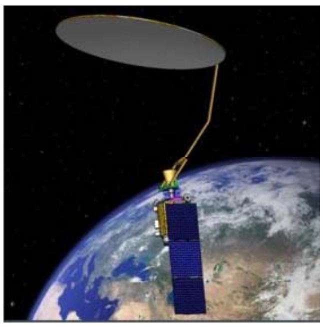
Cassegrain reflector: It is a combination of a parabolic primary concave mirror and a hyperbolic secondary convex mirror. They are usually used in optical telescopes where a high gain is required.



Cassegrain reflector: It is similar to the previous type, but instead of using a primary mirror with parabolic shape, it is used an elliptical mirror.



Reflector types (III)



Feeders for reflector antennas

• Waveguide

• Horns

• Dipoles

Gain of reflector antennas

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

$$\eta = \eta_I \, \eta_S \, \eta_P \, \eta_X \, \eta_B \, \eta_E$$

η_I = Illumincation Efficiency

η_S = Spillover Efficiency

η_P = Phase Error Efficiency

η_X = Crosspolarization Efficiency

η_B = Blockage Efficiency

η_E = Surface Error Efficiency

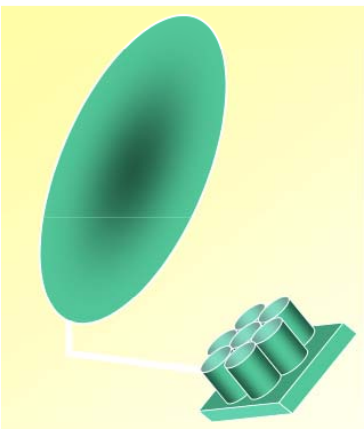
Conformal antennas

Multifed reflectors

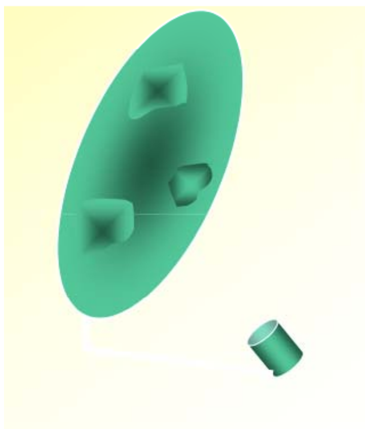
Conformal reflectors

Conformal basis

- Conformal antennas allow flexible design options.
- It is possible to configurate *ad hoc* radiation patterns.
- Used in satellite communications.
- Two alternatives: Multifeeding and Conforming surfaces



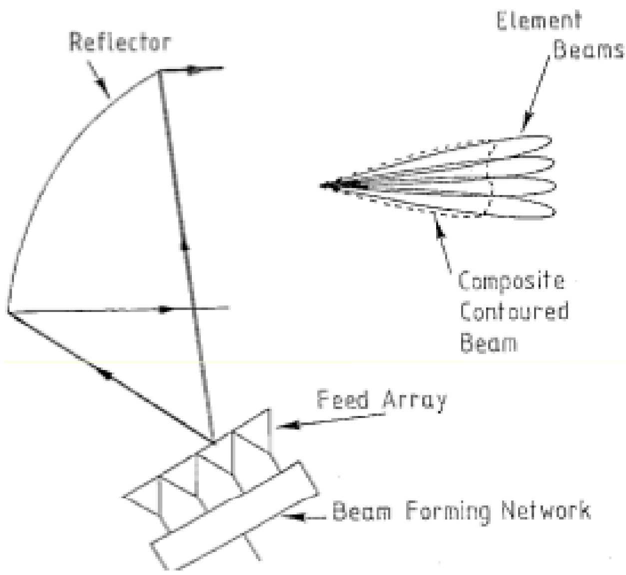
Multifeeding



Conformal surfaces

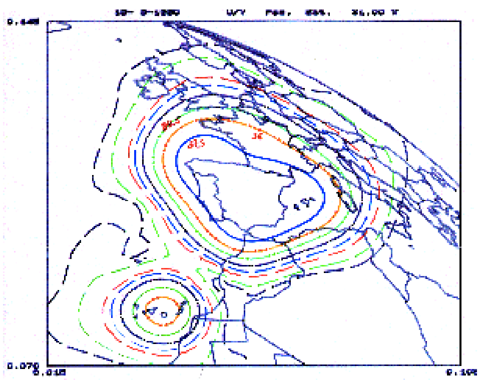
Multi-fed reflectors (I)

- The reflector is a canonical conic surface: Hyperboloid, paraboloid
- A concrete feed horn-array must be set up.
- Thus, a microwave feeding network is required.
- The radiated beam is a sum of the contributions from each feeding horn.
- Drawbacks: complexity, weight, volume of BFN.



Multi-fed reflectors (II)

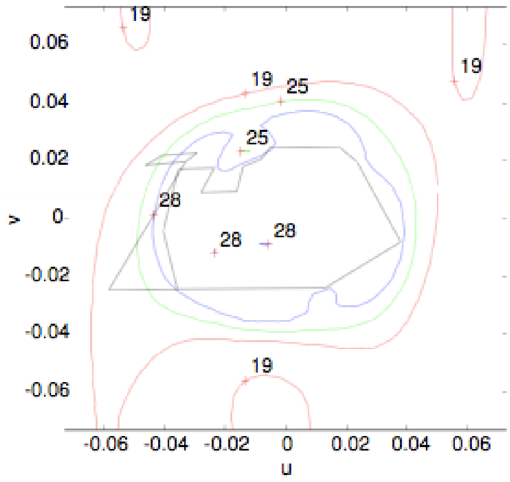
- Each horn must be feed correctly: amplitude and phase.
- The design consists on optimizing the feeding scheme.



Hispasat 1A

Conformal reflectors (I)

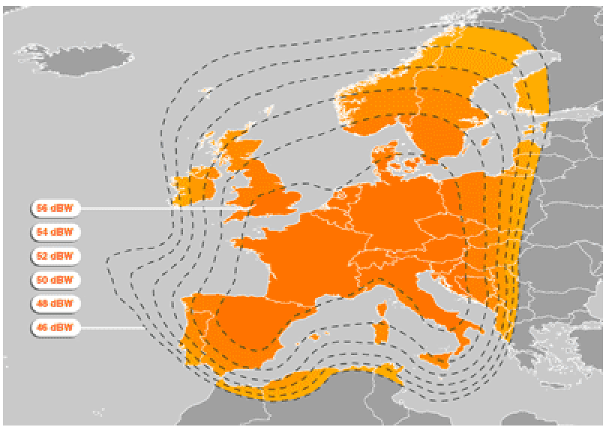
- The specifications are coverage contours in dBW
- The design consists on changing the shape of the reflector.
- A concrete surface must be set up, starting from a concrete canonical design: Paraboloidal, Cassegrainian…

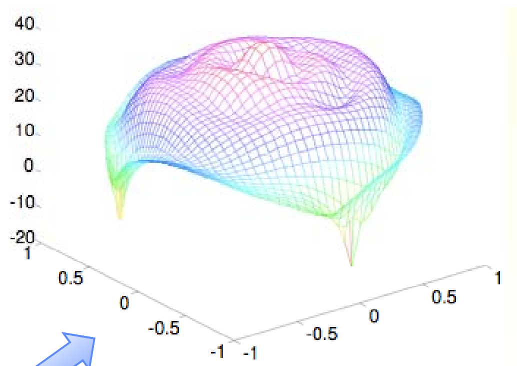


Coverage contours

Conformal reflectors (II)

- The design techniques are based on Physical Optics



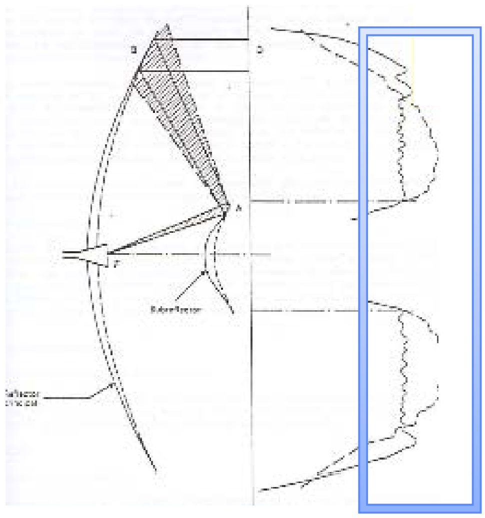


Ad hoc design for

EutelSat

Aperture optimization

- Conforming a reflector can improve the aperture efficiency.
- The goal is to get more uniform amplitude distributions in the aperture.
- The phase front must be plane in the aperture.
- Two constraints and two design elements: reflector and subreflector.



Cassegrain optimized design