
SOLAR RESEARCH FACILITIES UNIT
WEIZMANN INSTITUTE OF SCIENCE

OPTICS OF SOLAR CONCENTRATORS

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Characteristics of Solar Energy

►Not uniformly distributed on Earth: sunny South vs. industrial North

►Cannot be stored and transported unless converted into another form

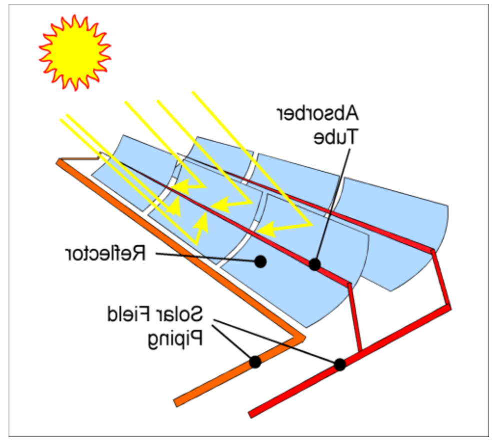
►Form available today: electricity (but electricity cannot be stored easily)

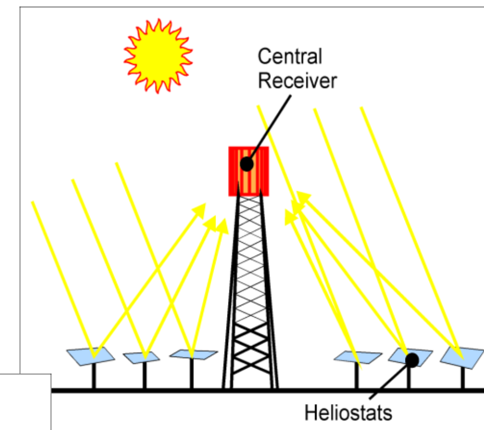
►Intermittent. Storage necessary: conversion into chemical energy could be a solution

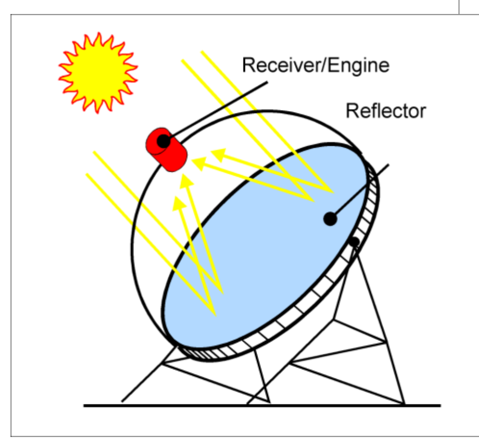
►Low concentration: <u>MUST BE CONCENTRATED !</u>

Solar Concentrating Technologies

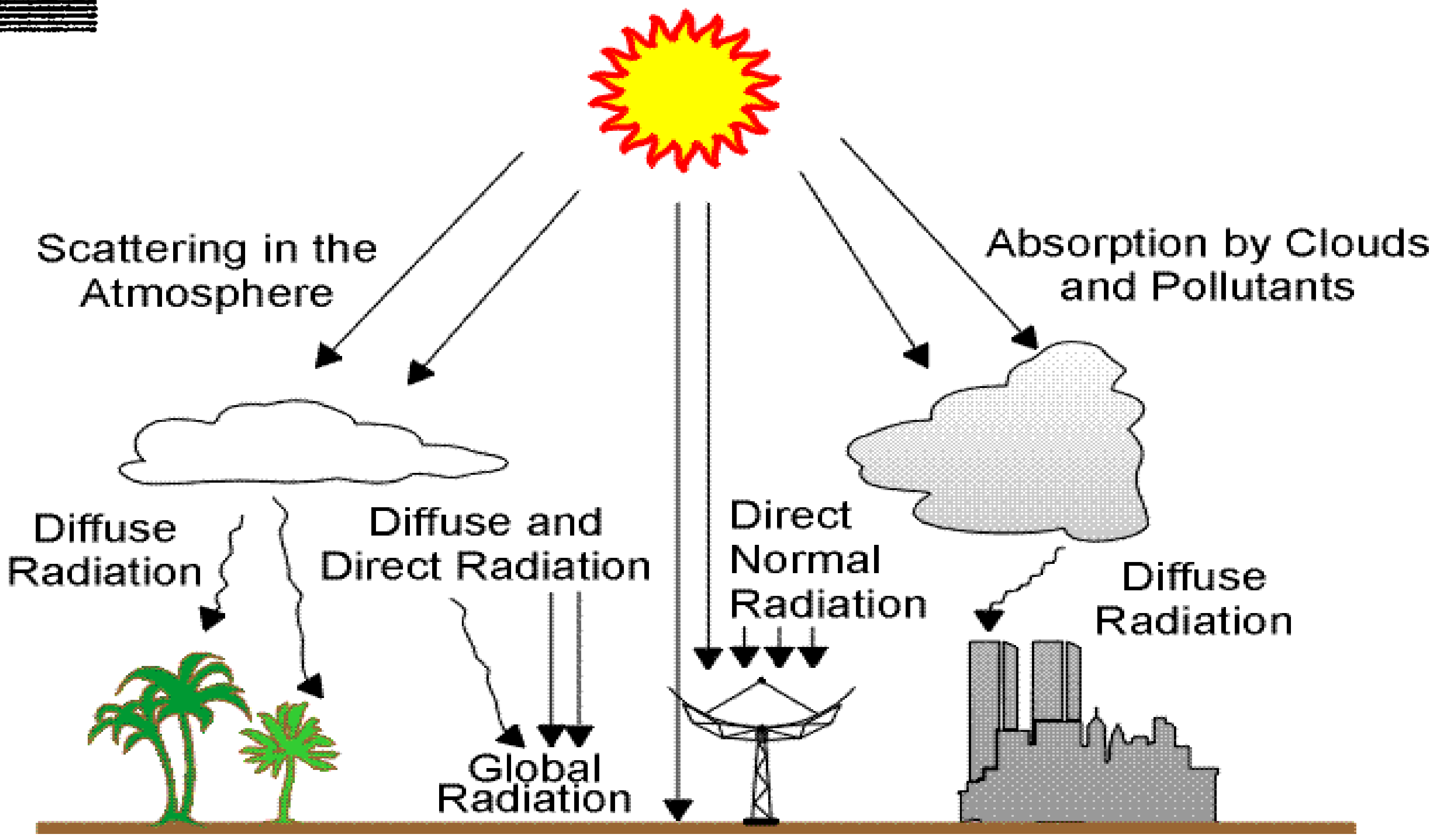
- Trough systems
- Tower systems
- Dish systems



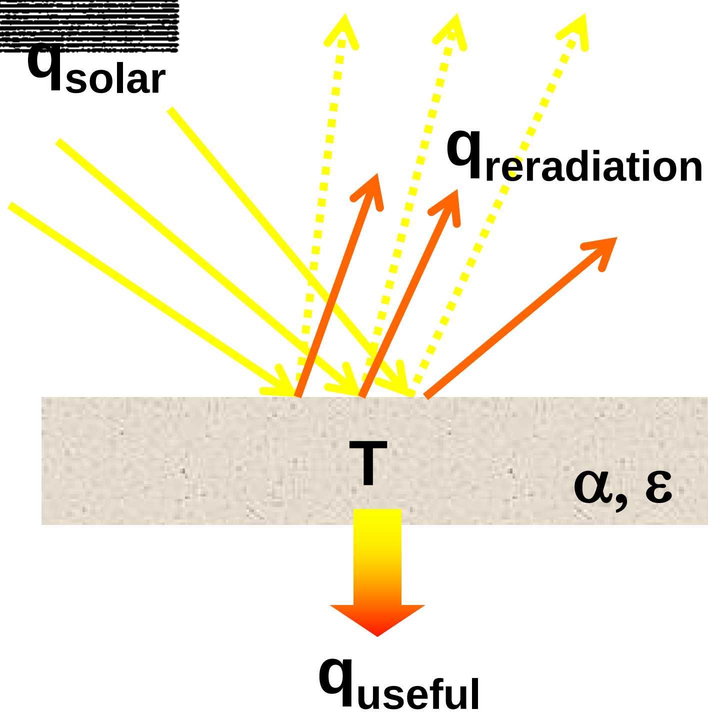




Solar Radiation



Why Concentrated Solar Power?



For:
$I = 1\ kW/m^2$ (1 sun)
$\sigma = 5.67\cdot10^{-8}\ W/m^2K^4$

C	$T_{stagnation}$
1	364 K
10	648 K
100	1152
1000	2049 K
5000	3064 K
10000	3644 K

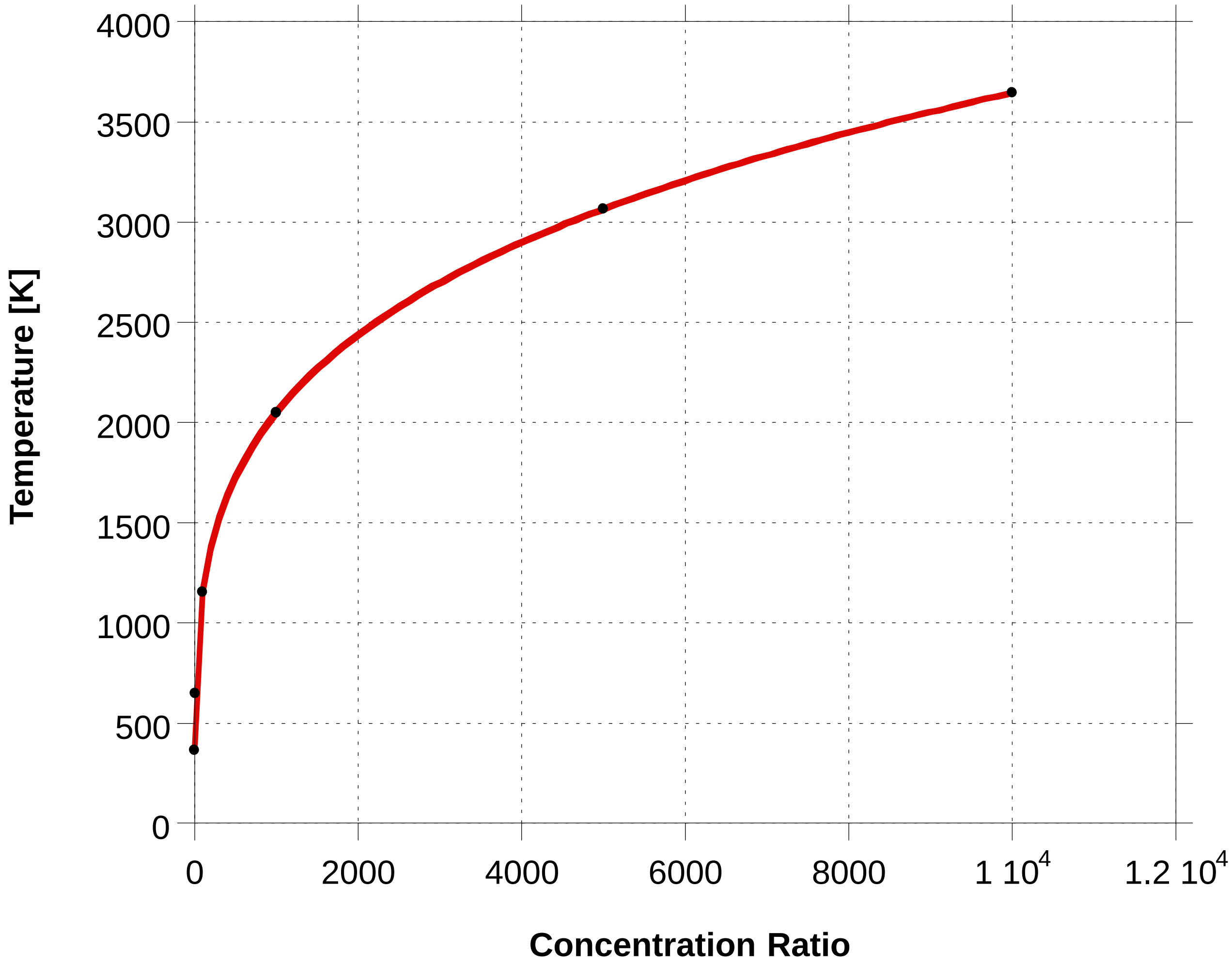
Thermal equilibrium:

$$q_{useful} = q_{absorbed} - q_{reradiation} = \alpha q_{solar} - \varepsilon\sigma T^4$$

σ = Stefan-Boltzmann constant $= 5.67051\text{x}10^{-8}\ W/(m^2\cdot K^4)$

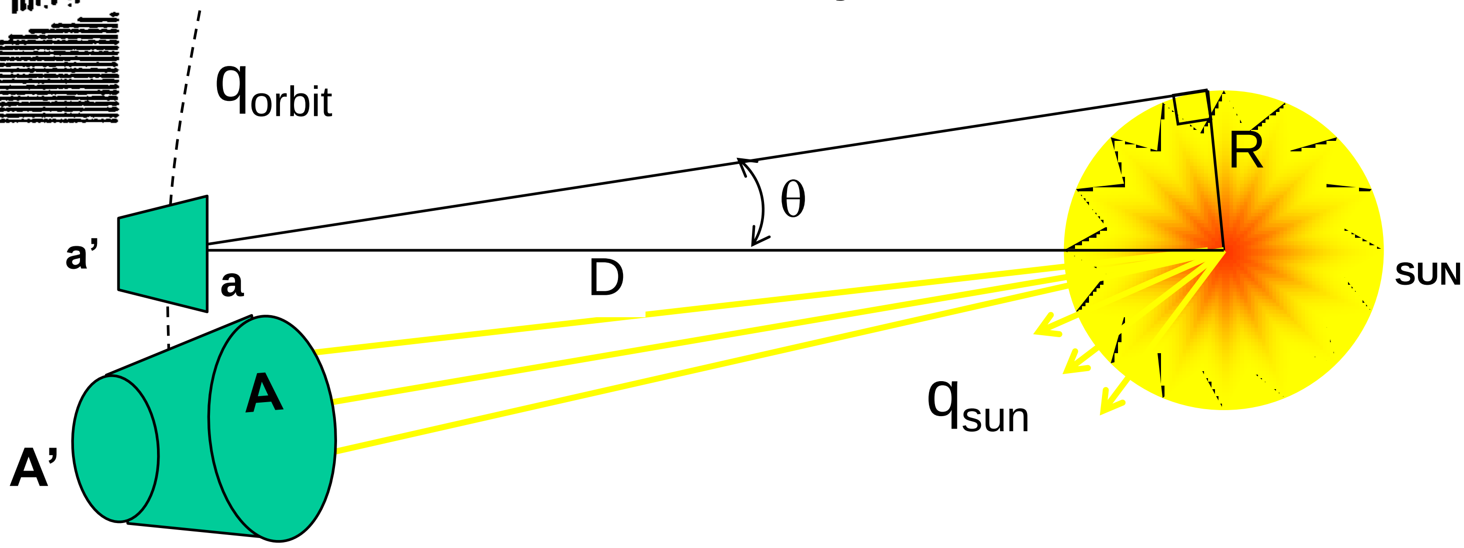
$$\text{For } q_{useful} = 0 \xrightarrow[\;q_{solar} = C\cdot I\;]{\alpha = \varepsilon = 1} T_{stagnation} = \left(\frac{C\cdot I}{\sigma}\right)^{0.25}$$

Why Concentrated Solar Power?



C	$T_{stagnation}$
1	364 K
10	648 K
100	1152
1000	2049 K
5000	3064 K
10000	3644 K

Maximum Thermodynamic Concentration



$$\left.\begin{aligned} R &= 6.9599 \cdot 10^{8}\ \text{m} \\ D &= 1.505 \cdot 10^{11}\ \text{m} \end{aligned}\right\} \rightarrow \theta = \sin^{-1}(R/D) = 16' = 4.65\ \text{mrad}$$

2-D

$\mathbf{q_s} = 2\pi R \sigma\, T_s^4 = \sigma\, T_s^4\, (2\pi R) / (2\pi D)\, \mathbf{a}$

$q = \sigma\, T^4 \mathbf{a'}$; $T \leq T_s$; $\mathbf{q_s = q \rightarrow a' = a\, R/D \rightarrow a' = a \sin\theta}$

$\mathbf{C_{2D\text{-}max}} = \mathbf{a/a' = 1/\sin\theta}$

3-D

$\mathbf{q_s} = 4\pi R^2 \sigma\, T_s^4 \quad \mathbf{q_A} = \sigma\, T_s^4\, (4\pi R^2) / (4\pi D^2)\, \mathbf{A} = \sigma\, T^4\, \mathbf{A'}$

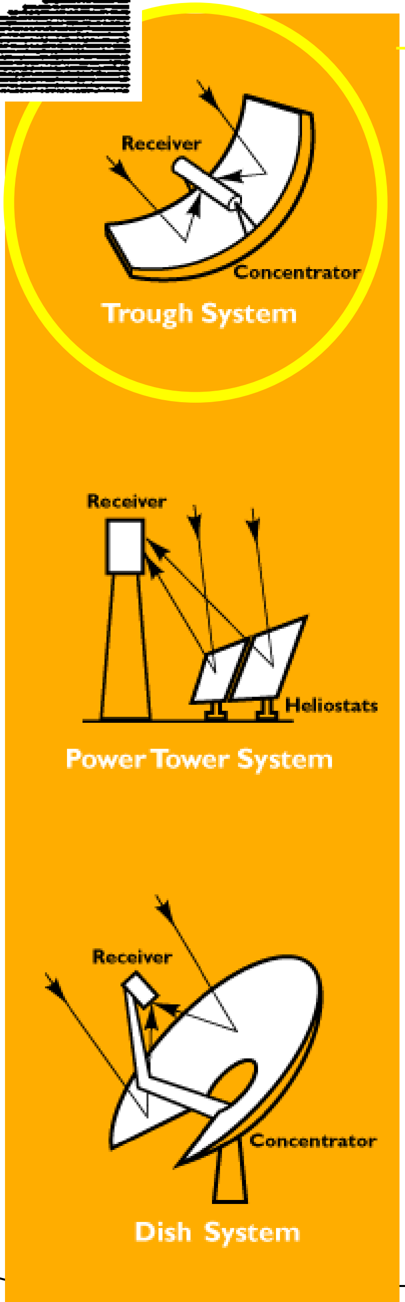
$\mathbf{A/A' = D^2/R^2 = 1/\sin^2\theta}$; $\mathbf{C_{3D\text{-}max} = 1/\sin^2\theta}$

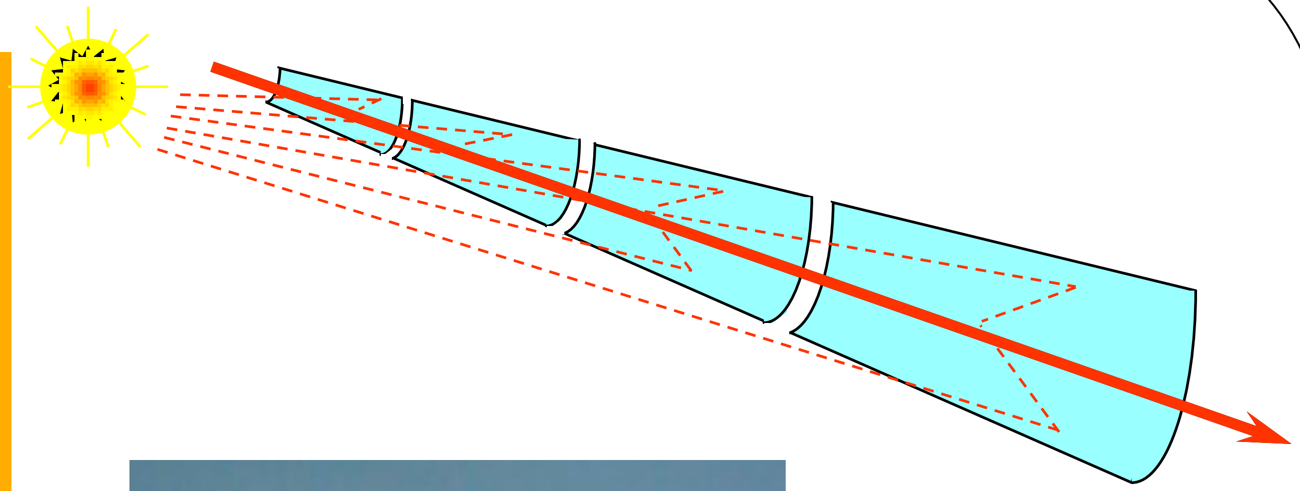
$\mathbf{C_{2D\text{-}max} = 1/\sin\theta}$

$\mathbf{C_{3D\text{-}max} = 1/\sin^2\theta}$

$\mathbf{C_{3D\text{-}max} = n^2/\sin^2\theta}$

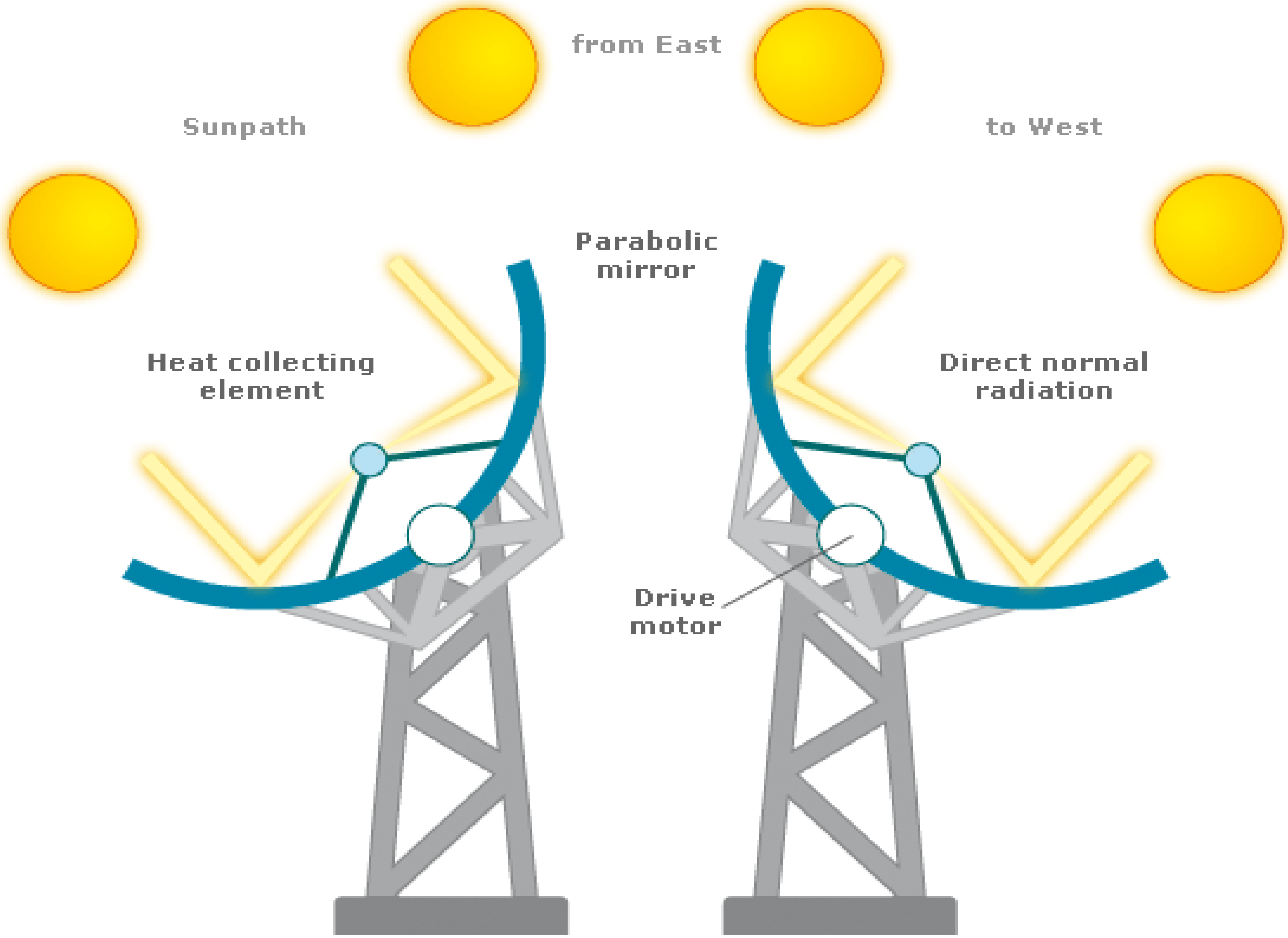
Parabolic Trough System

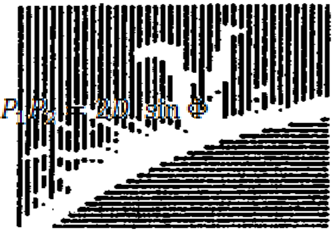


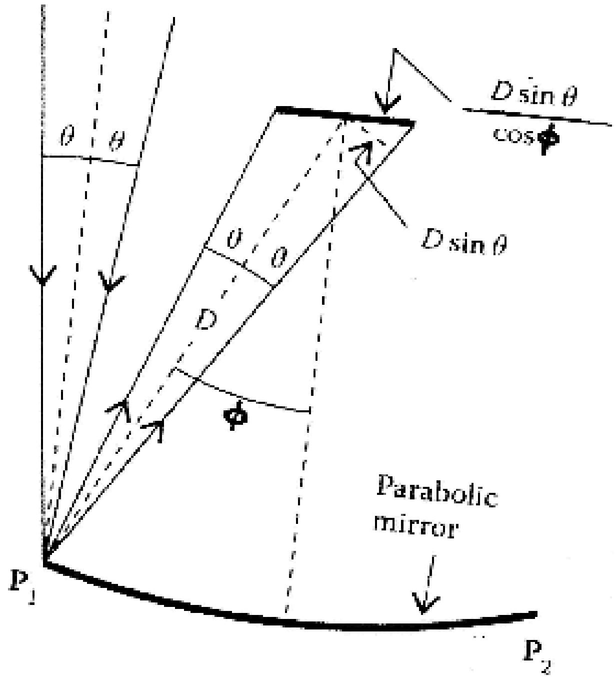


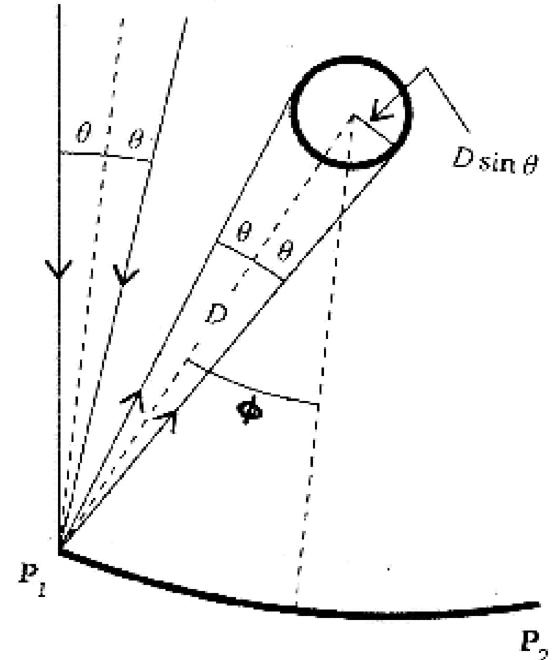
- Line focusing.
- C = 30 - 80.
- Unit 30 - 80 MW.
- Unidirectional trough curvature.
- 1-axis tracking E-W.

Parabolic Trough technology bases its operation on solar tracking and the concentration of solar rays on receiving tubes with high thermal efficiency, located on the focal line of the cylinder.









flat absorber: $L_{absorber} = 2D \sin\theta / \cos\Phi$

$$C_{2D} = \frac{P_1P_2}{L_{absorber}} = \frac{\sin 2\Phi}{2\sin\theta}$$

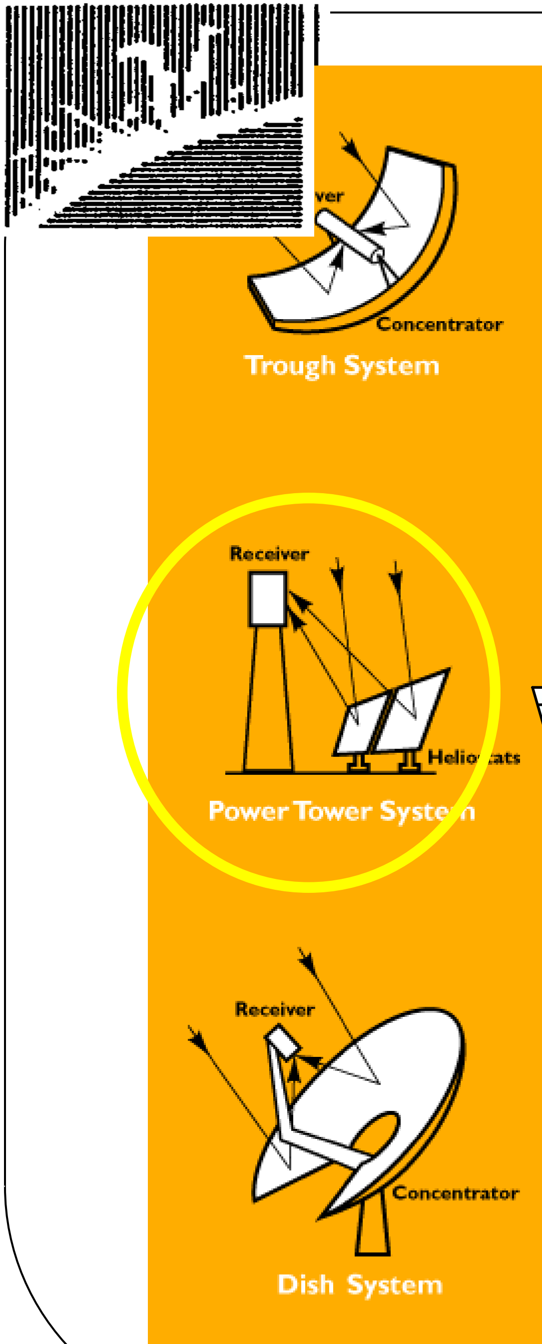
$$for\ \Phi = \frac{\pi}{4};\ C_{2D\,max} = \frac{1}{2\sin\theta} = \frac{1}{2} C_{2D\,ideal}$$

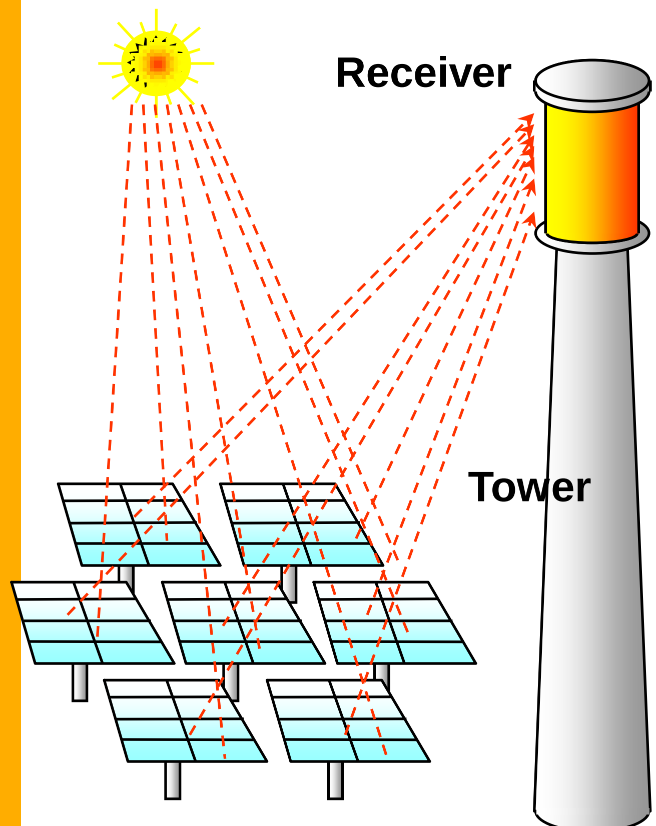
circular absorber: $R = D\sin\theta$

$$C_{2D} = \frac{P_1P_2}{2\pi R}$$

$$for\ \Phi = \frac{\pi}{2};\ C_{2D\,max} = \frac{1}{\pi\sin\theta} = \frac{1}{\pi} C_{2D\,ideal}$$

Solar Tower System



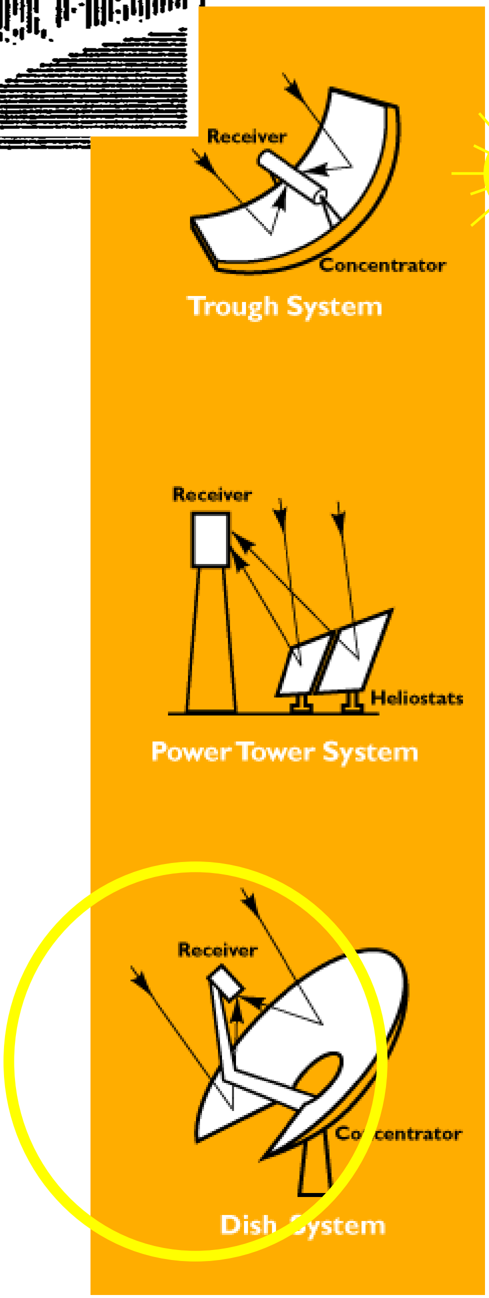


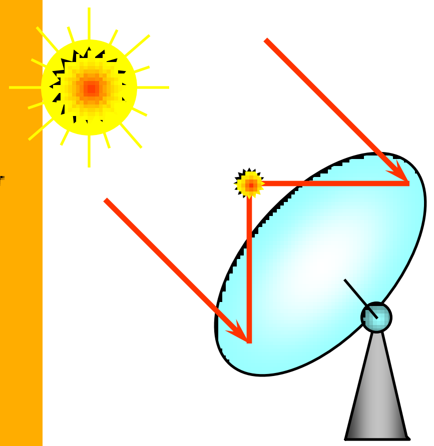
Heliostat Field

- Point focusing.
- C = 200 - 1000.
- Unit 30 - 200 MW.
- 2-axis tracking heliostats:
  elements of different parabolas with varying focal length.

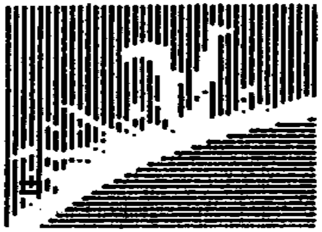
Central Solar Plants: PS10, PS20
(Sanlúcar la Mayor, SPAIN)

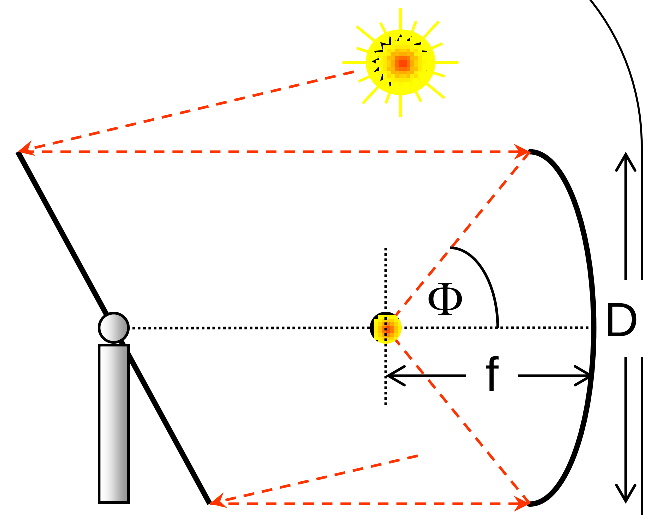
Solar Dish System



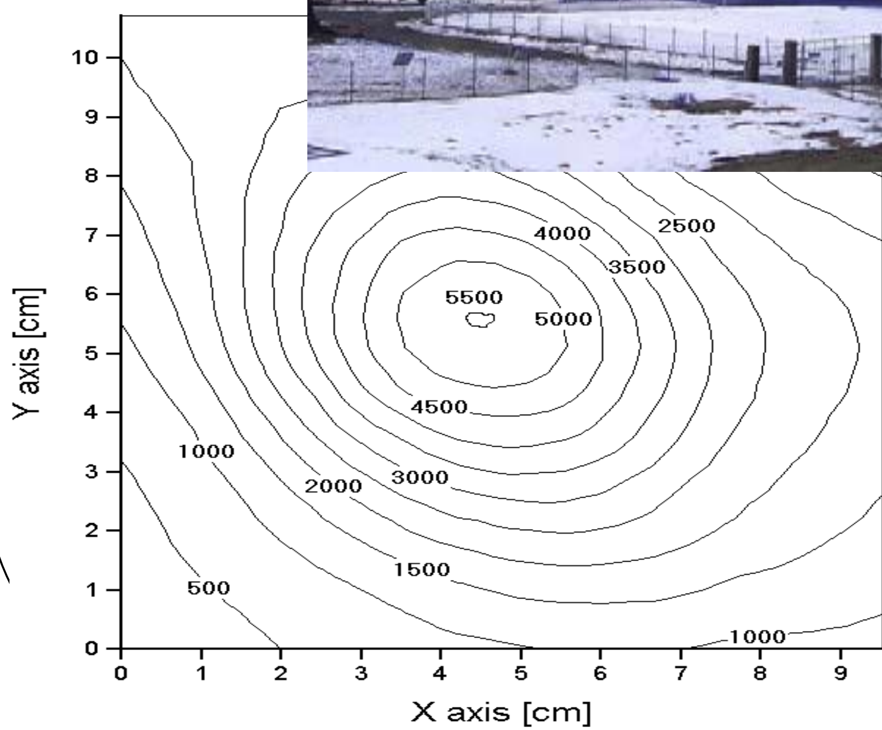


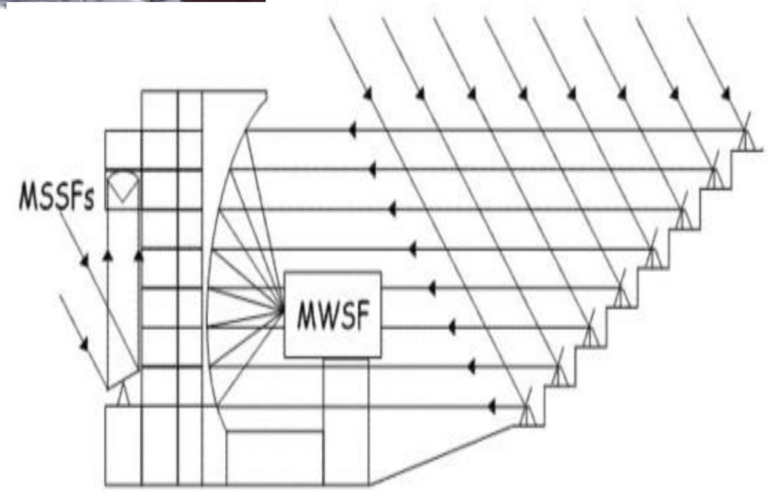
- Point focusing.
- C = 1000 - 12,000.
- Unit 7.5 - 100 kW.
- 2-axis tracking parabolic dish.
- Modularity.
- Remote applications.

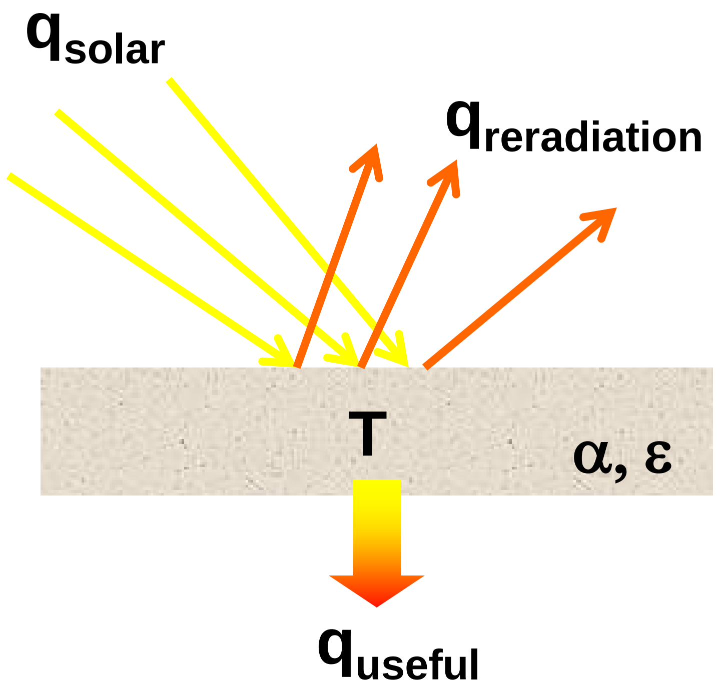




$$\frac{f}{D} = \frac{1 + \cos\Phi}{4\ \sin\Phi}$$







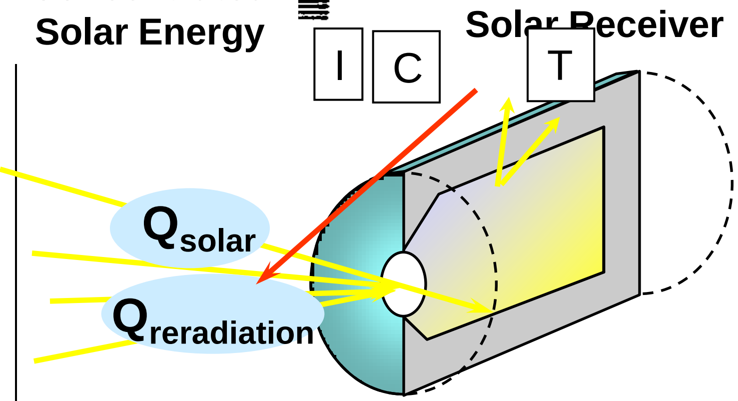
In thermal equilibrium:

$$q_{useful} = q_{absorbed} - q_{reradiation}$$

$$q_{useful} = \alpha q_{solar} - \varepsilon \sigma T^4$$

$$Q_{useful} = \alpha Q_{solar} - \varepsilon A \sigma T^4$$

Concentrated Solar Energy



$$\eta_{absorption} = \frac{\underbrace{[\ \alpha\, Q_{solar}\ ]}_{\text{Power absorbed}} - \underbrace{[\ \varepsilon\, A\, \sigma T^4\ ]}_{\text{Power re-radiated}}}{\underbrace{[\ Q_{solar}\ ]}_{\text{Solar Power Input}}}$$

Power absorbed — ***Power re-radiated*** — ***Solar Power Input***

$$\left.\begin{aligned} &\alpha = \varepsilon = 1 \\ &C = \frac{Q_{solar}}{A \cdot I} \end{aligned}\right\} \Rightarrow \eta_{absorption} = \left(1 - \frac{\sigma T^4}{C \cdot I}\right)$$

$$\eta_{exergy,ideal} = \eta_{absorption} \cdot \eta_{Carnot} = \left(1 - \frac{\sigma T^4}{C \cdot I}\right) \cdot \left(1 - \frac{T_L}{T}\right)$$

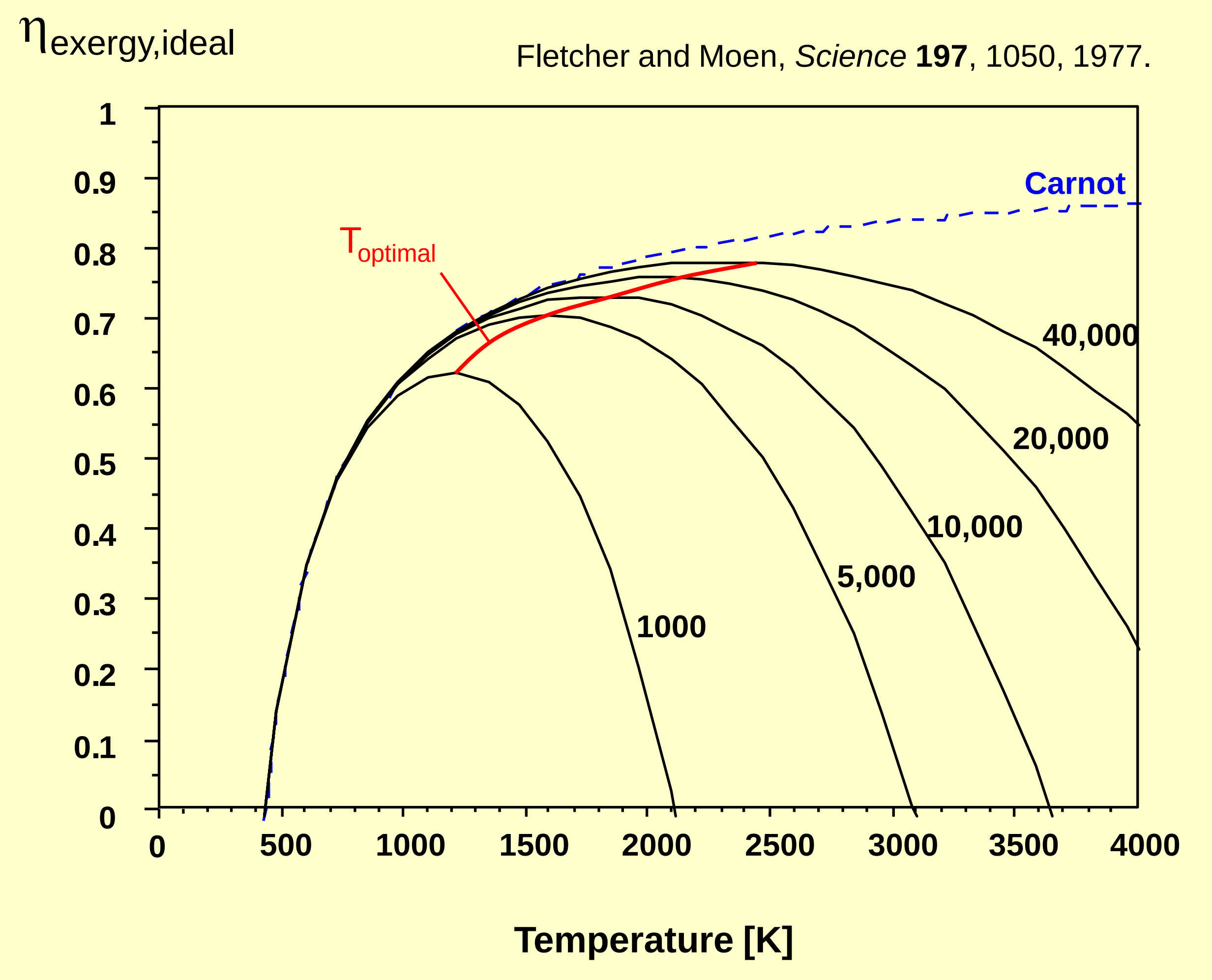
$$\eta_{exergy,ideal} = \eta_{absorption} \cdot \eta_{Carnot} = \left(1 - \frac{\sigma T^4}{C \cdot I}\right) \cdot \left(1 - \frac{T_L}{T}\right)$$

$$\eta_{exergy} = 0 \rightarrow T_{stagnation} = \left(\frac{C \cdot I}{\sigma}\right)^{0.25}$$

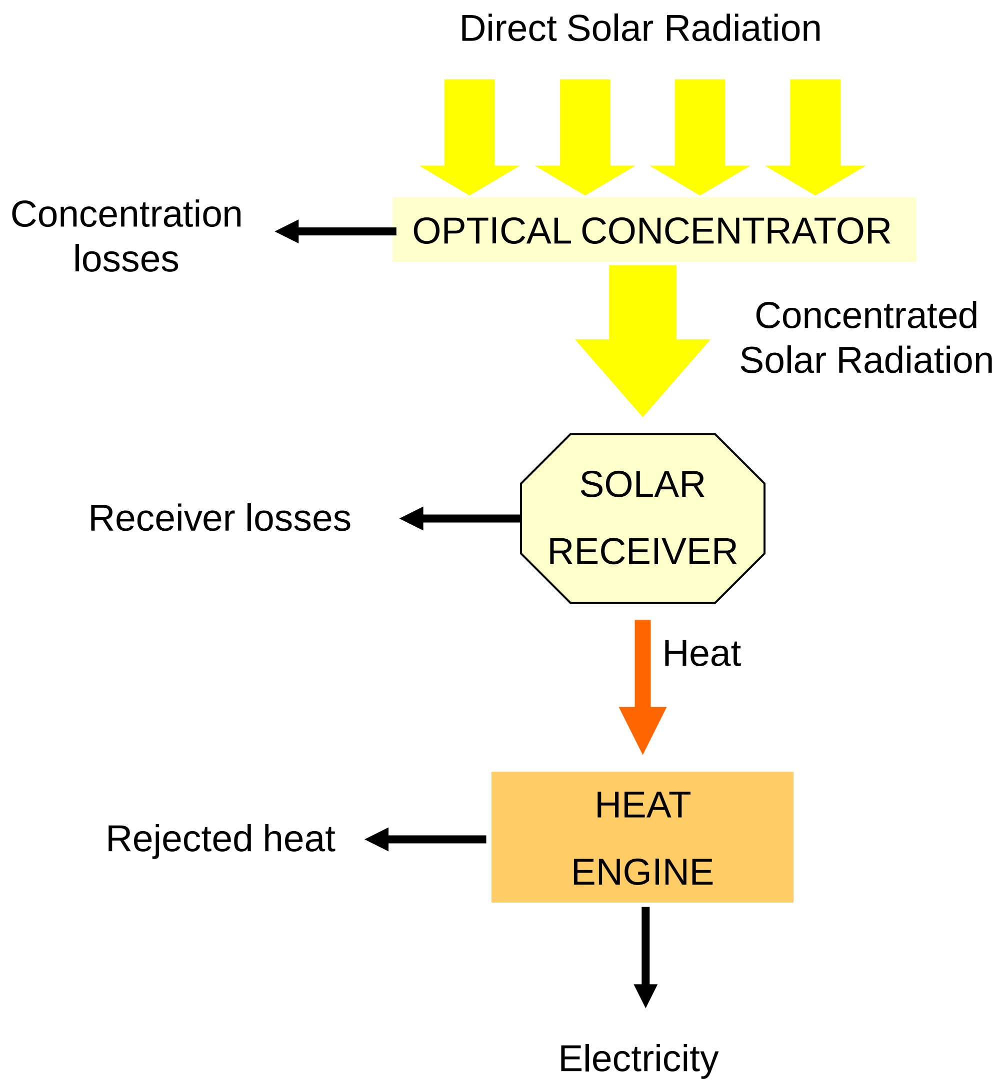
$$\frac{\partial \eta_{exergy}}{\partial T} = 0 \rightarrow \left(T_{optimal}\right)^5 - 0.75 T_L \left(T_{optimal}\right)^4 - \left(\frac{T_L IC}{4\sigma}\right) = 0$$

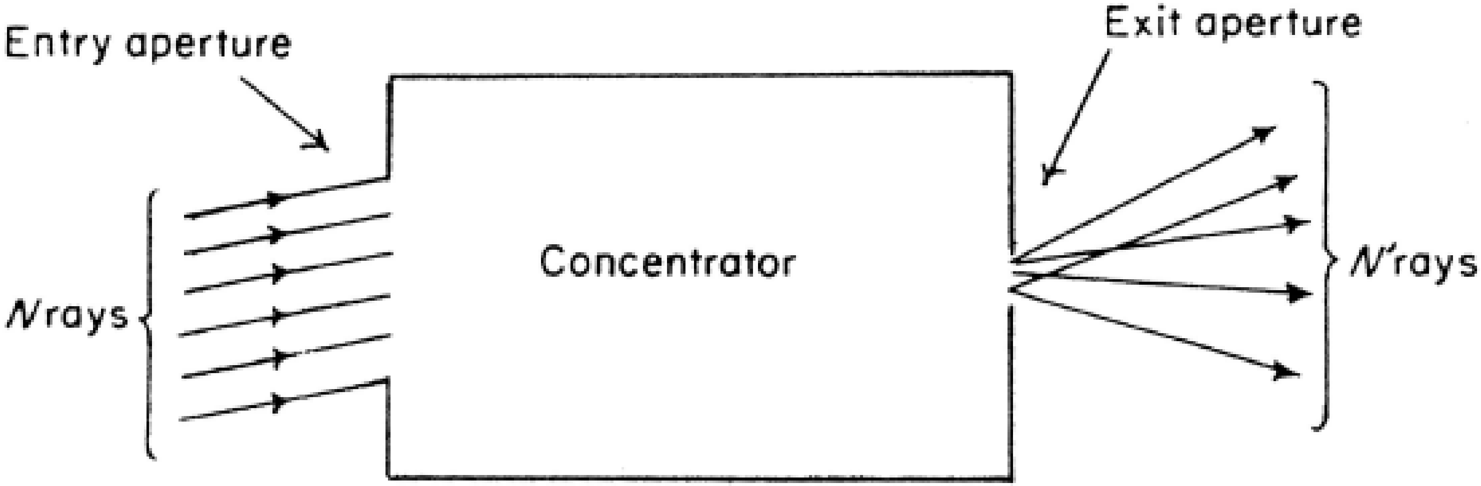
For:
$I = 1\ kW/m^2$ (1 sun)
$\sigma = 5.67 \cdot 10^{-8}\ W/m^2K^4$

C	$T_{stagnation}$	$T_{optimal}$
1000	2049 K	1106 K
5000	3064 K	1507 K
10000	3644 K	1724 K

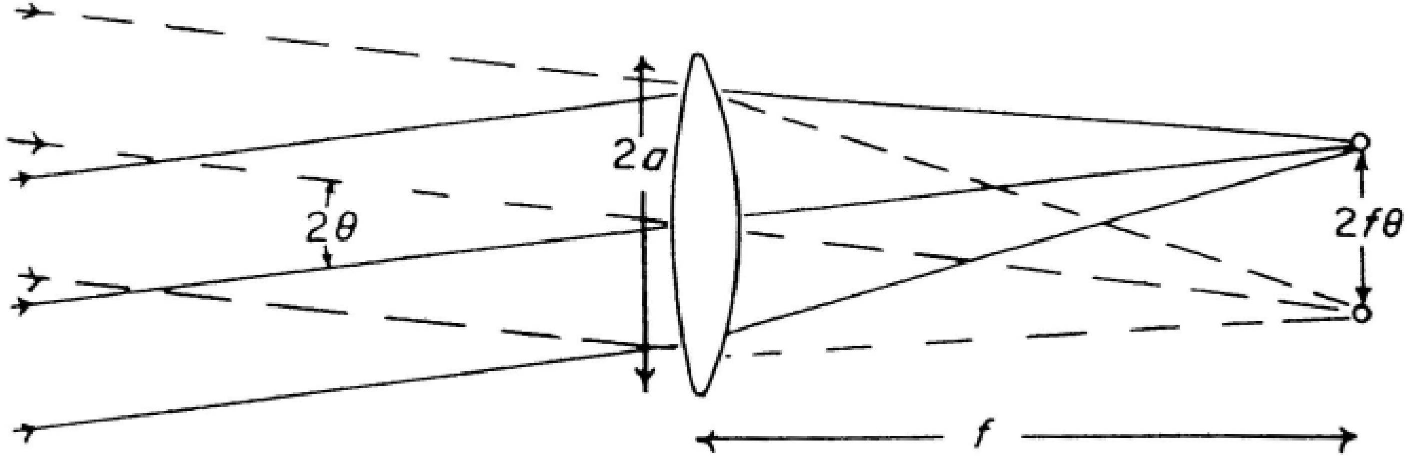


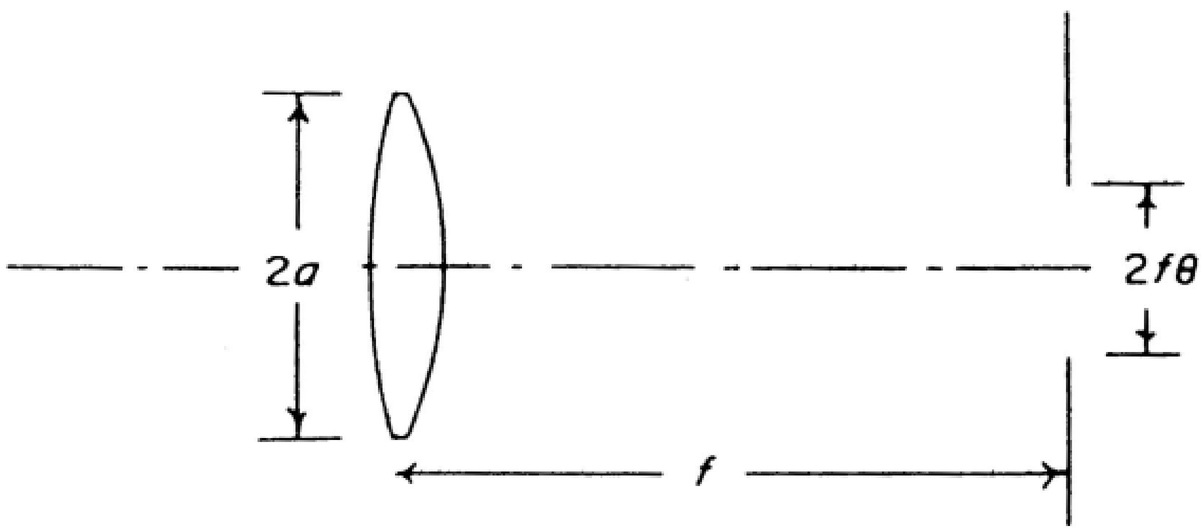
$$\eta_{solar-to-electrcity} = \eta_{optics} \cdot \underbrace{\eta_{receiver}}_{<\eta_{absorption}} \cdot \underbrace{\eta_{heat-to-electricity}}_{<\eta_{Carnot}}$$



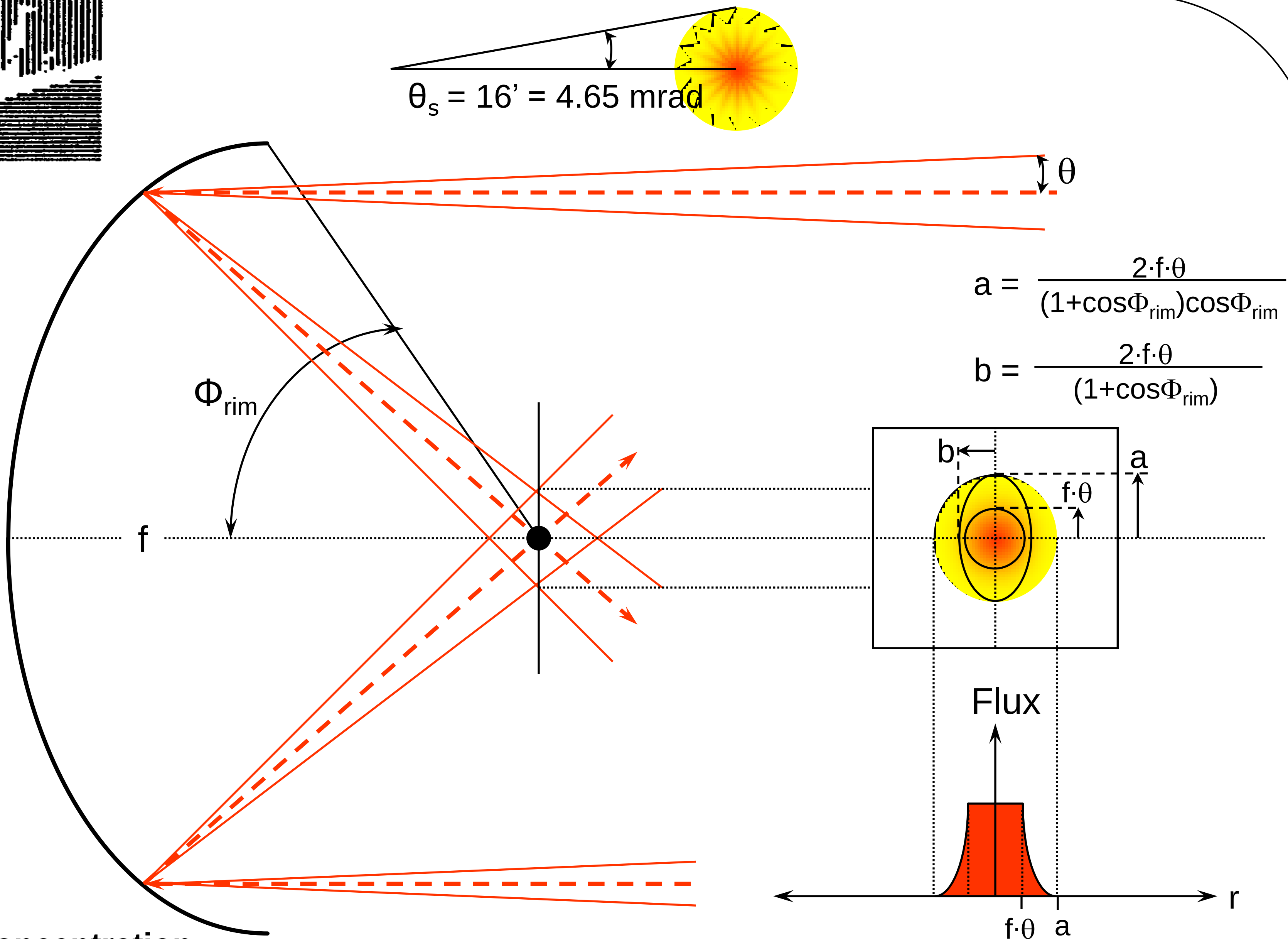

Entry aperture
Exit aperture
Concentrator
N rays
N′ rays

Imaging Optical Concentrators:
- Lens
- Parabolical / Spherical mirrors





$C_{3D} = (a/f\theta)^2$



Dish concentration:

$$C = \sin^2(2\Phi_{rim})/(4\sin^2\theta_s)$$

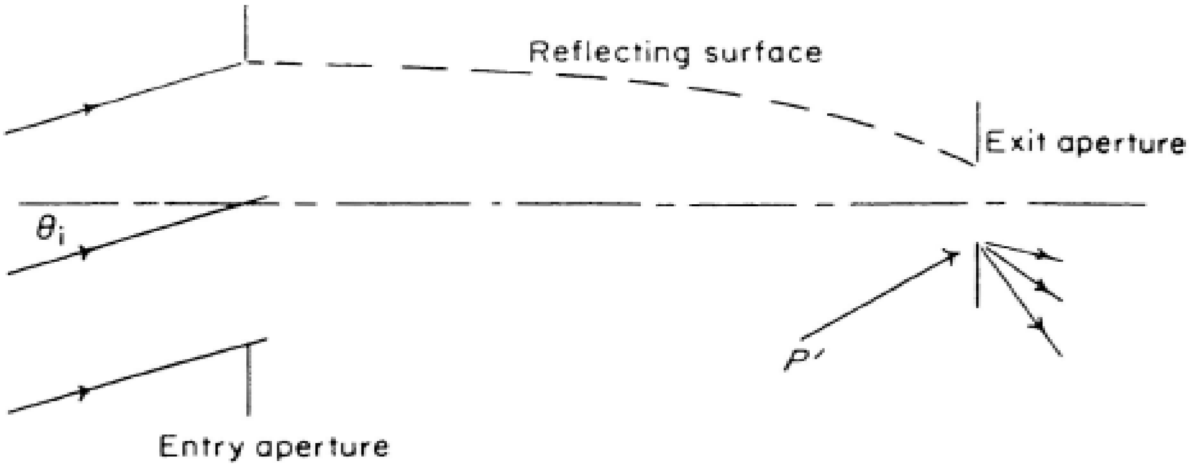
$\theta_s = 4.65$ mrad
$\Phi_{rim} = \pi/4$ } → $C \approx 11{,}500$

Nonimaging Optical Concentrators: Compound Parabolic / Elliptic Concentrators (CPC / CEC) Invented by Hinterberger & Winston probably simultaneously with Baranov (1965 published 1966)

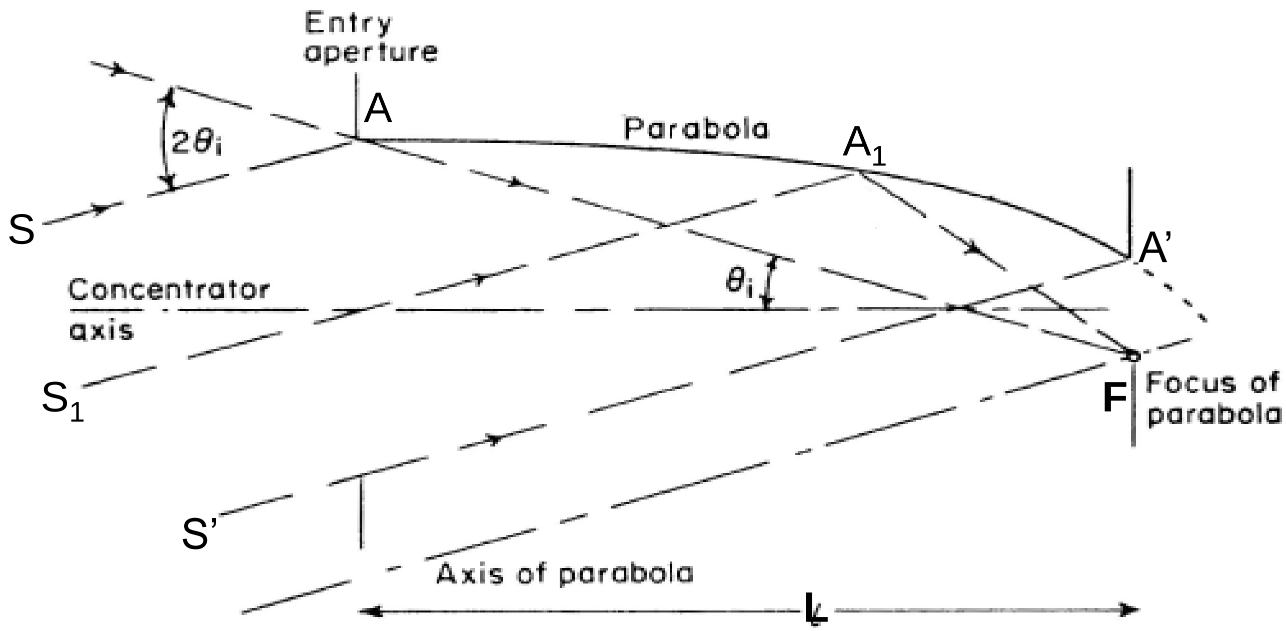
References:

H. Hinterberger and R. Winston, Rev. Sci. Instrum. 37, 1094 (1966).

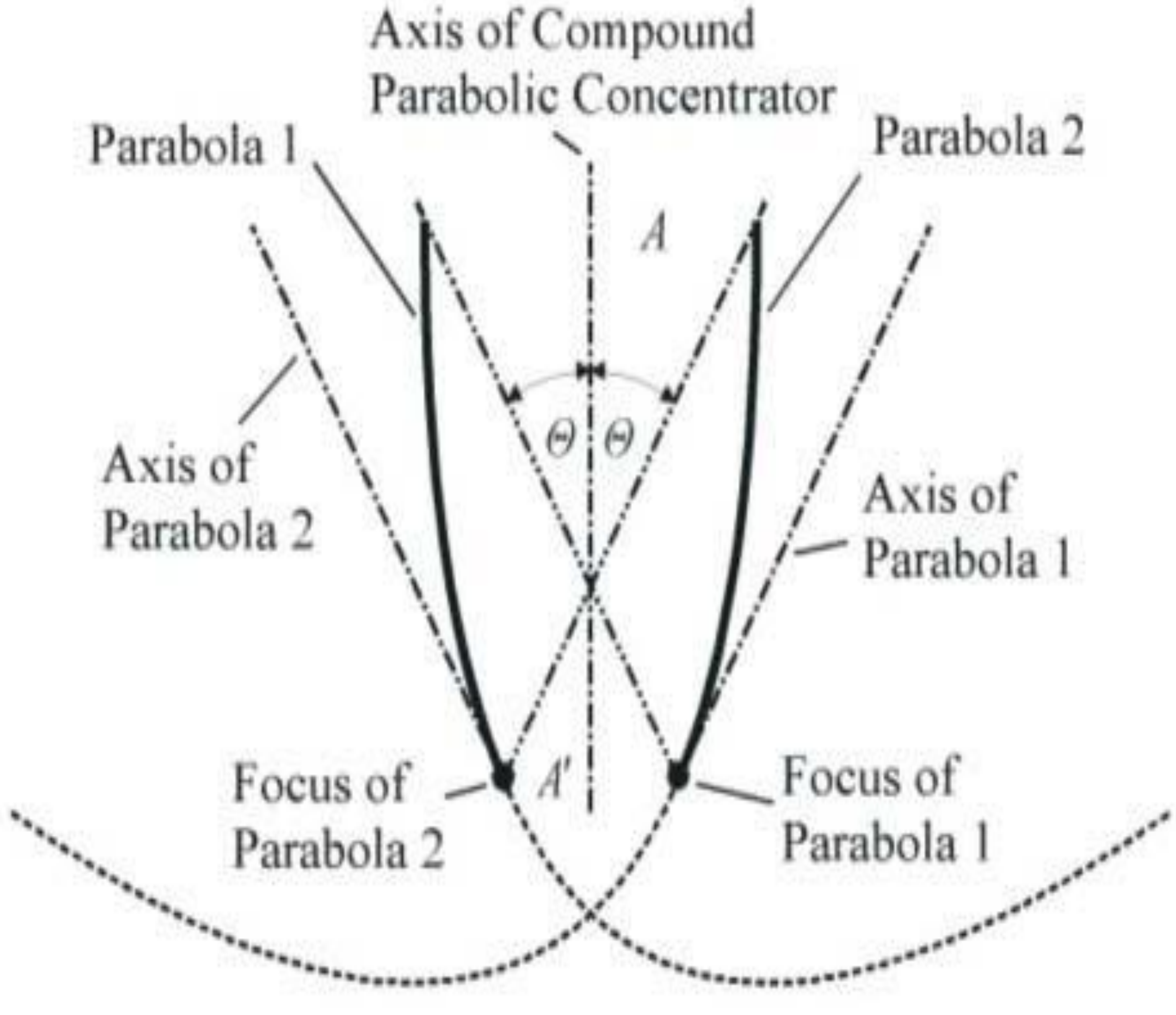
V. K. Baranov, Geliotekhnika 2, 11 (1966).



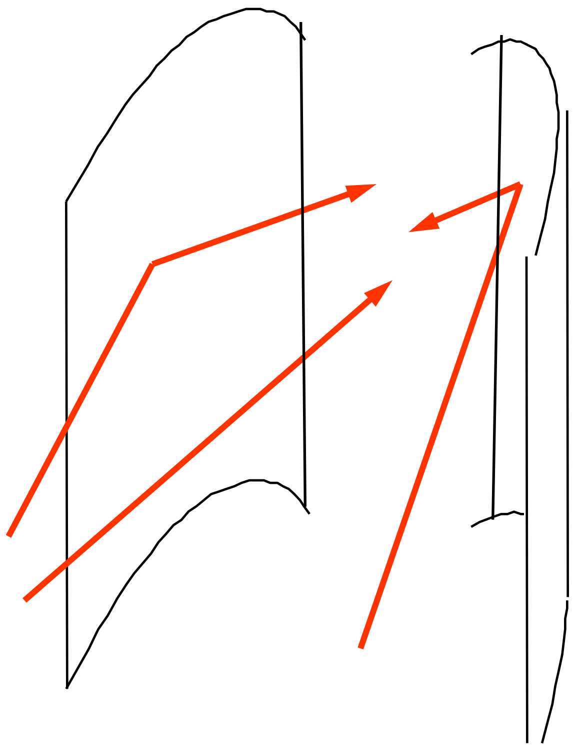
Edge ray principle



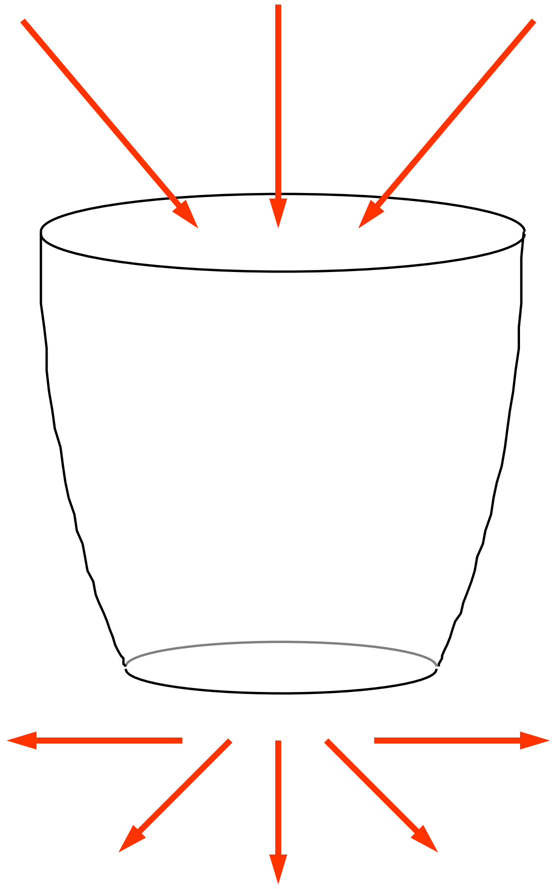
Compound Parabolic Concentrator (CPC)



CPC – Compound Parabolic Concentrator

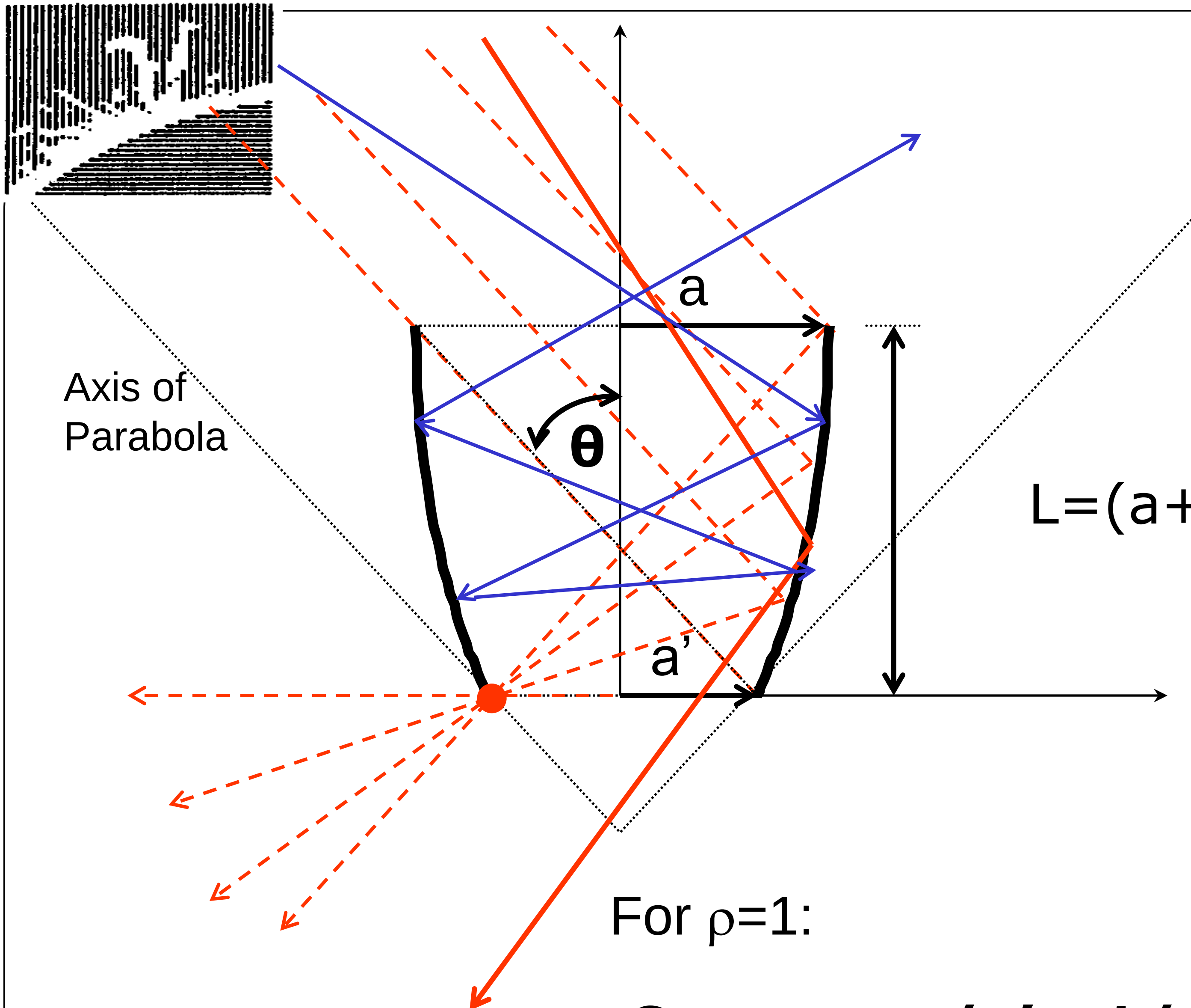


2D - CPC



3D - CPC

Ref.: Winston R., Minano J. C., Benitez P (2005).
NONIMAGING OPTICS
E;lsevier Academic Press, Amsterdam, Boston,…

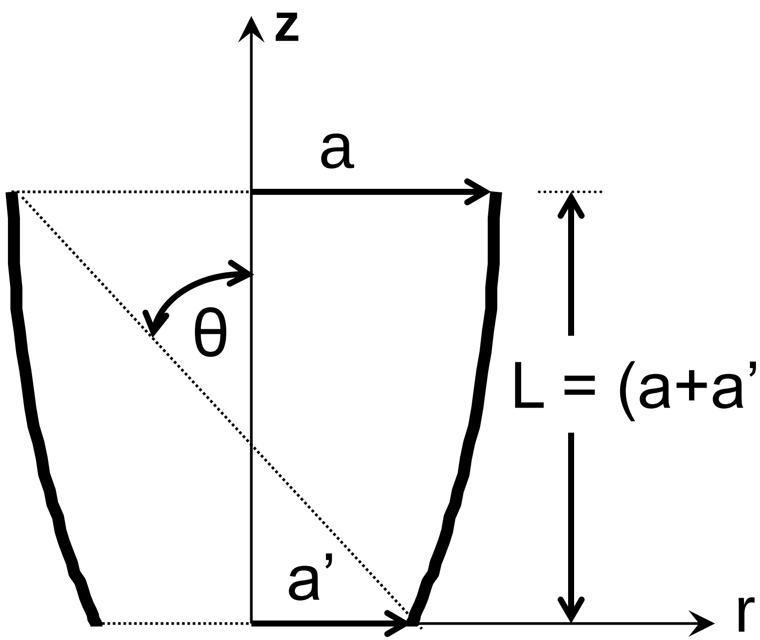


$L=(a+a')/\tan\boldsymbol{\theta}$

For ρ=1:

$$\mathbf{C_{2D\text{-}CPC} = a/a' = 1/\sin\theta}$$
$$\mathbf{C_{3D\text{-}CPC} = (a/a')^2 = 1/\sin^2\theta}$$

The CPC equations

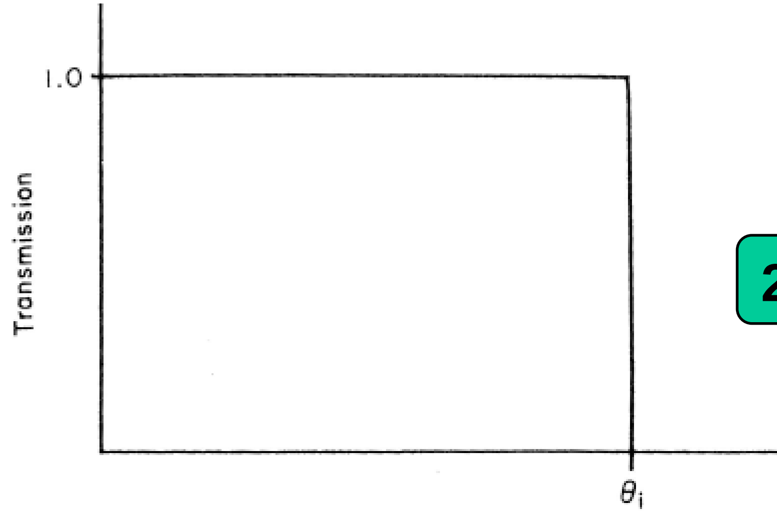


$L = (a+a')/\tan\theta$

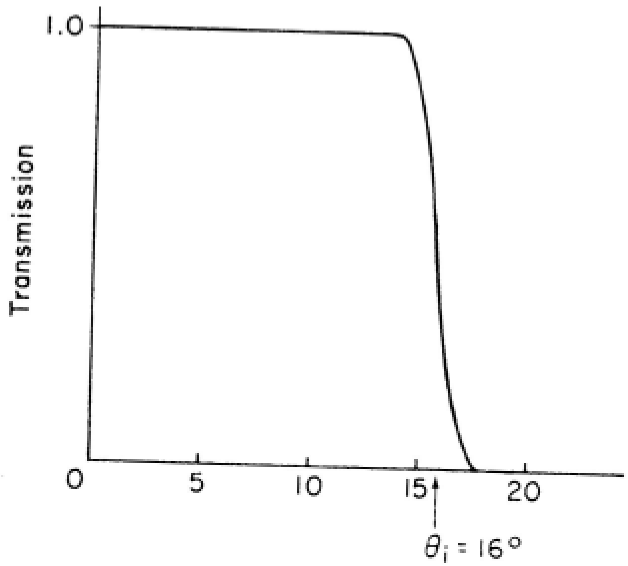
$a' = a \sin\theta$

$$\left(r\cos\theta + z\sin\theta\right)^2 + 2a's^2r - 2a'\cos\theta\,(1+s)z - a'^2s(2+s) = 0$$

$$s = 1 + \sin\theta$$


1.0
Transmission
θ_i

2D-CPC


1.0
Transmission
0
5
10
15
20
$\theta_i = 16°$

3D-CPC

Example:

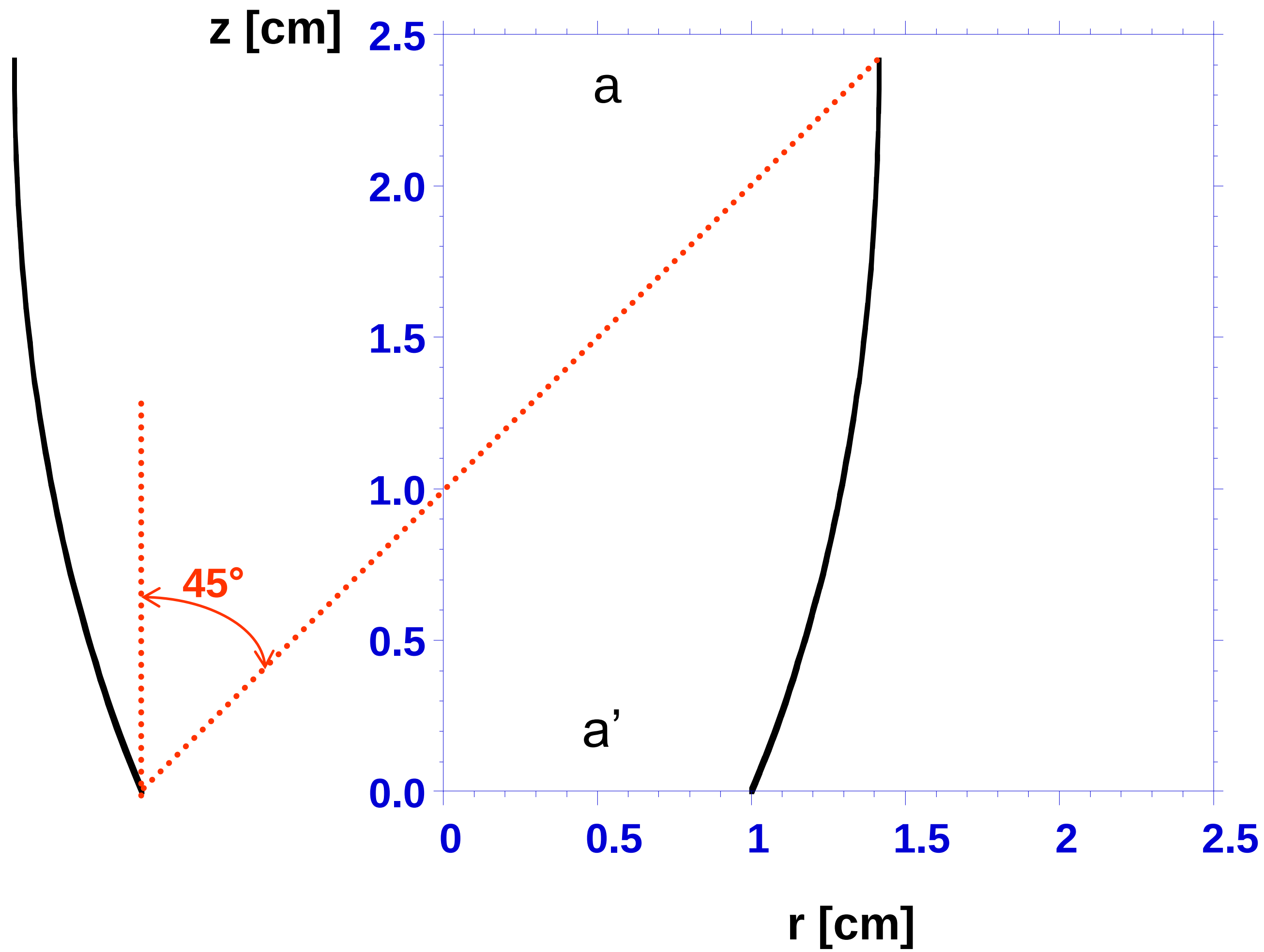
θ= 45°

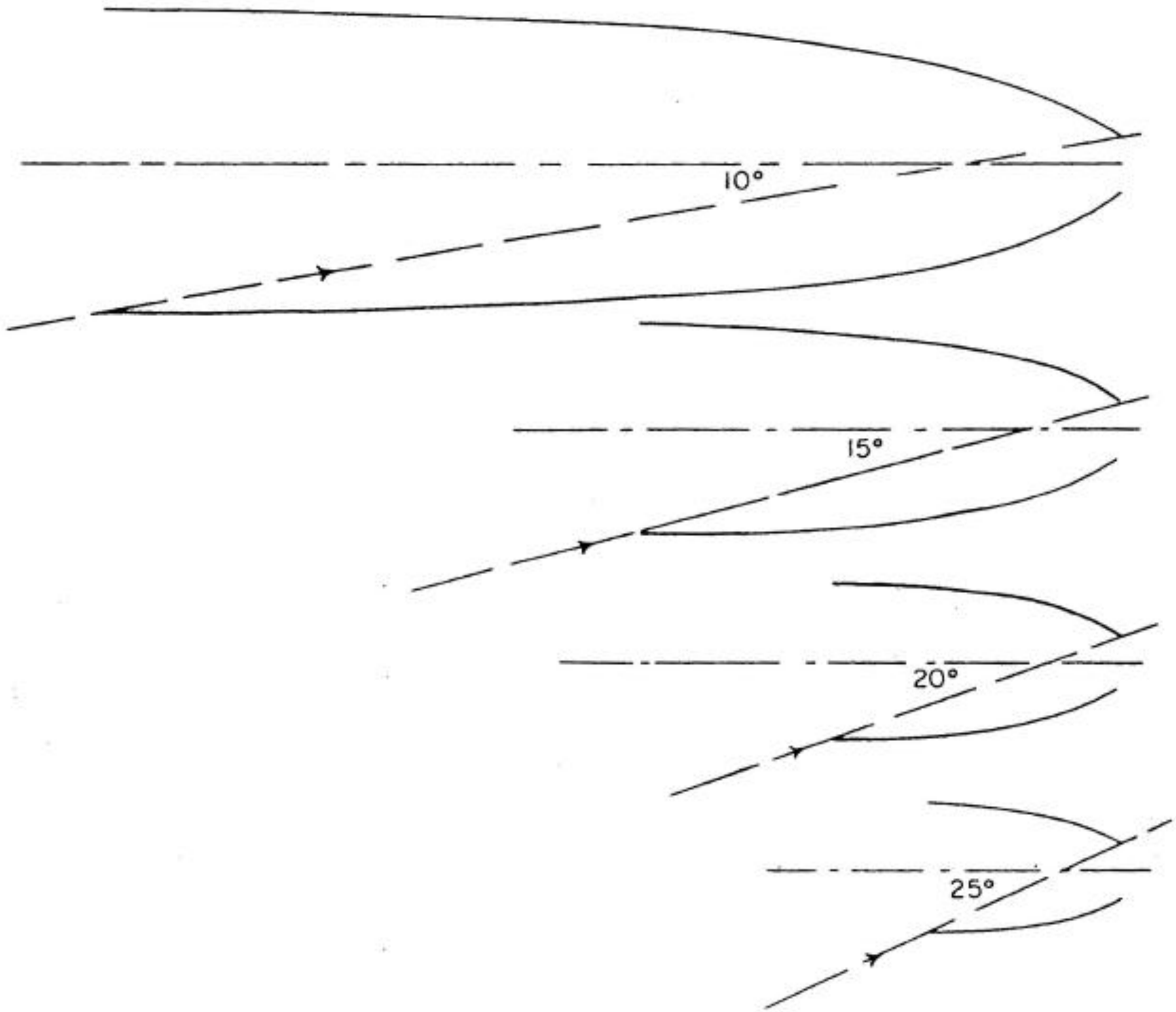
a'= 1cm

a = a'/sinθ = 1.414cm

L = (a+a') /tan θ = 3.414m

C = $(a/a')^2$ = 2





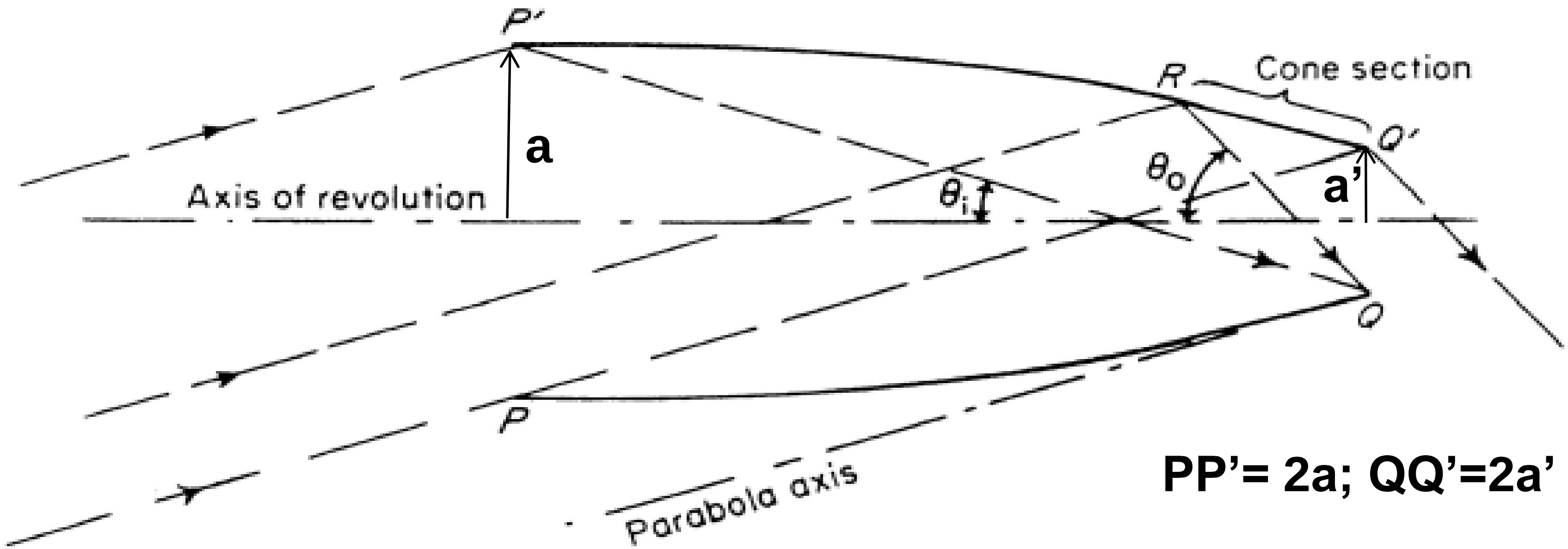
$C_{3D,ideal} = 33$

$C_{3D,ideal} = 15$

$C_{3D,ideal} = 8.5$

$C_{3D,ideal} = 5.6$

CPC with exit angle less than π/2



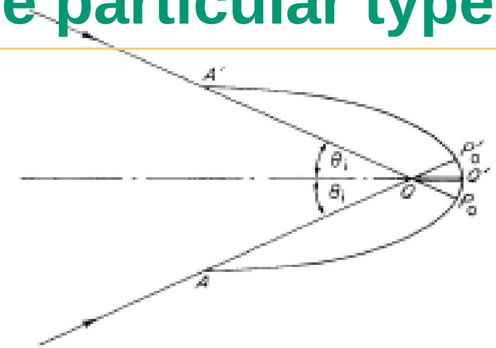
PP'= 2a; QQ'=2a'

CPC for θ= 20º, θ_o=70º, a'=0.2m

$$(r\cos\theta + z\sin\theta)^2 + 2a'(1 + s\sin\theta)r - 2a's\cos\theta\, z - a'^2(s^2 - 1) = 0$$

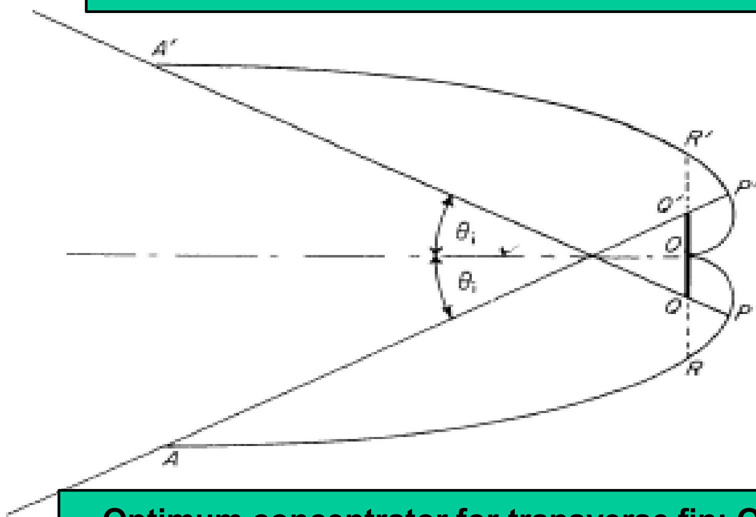
$$s = 2\sin\theta_0 + \sin\theta \qquad a' = a\sin\theta/\sin\theta_o \qquad L = (a + a')/\tan\theta$$

Some particular types of 2D-Concentrators



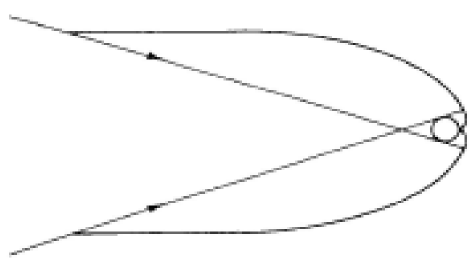
P_0P_0' arc of circle with center Q
A'P_0' parabola focus Q axis AQP_0'

Optimum concentrator for an edge-on fin: QQ'



OP' arc of circle with center Q'
P'R' parabola focus Q' axis AQ'P'
R'A' parabola focus Q axis ||AQ'P'

Optimum concentrator for transverse fin: QQ'

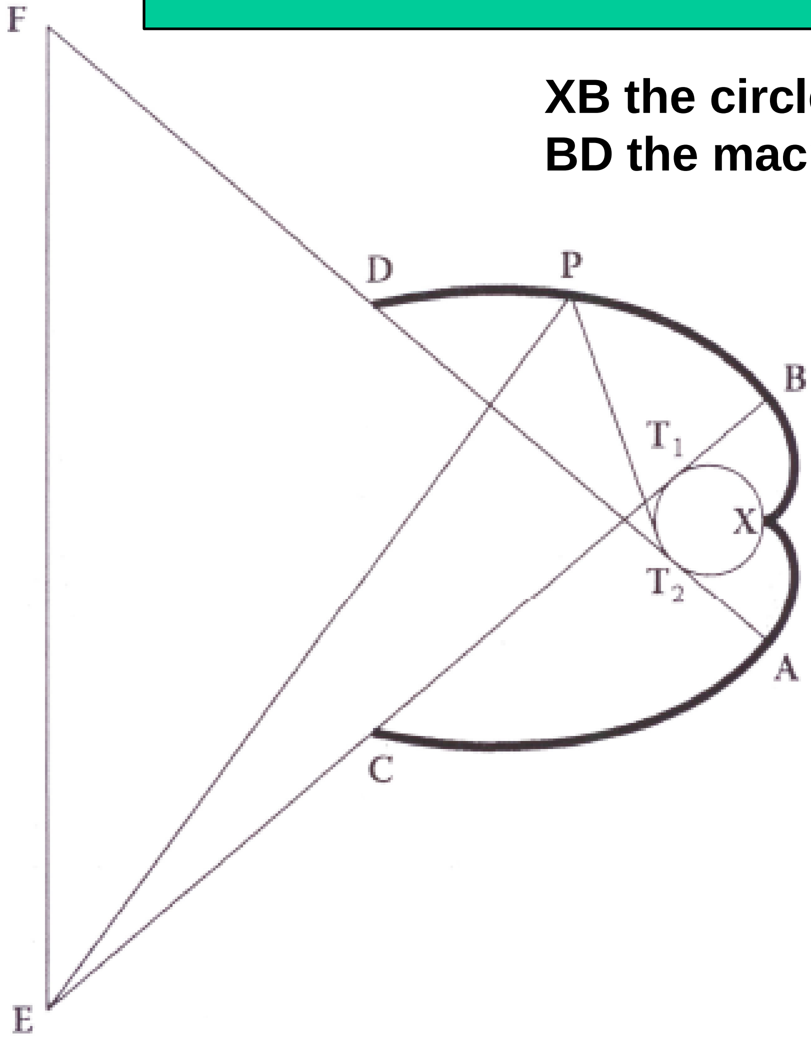


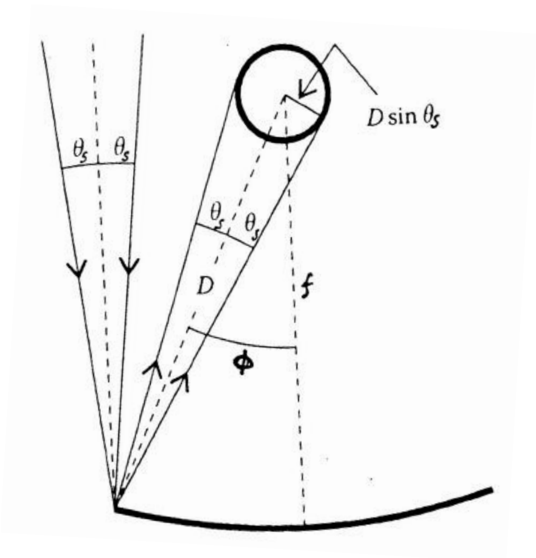
See next slide

Optimum concentrator for a cylindrical absorber

Ideal 2D-concentrator with cylindrical absorber

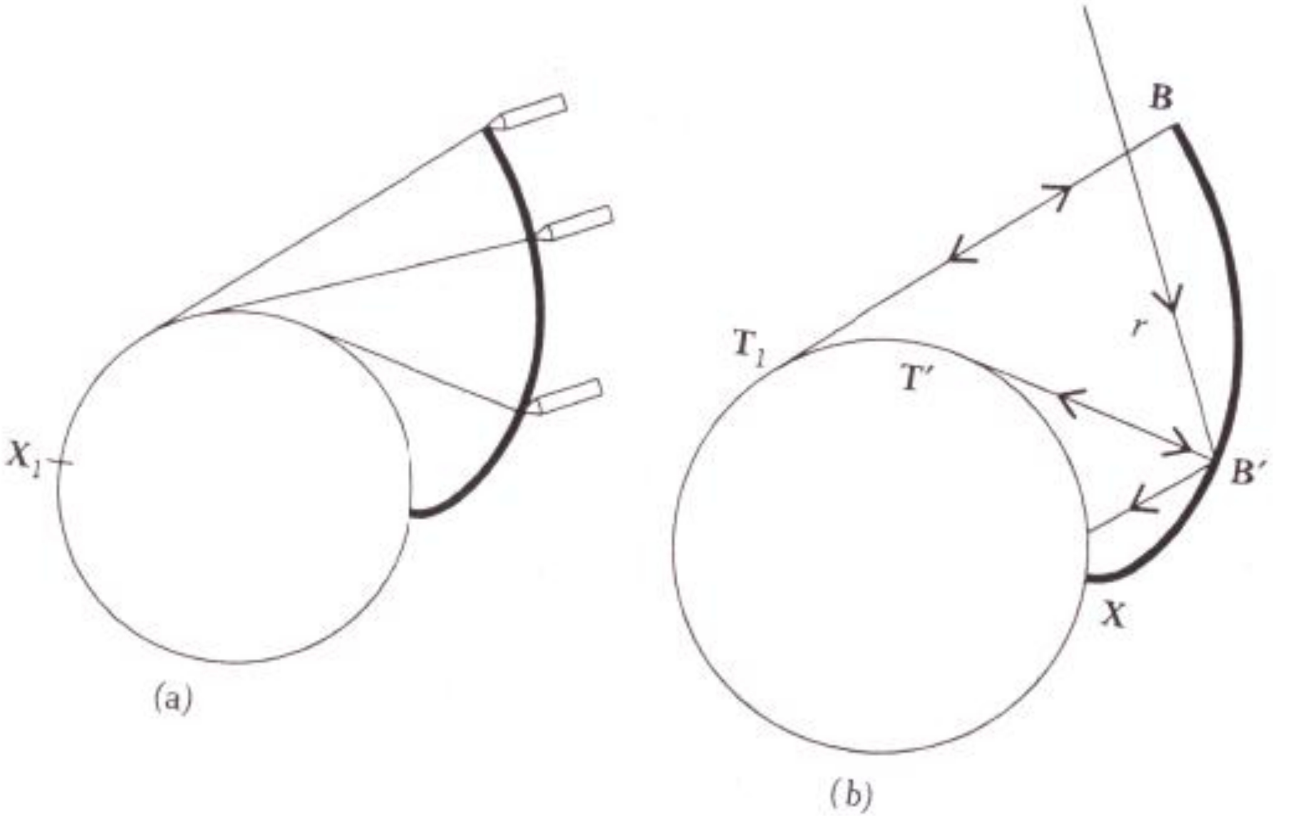
XB the circle involute
BD the macrofocal parabola





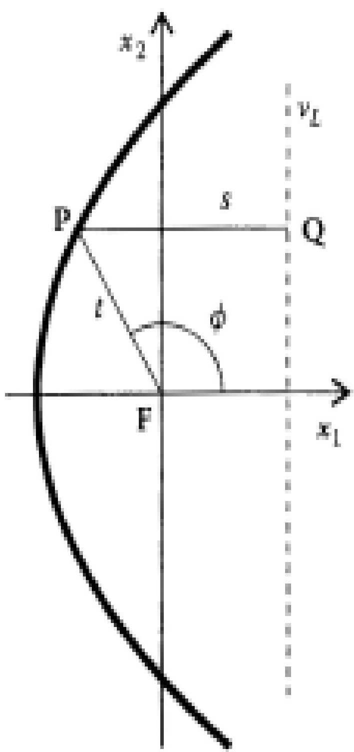
‘Classical’ trough with cylindrical absorber (including shading): $C=1/\pi\,(C_{2D\text{-}ideal} - 1)$

Design of a circle involute

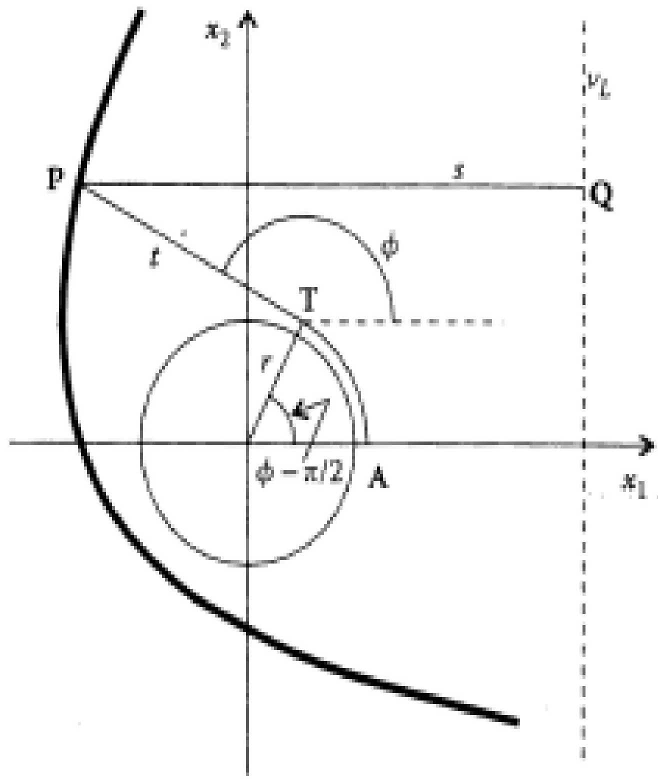


Macrofocal Parabola (MFP)

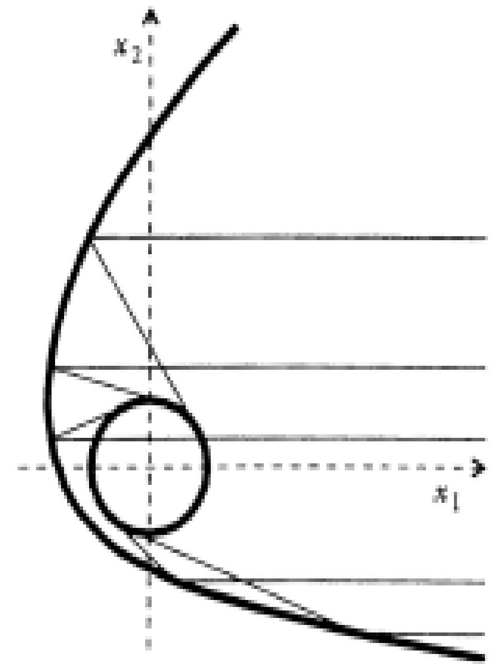
Parabola definition
FP+PQ=const & PQ⊥v_1



MFP definition
AP+PQ=const & PQ⊥v_2

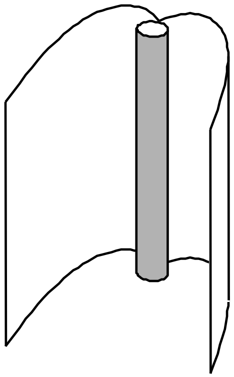


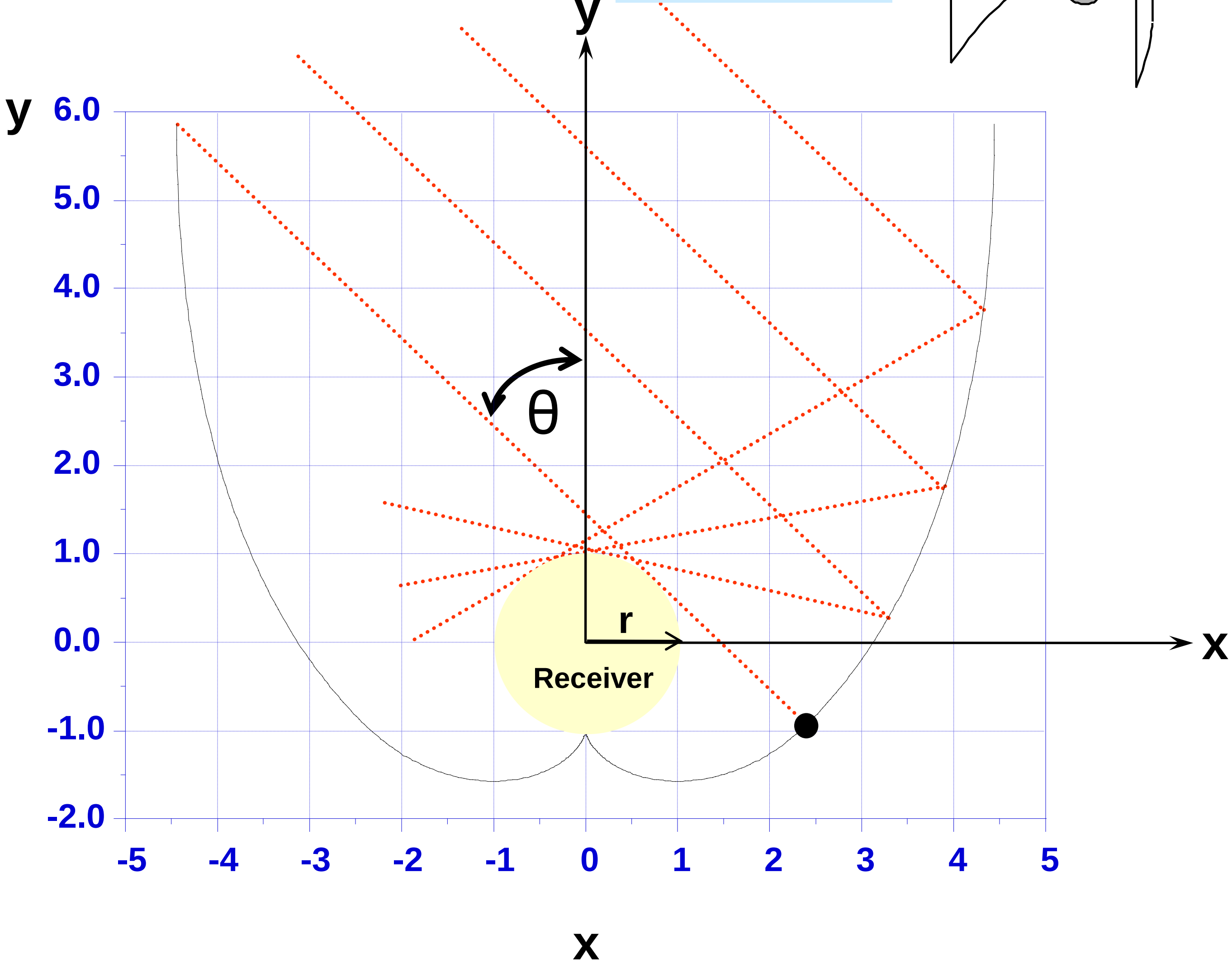
A MFP reflects parallel rays to became tangent to a circular MF



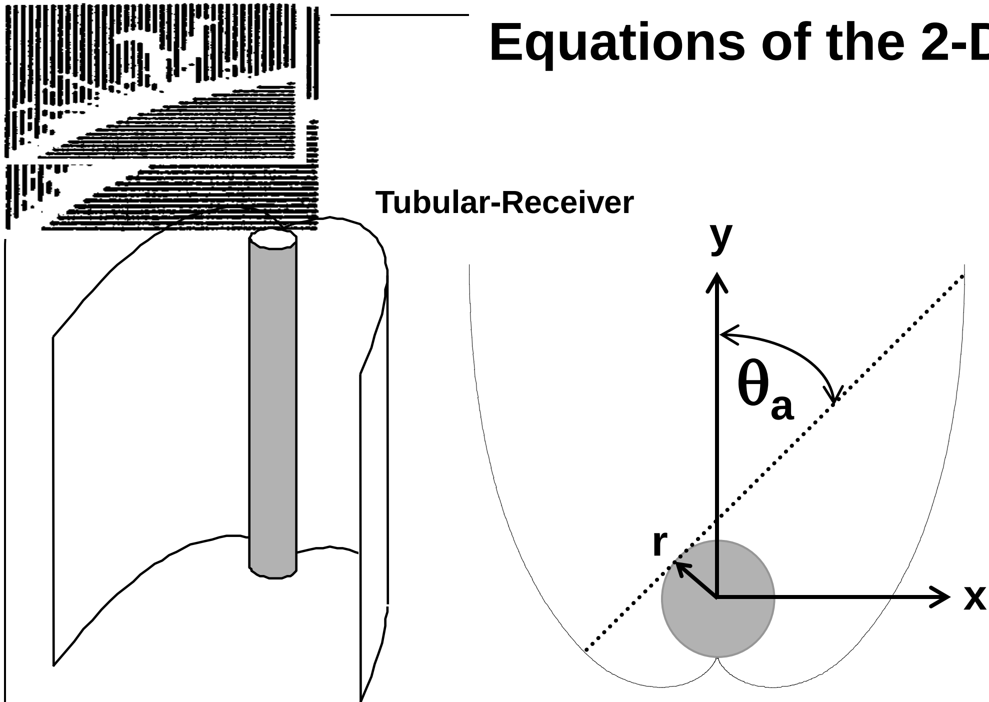
Example of 2D-CPC + involute:

r = 1 cm
θ = 45°





Equations of the 2-D CPC + involute



$$\begin{cases} x = r[\sin\theta - M(\theta)\cos\theta] \\ y = r[-\cos\theta - M(\theta)\sin\theta] \end{cases}$$

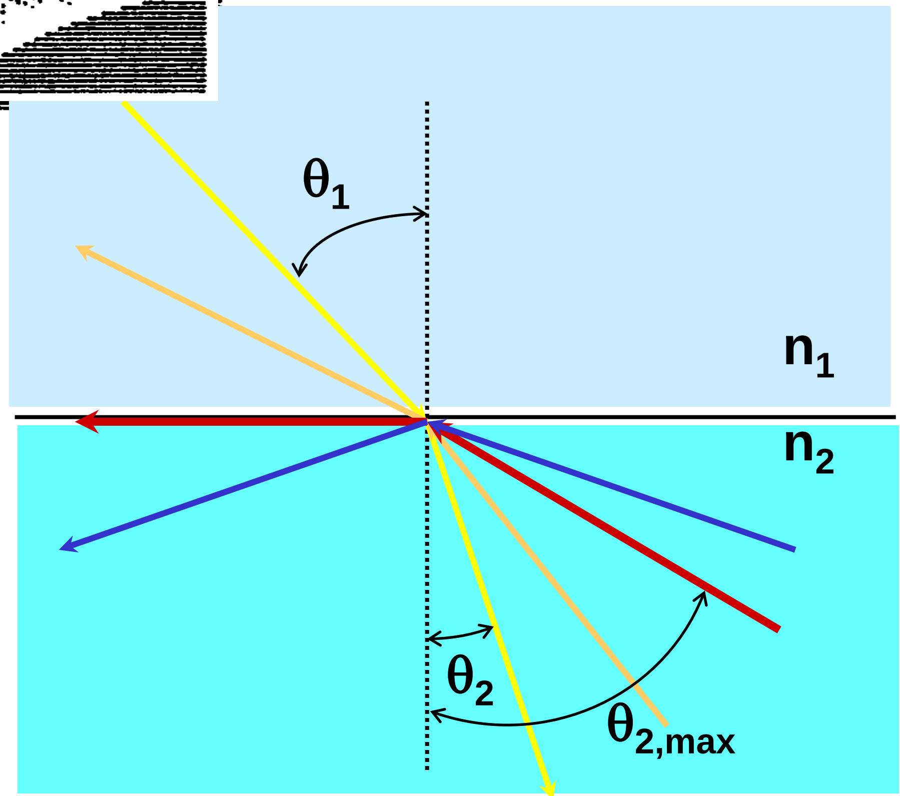
$$M(\theta) = \begin{cases} \theta & for \;\; 0 \le \theta \le \dfrac{\pi}{2} + \theta_a \\ \dfrac{\pi/2 + \theta_a + \theta - \cos(\theta - \theta_a)}{1 + \sin(\theta - \theta_a)} & for \;\; \dfrac{\pi}{2} + \theta_a \le \theta \le \dfrac{3\pi}{2} - \theta_a \end{cases}$$

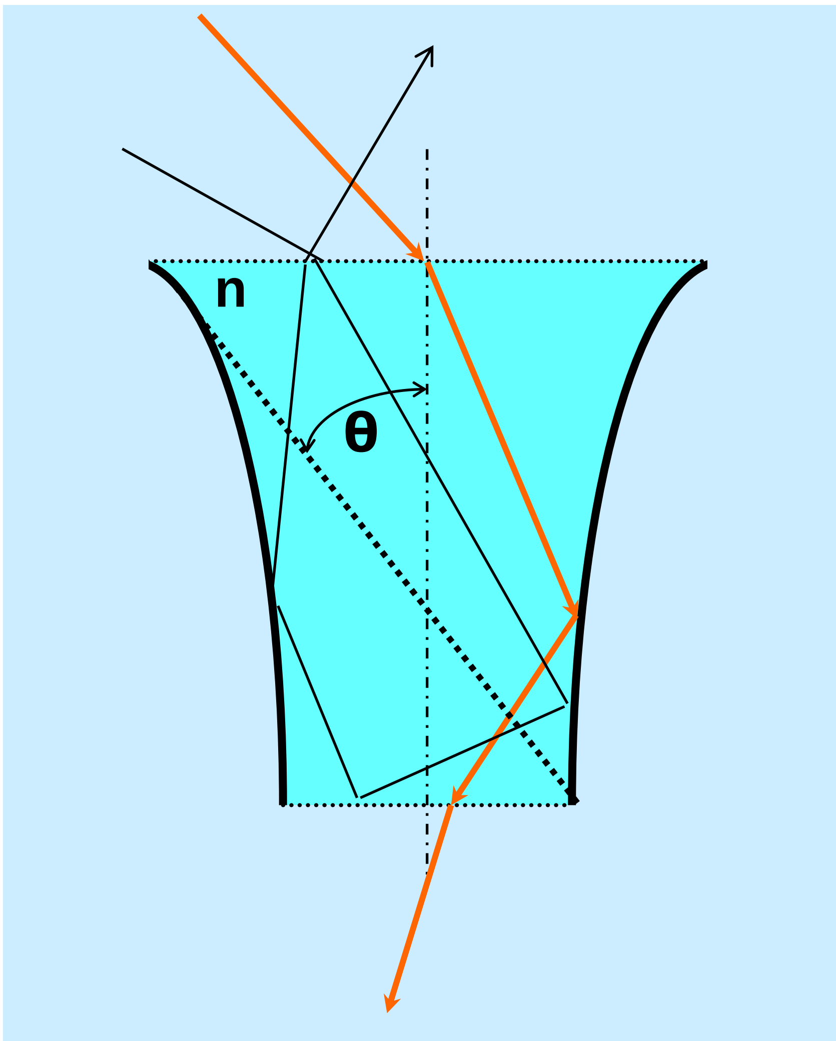
θ_a CPC‘s half acceptance angle and is taken equal to the rim angle of the primary parabolic concentrator.

r radius tubular receiver.

Nonimaging optical concentrators with dielectrics n >1

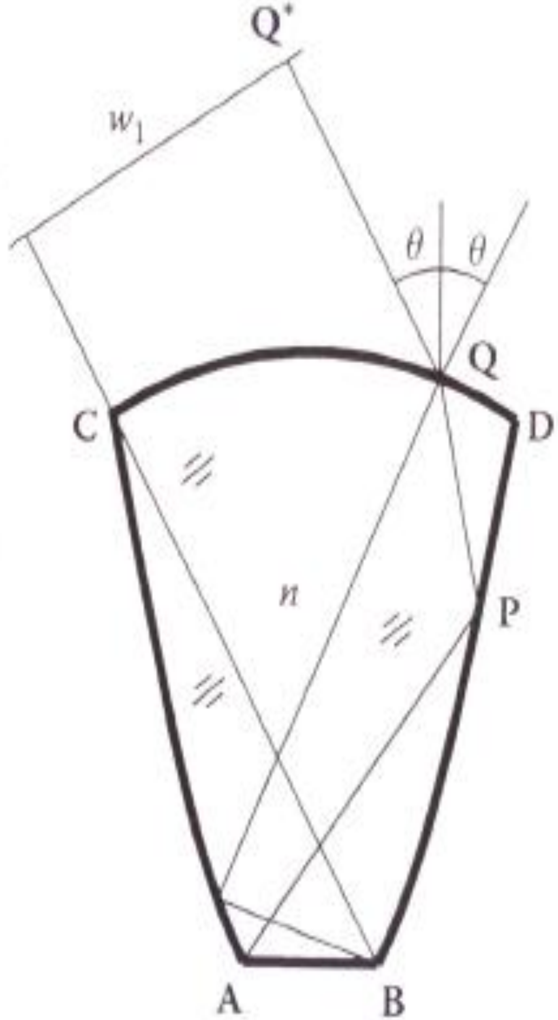
Refractive CPC

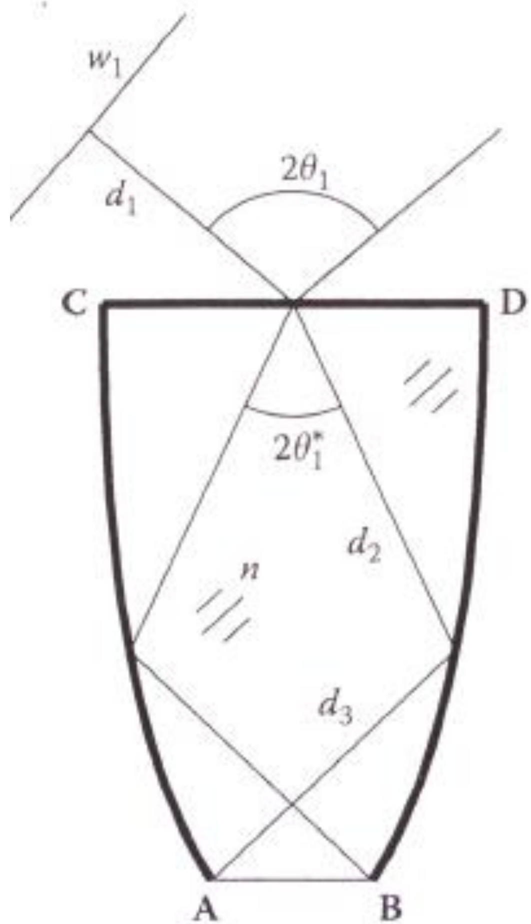




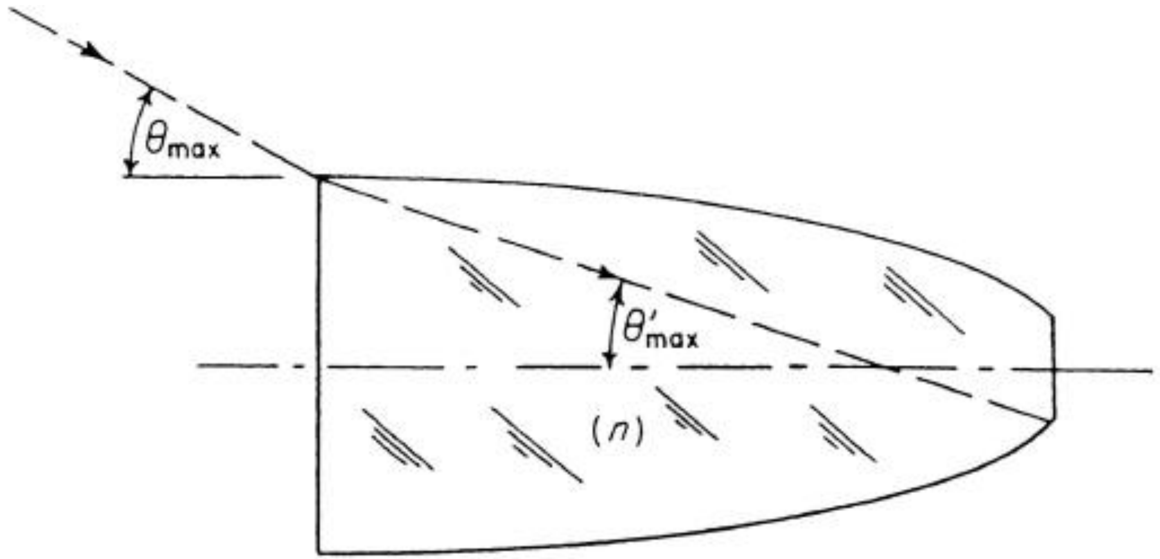
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$\theta_{1,max} = \pi/2$$
$$\theta_{2,max} = \arcsin(n_1/n_2)$$

$$C_{2D\text{-}CPC} = n/\sin\theta$$
$$C_{3D\text{-}CPC} = n^2/\sin^2\theta$$

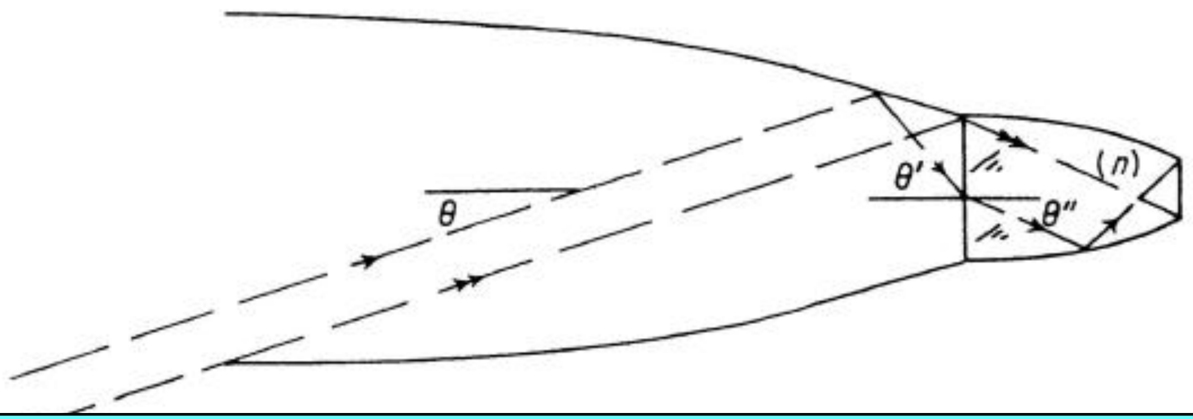




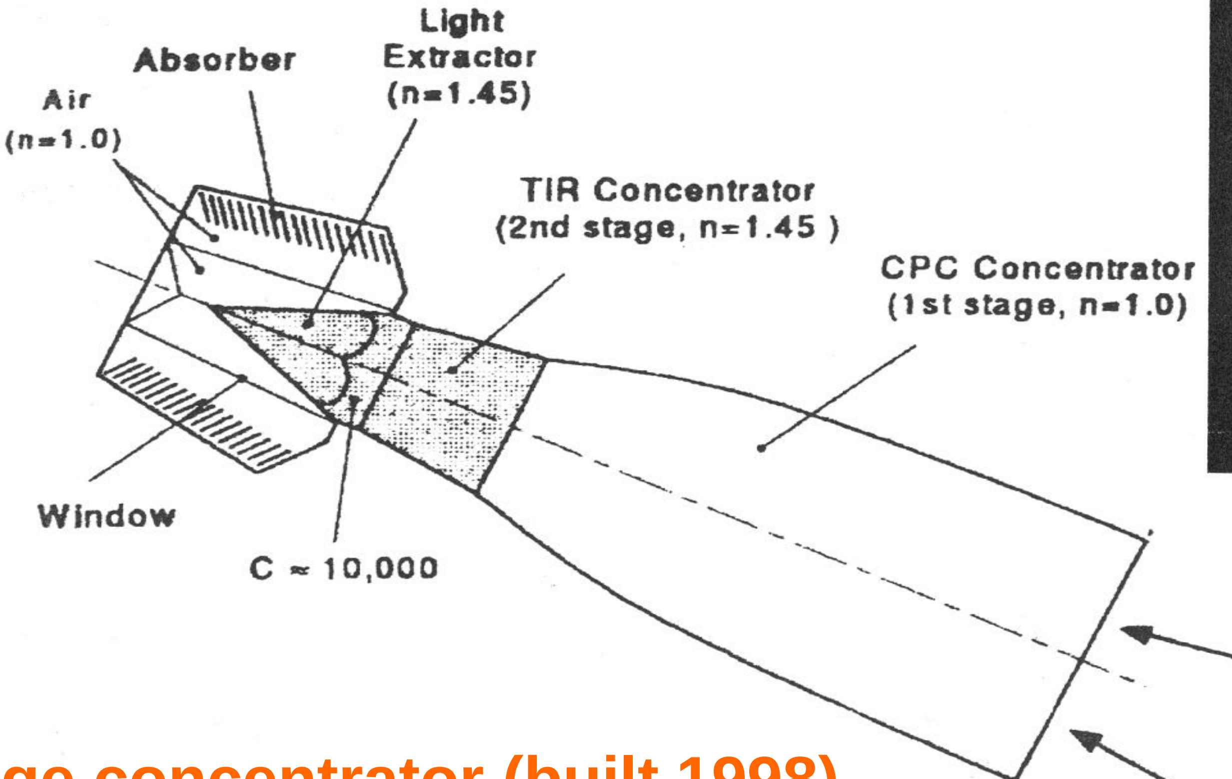
Ref: Ning X.,O'Gallagher J.J.,Winston R,.*Appl.Opt*.,**26,** 300, (1987)

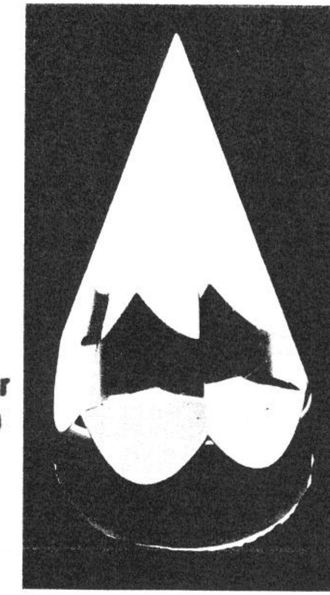


A dielectric-filled compound parabolic concentrator



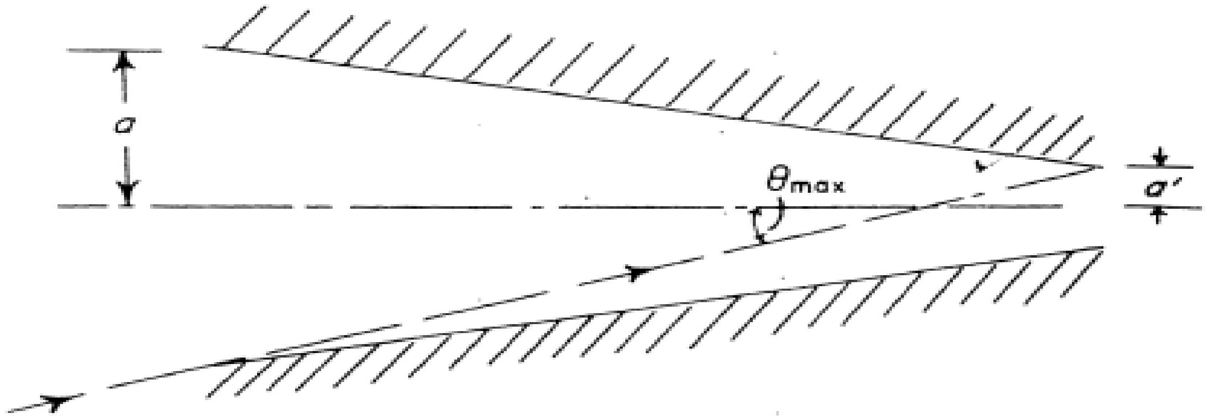
Two stage ending in a dielectric of index n: first stage CPC mirror, second stage: dielectric with total internal reflection



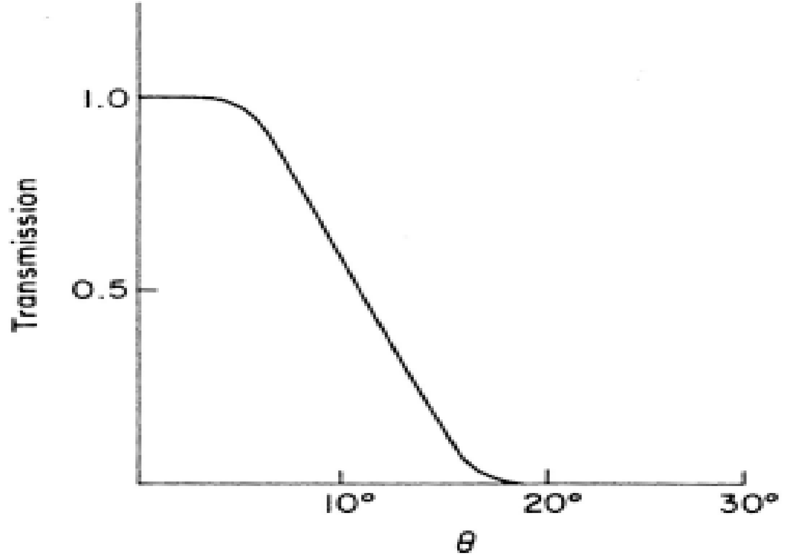


Two stage concentrator (built 1998). Power absorbed in receiver 96kW; concentration 10,000 suns

Reference: Ries H., Segal A., Karni J., *Appl.Opt.*,**36**,2829, (1997)

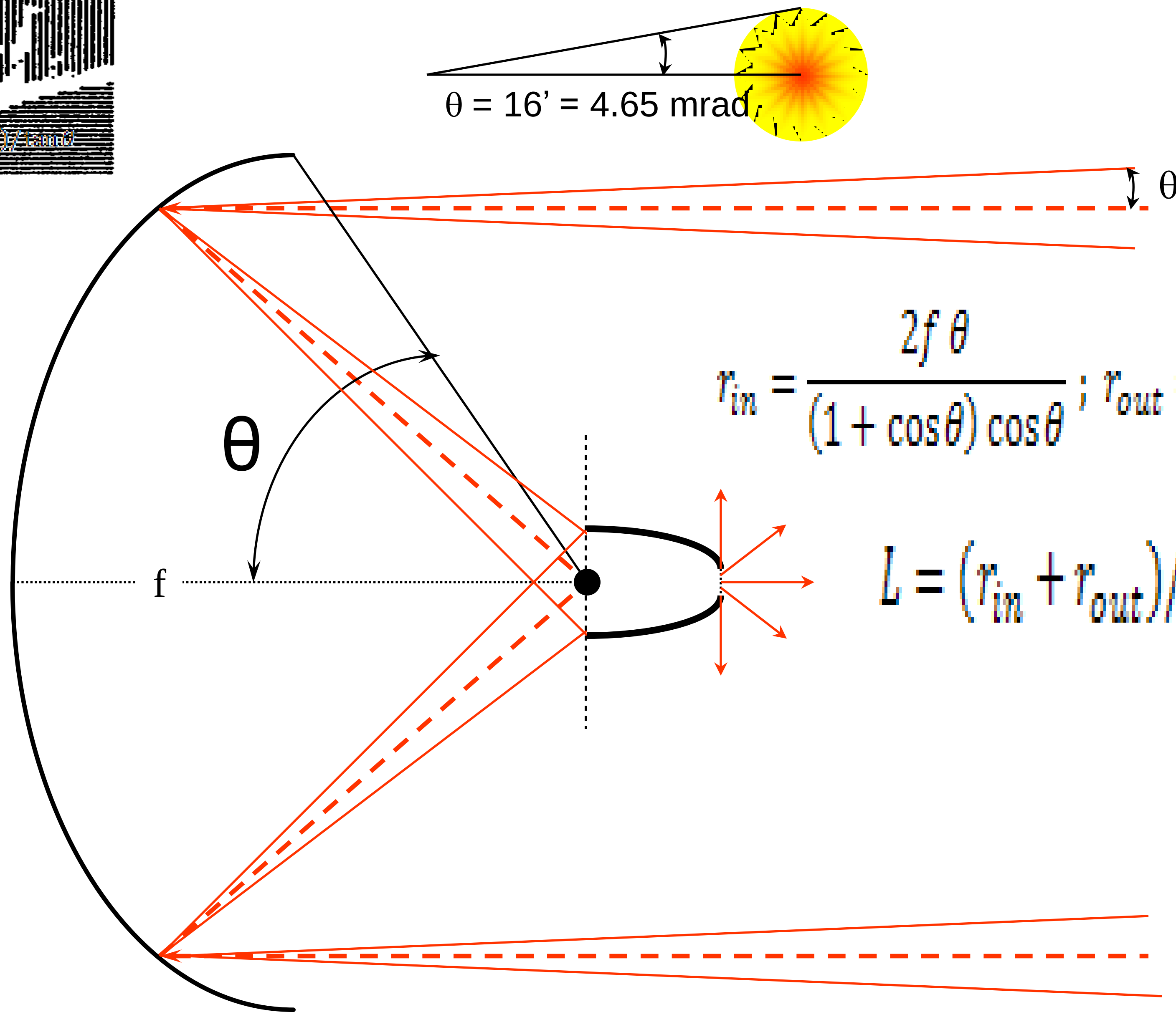


Cone concentrator



Transmission-angle curve for a cone with $\theta_{max} = 10^{o}$

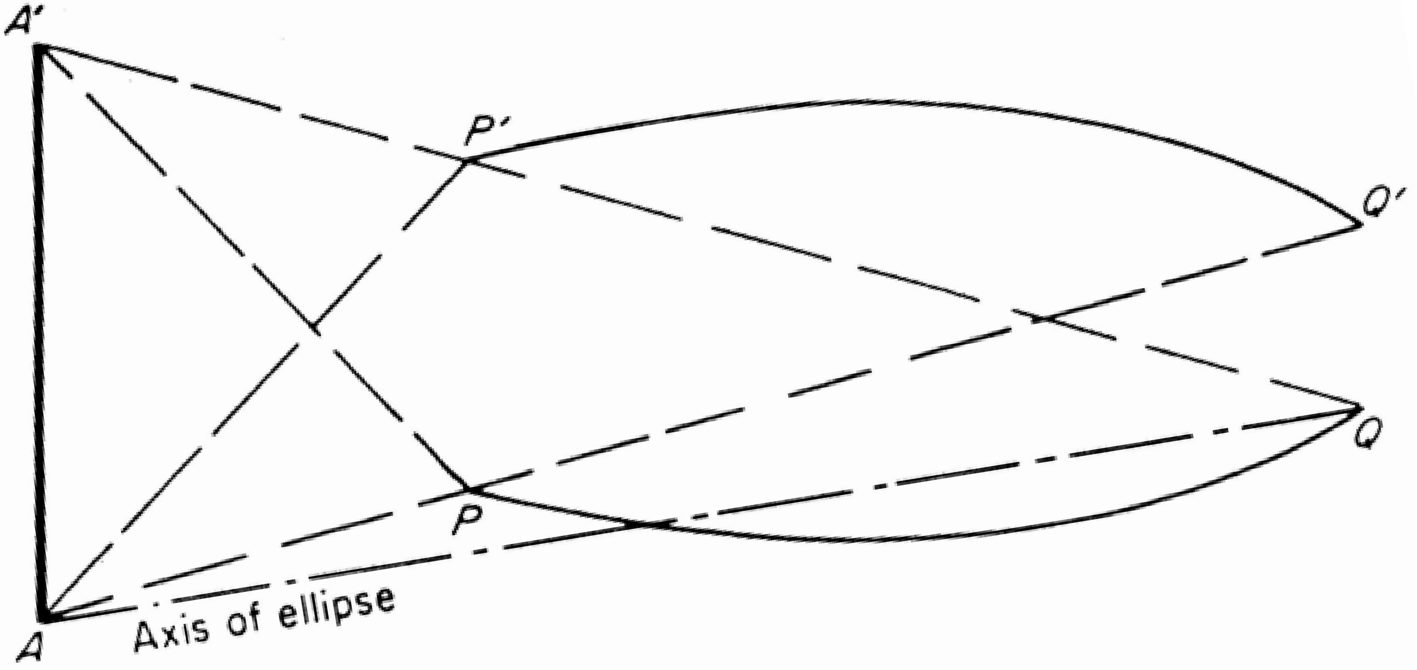
Compound Elliptic Concentrators (CEC)



$$r_{in} = \frac{2f\,\theta}{(1+\cos\theta)\cos\theta}\;;\; r_{out} = r_{in}\sin\theta$$

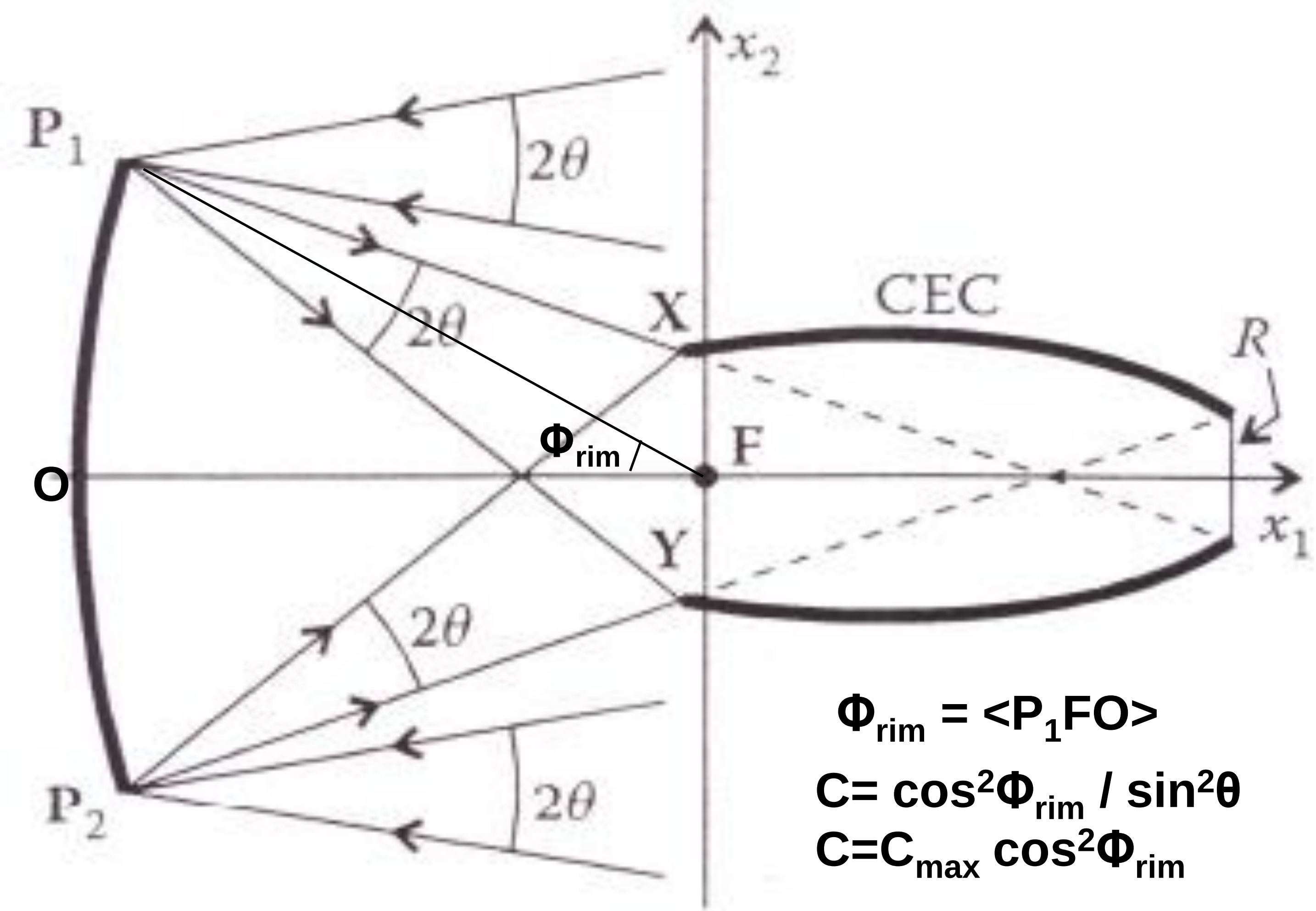
$$L = (r_{in} + r_{out})/\tan\theta$$

Two stage concentrator: stage 1 – dish,
stage 2 – CPC concentrator - (but…it is not the best solution !)



Concentrator suitable for a source AA' at a finite distance; design of a new profile is based on edge ray principle

Compound Elliptic Concentrator (CEC) concentrator for dishes

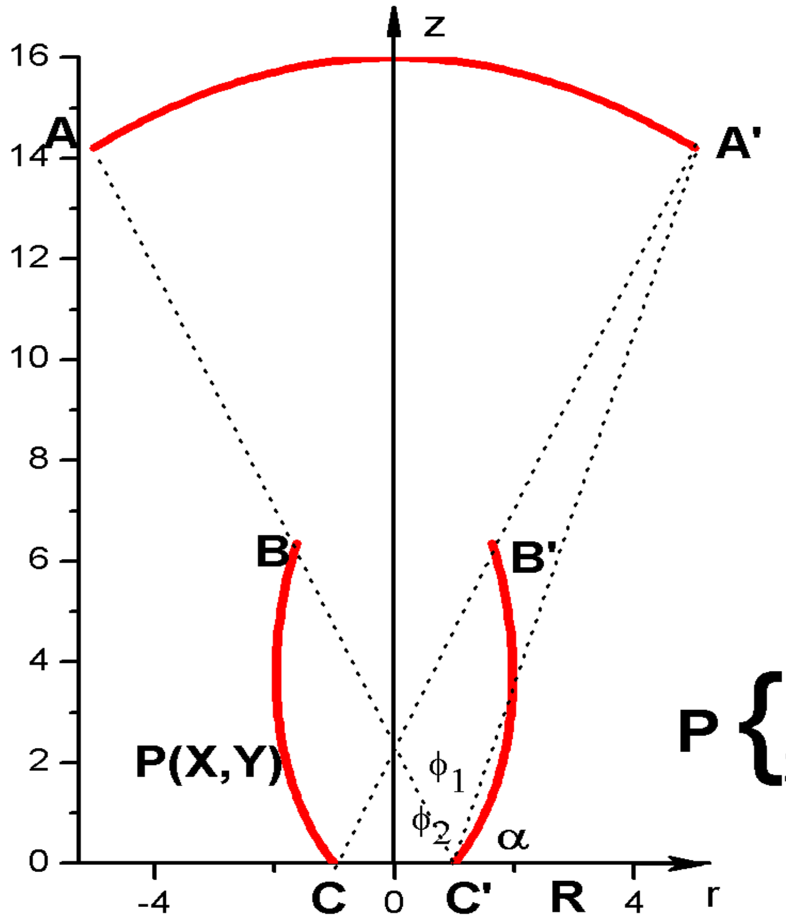


$\Phi_{rim} = \langle P_1FO \rangle$

$C = \cos^2\Phi_{rim} / \sin^2\theta$

$C = C_{max} \cos^2\Phi_{rim}$

Compound Elliptic Concentrator(CEC) concentrator for dishes



AA' = 2a

BB' = 2b

CC' = 2c

A'C' = f

ϕ_1 = <AC'A'>

ϕ_2 = <CC'A'>

$\phi_1 < \phi < \phi_2$

α = < A'C'R >

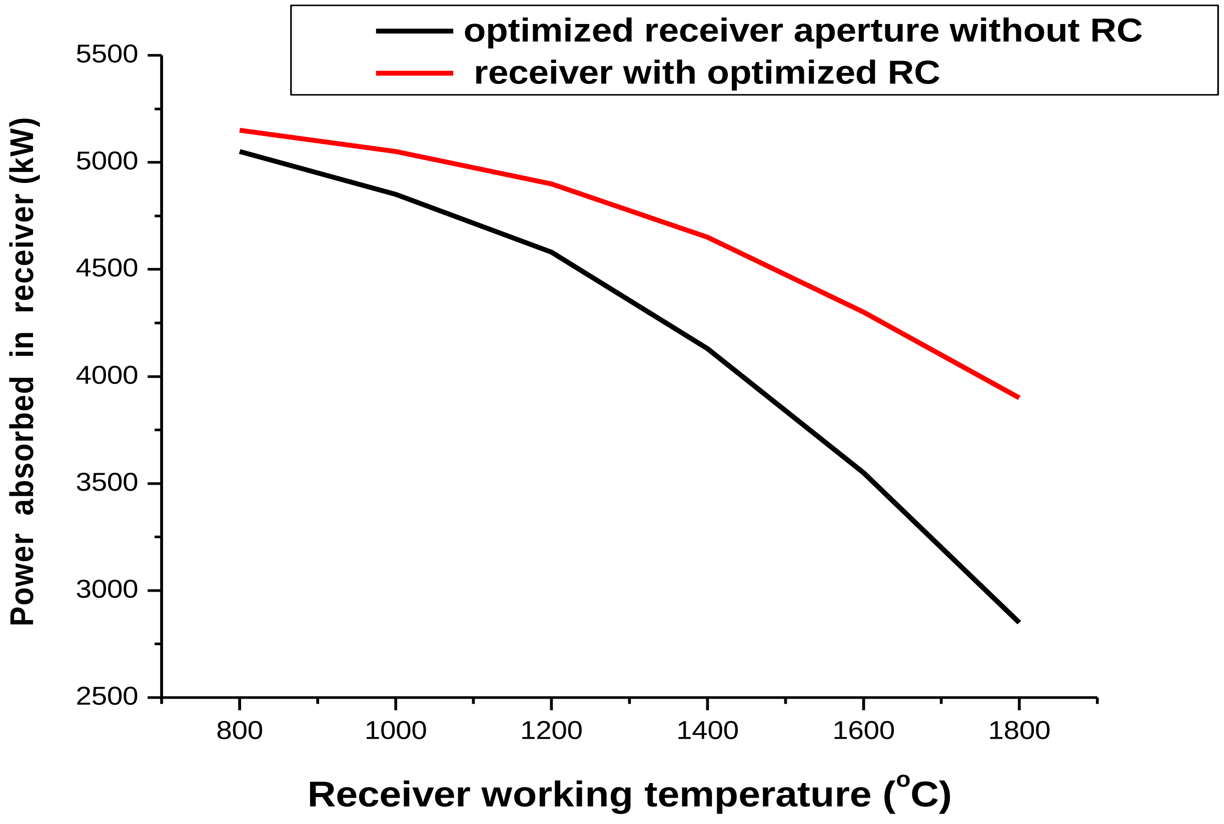
$$Kf = (K^2 - f^2) / (2K - 2f \cos\phi)$$

$$P \begin{cases} r = -Kf \cos(\phi + \alpha) + r(C) \\ z = Kf \sin(\phi + \alpha) \end{cases}$$

$$L = (b+c)/\tan(\phi_1)$$

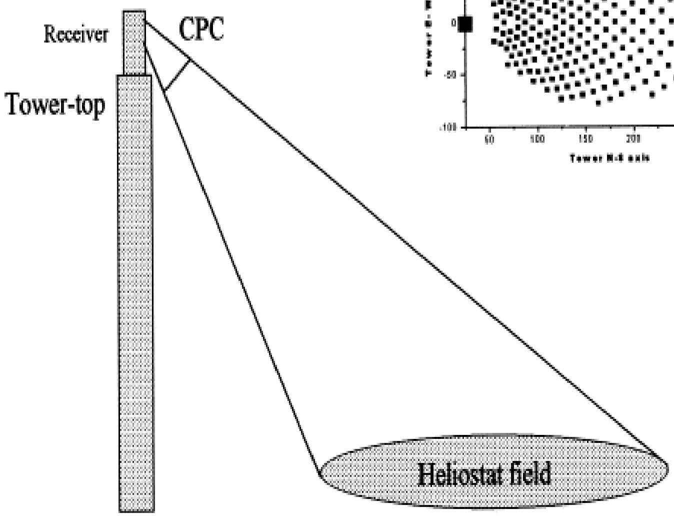
Using the optical concentrators in the central solar plants

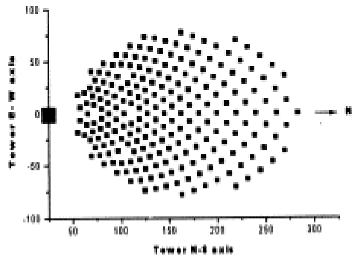
When is useful the receiver concentrator (RC) in tower-top optics ?

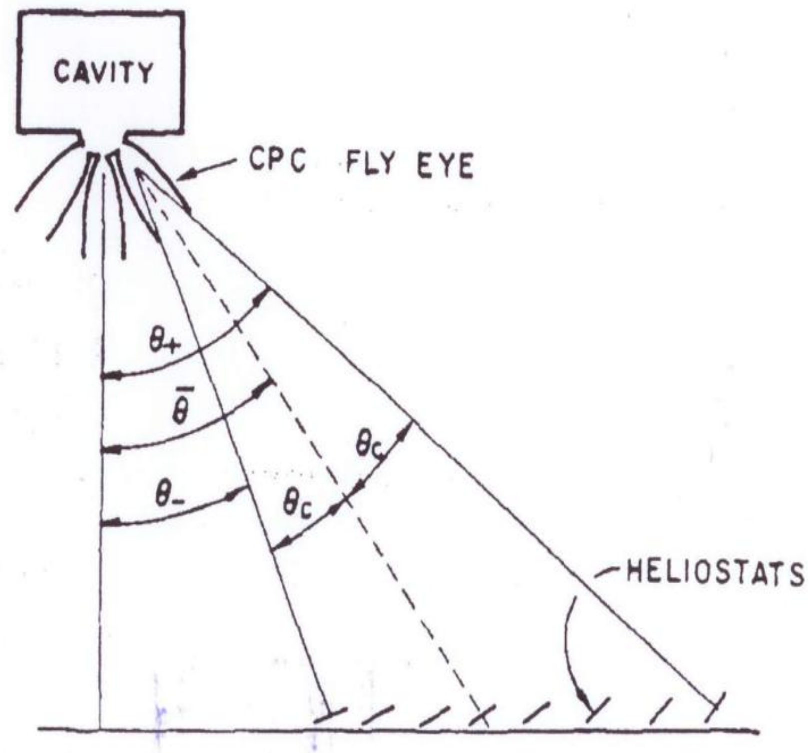


Identification of best available correlation between the CPC(s) adapted at receiver(s) used for central solar plants and the field of heliostats

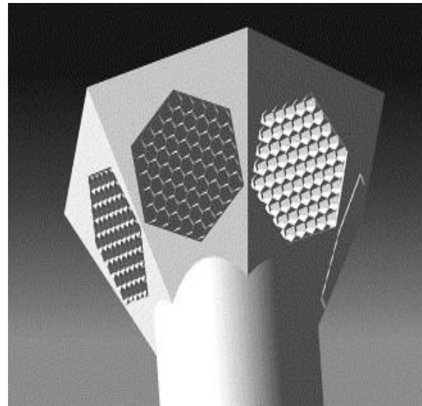
Rabl A., Solar Energy, **18**, p.99,1976



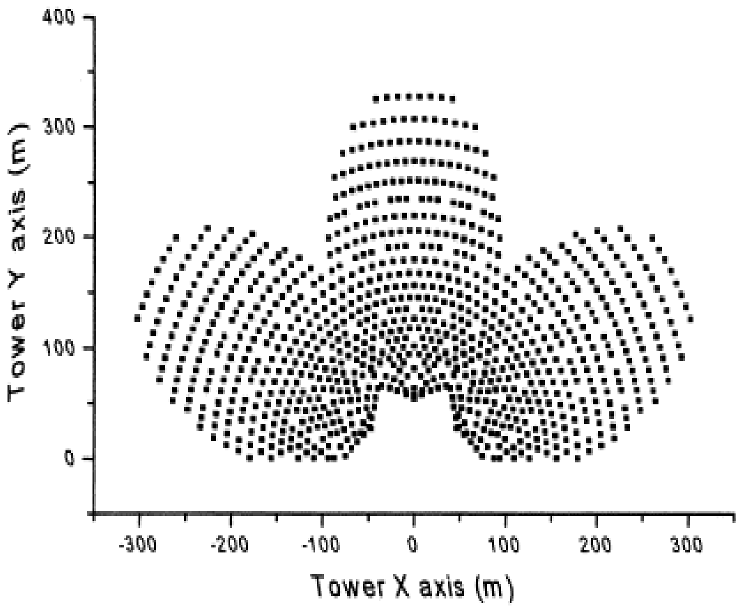


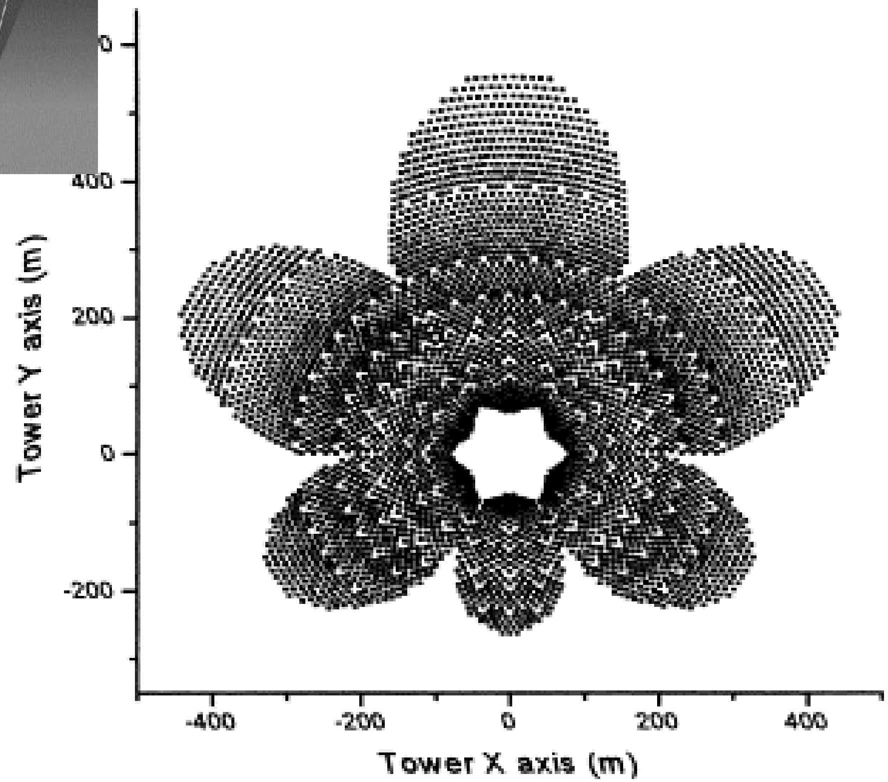


New concepts in designing the future central solar plants when secondary concentrators are provided

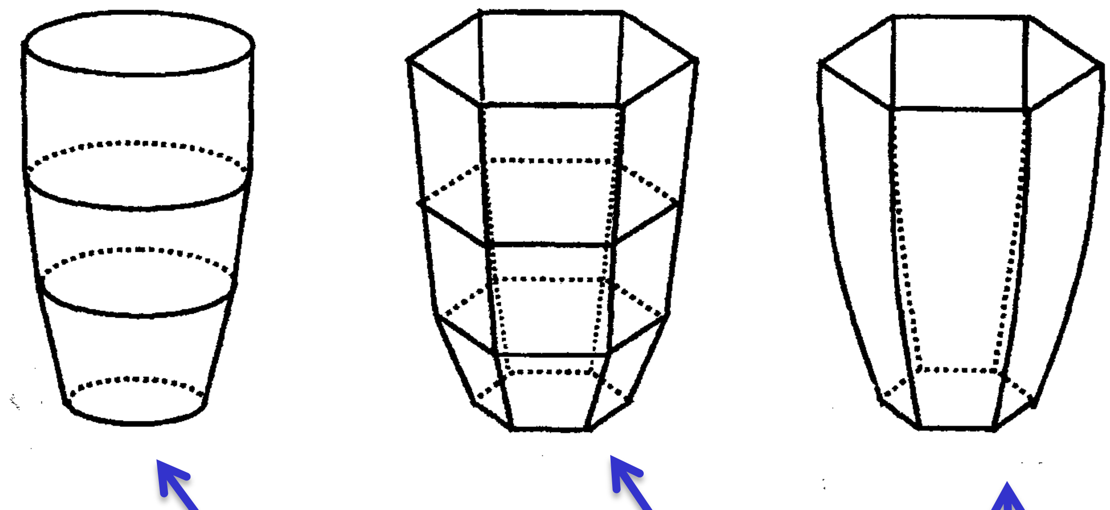


Schmitz et.al.,
Solar Energy,80,p.111,2006



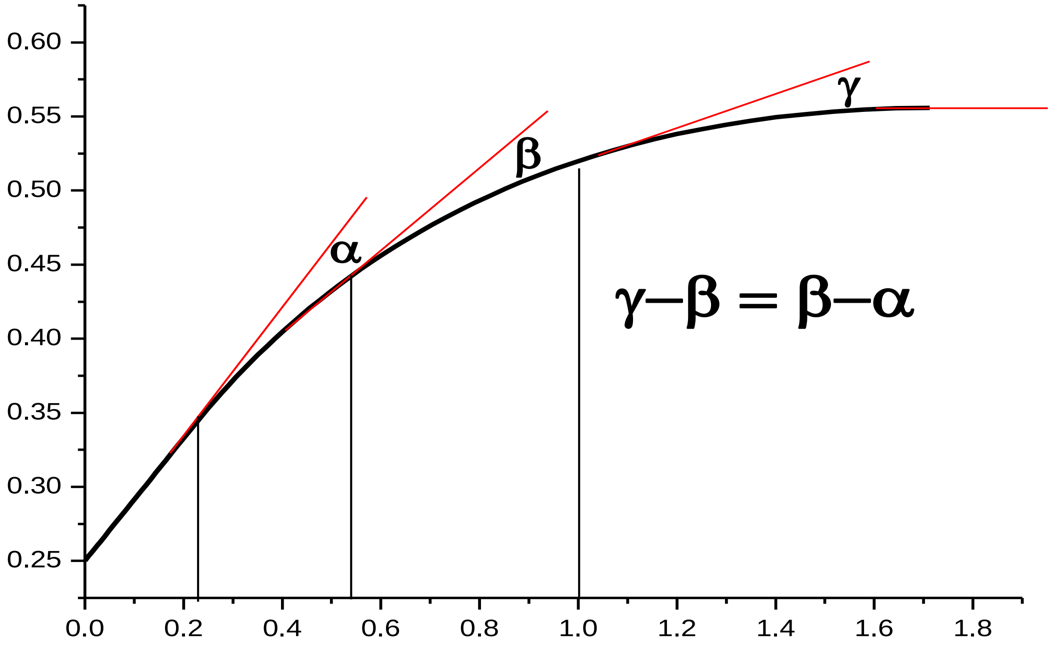


Segal and Epstein, Solar Energy, 65,p.206,1999



CPC approximated by truncated cones, truncated pyramids, 1-D curved facets

Identification of best available approximation of the mathematical profile of CPC in truncated cones or pyramids

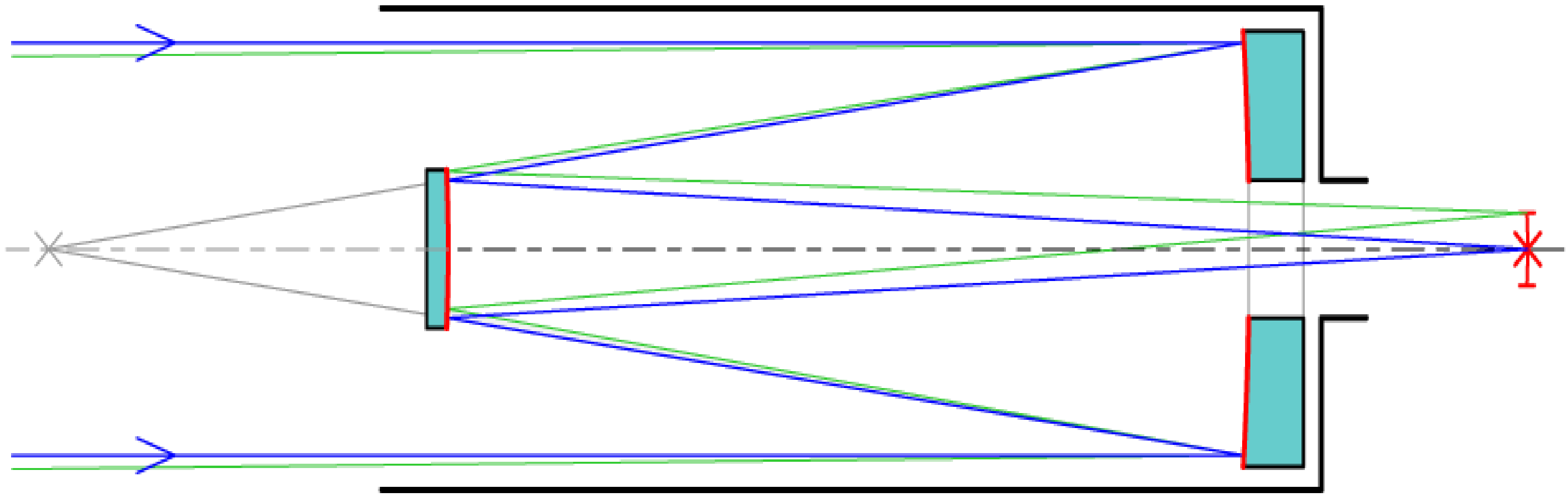


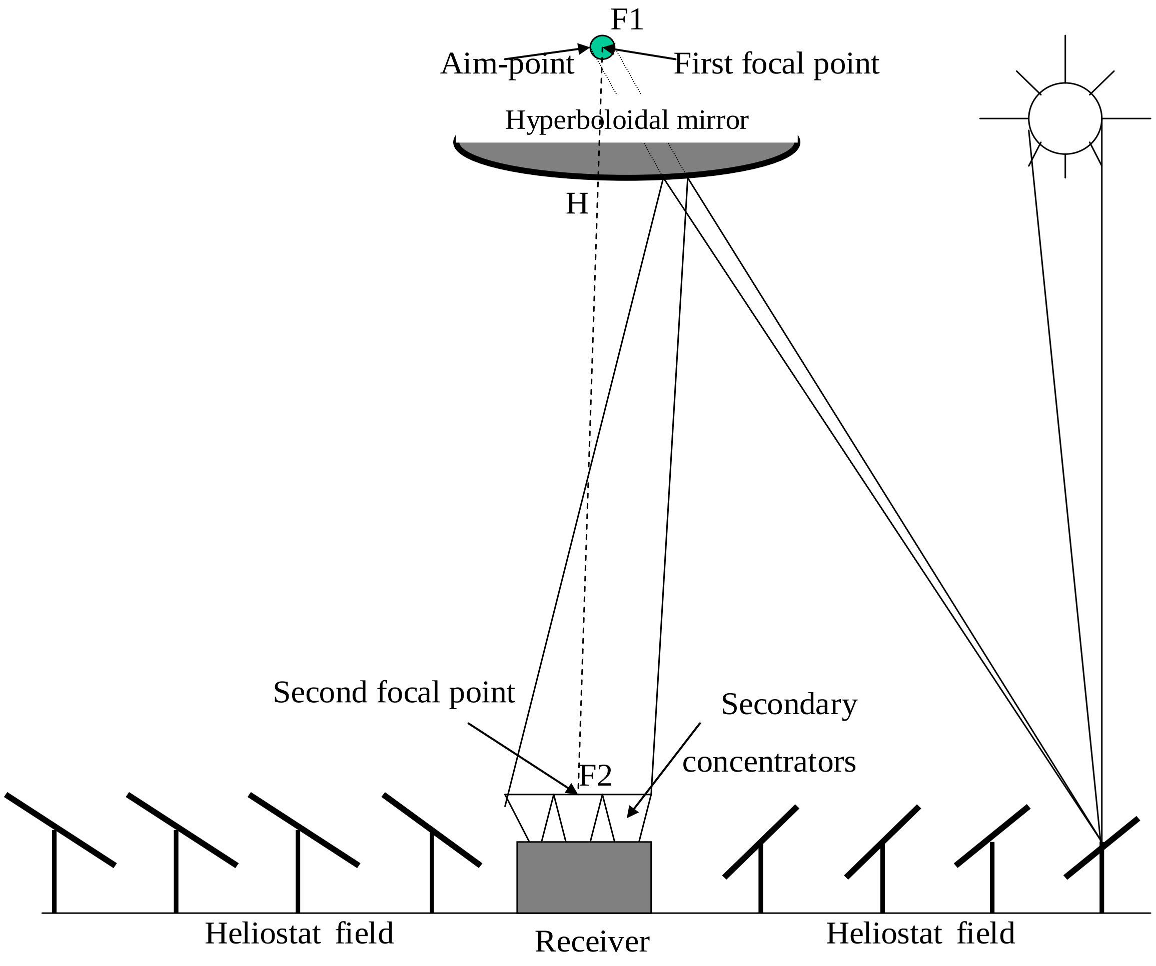
The optimum division: those points on the CPC profile satisfied the condition that difference between consecutive slopes remains constant.

A new optical concept prevails over the design of the solar plants with central receiver: the Beam-Down Optics

BEAM-DOWN OPTICS

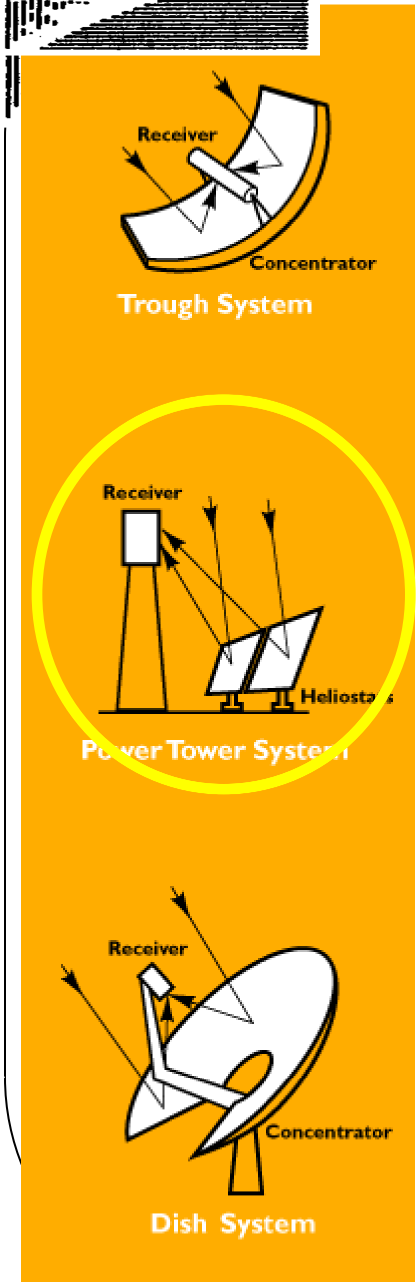
Cassegrain optics (17th century !!)
Cassegrain telescope (about 1850 !!)

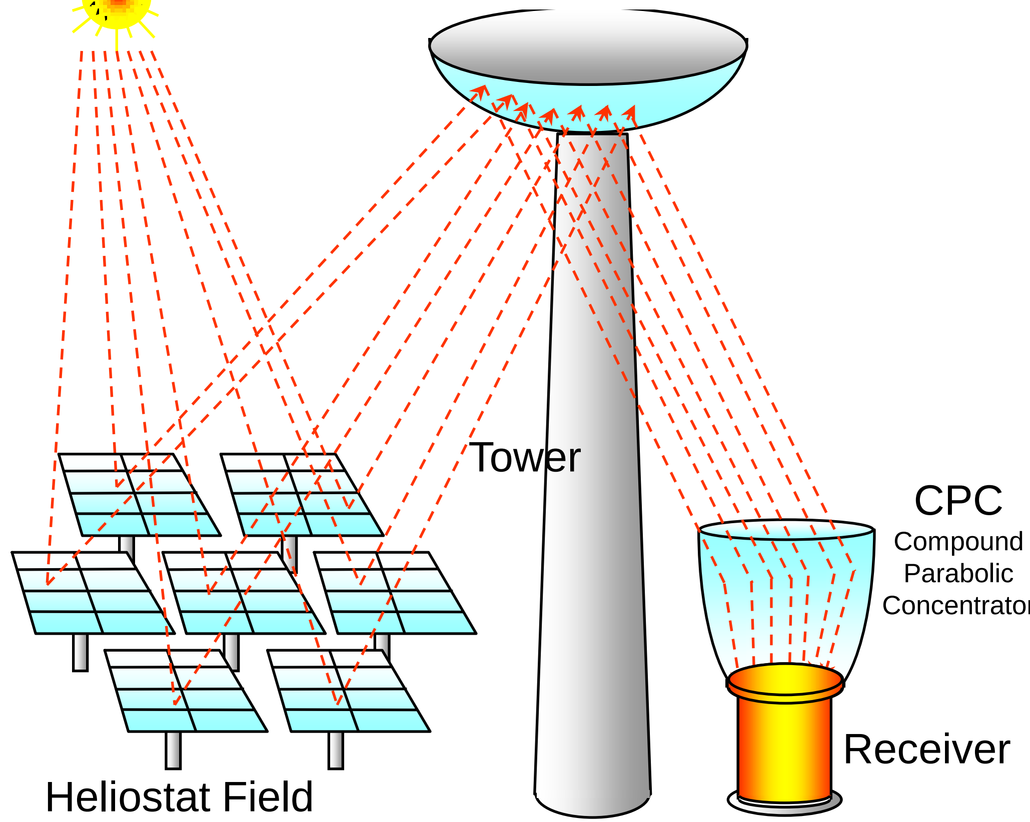


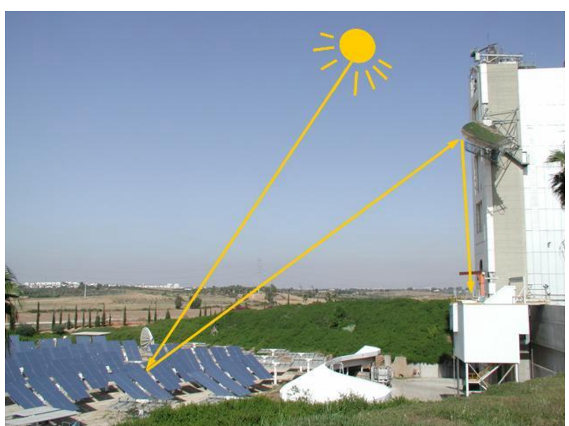


Principle of the Beam-Down Optics

Tower Reflector

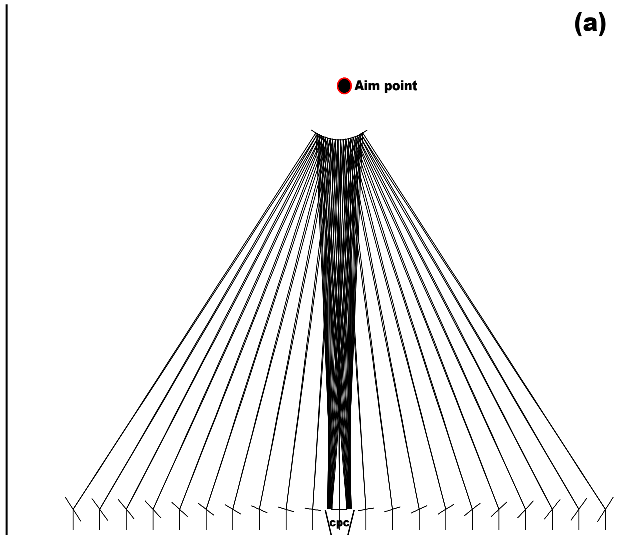


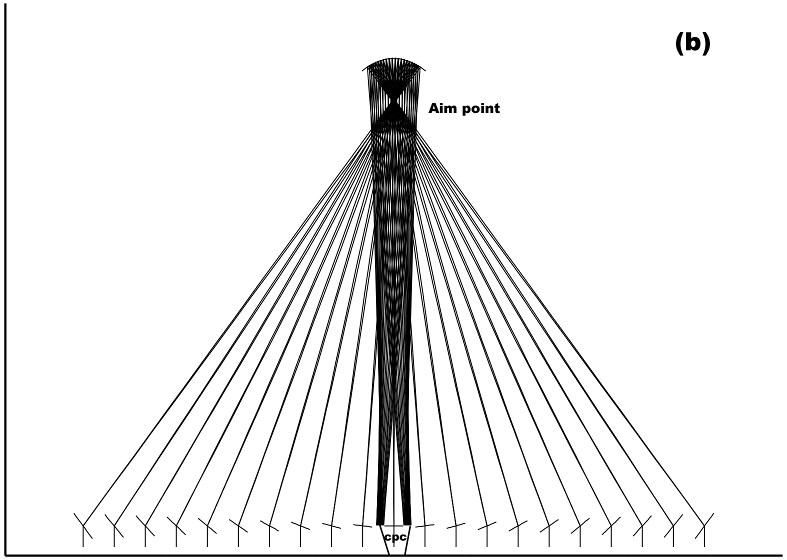


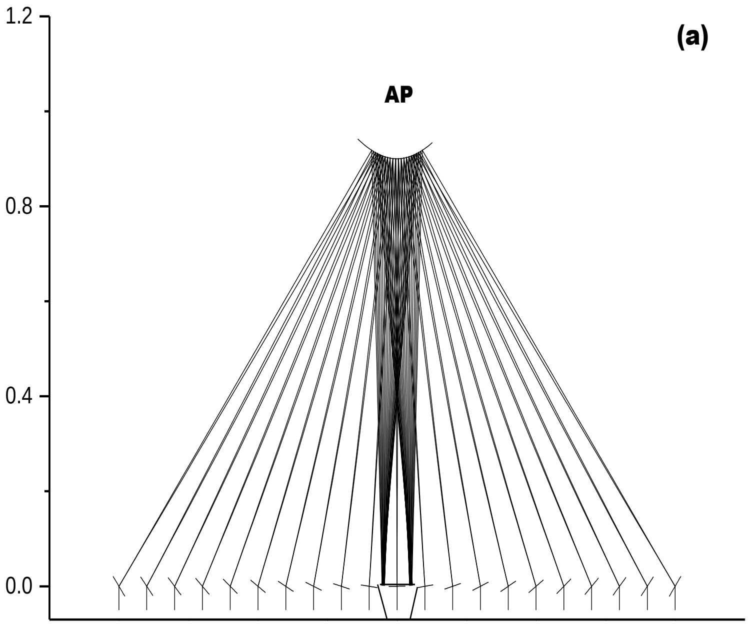


- Heliostat field + Tower Reflector (Cassegrainian
- Beam-down on CPC.
- C = 5,000 - 10,000.
- Major hardware on groun level.

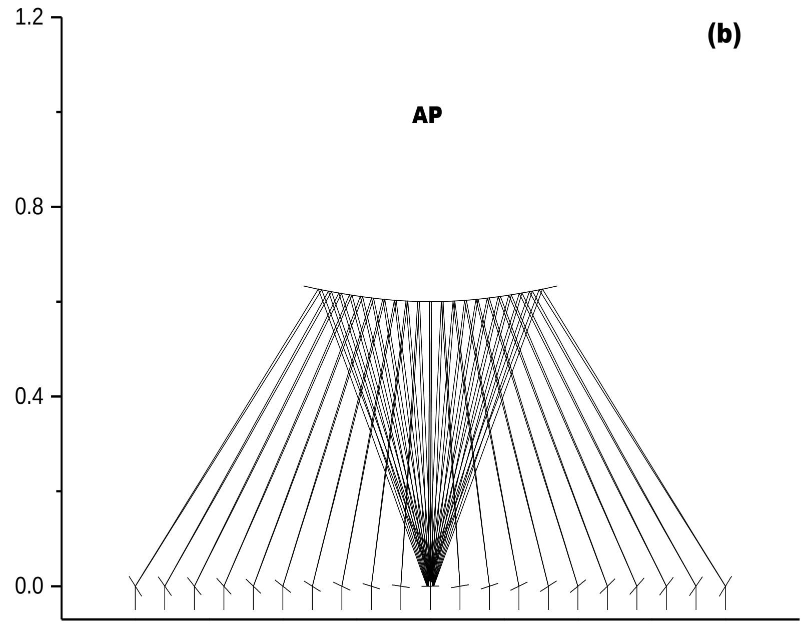
Tower reflector optics two options are available: hyperboloid and ellipsoid



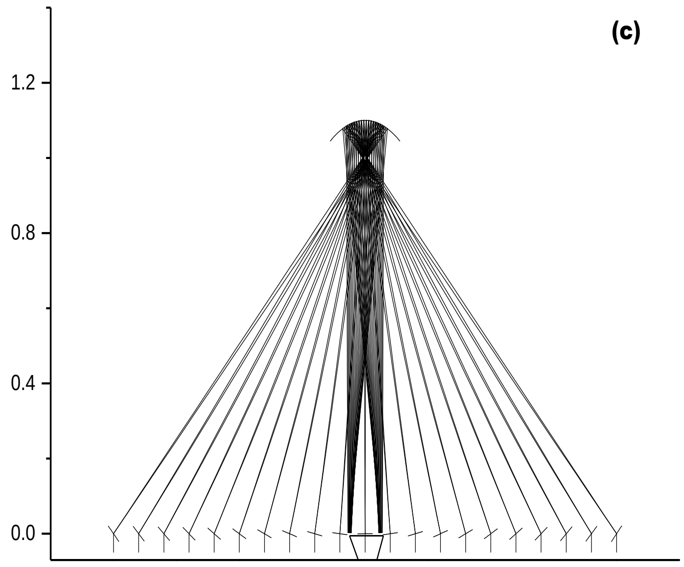


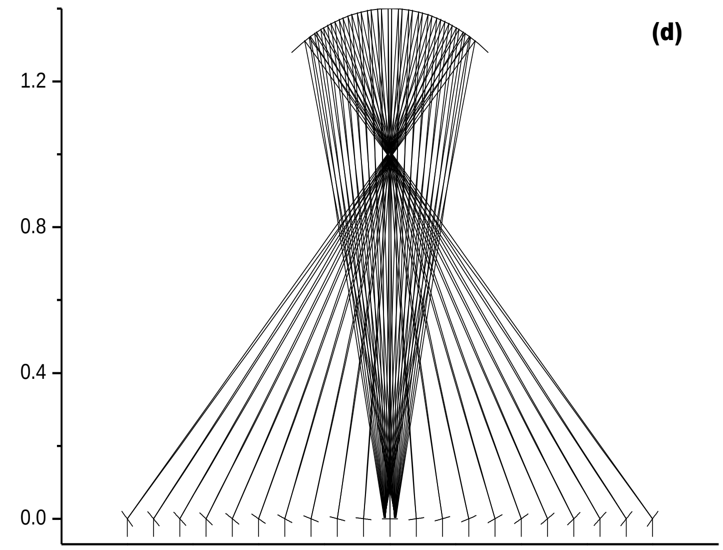


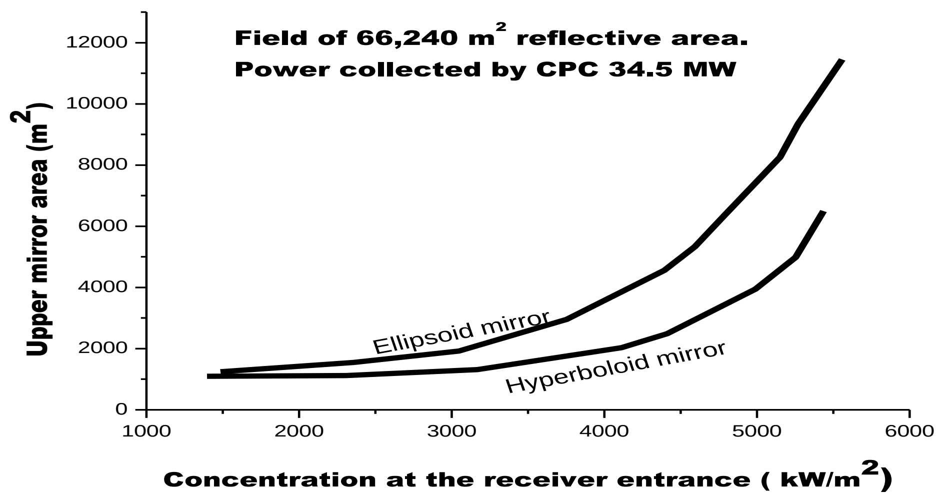
Smaller tower mirror, high flux on mirror, larger image on the ground focal plane



Larger tower mirror, lower flux on mirror, Smaller image on the ground focal plane



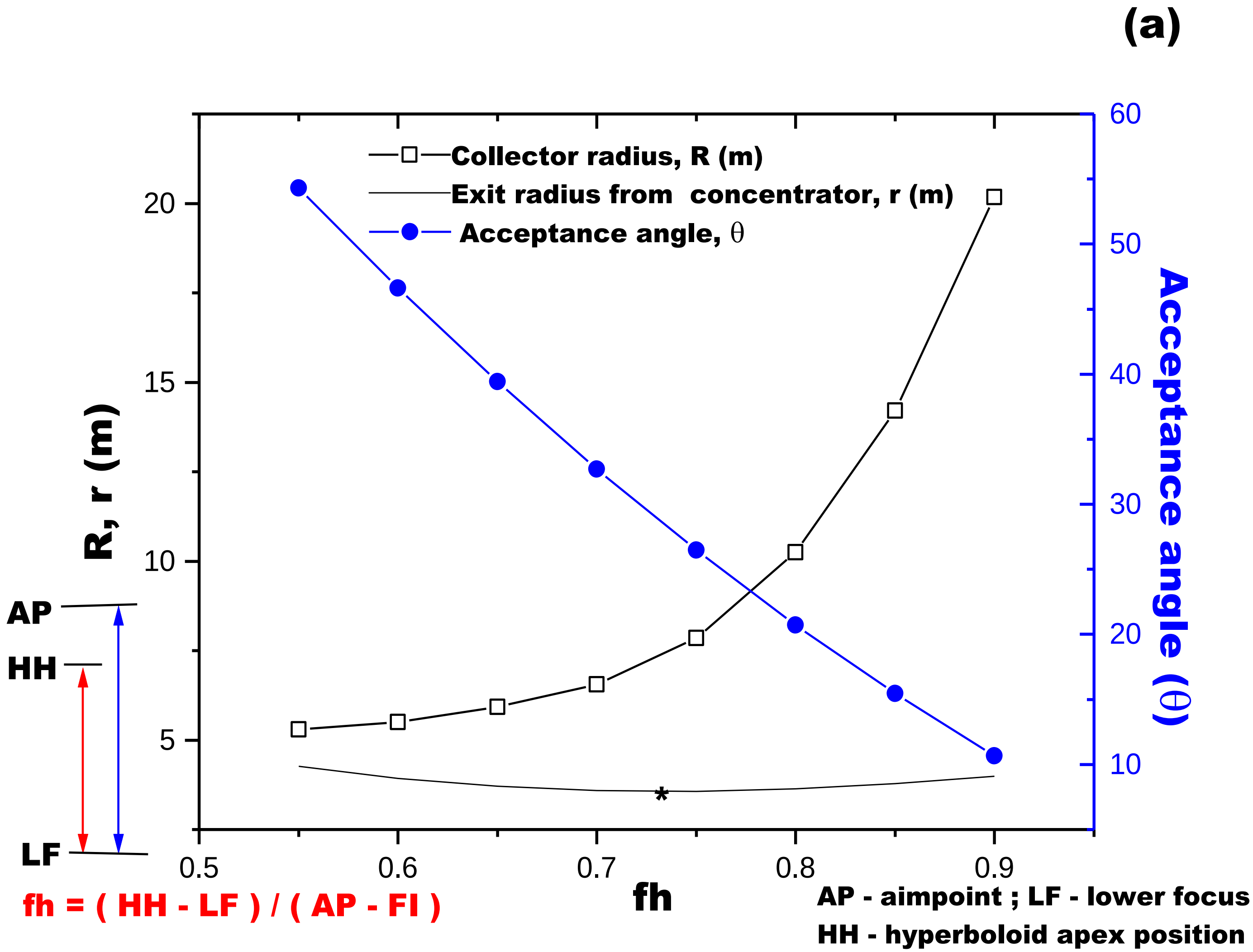


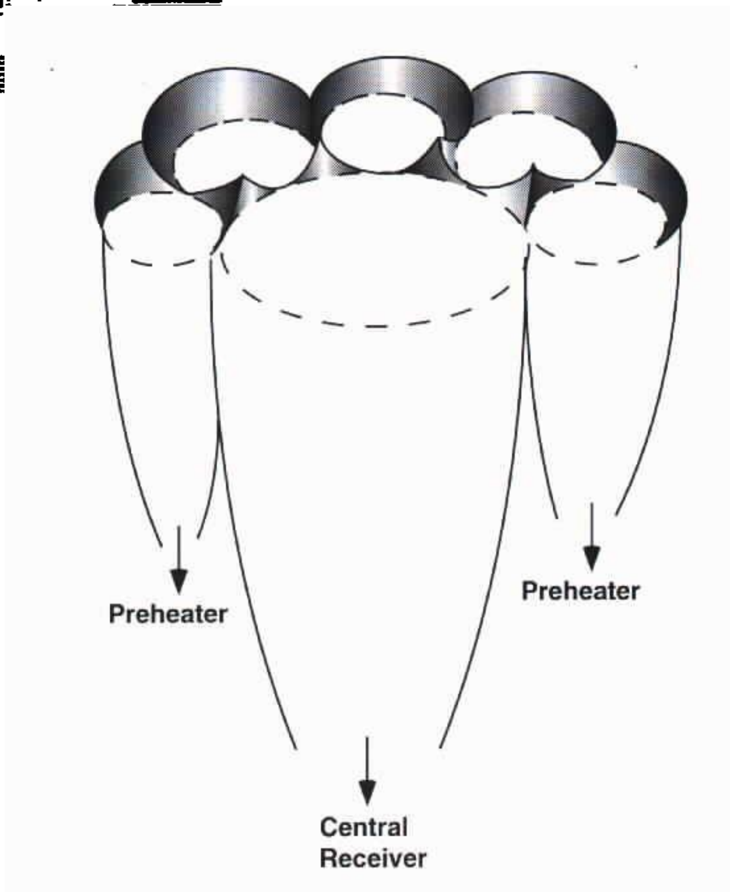


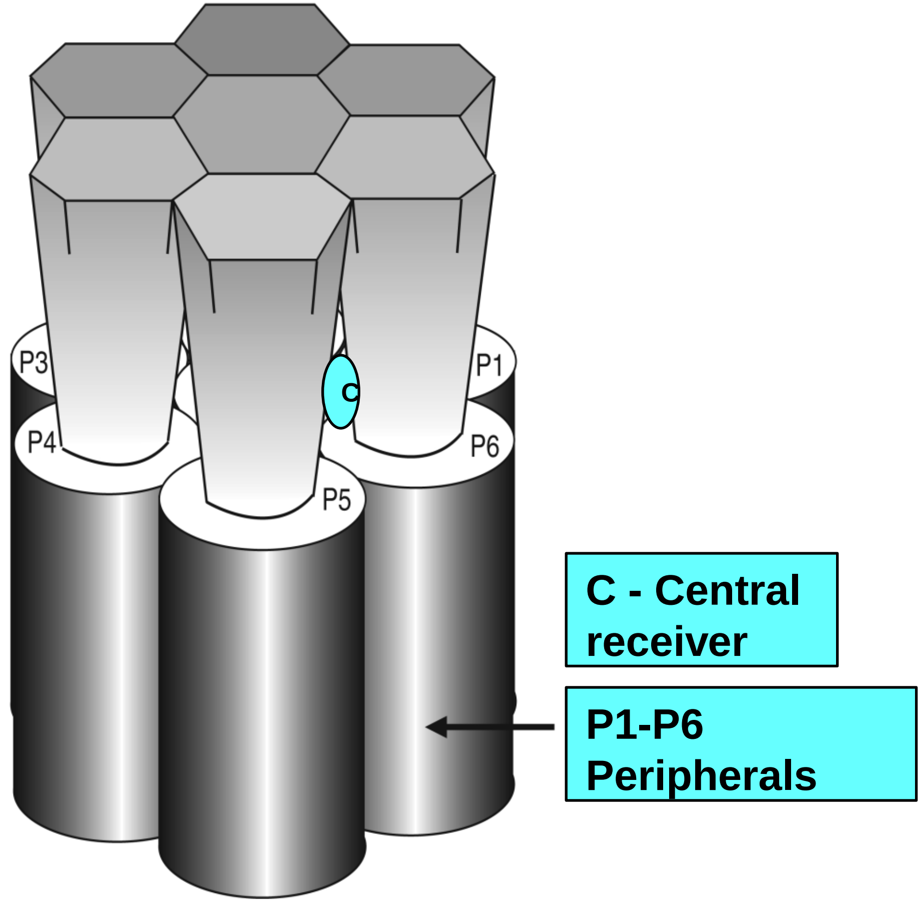
Comparison hyperboloid ellipsoid:
= at the same concentration at the receiver entrance, the ellipsoid area is greater than the hyperboloid area;
= at same area the hyperboloid gives a higher concentration

Ref.: A.Segal and M.Epstein - "The Optics of the Solar Tower Reflector" – *Solar Energy* **69** (Suppl.), pp. 229-241, 2000

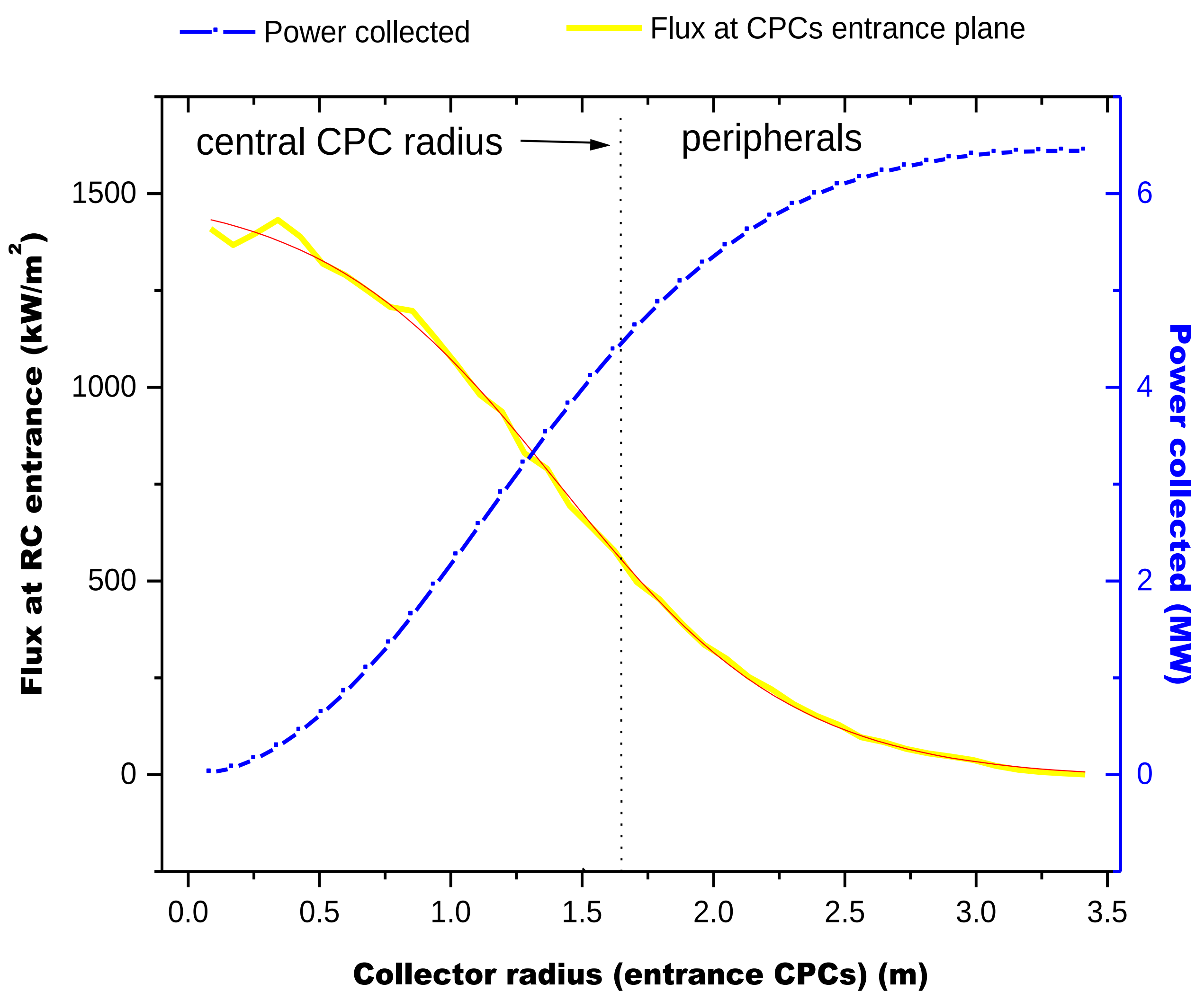
Collector radius and acceptance angle at various positions of the reflector (fh)



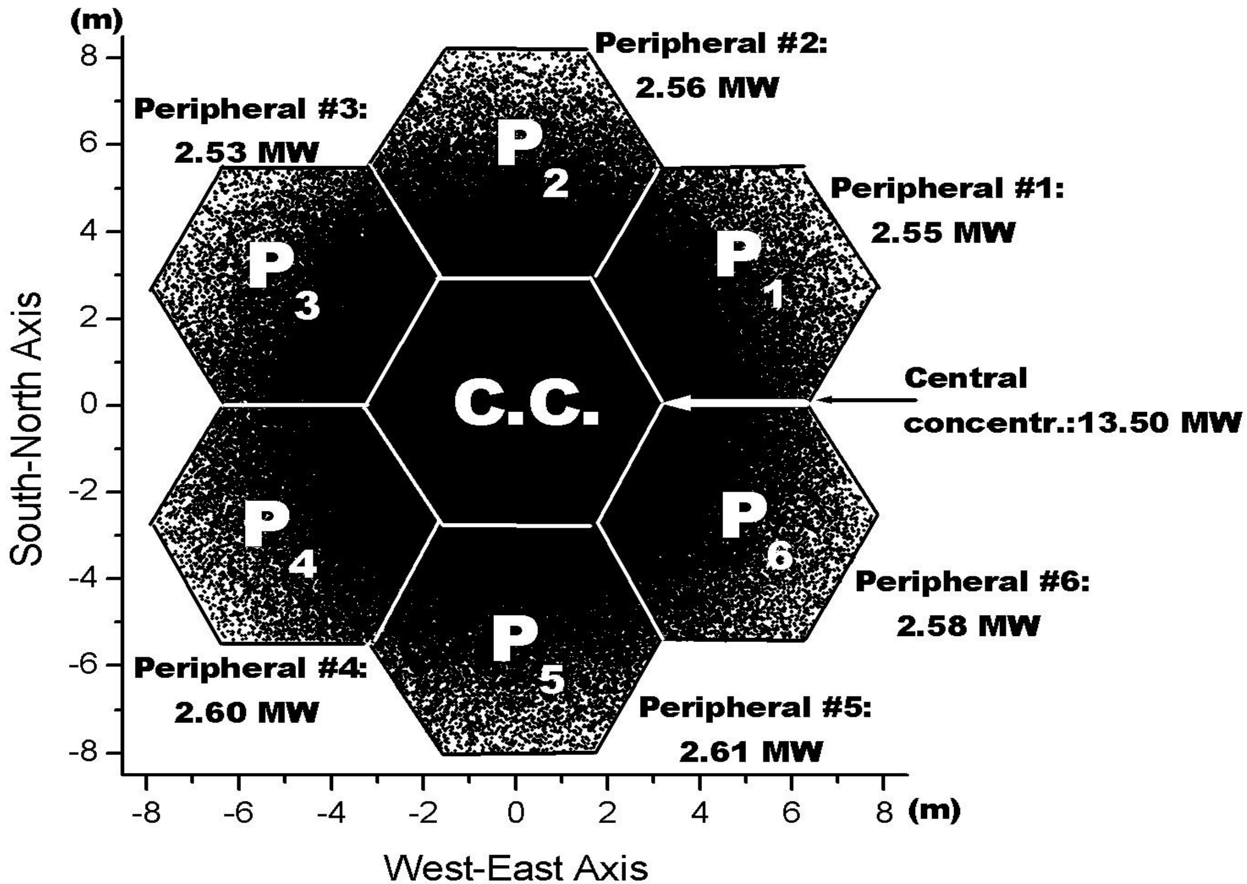

Preheater
Preheater
Central
Receiver

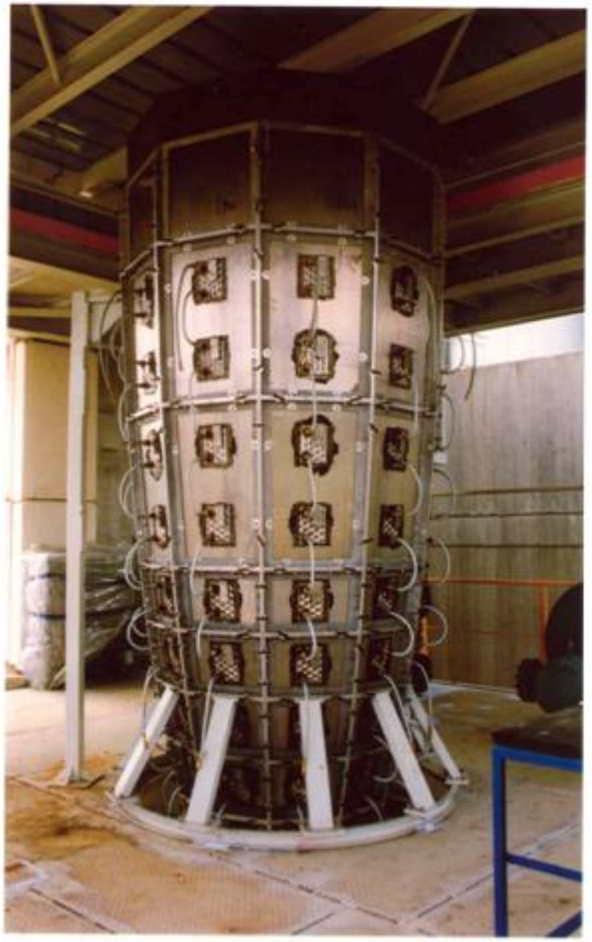

P3
P1
C
P4
P6
P5
C - Central
receiver
P1-P6
Peripherals

Flux and power vs. collector radius

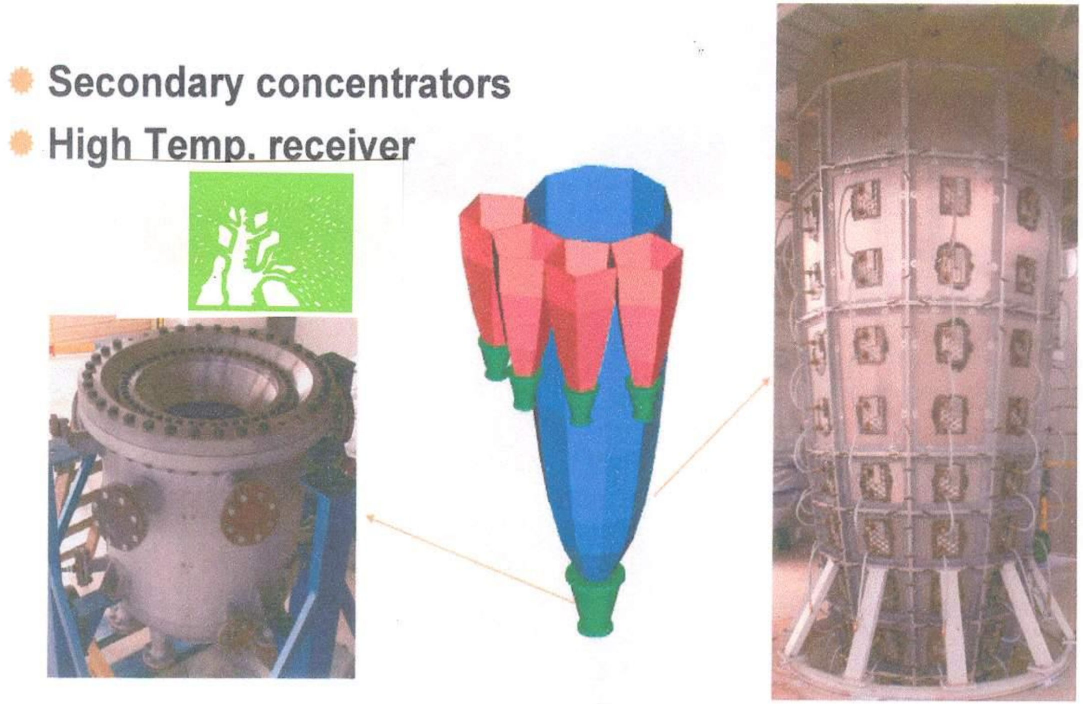


Ray tracing at the entrance plane of the ground concentrators





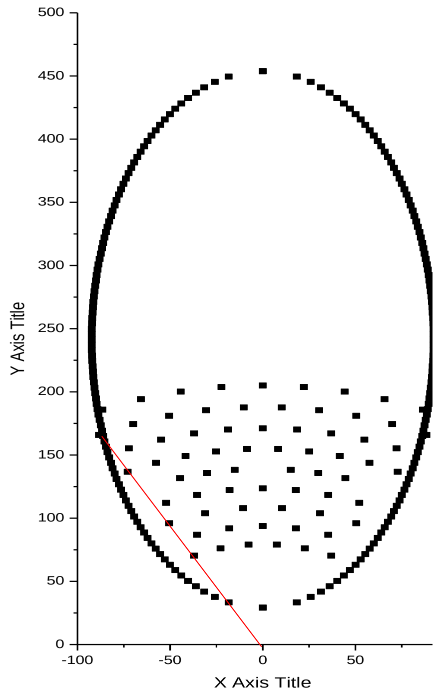
The World’s biggest concentrator: decagonal section; 10 segments; H=5m,D=2.2m, d=0.45m, θ=11˚

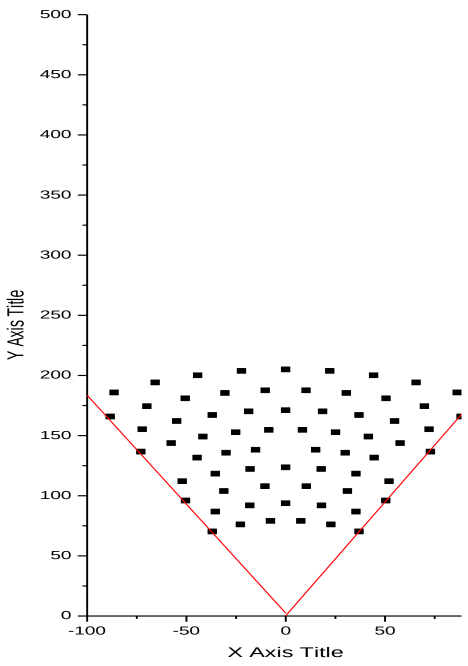


WIS central concentrator with designed peripheral concentrators

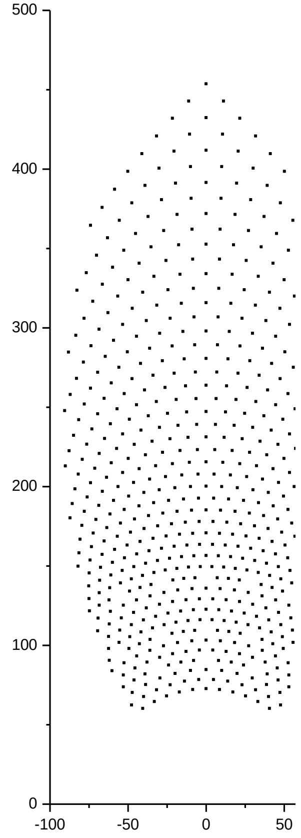
Application: Optical design for a central solar plant for 10MW

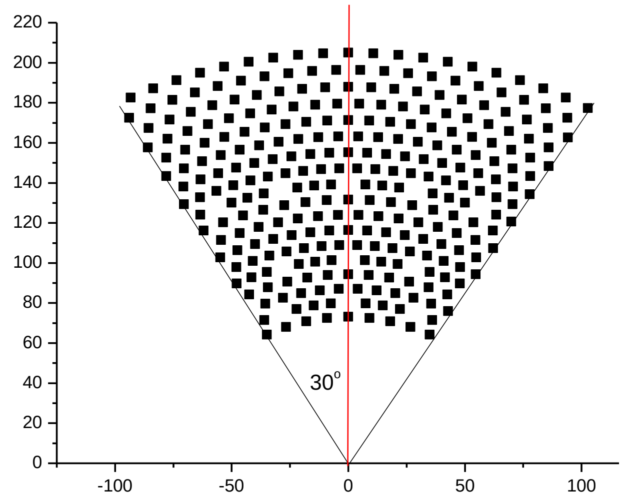
Restrictions: the receiver(s) is/are provided with window(s) having max. diameter 0.45m.
A cluster of 7 concentrators (accept.angle 30deg.) will have an equivalent diameter of 2.2m



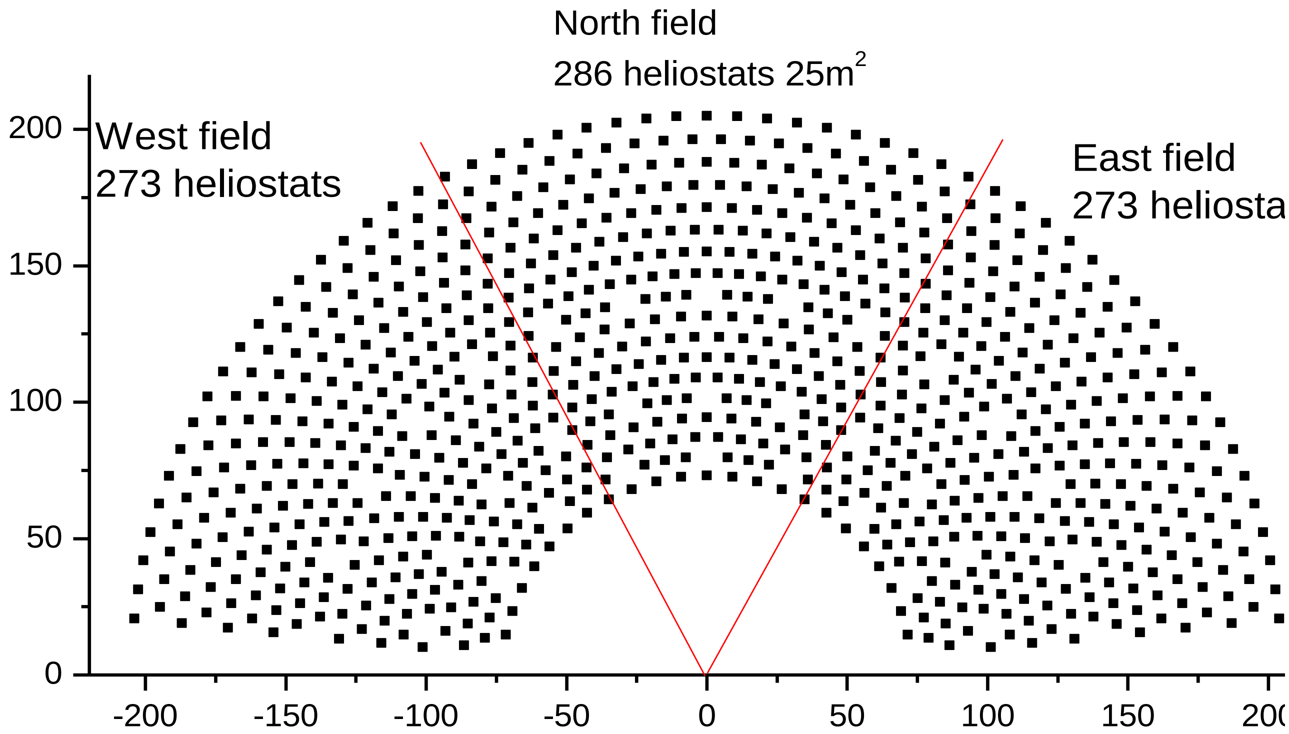


Stages in the field design





Field 832 heliostats x 25m2 each



Existing software at W.I.S (1)

Design of CPC : CPCdesign.for

Input: -exit radius; acceptance angle; exit angle.

Output: -numerical CPC profile

Options for output:

- **CPC truncation:**

= given maximum entrance radius is calculated the corresponding length or

= given maximum length is calculated the entrance radius

- **CPC approximated by 'n' segments; options:**

  = equal segments

  = non-equal segments;

  = truncated height

exit radius(m) acceptance angle(grd) exit angle(grd) steps

0.20 20. 70. 10000

cpc dimensions:

acceptance angle	(deg):	20.0	
maximum exit angle	(deg):	70.0	
exit radius/diameter	(m):	0.200	0.400
conic radius/diameter	(m):	0.282	0.564
length of conic part	(m):	0.175	
CPC entrance radius/diam	(m):	0.549	1.098
concentrator length	(m):	2.059	
CPC area	(m^2):	6.022	

CPC entrance radius/diam (m): 0.549 1.098
concentrator length (m): 2.059
CPC area (m^2): 6.022

interpolations for truncated CPC :

- given radius calculate height - enter: 1 "radius (m)"
- given height calculate radius - enter: 2 "height (m)"
- for nonequal partitions - enter: 3 "number_of_partitions"
- for equal partitions - enter: 4 "number_of_partitions"
- to finish - enter: 0 0

1 0.55
radius greater than maximum possible: 0.549530
1 0.50
r= 0.500000 z= 1.068932
CPC dimensions (truncated):
truncated CPC entrance radius/diam (m): 0.5000 1.0000
truncated concentrator length (m): 1.0690
CPC area (m^2): 2.6933

2 1.07

z= 1.069000 r= 0.500008

cpc dimensions (truncated):

truncated CPC entrance radius/diam (m): 0.5000 1.0000

truncated concentrator length (m): 1.0693

CPC area (m^2): 2.6942

3 4

Lmax

1.069

partition in 4 non-equal segments;Lmax= 1.0690

	r	z	Δz	grd.	Δgrd.
	0.2000	0.0000			
segm.1	0.2818	0.1754	0.1754	25.0	
segm.2	0.3505	0.3475	0.1721	18.9	6.1
segm.3	0.4249	0.6146	0.2671	12.8	6.1
segm.5	0.5000	1.0693	0.4547	6.7	6.1

CPC dimensions (truncated):

truncated concentrator length(m): 1.0690

truncated CPC area (m^2): 2.6933

4 4

Lmax

1.069

partition in 4 equal segments Lmax=1.069;

	r	z	Δz
	0.2000	0.0000	
segm.1	0.2828	0.1754	0.1754
segm.2	0.3893	0.4732	0.2978
segm.3	0.4565	0.7711	0.2979
segm.4	0.5000	1.0690	0.2979

CPC dimensions (truncated):

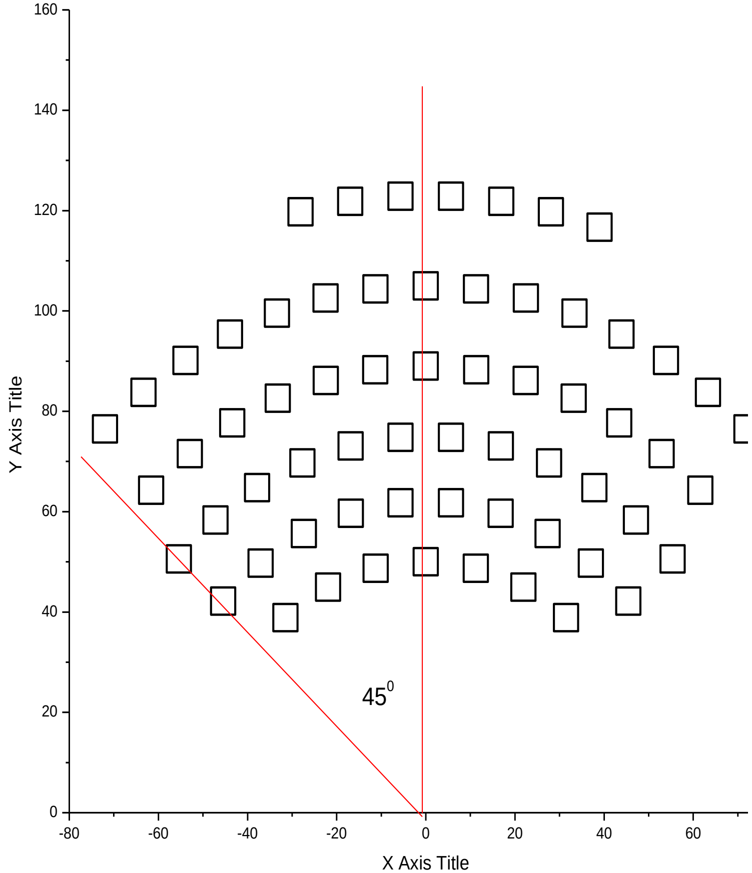
truncated concentrator length(m): 1.0690

truncated CPC area (m^2): 2.6933

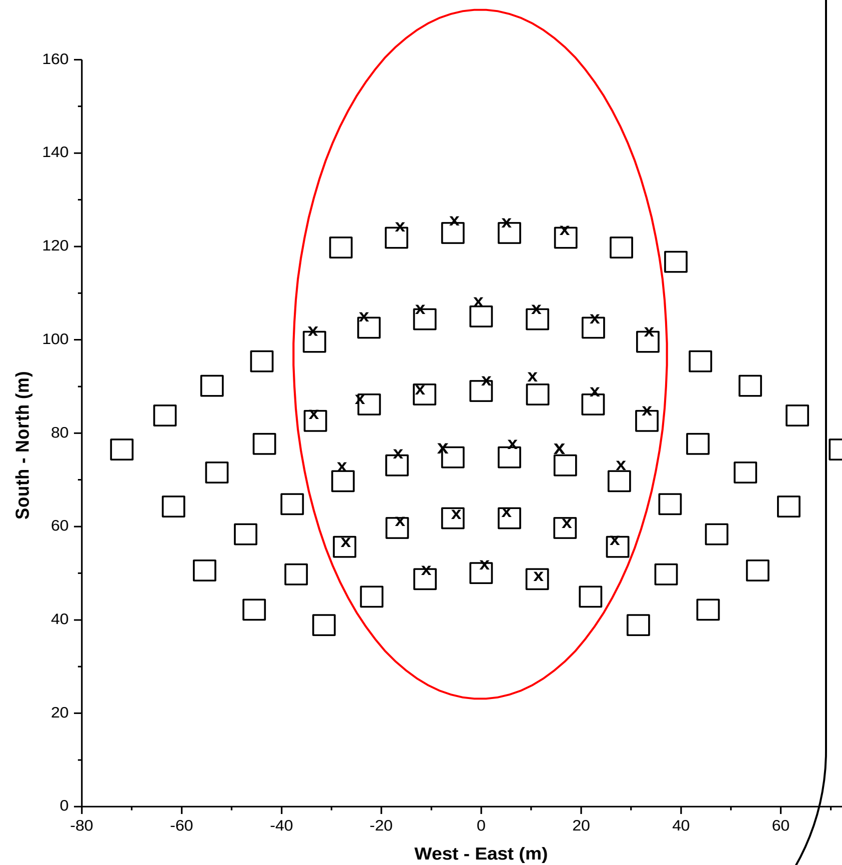
Existing software at W.I.S (2)

Transmission by CPC : ASsfera.for
Input is the output from CPCdesign.for
Options:
no=1; Only a circular aperture of given diameter;
no=2; CPC mathematical perfect;
no=3; CPC approximated by n cone segments;
no=4; CPC approximated by n pyramid segments; having cross section regular polygons with m sides;
no=5; CPC approximated as at previous point + CPC peripherals (possible combinations m=3,p=6; m=6, p=6; m=10, p=5)

Heliostat field at WIS
64 heliostats 54m^2 reflective surface



Part of the WIS field (37H) seen by a CPC having θ=20˚ d=0.4m; at H= 44.8m, tilted δ=-37˚ (used only 33H)



INPUT:

file: 'trasol.ray' **(produced by TRASOL.FOR with input from 33 heliostats from WIS field)**

file:'geom.dat': **(produced by CPCdesign.FOR CPC: r=0.2m, $\theta=20^o$, $\theta_o=20^o$ truncated 1.8m)**

.54673	6	
.50675	.67078	h1+..+h6=1.8000
.44965	.39616	..
.39072	.25563	..
.33442	.17589	..
.28177	.12699	h1+h2=0.3023
.20000	.17535	h.conical segm
3.00000		

OUTPUT:

field with 33 heliostats
having the tracing errors 0.50 + 0.50 mrad
and the surface errors   1.10mrad
insolation 800. W/m2

run for the day 21 March   hour 12.00

average cos(f)   0.9643
average shadowing(%)   0.00
average blocking (%)   1.26

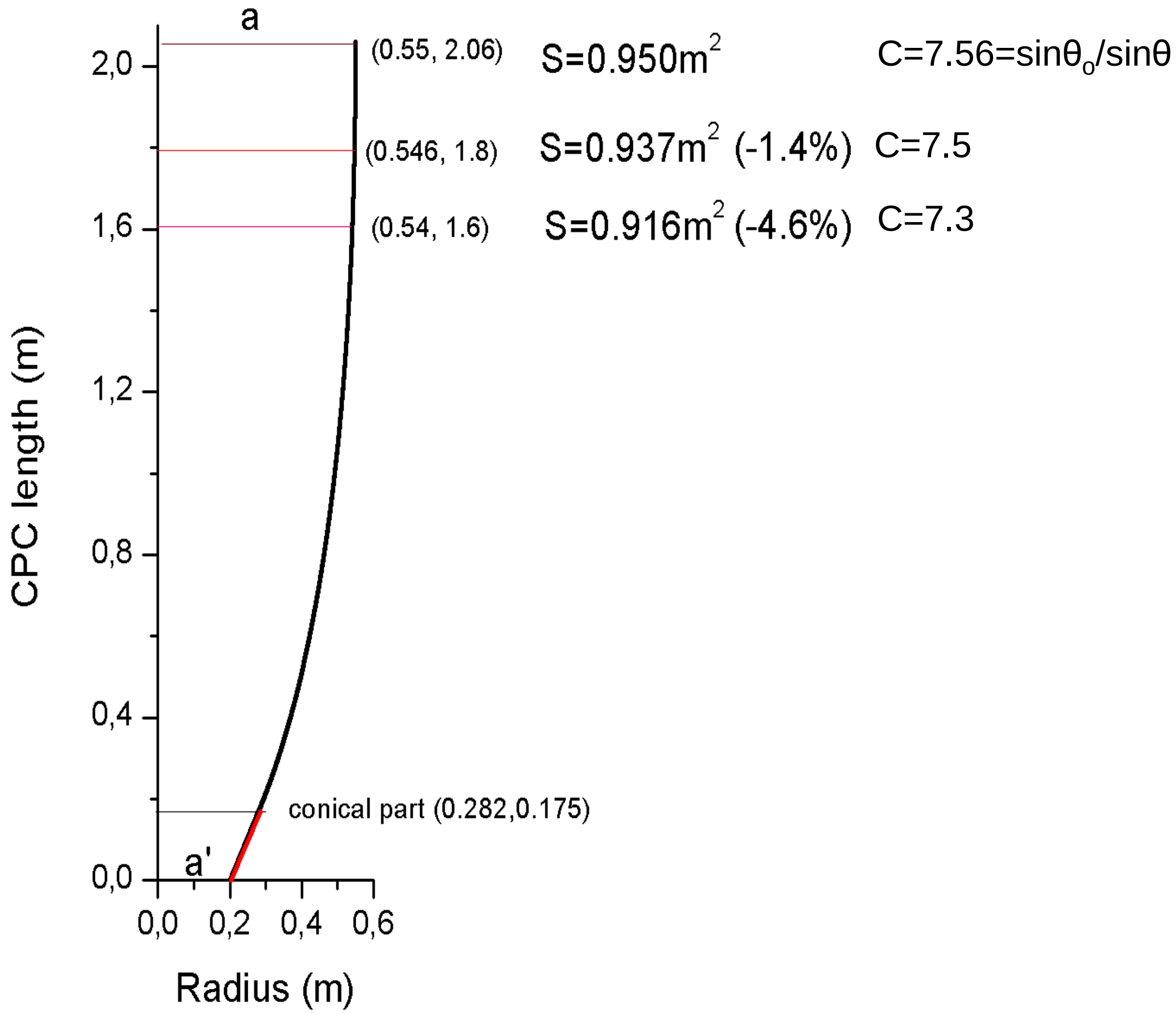
Concentrator dimensions
CPC with the circular cross section
radius at the CPC entrance 0.5467m
radius at the CPC exit   0.2000m
total concentrator height   1.8000m
the concentrator axis is tilted -33.deg with the horizontal

power balance

number of rays analyzed:	1281.5
hit tower before target	0.0
spillage	821.2
rays enter concentrator:	460.3
rejected in concentrator:	31.9
absorbed in concentrator:	76.5
rays transmitted:	351.9
problematic rays:	0.1

average number of reflect: 1.22

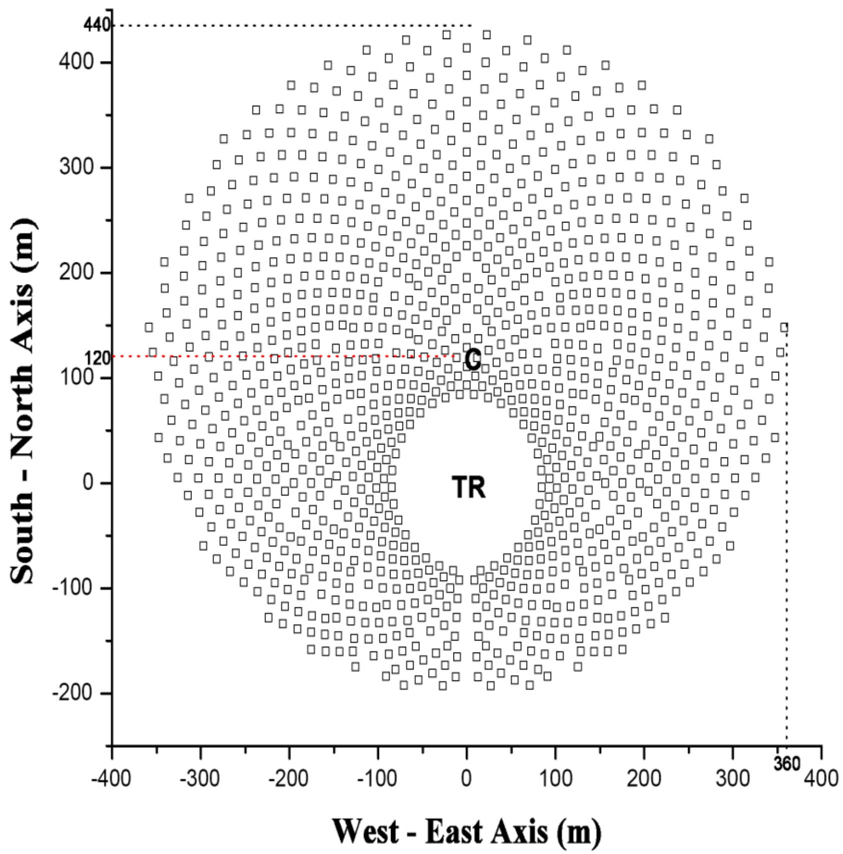
average flux in receiver : 2800. kW/m2


a
(0.55, 2.06)
S=0.950m²
C=7.56=sinθo/sinθ
(0.546, 1.8)
S=0.937m² (-1.4%)
C=7.5
(0.54, 1.6)
S=0.916m² (-4.6%)
C=7.3
conical part (0.282,0.175)
a'
CPC length (m)
Radius (m)
2,0
1,6
1,2
0,8
0,4
0,0
0,0
0,2
0,4
0,6

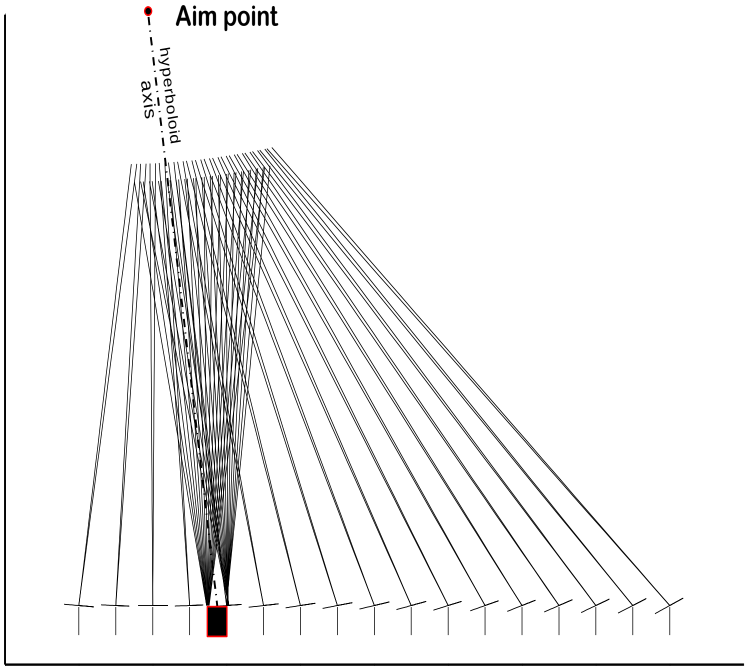
RESULTS

	d(m) / θ / θ_o	D(m)	L(m)	Spillage (kW)	Enter CPC(kW)	Losses (kW)	Enter rec.(kW)
CPC perfect	0.4/20°/70°	1.10	**2.06**	815	477	121	356
Perfect,TRUNCATED	0.4/20°/70°	1.09	**1.80**	821	460	115	345
CPC 6cones; NEq	0.4/20°/70°	1.09	1.80	821	460	108	352
CPC 6cones; Eq	0.4/20°/70°	1.09	1.80	821	460	112	349
CPC 6trunc.pyr;NEq	0.4/20°/70°	1.09	1.80	825	457	119	337
CPC18trunc.pyr;NEq	0.4/20°/70°	1.09	1.80	825	457	115	**342**
Perfect, TRUNCATED	0.4/20°/70°	1.08	**1.60**	831	450	111	339
CPC 6cones; NEq	0.4/20°/70°	1.08	1.60	831	450	112	338
CPC 6cones; Eq	0.4/20°/70°	1.08	1.60	831	450	115	335
CPC 18cones; NEq	0.4/20°/70°	1.08	1.60	831	450	111	**339**

LARGE FIELD 90MW$_{thermal}$

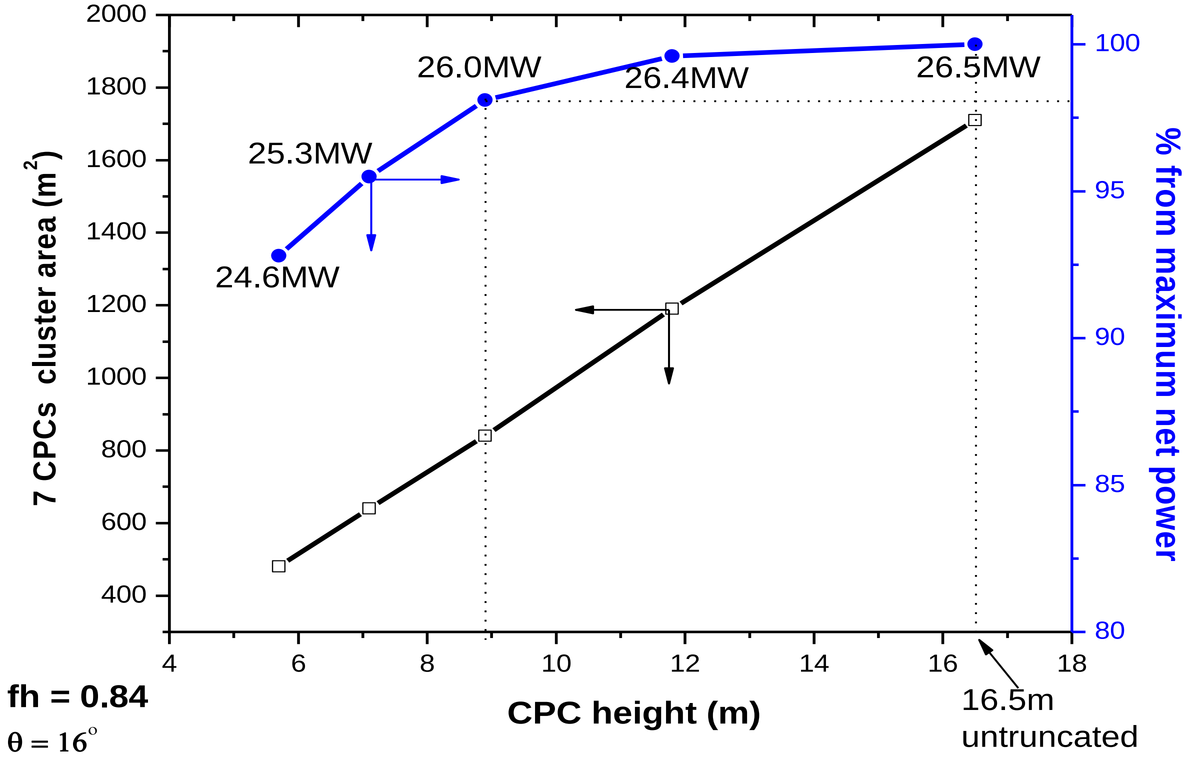


Asymmetric field: hyperboloid axis is tilted

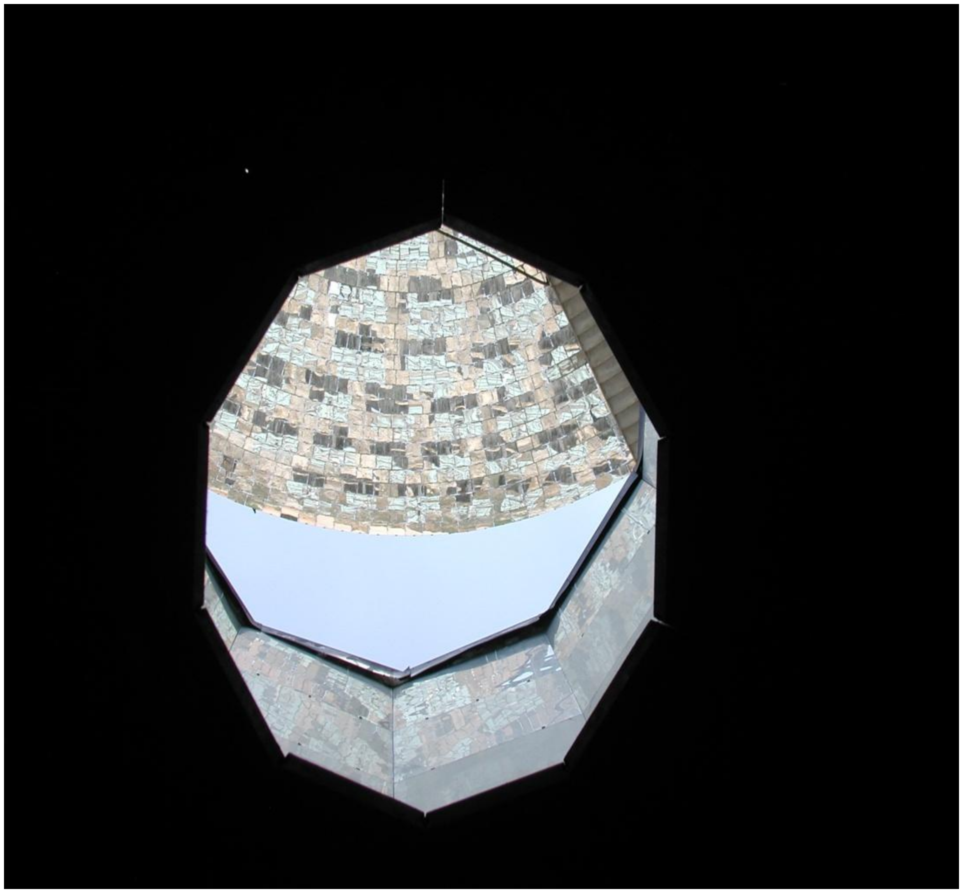


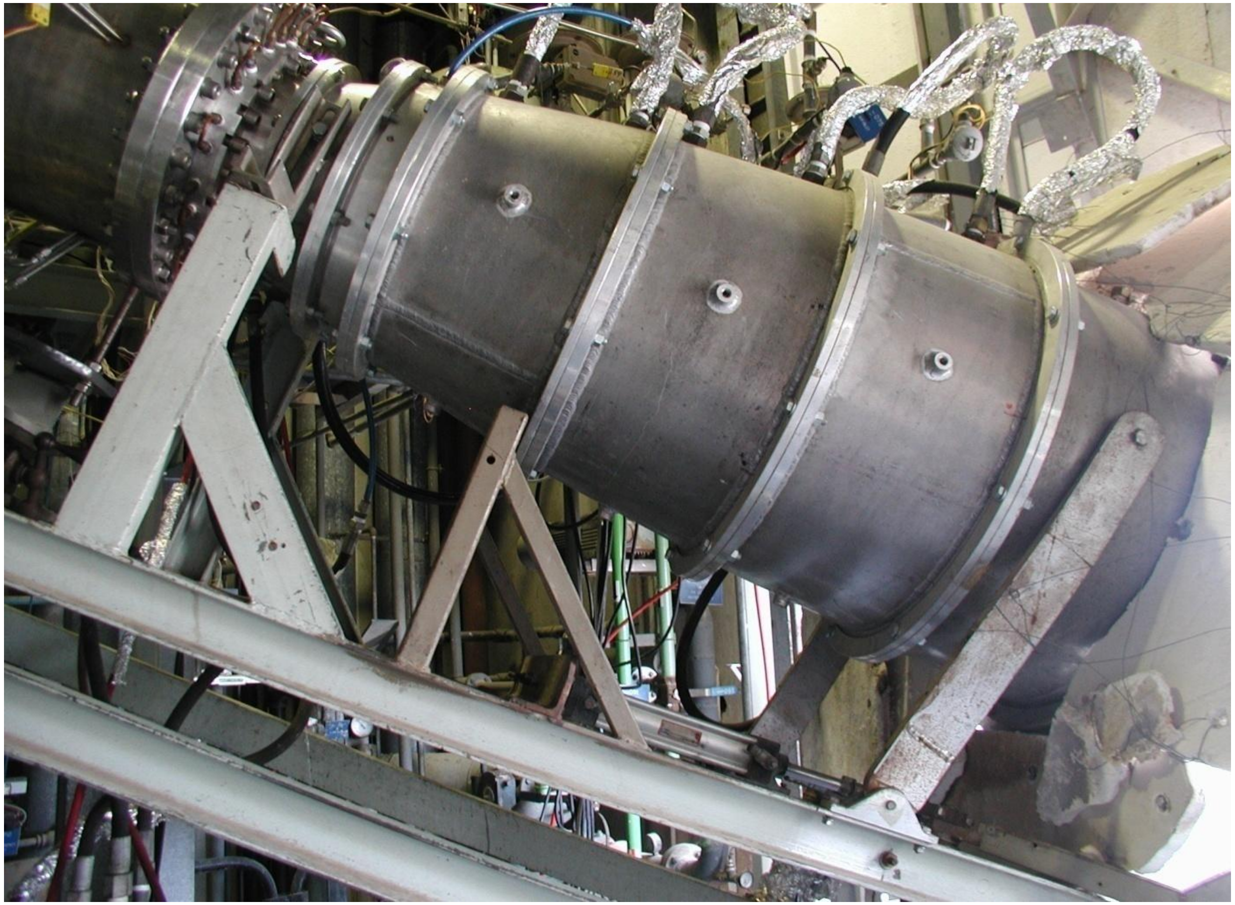
Field design for 1108 heliostats 100m^2 each ; tower reflector 3180m2; power in CPCs 63.5MW; power in central CPC 26.8MW

CPC height (m)	Entrance radius of single CPC unit (m)	7 CPCs cluster area (m^2)	Spillage around entrance (MW)	**Total power entered the CPC cluster (MW)**	**Net power absorbed** (MW) (after losses)	% from line 1
19.7 CPC height untruncated	5.34	3160	2.7	**63.5**	**51.3**	100.
14.1	5.20	2250	2.9	62.7	51.0	99.4
12.6	5.10	1990	3.2	62.4	50.7	98.9
10.5	4.90	1620	3.8	61.8	50.2	97.8
8.90	4.70	1350	4.6	61.0	49.5	96.5



Net power into receiver with truncated CPC





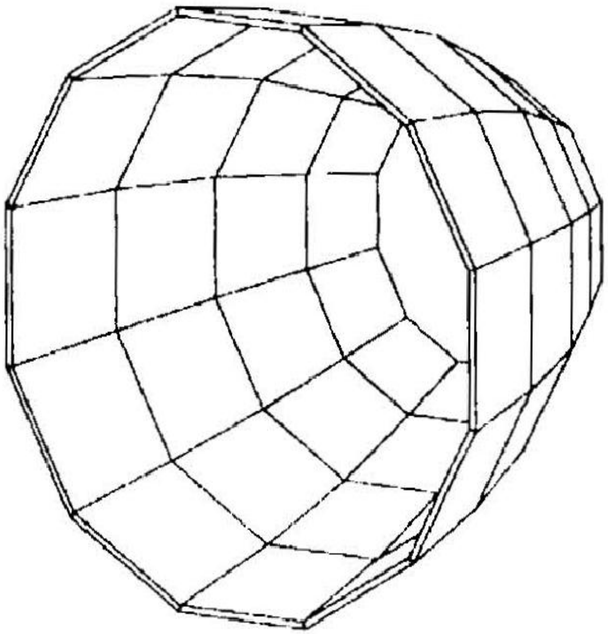
The 30 KW Reformer CPC

H = 1.7m; D_{in}= 64cm; D_{out} = 15cm; Θ = 12°

The 500 KW Reformer CPC

H = 1.05m; D_{in}= 1.17m; D_{out} = 0.58m; Θ = 20°

12 Facets; 4 Rows



Principal references:

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2. Welford W.T., Winston R., “High Collection Nonimaging Optics”, Academic Press, San Diego, 1989
3. Winston R., Miňano J.C., Benitez P. *et all*, “Nonimaging Optics”, Elsevier Academic Press, Amsterdam, 2005
4. Chaves J., “Introduction to Nonimging Optics”, CRC Press, Boca Raton, 2008
5. O’Gallager J.J., “Nonimaging Optics in Solar Energy”, Morgan&Claypool Publishers, Chicago, 2008

and more than one hundred papers published since 1976 until now

Finally, we reached the

END !!

Thank you for your attention !