Energy Harvesting: A Ground-source Thermoelectric Generator

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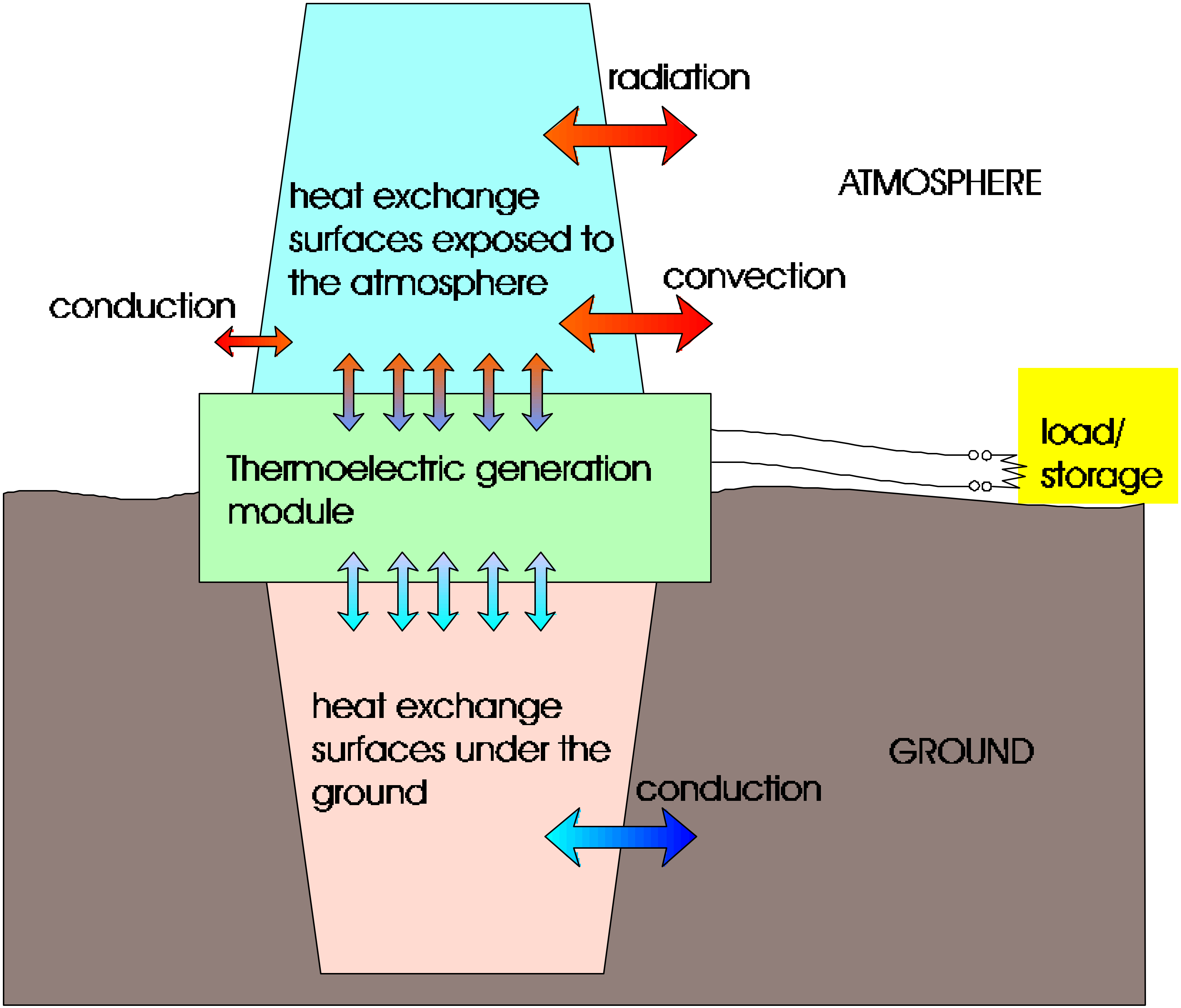
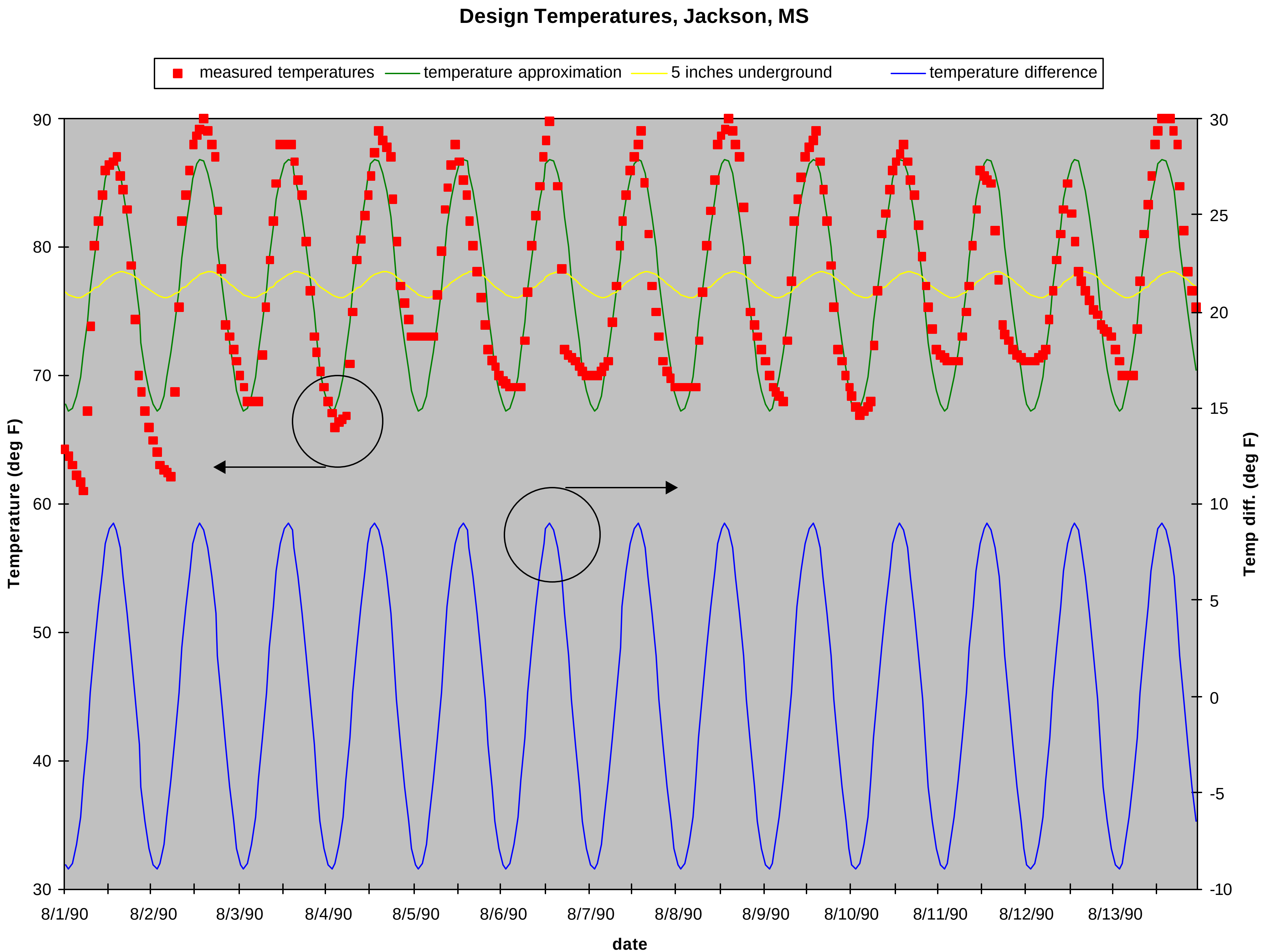
Outline

1. Overview
2. Design phase results
3. Prototype phase plans
4. Conclusion

Ground-source Heat Engine

- use temperature difference between the air and the ground to generate power
- use thermoelectric generator to produce electricity


radiation
ATMOSPHERE
heat exchange surfaces exposed to the atmosphere
convection
conduction
load/ storage
Thermoelectric generation module
heat exchange surfaces under the ground
GROUND
conduction


Design Temperatures, Jackson, MS
measured temperatures
temperature approximation
5 inches underground
temperature difference
Temperature (deg F)
Temp diff. (deg F)
90
80
70
60
50
40
30
30
25
20
15
10
5
0
-5
-10
8/1/90
8/2/90
8/3/90
8/4/90
8/5/90
8/6/90
8/7/90
8/8/90
8/9/90
8/10/90
8/11/90
8/12/90
8/13/90
date

Ground-source Heat Engine

- solid-state: very rugged compared to photovoltaics
- long life: O(10+ yrs)
- dependable
- low visibility: no noise, very small thermal signature
- operates day & night, summer and winter, no dependence on direct sunlight

Ground-source Heat Engine

- very low efficiency
- Why?
- Why does it matter?

$$\eta_{Carnot} = \frac{\Delta T}{T_H} \approx \frac{10°F}{530°R} \approx 1.9\%$$

$$\eta_{TE} \approx 0.15\eta_{Carnot}$$

$$Size \propto \frac{1}{\eta_{TE}}$$

Ground-source Heat Engine

- Figure of merit: thermal efficiency, 0.2 –1.0%
- Size: very roughly, breadbox size for O(100 mW), thermos size for O(10 mW)
- Applications: long term unattended sensors or transmitters, land or water, cold regions

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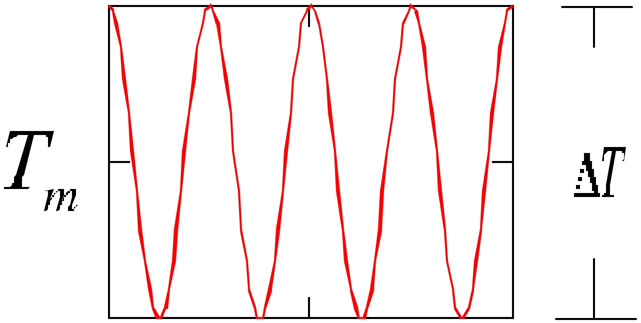
   e) heat transfer correlations

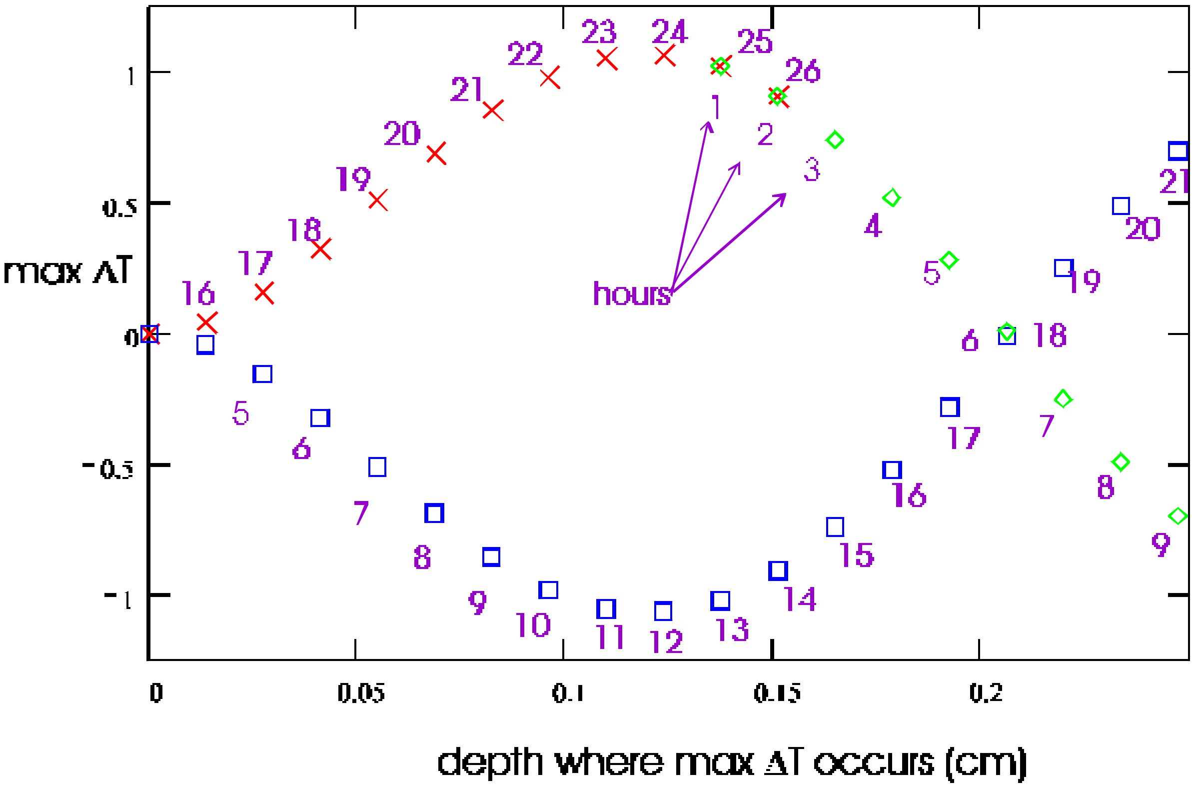
$$T(t) = T_m + \Delta T \cos(pt)$$



$$T(x,t) = T_m + \Delta T * e^{-x\zeta} * \cos(pt - x\zeta)$$

$$\zeta = \sqrt{\frac{\pi}{a t_o}}$$

$$p = \frac{2\pi}{t_o}$$



$$\frac{d(T_A - T_G)}{dx} = 0$$

$$g(x) = \int_{period} \Delta T_{AG}^2 \, dt$$

$$f(x) = \frac{dg}{dx} = 8p^2 e^{-zx}\left[\sin(zx) + \cos(zx) - e^{-zx}\right]$$

f(x)=0 @ 11.9 cm where ΔT=1.07

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Angrist, 1976

$$h_{TE} = \frac{I^2 R_{e,o}}{K\Delta T_{TE} + \alpha T_H I - \frac{1}{2} I^2 R_e}$$

max efficiency

$$\frac{\gamma_n}{\gamma_p} = \left(\frac{\rho_n k_p}{\rho_p k_n} \right)^{1/2}$$

max power

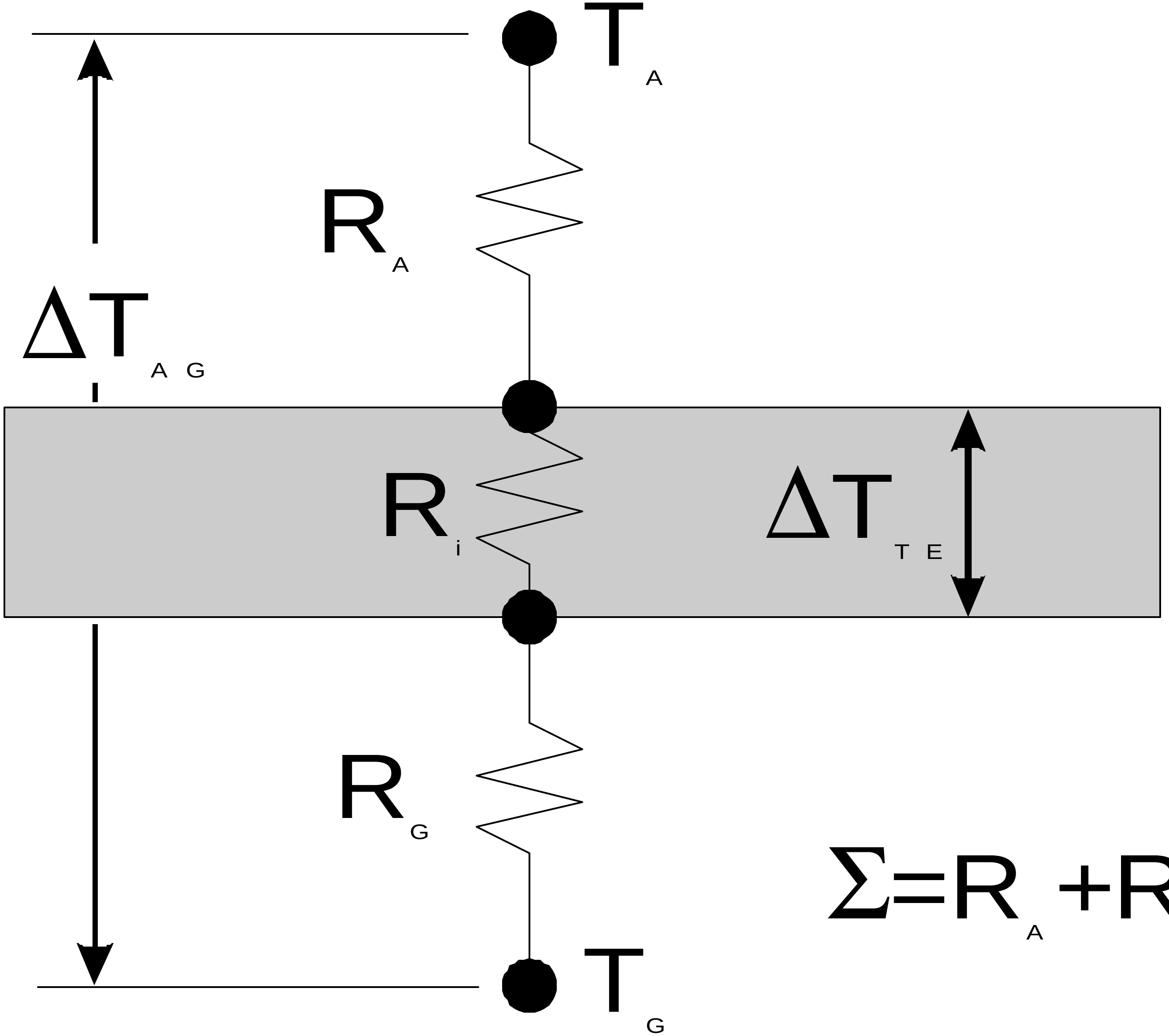
$$\frac{\gamma_n}{\gamma_p} = \left(\frac{\rho_n}{\rho_p} \right)^{1/2}$$

ρ is the electrical resistivity

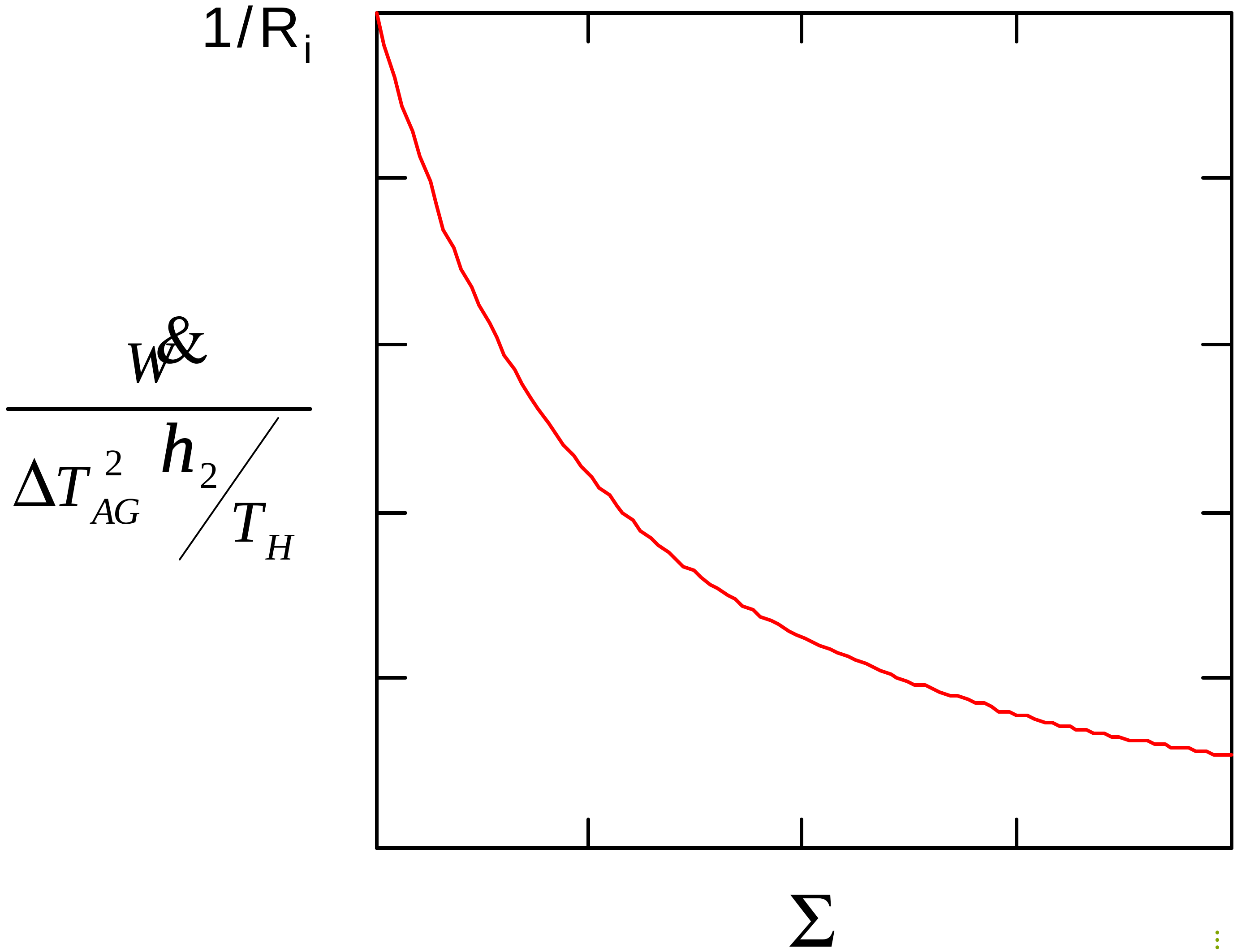
k is the thermal conductivity

γ is the ratio of cross-sectional area to length

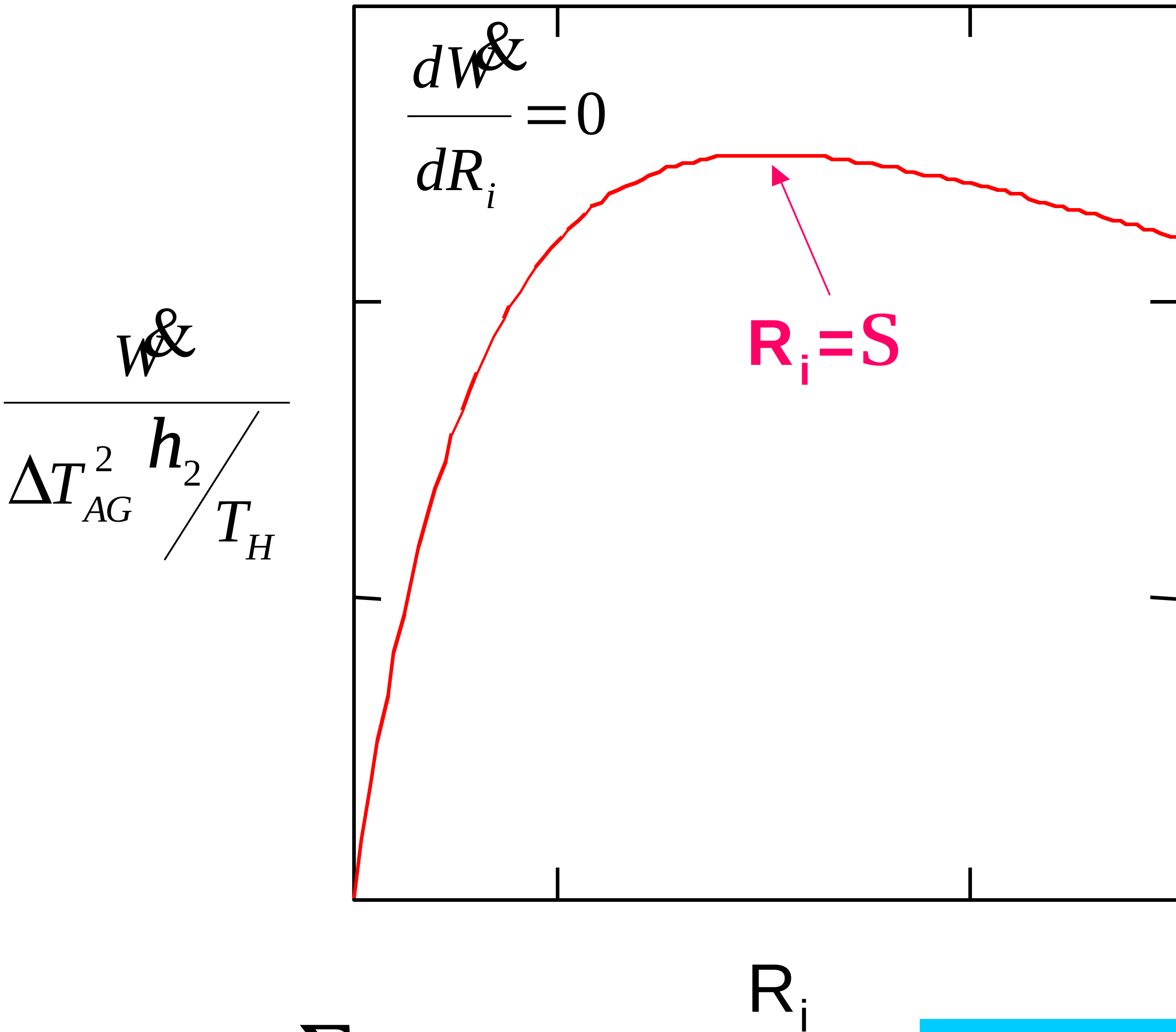
Only the *ratio* of the aspect ratios is given



$$\Sigma = R_A + R_G$$



constant R_i



constant Σ

ΔT is split evenly between HX's and TE module

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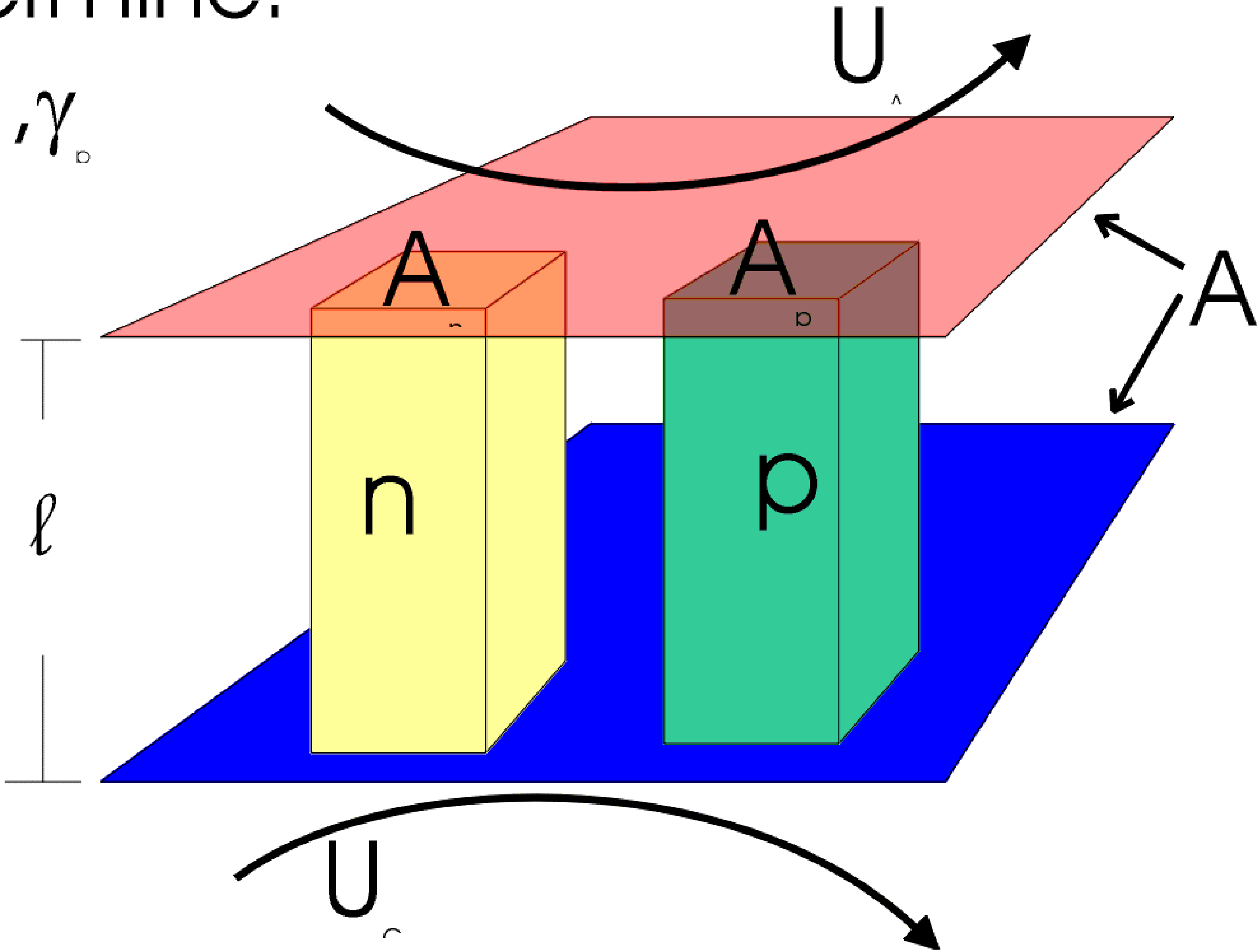
Determine:

$\ell, A, \gamma_n, \gamma_p$



$$\frac{h_2 \Delta T_{AG}^{2}}{4W\&T} = \Sigma$$

$$R_i = \left(k_n g_n + k_p g_p\right)^{-1}$$

$$A = \frac{1}{\Sigma}\left[\left(\frac{1}{U}\right)_G + \left(\frac{1}{U}\right)_A\right]$$

max efficiency

$$\frac{g_n}{g_p} = \left(\frac{r_n k_p}{r_p k_n}\right)^{1/2}$$

max power

$$\frac{g_n}{g_p} = \left(\frac{r_n}{r_p}\right)^{1/2}$$

γ_n, γ_p

$$l = \frac{Af}{g_n + g_p}$$

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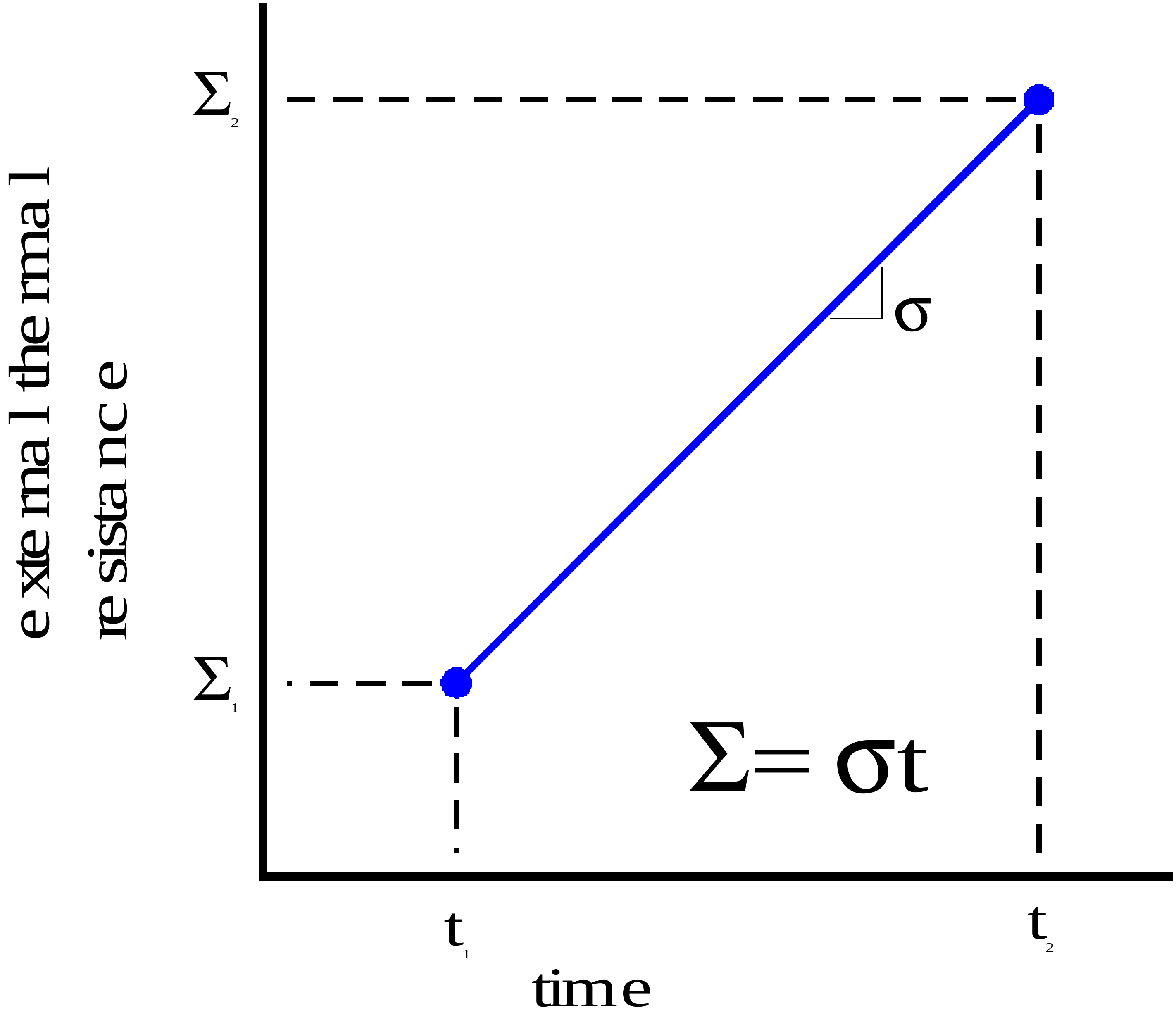
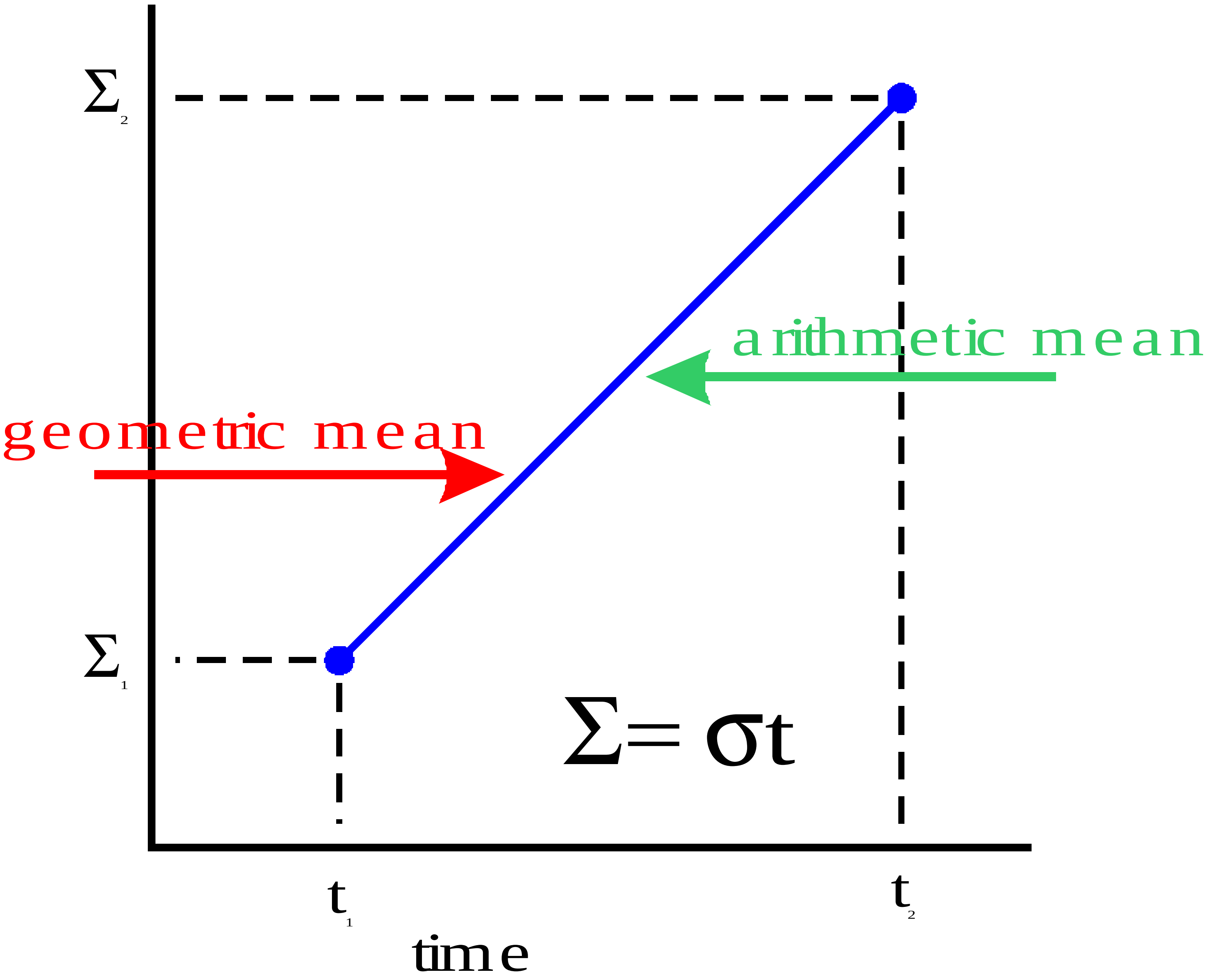
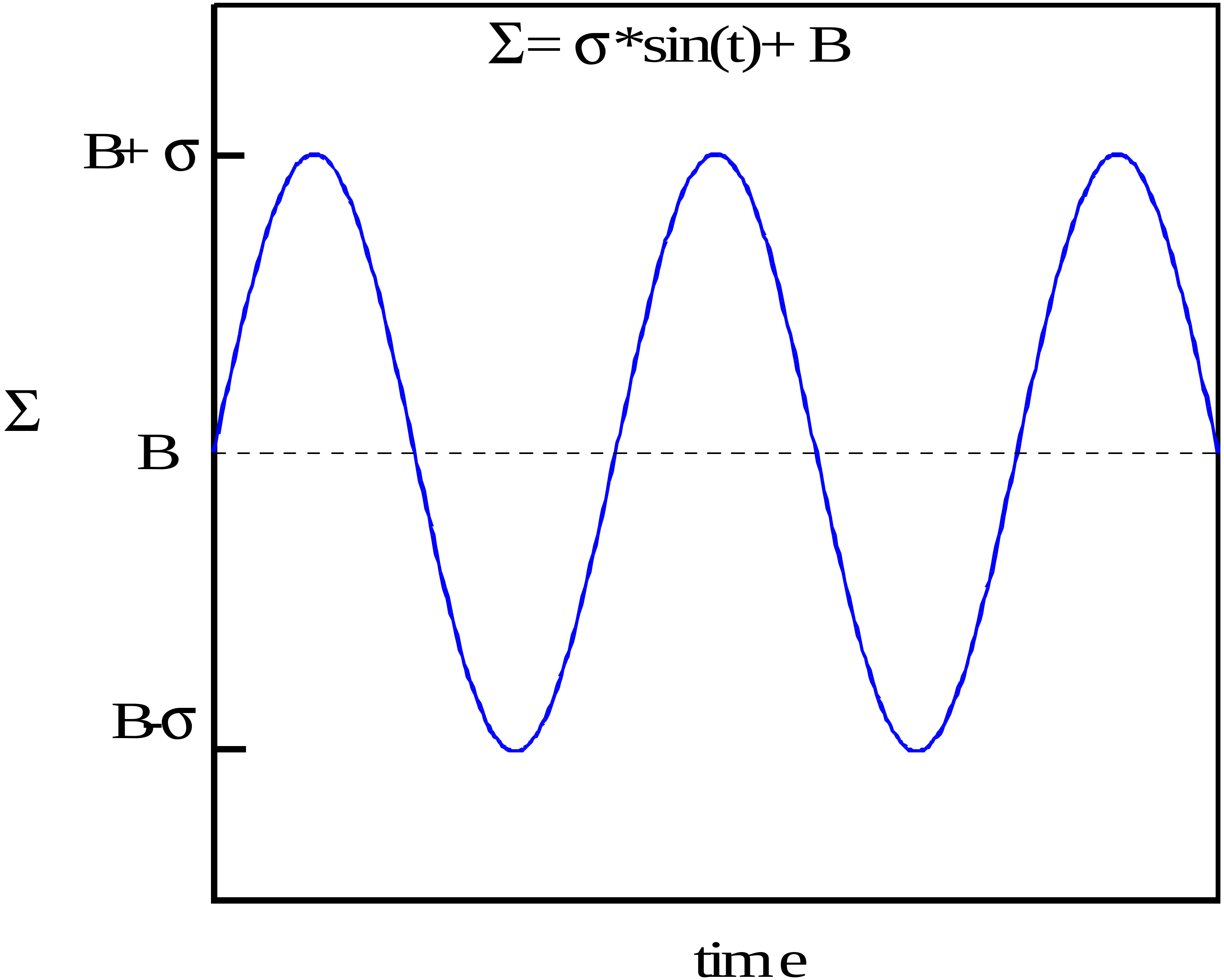


external thermal resistance
Σ_2
Σ_1
σ
$\Sigma = \sigma t$
t_1
t_2
time

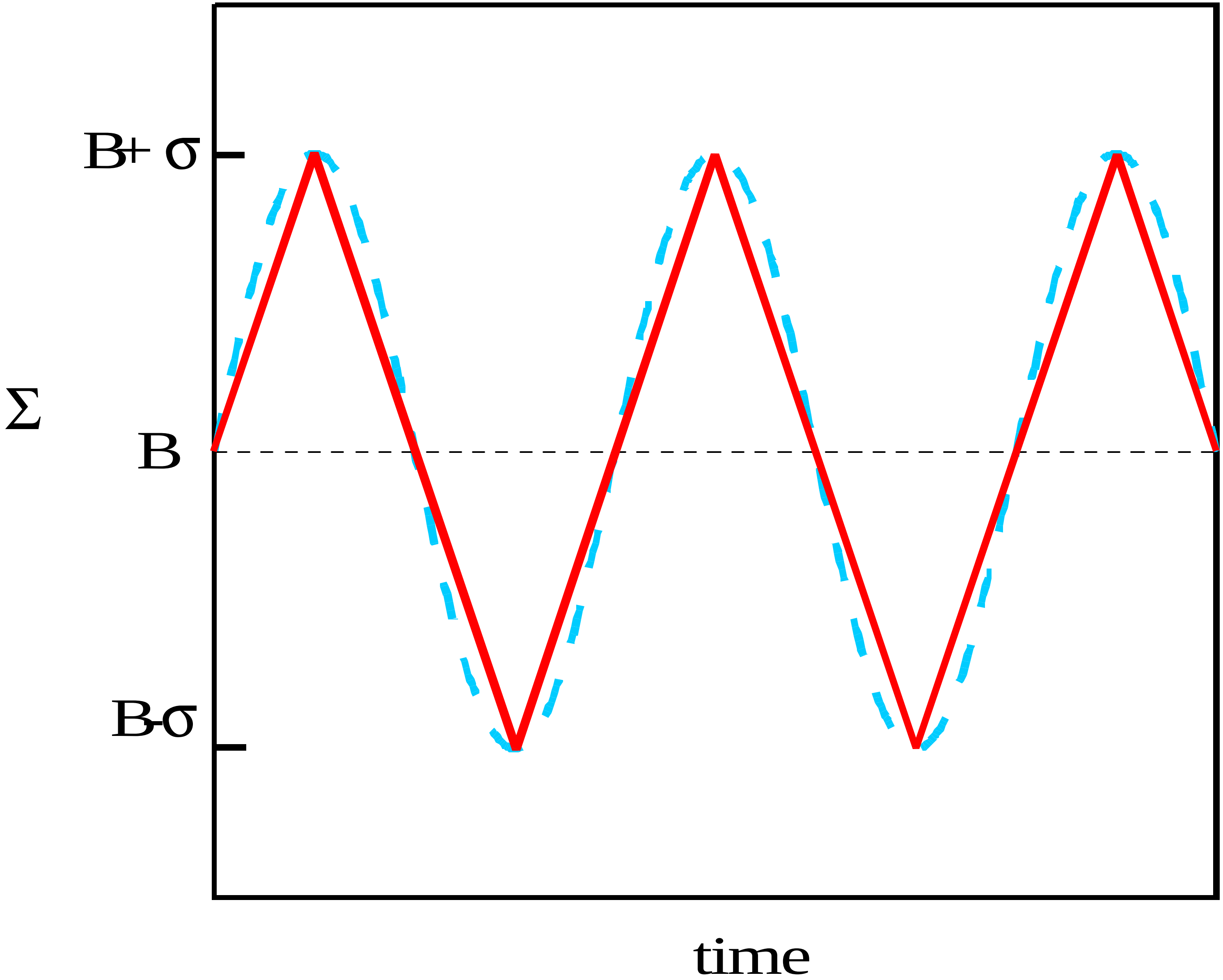
$$R_i = \left(s^{2} t_2 t_1 \right)^{1/2} = \sqrt{\Sigma_2 \Sigma_1}$$



Σ_2
arithmetic mean
geometric mean
Σ_1
$\Sigma = \sigma t$
t_1
t_2
time



Σ= σ*sin(t)+ B
B+ σ
Σ
B
B-σ
time


B+ σ
Σ
B
B-σ
time

Sawtooth:

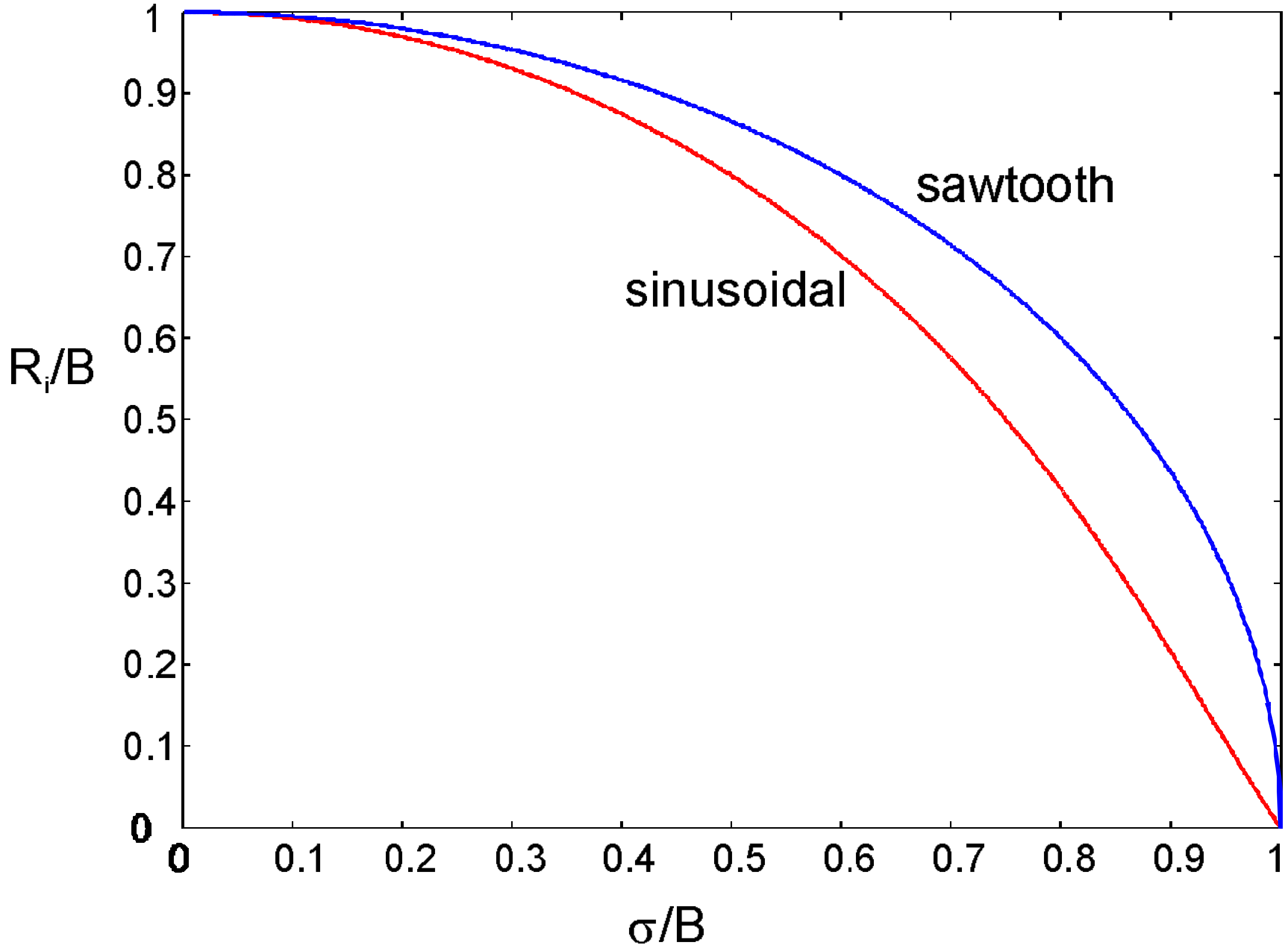
$$R_i = \sqrt{(B+s)(B-s)}$$

$$R_i/B = \left(1-\left(s/B\right)^2\right)^{1/2}$$

Sinusoidal:

roots of:

$$\left(\frac{R_i}{B}\right)^3 + \left(\frac{R_i}{B}\right)^2 - \left(1-2\left(\frac{s}{B}\right)^2\right)\left(\frac{R_i}{B}\right) - \left(1-\left(\frac{s}{B}\right)^2\right) = 0$$



sawtooth
sinusoidal
R_i/B
σ/B
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

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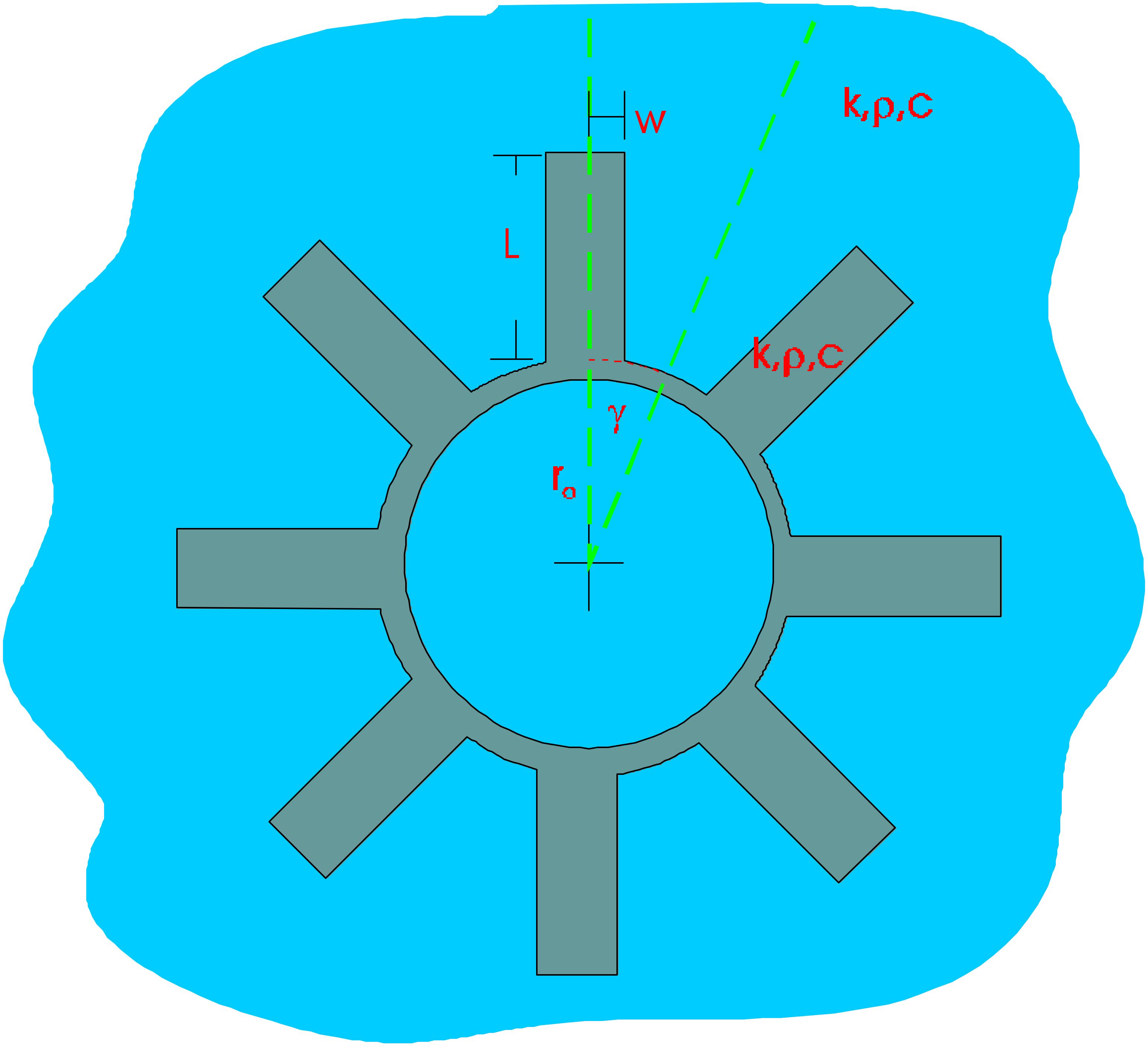
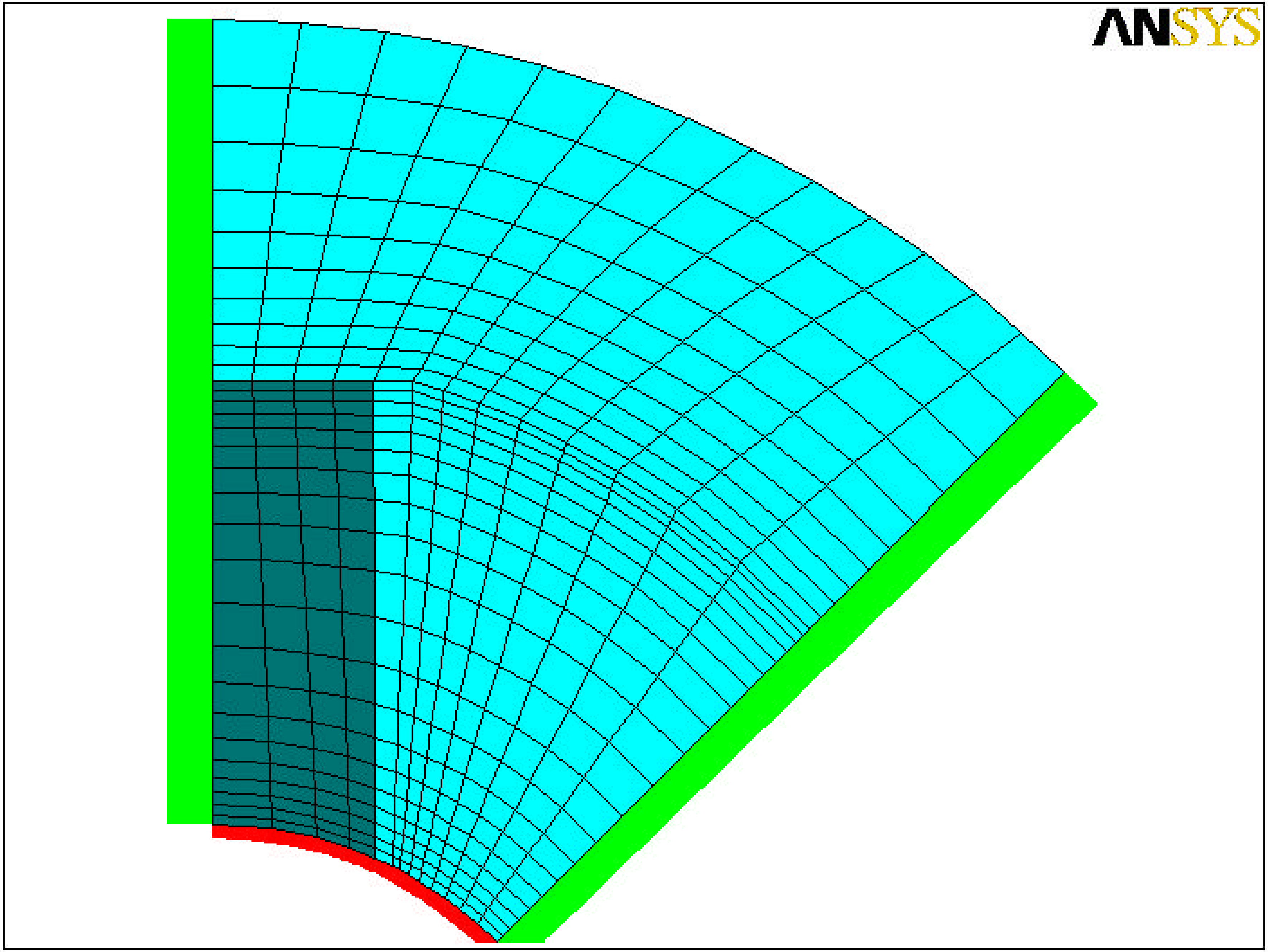
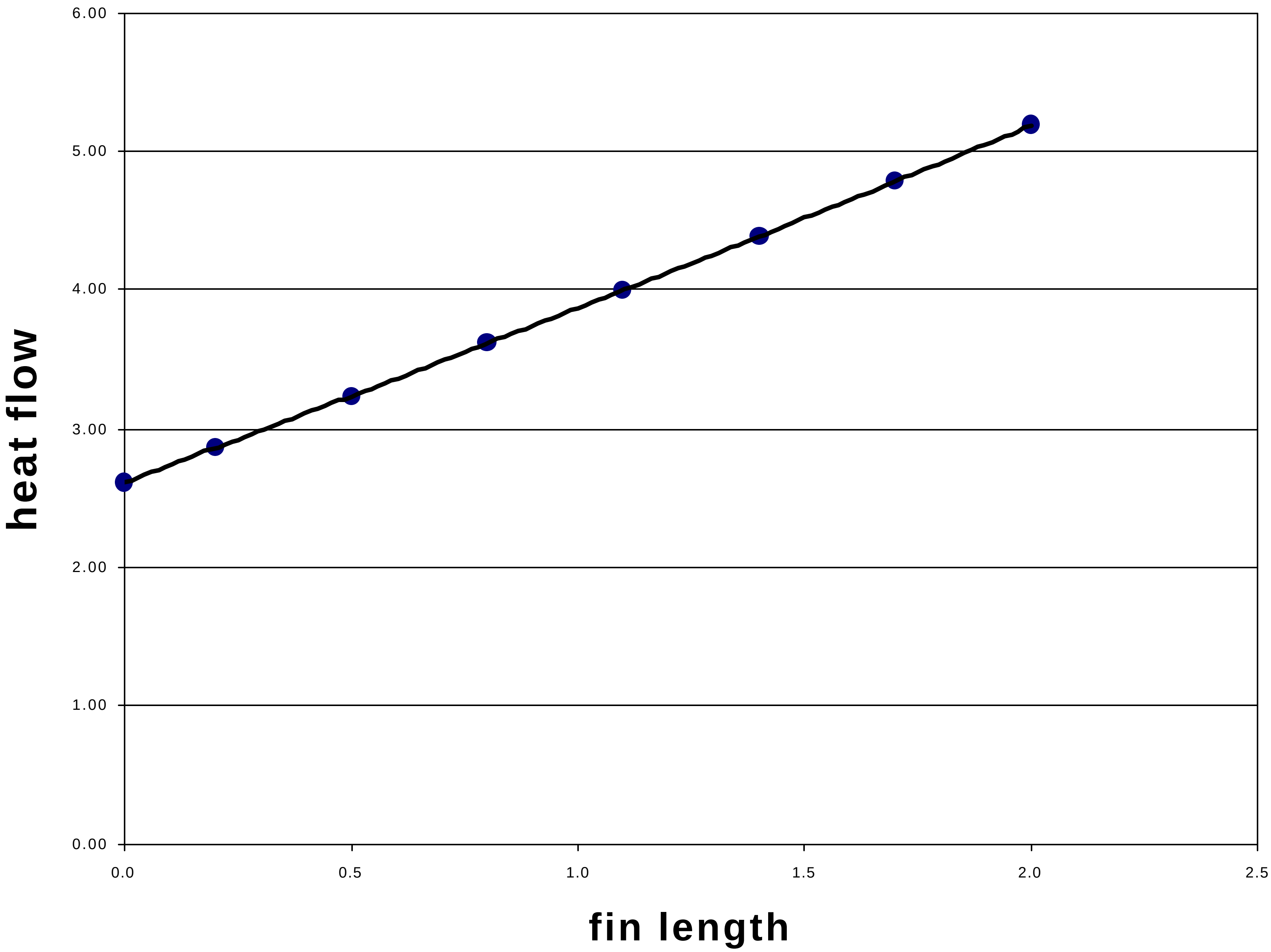


W
k,ρ,c
L
k,ρ,c
γ
r_o

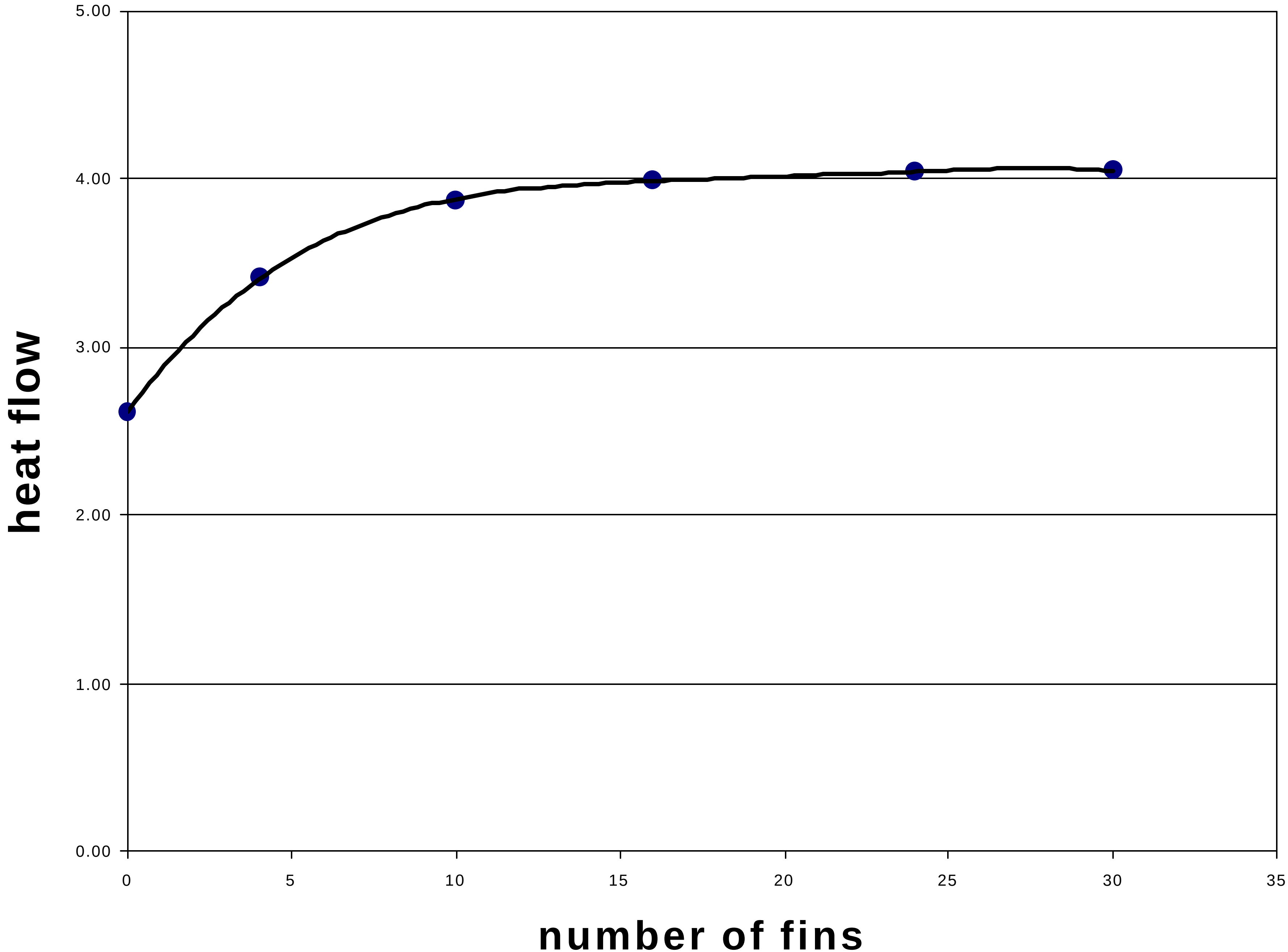
Non-dimensionalization

- $\alpha^*_{ground} = \alpha_g t_p / r_o^2$
- $\alpha^*_{fin} = \alpha_f t_p / r_o^2$
- $L^* = L / r_o$
- $w^* = w / r_o$ ($< \sin(\gamma)$)
- k_f / k_g
- γ





6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.0
0.5
1.0
1.5
2.0
2.5
heat flow
fin length



heat flow
number of fins
5.00
4.00
3.00
2.00
1.00
0.00
0
5
10
15
20
25
30
35

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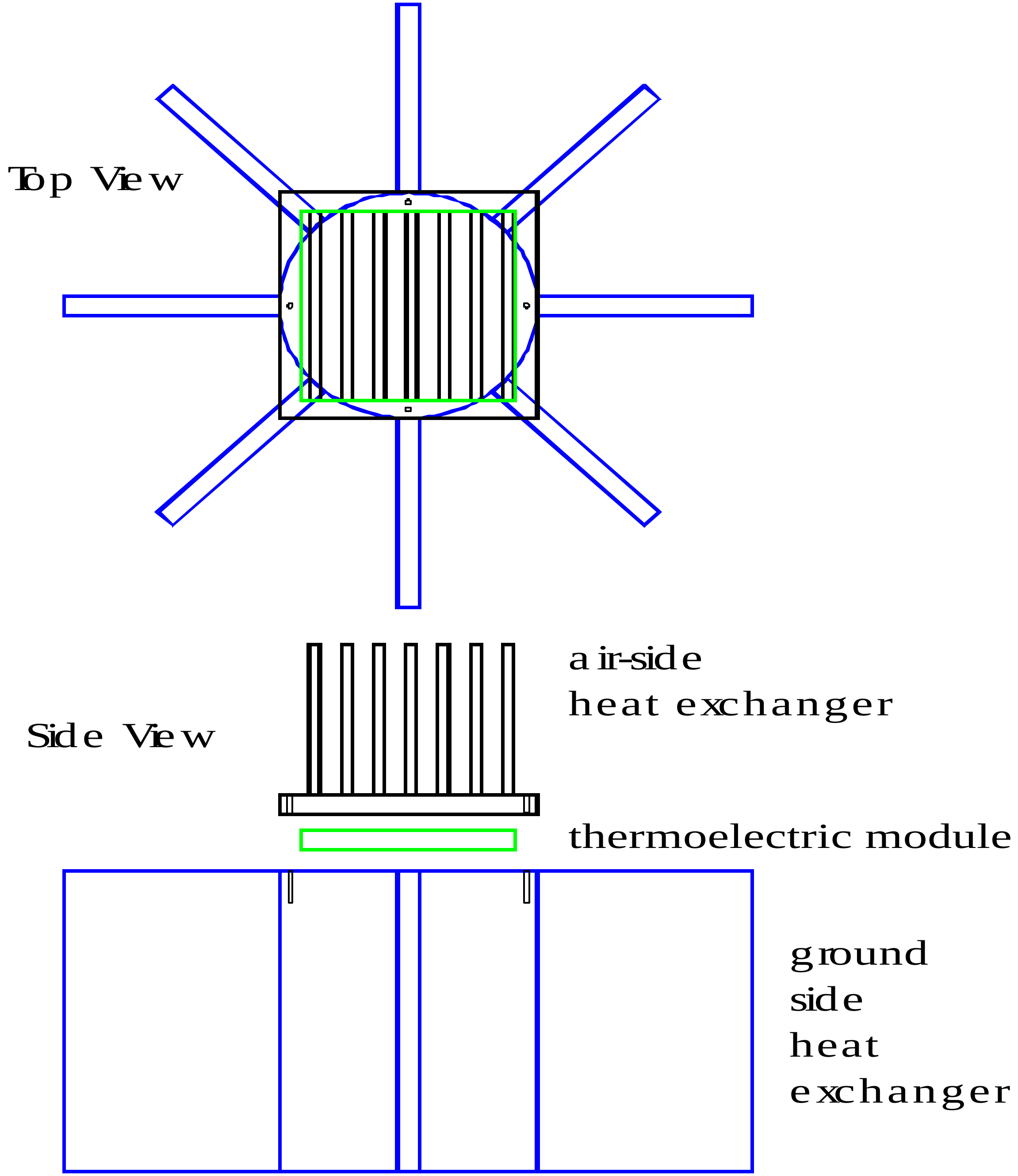
Top View
Side View
air-side
heat exchanger
thermoelectric module
ground
side
heat
exchanger

Conclusion

- a ground-source heat engine will provide small amounts of power with low efficiency , but high reliability, low visibility, and low cost
- several important system and heat transfer design issues have been addressed
- a prototype will be built, instrumented and tested

Return to Agenda