A Ladder Thermoelectric Parallelepiped Generator

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$$E=mcT$$

E = Energy
m = Mass
c = Heat Capacity
T = Temperature

Content of this Presentation:

- Background: Geothermal Source for TEG
- Economics: Does Low TEG Efficiency Matter?
- Application: Generating Light with a TEG
- Inductive and Capacitive Characterisation
- Unfamiliar Mathematical Expressions!

Geothermal Harvesting:

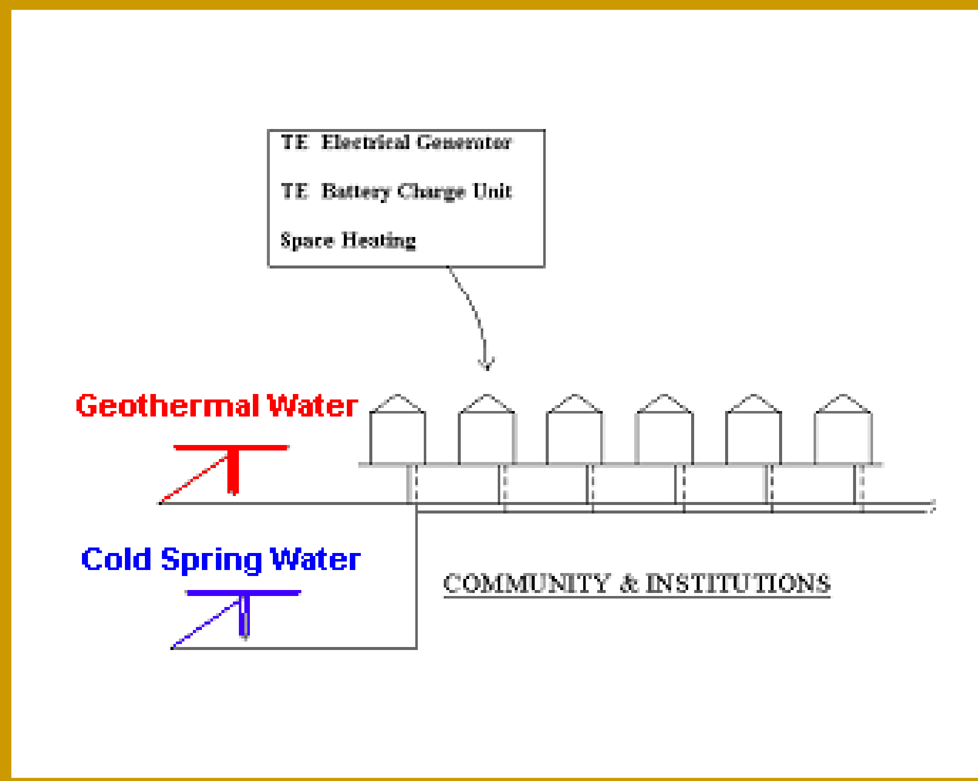
Nesjavellir, Iceland

Water as an Energy Medium:

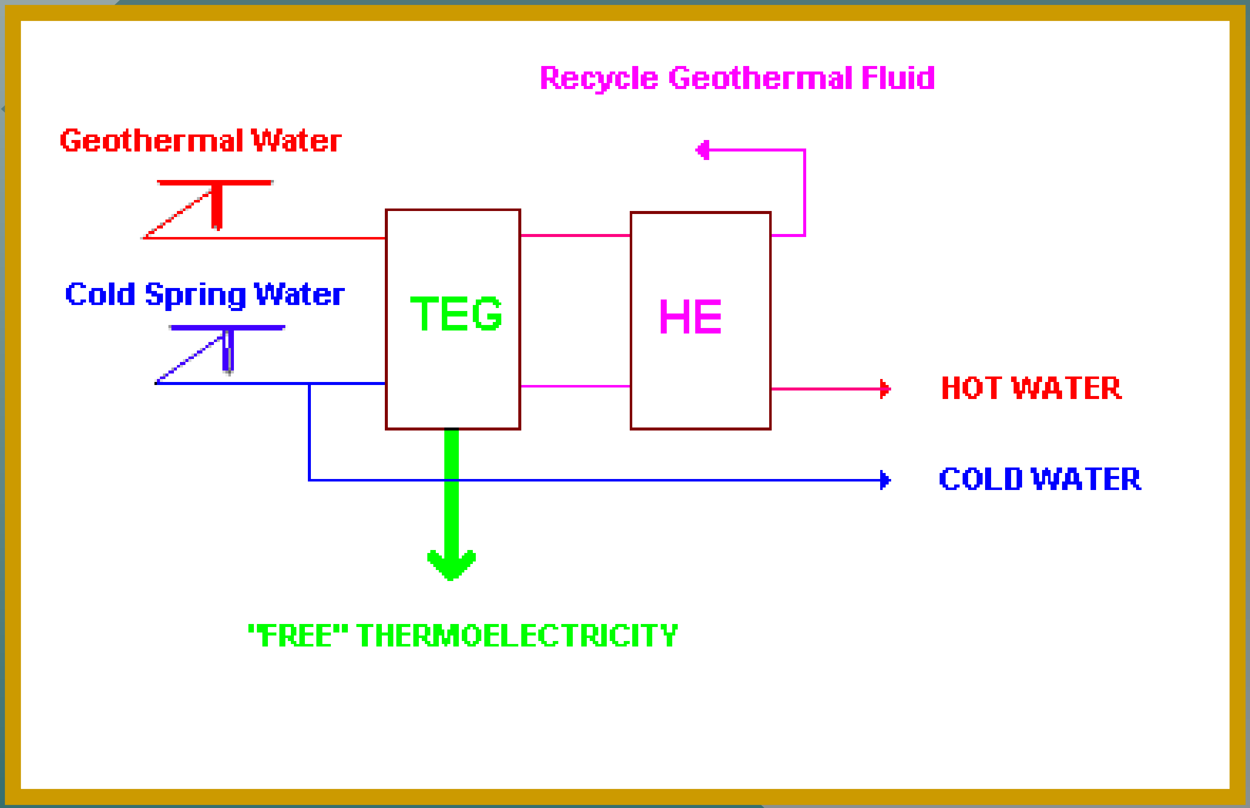
The energy released when one kilogram of hot water is cooled by 50°C, is equivalent to:

- 1000 Kg falling down 21 metres, for example in a Hydroelectric Power Plant.
- 1 Kg canonball accelerated to 646 m/s > 2300 Km/h.
- 10 Amper-Hours from a 6 volt Battery.
- 2000 atm pressure in one litre container.

Hot and Cold Water Community:



Up to 90% TEG System Efficiency ...



... when used before a Heat Exchanger!

Comparing the Cost of Energy:

• Electricity for resident homes:	9.7 ¢/KWh	=	2.7 ¢/MJ
• Electricity for light industry:	4.8 ¢/KWh	=	1.3 ¢/MJ
• Electricity for heavy industry:	2.4 ¢/KWh	=	0.68 ¢/MJ
• Geothermal Hot Water for resident homes:	85 ¢/t	=	0.33 ¢/MJ
• Geothermal Hot Water for light industry:	43 ¢/t	=	0.15 ¢/MJ

Prices in US cents, 15.Aug,2003

Thermal utilasitation: ΔT = 60°C

Energy Content of Water versus some other Energy Sources:

• Boiling Water 100°C	E=0.41 MJ/Kg
• Gasoline	E=48 MJ/Kg
• Methanol	E=24 MJ/Kg
• Coal	E=29.3 MJ/Kg
• TNT	E=4.6 MJ/Kg
• Lead-Acid Battery	E=0.15 MJ/Kg

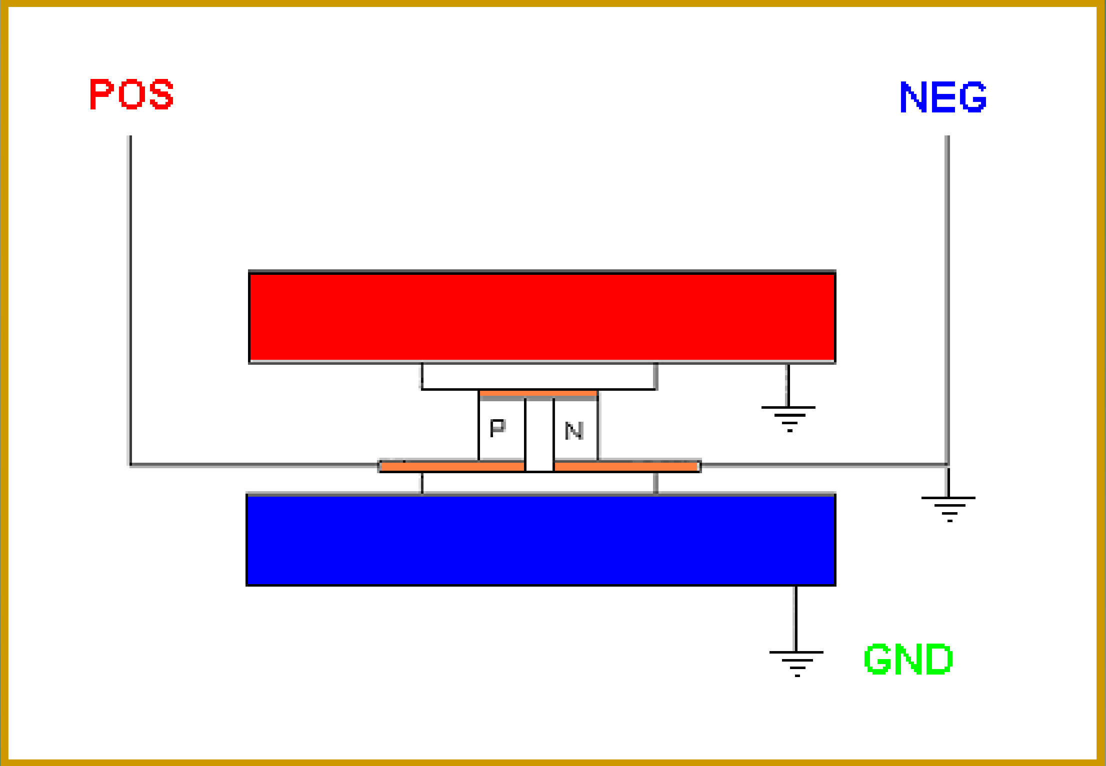
Water and Gasoline:

- The Thermal Energy in 100 liters of boiling water is equivalent to one liter of Gasoline!
- Geothermal Hot Water can compete with Gasoline if a Heat Exchanger is Mandatory!

Let there be Light!

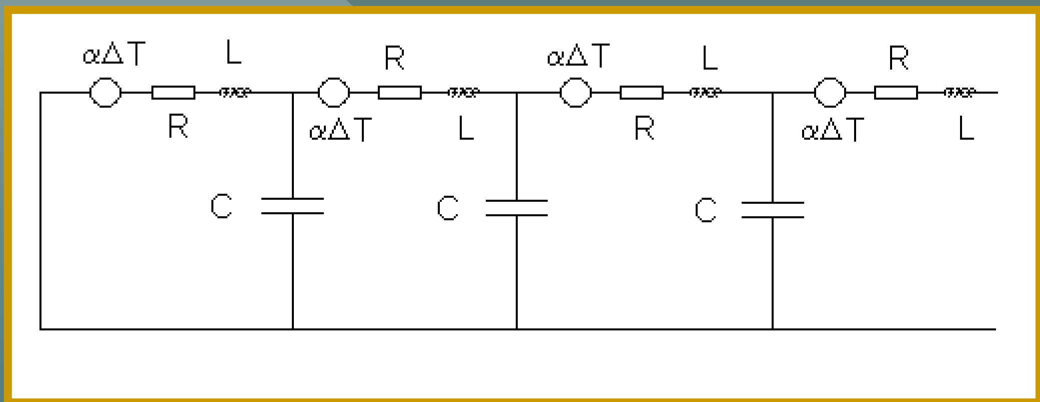
Geothermal Greenhouse Experiment in Iceland.

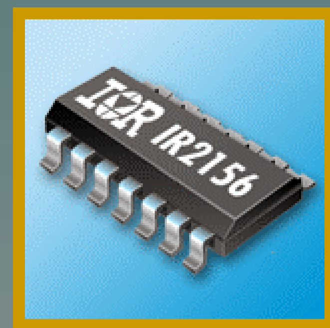
The presence of Heat Source and Cold Sink introduces Electrical Capacitors!

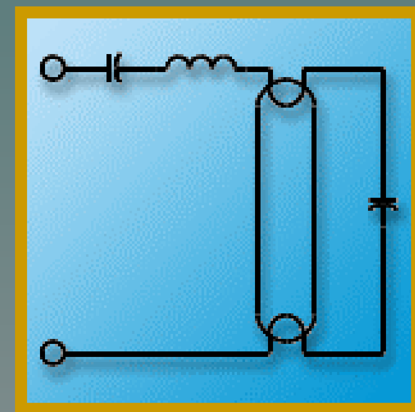


To ground or not to ground, that is the question!

Grounded Thermoelectric Generator Operating at a High Frequency:







- Generator (4 pellets shown)
- Driver
- Load

Impendance of 4 TE Pellets in a Grounded Ladder TE Generator:

$$Z_4 = R + L \cdot s + \cfrac{1}{C \cdot s + \cfrac{1}{R + L \cdot s + \cfrac{1}{C \cdot s + \cfrac{1}{R + L \cdot s + \cfrac{1}{C \cdot s + \cfrac{1}{R + L \cdot s}}}}}}$$

$s = \beta + i\omega$

Impendance of 1, 2, 3 & 4 Pellets in a Grounded Ladder TE Generator:

$$Z_1 = R + L \cdot s$$

$$Z_2 = Z_1 \cdot \left(\frac{2+a}{1+a} \right)$$

$$Z_3 = Z_1 \cdot \left(\frac{3 + 4 \cdot a + a^2}{1 + 3 \cdot a + a^2} \right)$$

$$Z_4 = Z_1 \cdot \left(\frac{4 + 10 \cdot a + 6 \cdot a^2 + a^3}{1 + 6 \cdot a + 5 \cdot a^2 + a^3} \right)$$

$$a = R\,C\,s + LC\,s^2$$

The Ladder TEG Impendance Coefficients for up to 6 Pellets:

Denominator :

1
1 1
1 3 1
1 6 5 1
1 10 15 7 1
1 15 35 28 9 1

Numerator :

1
2 1
3 4 1
4 10 6 1
5 20 21 8 1
6 35 56 36 10 1

Find the general formula ...

General Formula for a Grounded Ladder TEG with n Pellets:

$$Z_n = Z_1 \cdot \left(\frac{n + \frac{1}{6} \cdot n \cdot \left(n^2 - 1\right) \cdot a + \cdots + \left(2 \cdot n - 2\right) \cdot a^{n-2} + a^{n-1}}{1 + \frac{1}{2} \cdot n \cdot \left(n - 1\right) \cdot a + \cdots + \left(2 \cdot n - 3\right) \cdot a^{n-2} + a^{n-1}} \right) = Z_1 \cdot \frac{P_n(a)}{Q_n(a)}$$

$$Q_1(a) = 1$$

$$Q_n(a) = Q_{n-1}(a) + a \cdot P_{n-1}(a)$$

$$Q_n(a) = 1 + a \cdot \sum_{k=1}^{n-1} P_k(a)$$

$$Q_n(a) = \prod_{k=1}^{n-1} \left(a + 4 \cdot \sin^2\left(\frac{\pi \cdot (2k-1)}{2 \cdot (2n-1)} \right) \right)$$

$$P_1(a) = 1$$

$$P_n(a) = Q_{n-1}(a) + \left(1 + a\right) \cdot P_{n-1}(a)$$

$$P_n(a) = 1 + P_{n-1}(a) + a \cdot \sum_{k=1}^{n-1} P_k(a)$$

$$P_n(a) = \prod_{k=1}^{n-1} \left(a + 4 \cdot \sin^2\left(\frac{\pi \cdot k}{2 \cdot n} \right) \right)$$

Poles & Zeros for a TEG Module:

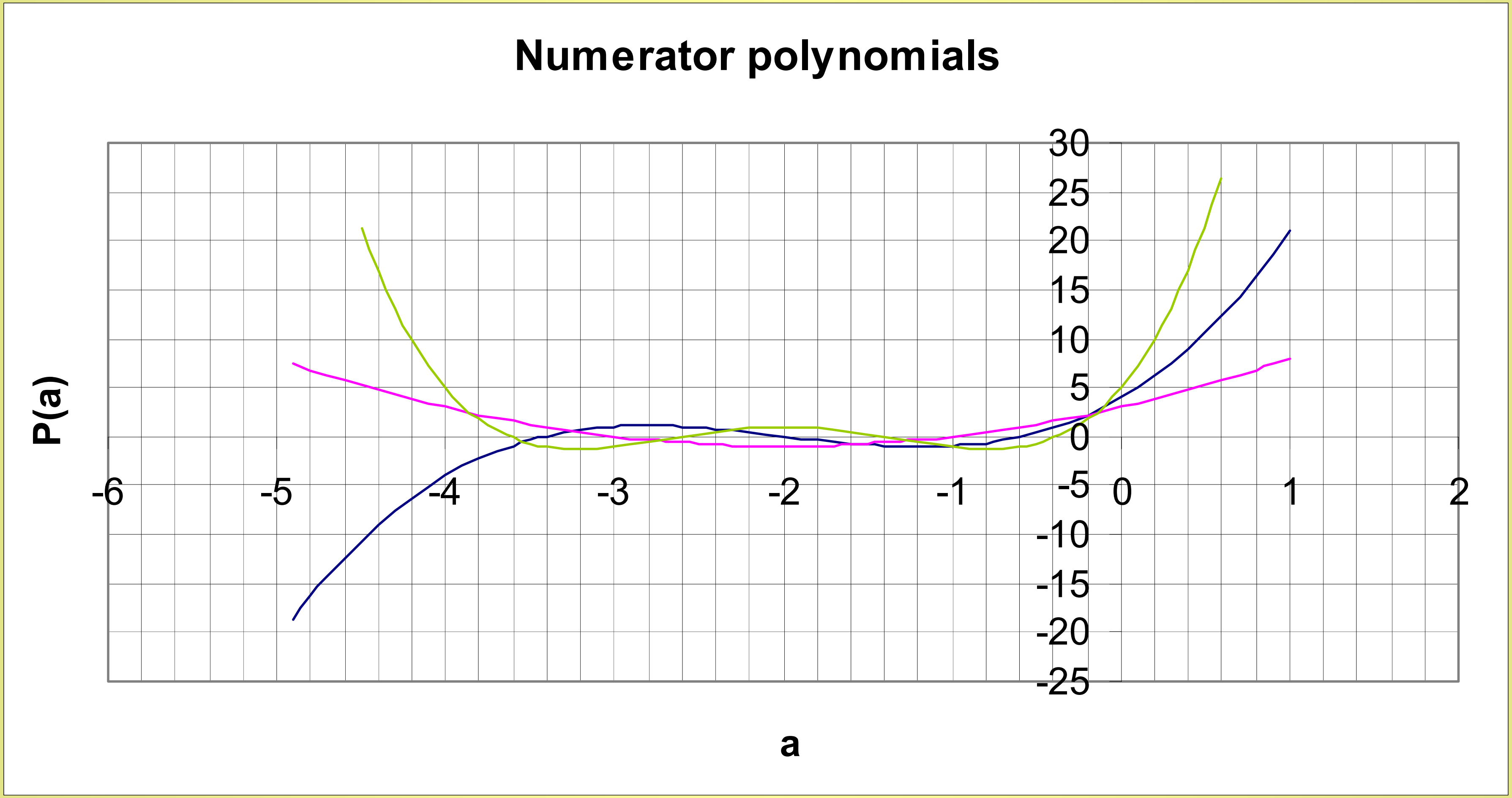
The 1st Pole:

$$a_{P1} = -4 \cdot \sin^2\left(\frac{\pi}{4 \cdot n - 2}\right) \quad \Rightarrow f_{P1} = 2 \cdot f_0 \cdot \sin\left(\frac{\pi}{4 \cdot n - 2}\right)$$

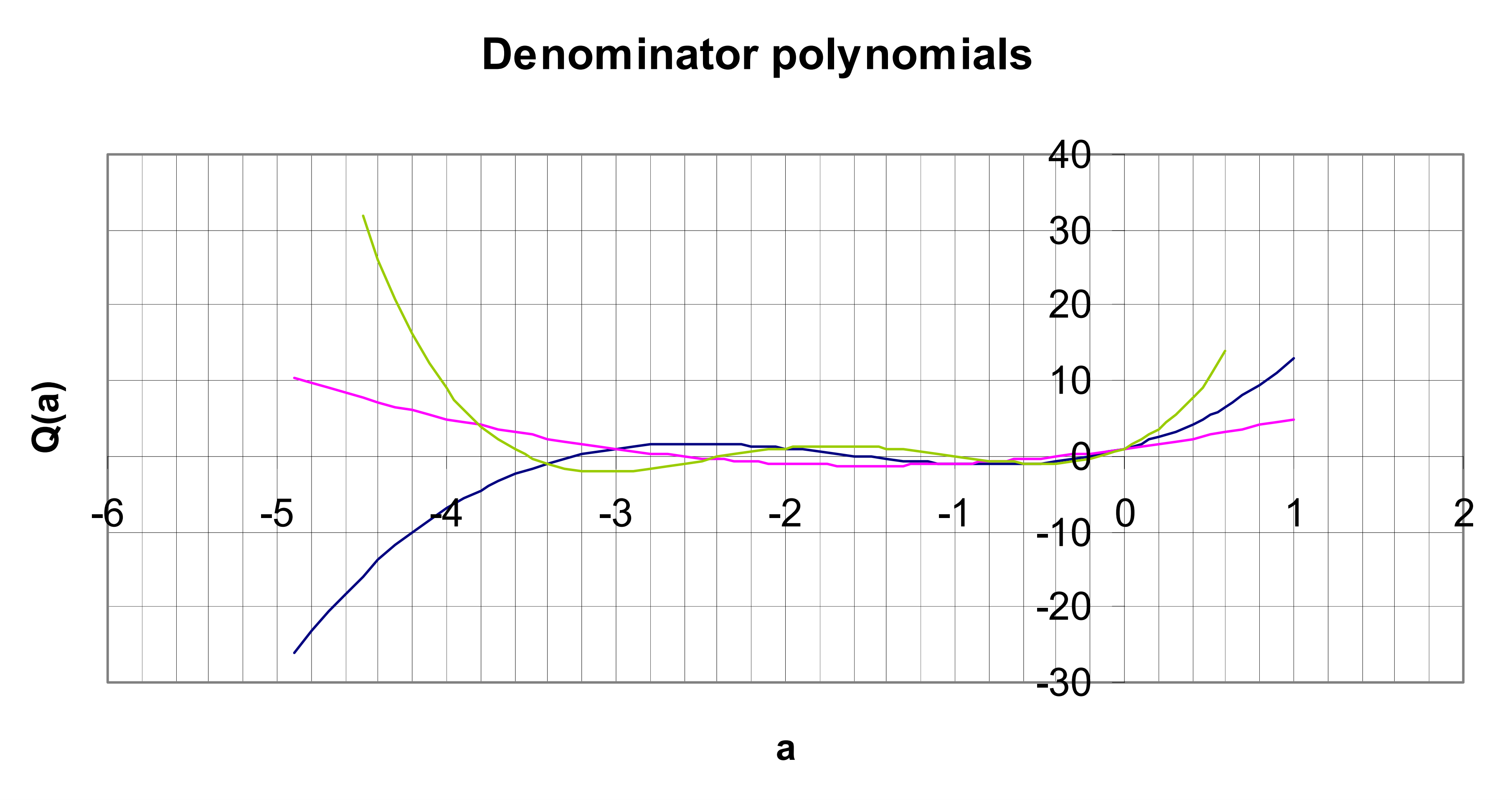
The 1st Zero:

$$a_{Z1} = -4 \cdot \sin^2\left(\frac{\pi}{2 \cdot n}\right) \quad \Rightarrow f_{Z1} = 2 \cdot f_0 \cdot \sin\left(\frac{\pi}{2 \cdot n}\right)$$

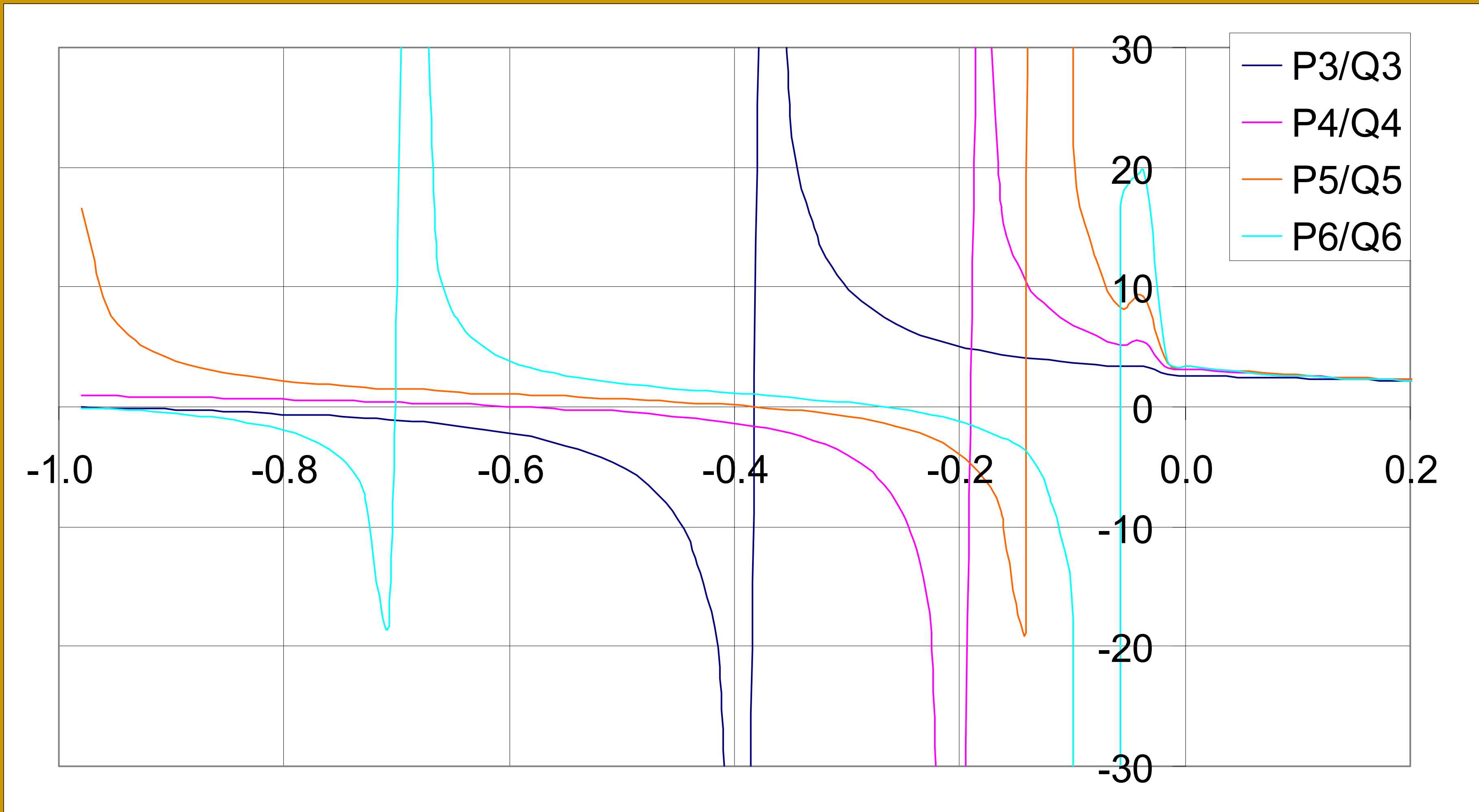
Zeros from the Numerator P(a)



Poles from the Denominator Q(a)



Poles & Zeros for a TE Module



A TEG Module* with 254 Pellets:

Measure with 100 MHz Spectrum analyzer

Result: Module Pole frequency was 40MHz

=> 100 TE Modules will have ca 400 KHz Pole which will register as an Inductance.

* 40x40x3mm with 0.6mm Ceramic Isolation