Permanent Magnet Figures of Merit: We need a better story

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Energy Efficiency and Inflation
The Motor Design Challenge
SMMA The Motor & Motion Association
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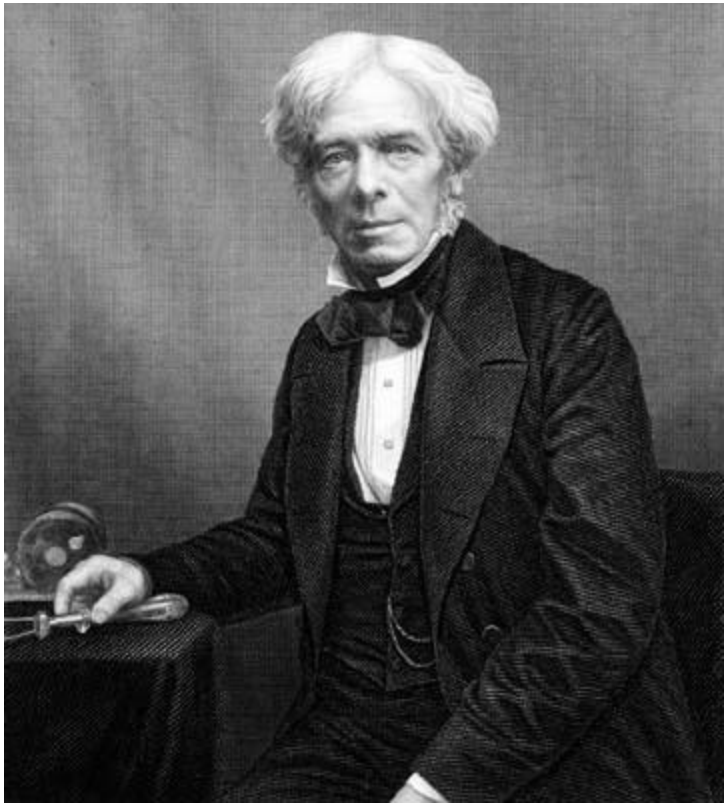
October 15-17, 2008
Sheraton Westport Plaza Hotel, St. Louis

Spontaneous Materials

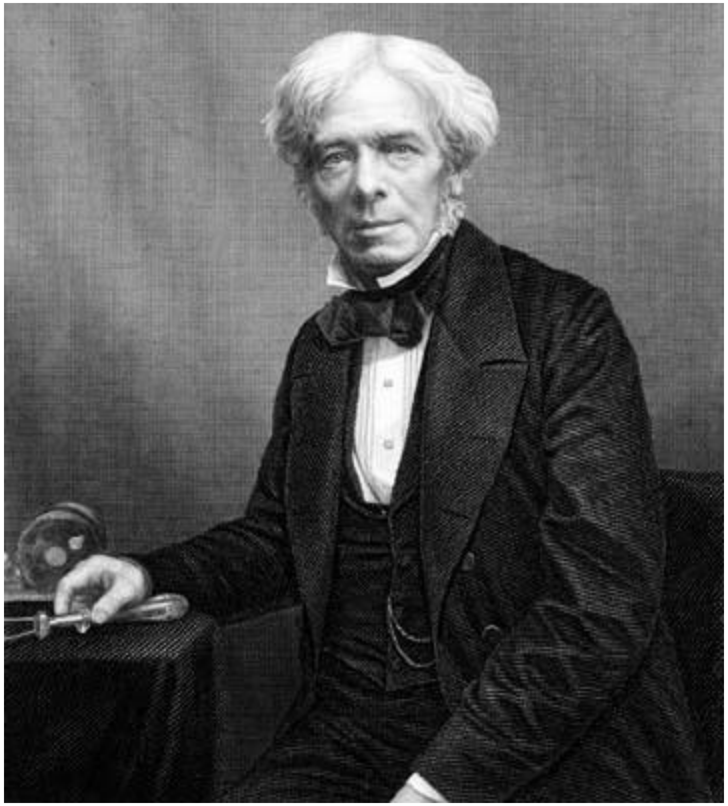
Michael Faraday



Source: St. Andrews College

- Physicist & Chemist
- 1791-1867
- The Farad
- Explained much of what we know about magnetic forces
- Made some of the first electric motors and generators

Michael Faraday



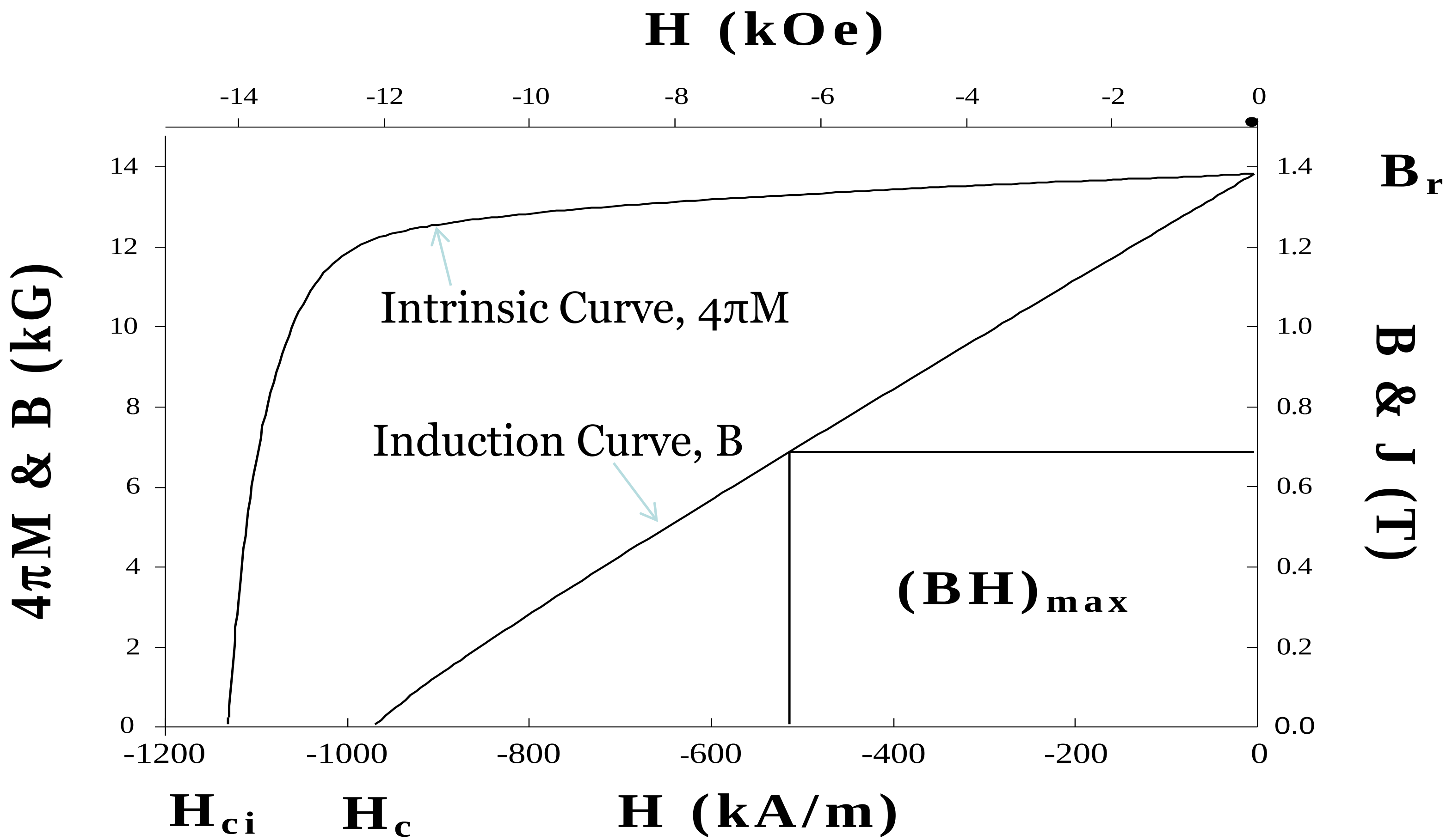
Source: St. Andrews College

- When asked by a politician what good they were, he replied "At present I do not know, but one day you will be able to tax them."

Outline

- Two common figures of merit
  - H_{ci}
  - $(BH)_{max}$
- What they tell us?
- What they don't tell us?
- Are they misleading?
- Other figures of merit
  - H_k
  - $(MH)_{max}$
  - Curie Temperature
  - Cost per pound
  - Flux/buck or J/$
- Quality Factor
- Conclusions

H_{ci} and $(BH)_{max}$



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Value of H_{ci}

What it tells us

- Strictly speaking
  - At H_{ci}, $M=0$
  - At H_c, $B=0$
  - $H_{ci} \geq H_c$
- Resistance to demagnetization

What it doesn't tell us

- Behavior at other points
- Available flux
- Cost

Is it misleading?

- *Never* used at H_{ci}
- As a thermal parameter

Value of $(BH)_{max}$

What it tells us

- Related to flux in gap

$$B_{gap} \approx \sqrt{\frac{(BH)_{max} V_{magnet}}{V_{gap}}}$$

- Most magnets operate near $(BH)_{max}$
- Near $(BH)_{max}$ is good enough

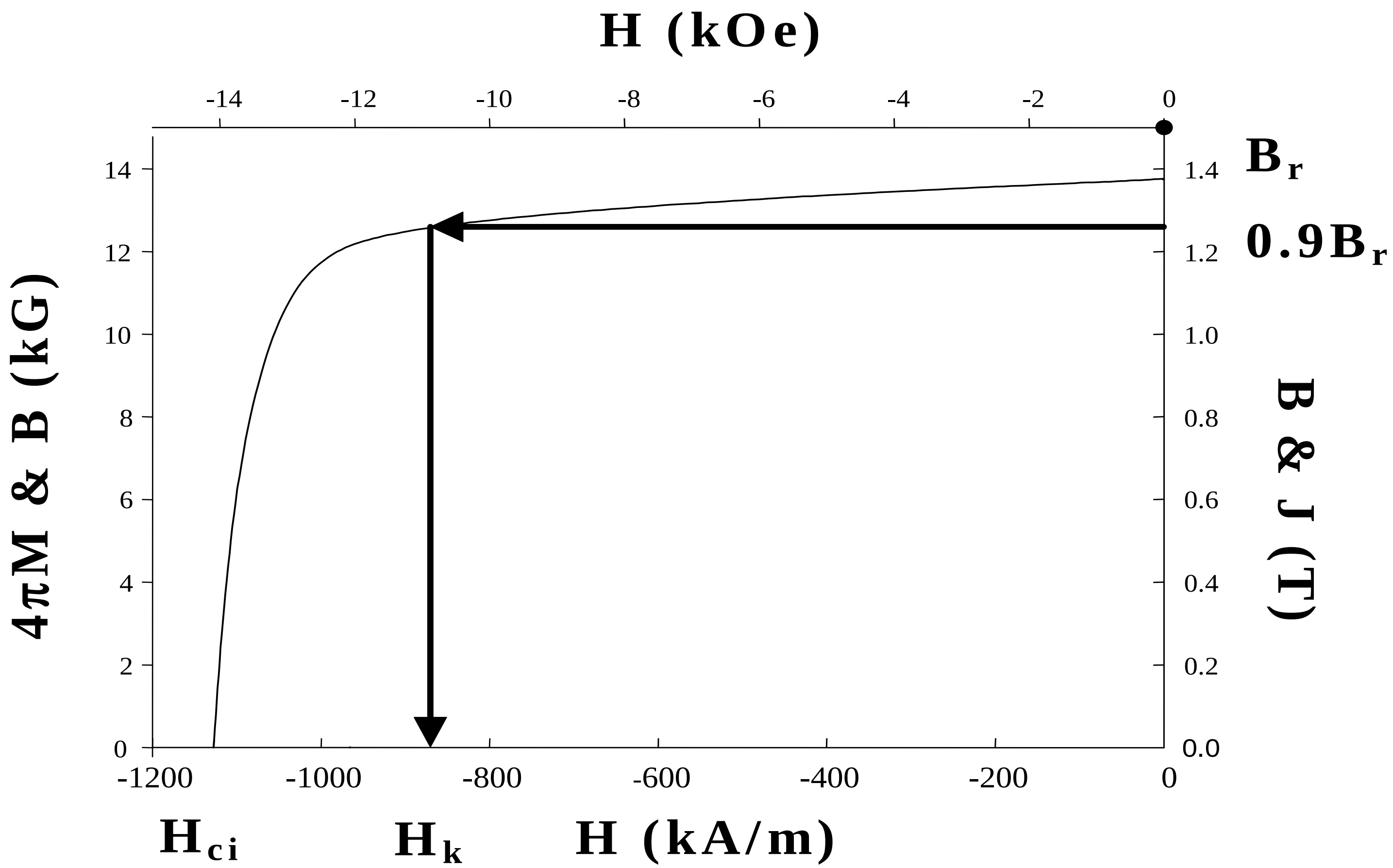
What it doesn't tell us

- Resistance to demag
- Cost
- Thermal

Is it misleading?

- A 10% increase in $(BH)_{max}$ is only a 5% increase in B_{gap}
- Over emphasized

Definition of H_k



Value of H_k

What it tells us

- Loop "squareness"
- No droopy loops
- Better than H_{ci}

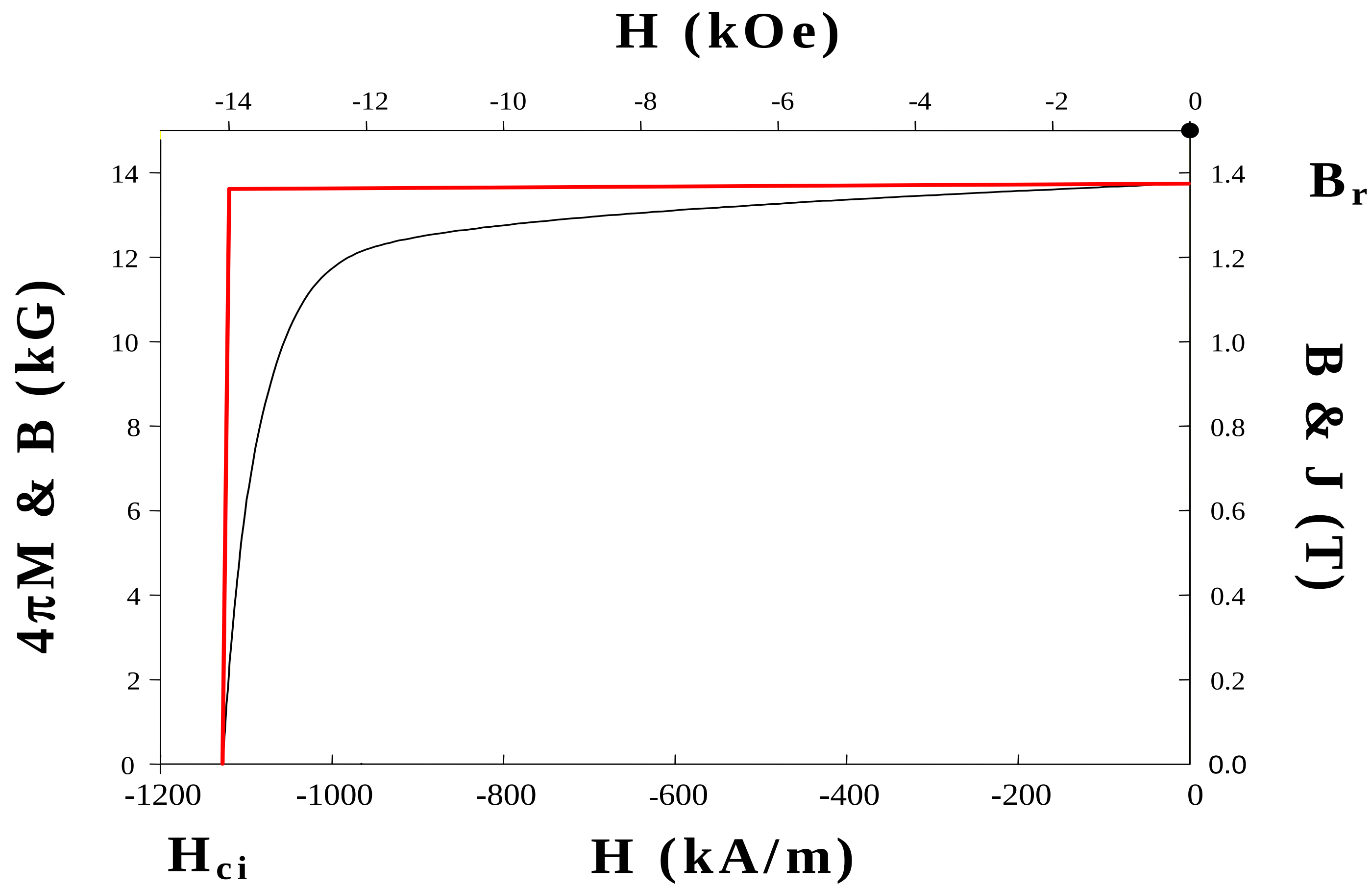
What it doesn't tell us

- Available flux
- Cost
- Thermal

Is it misleading?

- Not really

Definition of $(MH)_{max}$



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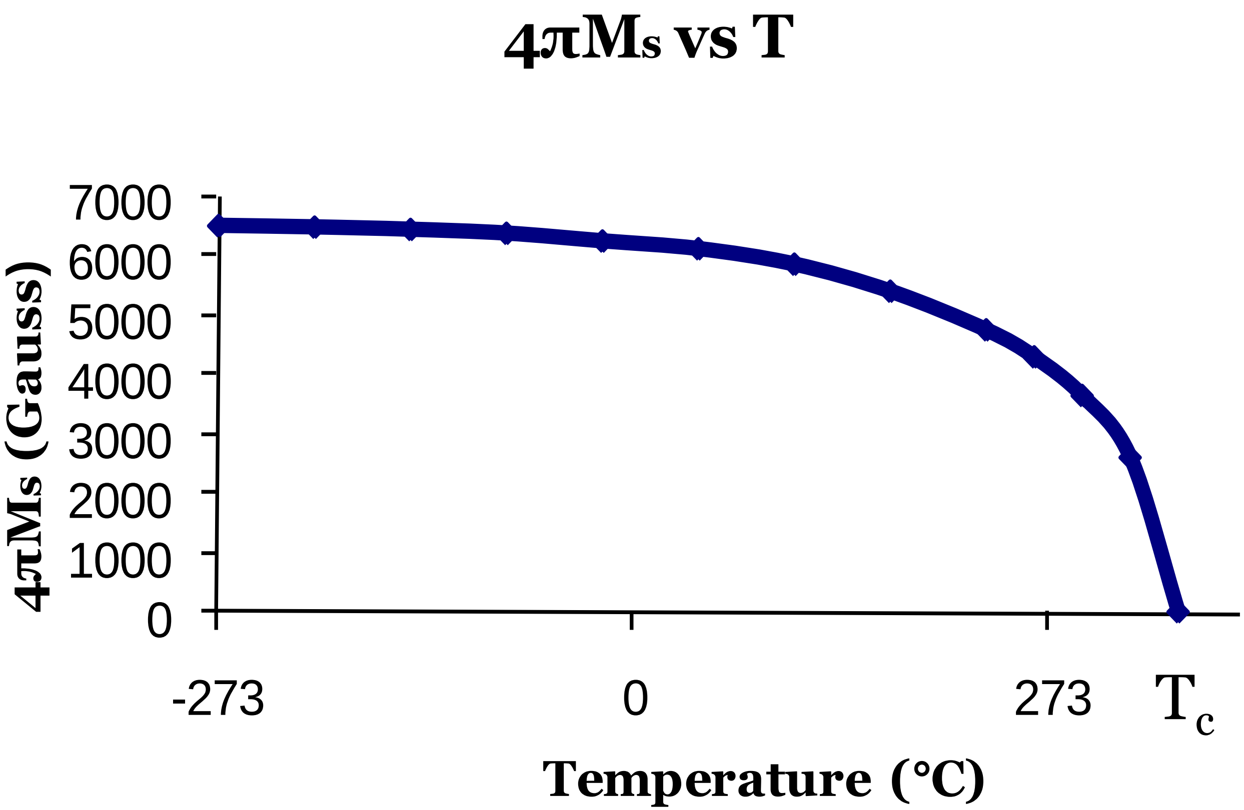
Curie Temperature



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Spontaneous Materials

Value of T_c

What it tells us

- Strictly speaking
  - M=0 at T_c
- Upper limit on use
- Universally understood

What it doesn't tell us

- Behavior at lower temps.
- Available flux
- Cost

Is it misleading?

- *Never* used at T_c
- No clue on realistic upper temperature limit

Basic Data

Material	B_r	H_{ci}	$(BH)_{max}$	H_k	T_C	cost	density	energy/$
	(kG)	(kOe)	(MGOe)	(kOe)	(°C)	($/lb)	(g/cm^3)	(J/$)
Ceramic 8	4	4	3.8	3.8	460	3	4.5	1.02
Alnico 5-7	12.5	0.64	5.5	0.6	890	20	7.3	0.14
MQ-1	6.9	9	10	3	360	60	6	0.10
SmCo	10.7	28	27	18	825	100	8.5	0.11
NdFeB	13.5	18	44	16	310	50	7.7	0.41

Cost data: Walt Benecki

Calculation of Joules/$

1/cost

$(BH)_{max}$

$$\frac{J}{\$}=\left(\frac{lb}{\$}\right)\left(\frac{cm^3}{g}\right)\left(\frac{GOe}{1}\right)\left(\frac{454g}{lb}\right)\left(\frac{J/m^3}{125.7GOe}\right)\left(\frac{1m^3}{10^6cm^3}\right)$$

1/density

Conversion factors

Key Parameters

Material	B_r (kG)	H_k (kOe)	T_C (°C)	energy/$ (J/$)
Ceramic 8	4	3.8	460	1.02
Alnico 5-7	12.5	0.6	890	0.14
MQ-1	6.9	3	360	0.10
SmCo	10.7	18	825	0.11
NdFeB	13.5	16	310	0.41

Absolute Temperature

Material	B_r (kG)	H_k (kOe)	T_C (K)	energy/$ (J/$)
Ceramic 8	4	3.8	733	1.02
Alnico 5-7	12.5	0.6	1163	0.14
MQ-1	6.9	3	633	0.10
SmCo	10.7	18	1098	0.11
NdFeB	13.5	16	583	0.41

Normalized Data

Material	B_r	H_k	T_C	energy/$
Ceramic 8	0.30	0.21	0.63	1
Alnico 5-7	0.93	0.03	1	0.13
MQ-1	0.51	0.17	0.54	0.10
SmCo	0.79	1	0.94	0.11
NdFeB	1	0.89	0.50	0.40

Best in column=1

Quality Factor

Material	Quality Factor product	sum	product w/o Tc	product w/o J/$
Ceramic 8	3.9%	2.14	6.3%	3.9%
Alnico 5-7	0.4%	2.09	0.4%	3.1%
MQ-1	0.5%	1.32	0.8%	4.6%
SmCo	8.4%	2.85	8.9%	74.8%
NdFeB	18.0%	2.79	36.0%	44.6%

Conclusions

- H_{ci} and $(BH)_{max}$ are useful but insufficient
- The Quality Factor may be more enlightening
- The Quality Factor can be made application specific
  - Omit irrelevant parameters
  - Accentuate critical parameters
- If you want the spreadsheet, send me a note strout@ieee.org