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TYPE 2G HIGH TEMPERATURE SUPERCONDUCTORS: TECHNOLOGY TRENDS AND CHALLENGES FOR NAVAL APPLICATIONS

Theater 4: Platform Design

PI INTEGRAL SOLUTIONS LIMITED - GERMANY

Manuel La Rosa Betancourt

THEVA DÜNNSCHICHTTECHNIK GMBH - GERMANY

Dr. Markus Bauer

Outline

- Motivation
- Problems and Challenges for Future Navy
- Status Quo of 2G High Temperature Superconductors
- Key Enabling Technology for Naval Applications
- Conclusions

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Motivation

THE ARCTIC CHALLENGE

- New shipping routes
- Ownership disputes of natural resources
- Strategic surveillance and control
- Vast territory with very few surface and underwater vessels

[1] Tromso, "Cosy amid the thaw," The Economist, March 24th 2012

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Problems and Challenges for Future Navy

Problems & Challenges

- High power propulsion systems for travelling large distances
- Highly efficient subsystems for long mission duration
- Noise and electromagnetic signature reduction
- Improve the performance of sensors
- Advanced defence systems

Problems and Challenges for Future Navy

Electric Propulsion

- Higher efficiency in a wider range of rotational speeds
- No need of reduction gear
- Smaller mass and volume
- Quieter than conventional turbines or internal combustion devices

Electric Power Generation

Electric Power Distribution

Electric Power Consumption

		Mechanical System	SMPM	SCM	HPM
Generator	Weight, tonnes	193.4	31.7	21.6	30
	Volume, m^3	53.3	7.7	4.4	10.6
Converter and controller	Weight, tonnes	-	13.6	13.6	8.6
	Volume, m^3	-	19.1	19.1	11.7

Energy Storage System

power converters

units

[2] J. P. Harbour, "Evaluation and comparison of electric propulsion motors for submarines," Master thesis, Departments of Ocean Engineering and Electrical Engineering, Massachusets

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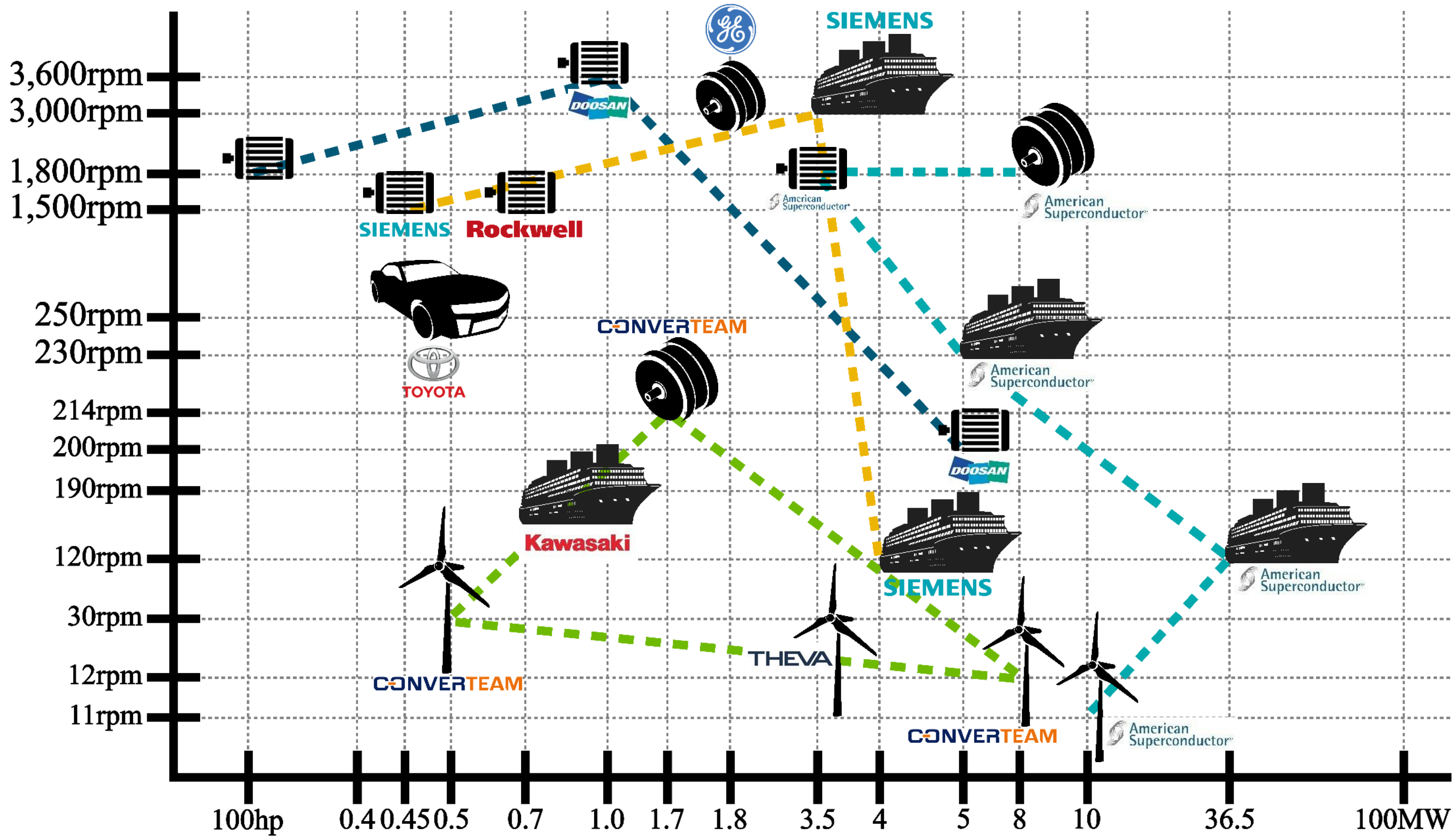
Problems and Challenges for Future Navy

Electric Propulsion

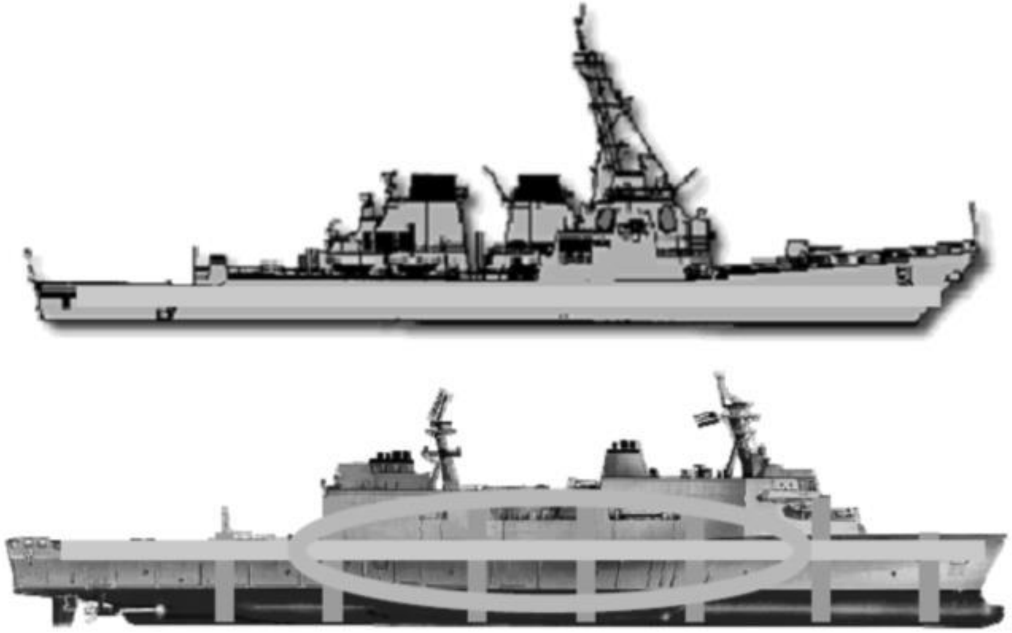


[3] © 2018 Copyright PI Integral Solutions based on Overview HTS Machines Marine RPM vs. Power, M Park, Changwon University. MT-22

Problems and Challenges for Future Navy

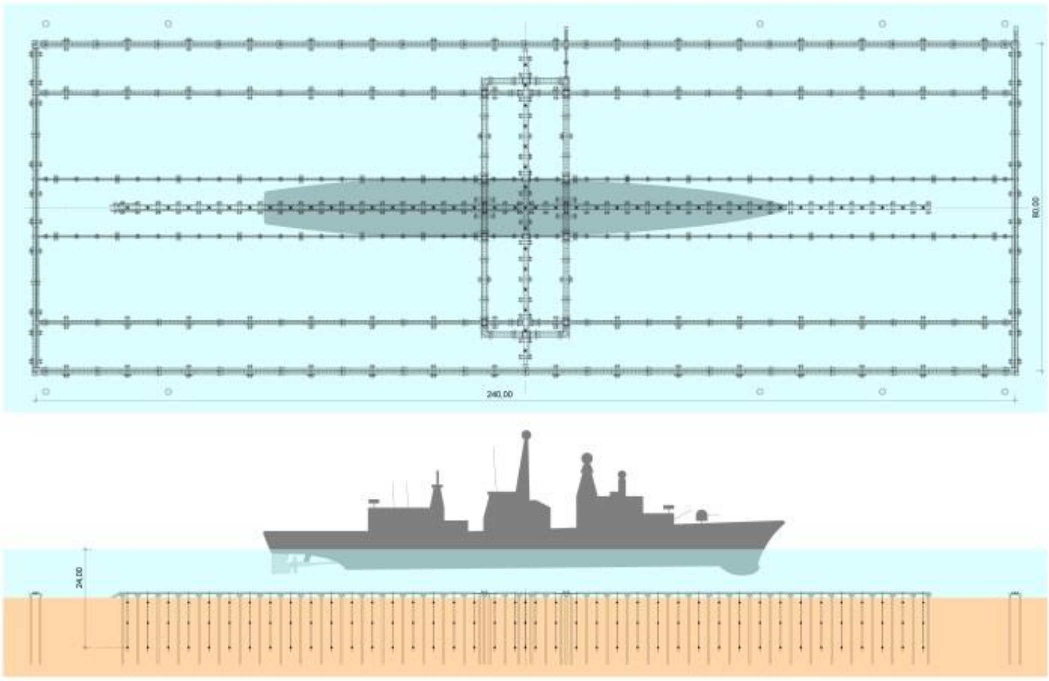
NOISE AND ELECTROMAGNETIC SIGNATURE

DEGAUSSING



[4] J. T. Kephart, B. K. Fitzpatrick, P. Ferrara, M. Pyryt, J. Pienkos and E. M. Golda, "High Temperature Superconducting Degaussing from Feasibility Study to Fleed Adoption," IEEE Transactions on Applied Superconductivity, vol. 21, no. 3, pp. 2229 - 2232, 2011

DEPERMING



[5] Wasserstraßen- und Schifffahrtsamt Lübeck, New construction of the demagnetization treatment plant of the Bundeswehr in Kiel-Friedrichsort, 2016, url; http://www.wsa-luebeck.wsv.de/aktuelles/baumassnahmen/emb_kiel/index.html, retrieved: June 2018

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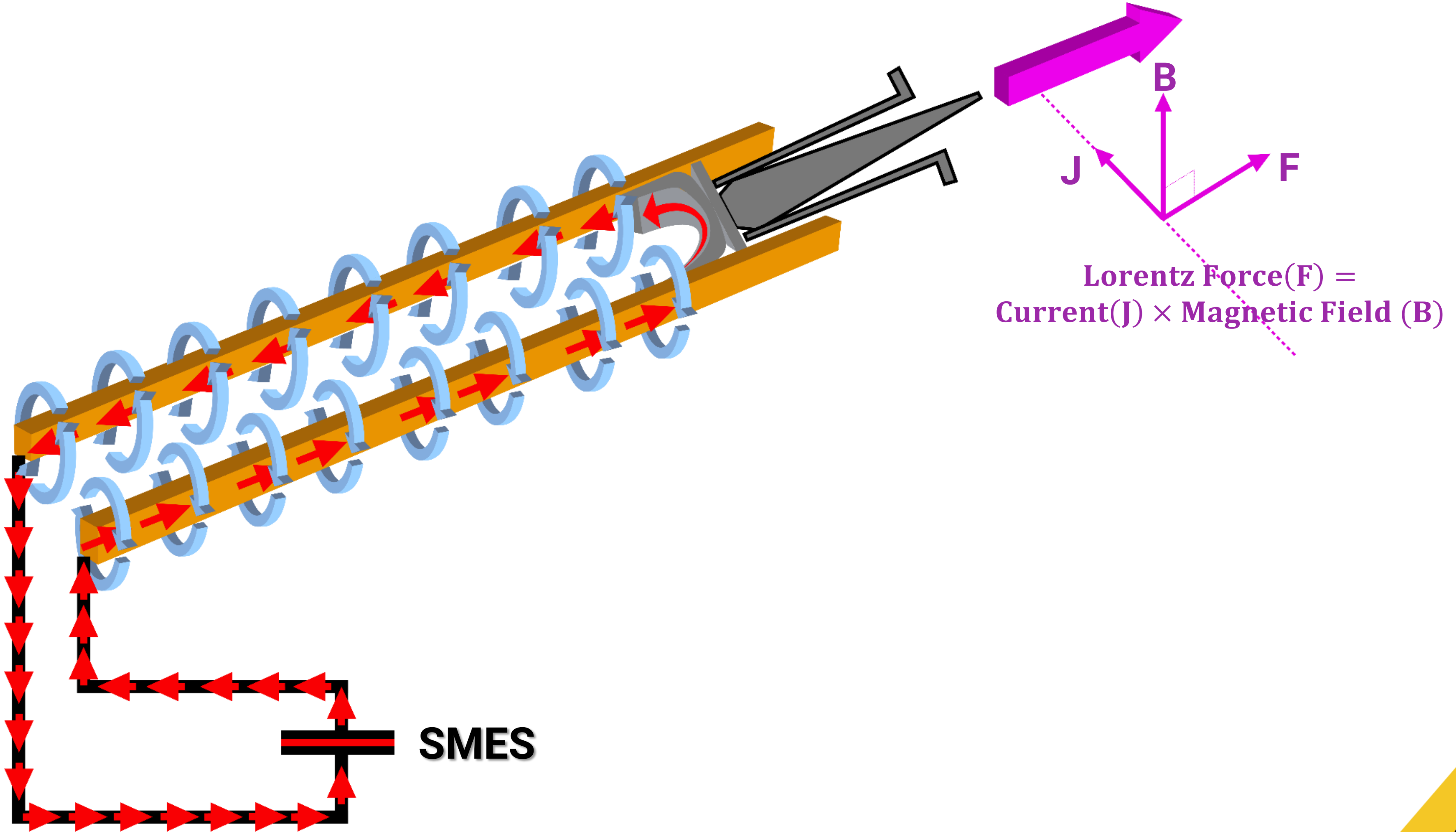
Problems and Challenges for Future Navy

Defence Systems

Energy and high power storage systems will enable the transition from explosively driven projectiles to the railgun technology



[6] © 2018 Copyright PI Integral Solutions based on B. Fitzpatrick, "Military Applications", Naval Surface Warfare Center. Carderock Division. 29th June 2010

Status Quo of 2G High Temperature Superconductors

1

TYPE 2G HTS

Materials
Main Properties

2

TAPE ARCHITECTURE

Production Technologies
Performance
Typologies

3

ECONOMIES OF SCALE

Production Capabilities
Product Development
Application Development

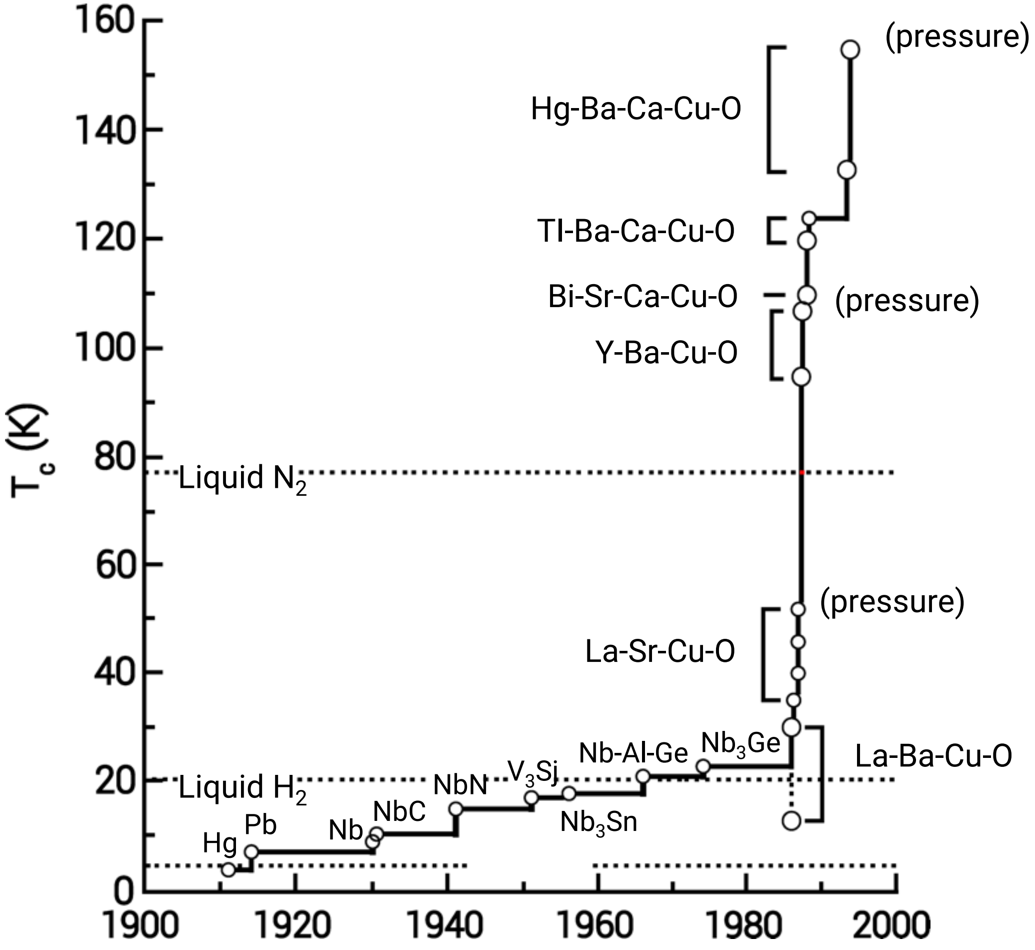
4

ALL ELECTRIC NAVAL VESSELS

High power propulsion → high efficiency
Mass and volume reduction → Lighter cables, DC bus bars, coils and magnets
Higher performance of sensors → low noise
High energy storage → for high power systems

Status Quo of 2G High Temperature Superconductors

TYPE 2G HTS



The highest known transition temperature as a function of time

Materials

[7] Thomas Frey, M. Kleber, H. Kinder, R. Gross Oxidation behavior of RE123 superconductors with time and place resolution. Published on August 2004 at the Technical University of Munich submitted and accepted by the Faculty of Physics on January 2005

TYPE 2G HTS

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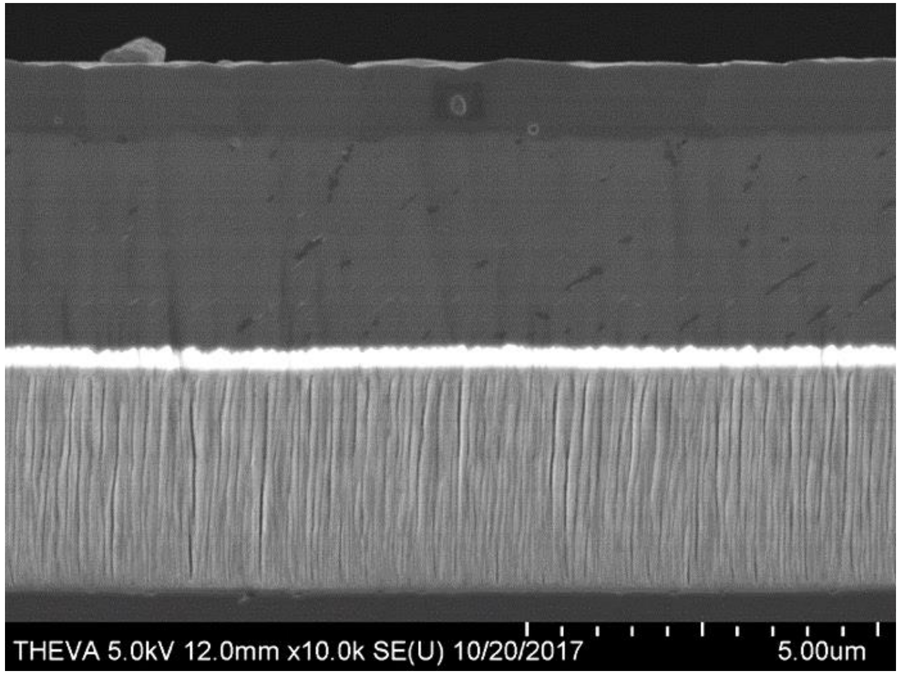
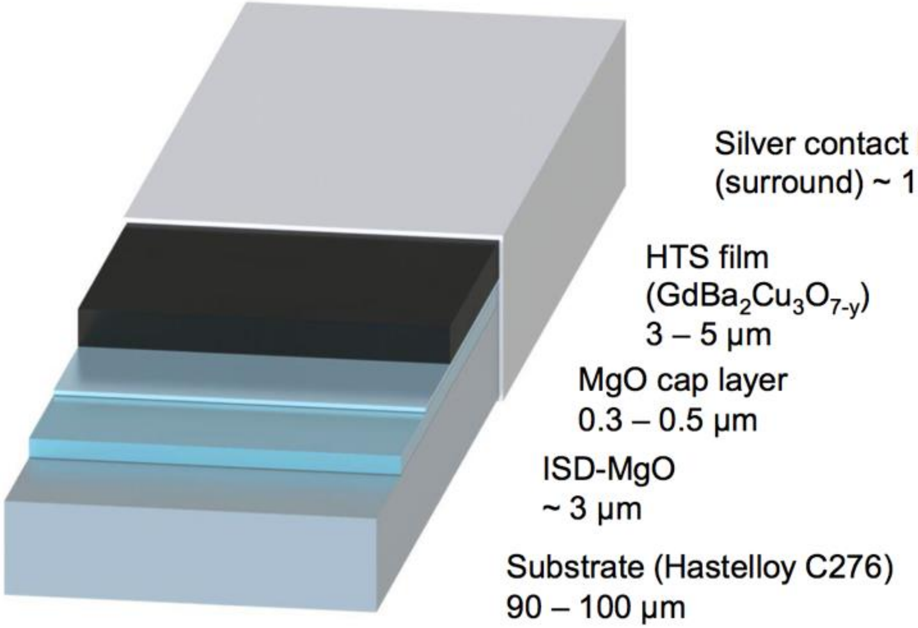
Materials





Status Quo of 2G High Temperature Superconductors

TYPE 2G HTS

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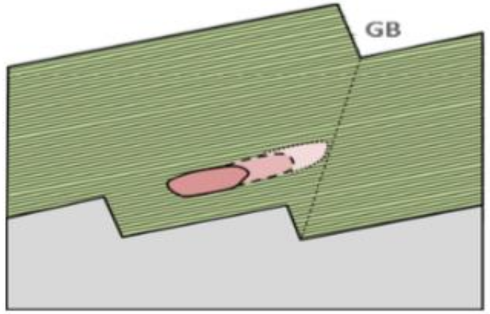
Main Properties

Tunable performance

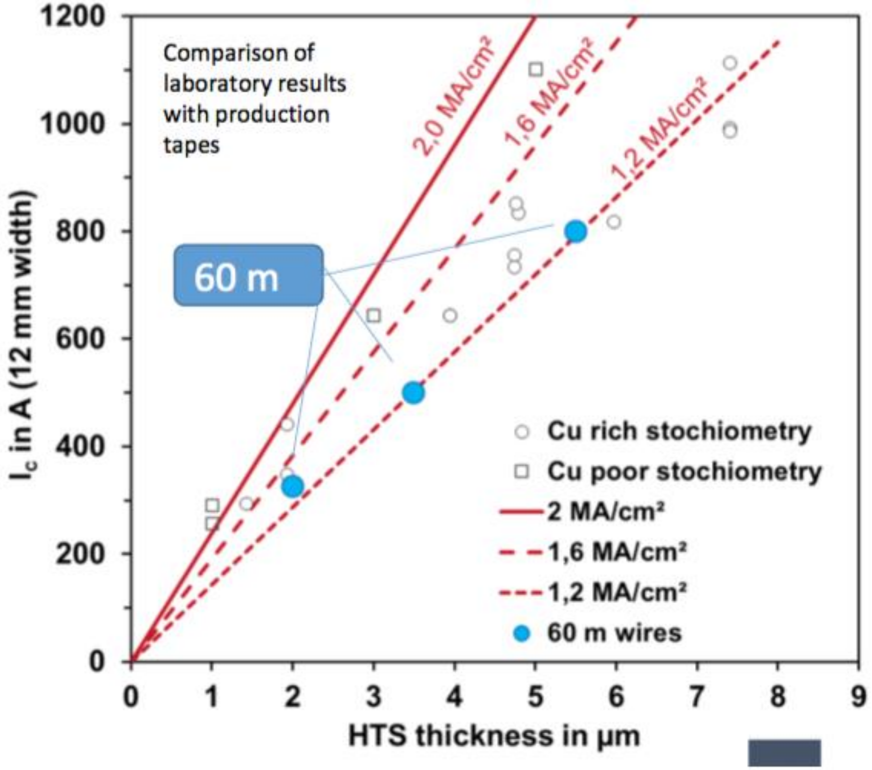
Positive effect of the tilt angle



Tilt leads to **textured** overgrowth of precipitates and misoriented regions

- J_c is thickness independent
- **Very high I_c possible**

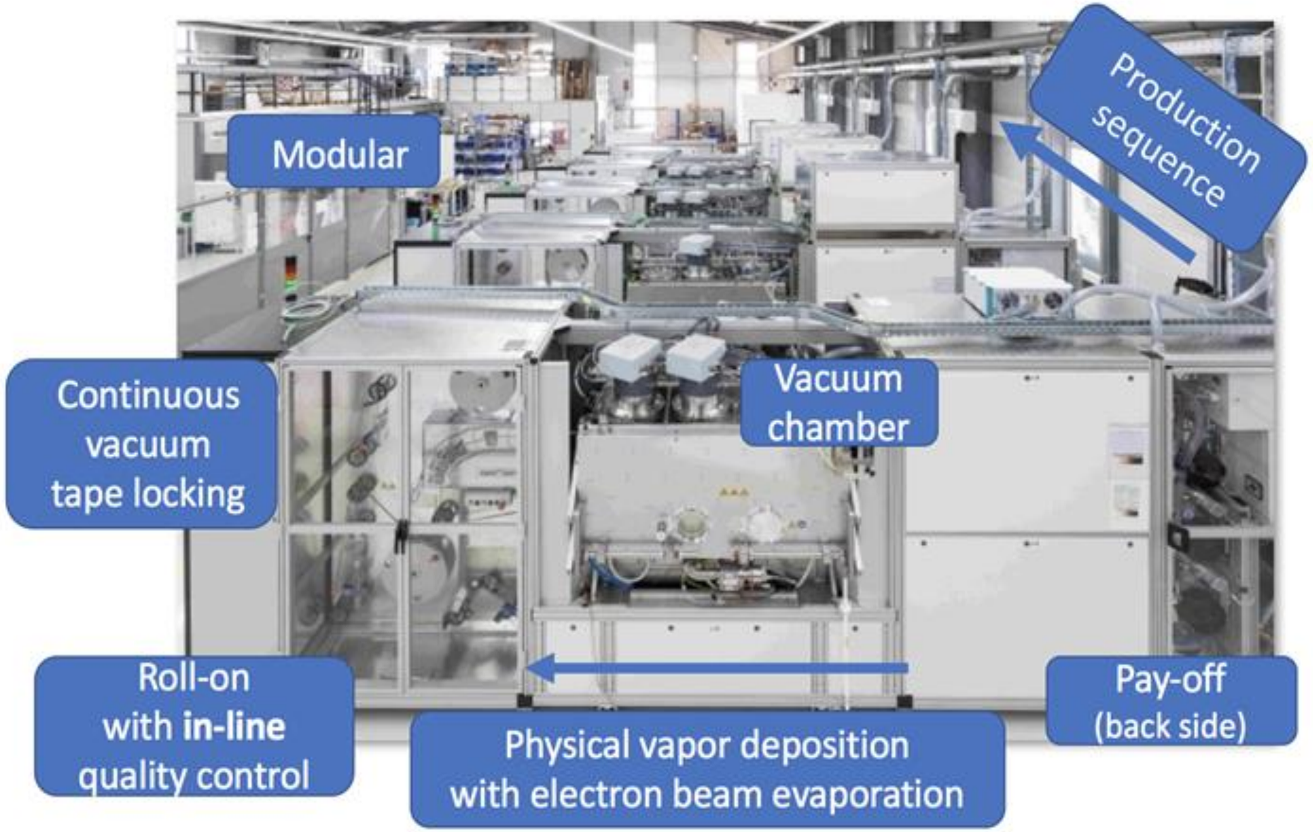
Previous results from 2016



Production Technologies

TAPE ARCHITECTURE

THEVA



- Cost efficient production
- Robust process allowing high yield
- Implementation of industrial standards
- Proof of production: high quality tape

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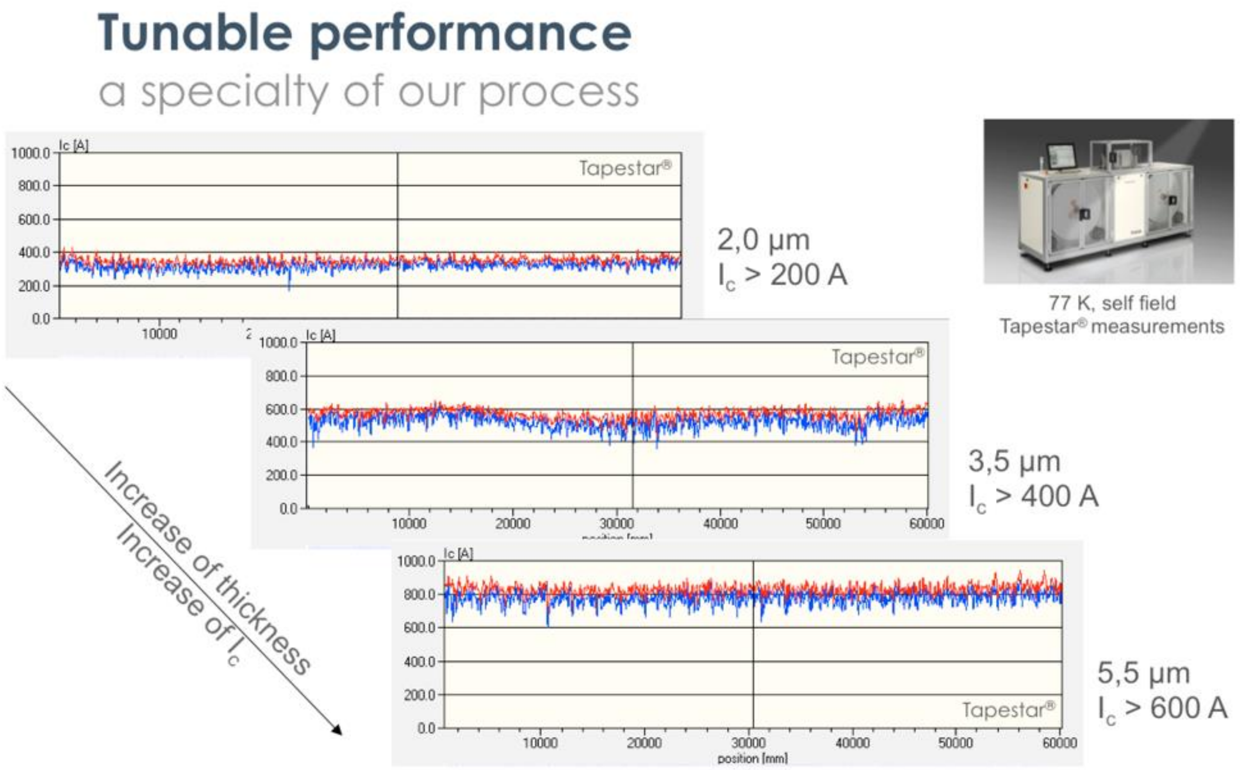
Status Quo of 2G High Temperature Superconductors

TAPE ARCHITECTURE

THEVA

Performance



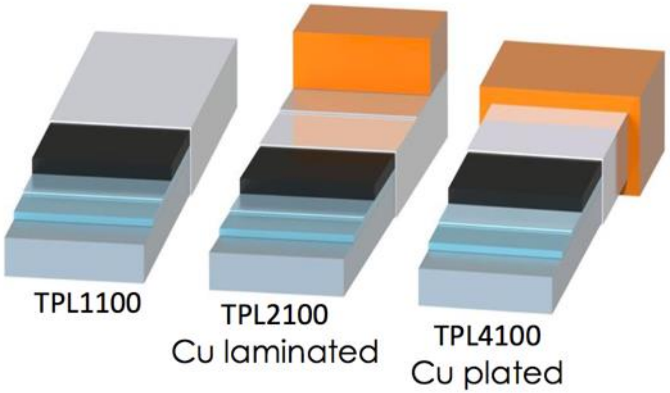
[8] Superconductivity Centennial Conference Working around HTS Thickness Limitations – towards 1000+ A/cm – Class Coated Conductors

Status Quo of 2G High Temperature Superconductors

TAPE ARCHITECTURE

THEVA

Typologies



- Cu stabilization according to application
- Standard width 12 mm
- Smaller width samples availabe

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ECONOMIES OF SCALE

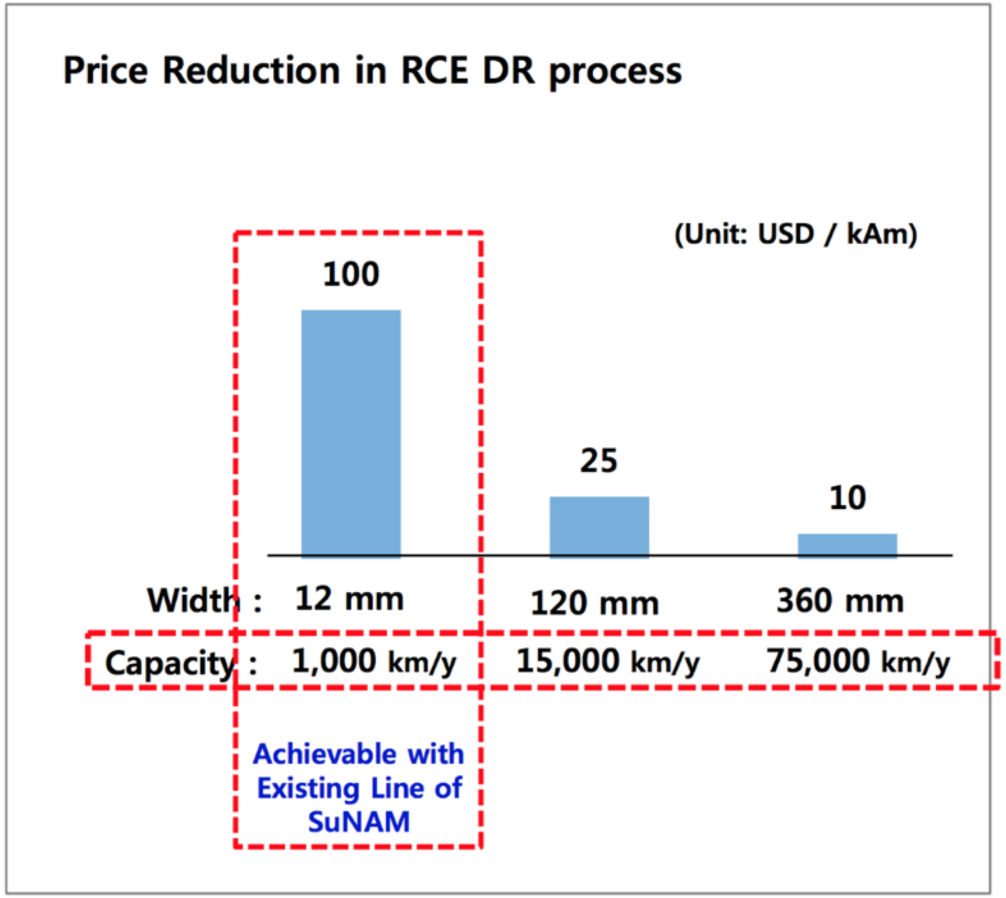
Production Capabilities

"Increasing Demand for HTS 2G wire has surpassed the supply"

"For market entrance $ 50 / kAm is the threshold "

"Price Reduction will ignite an exponential growth of demand for HTS 2G wire"

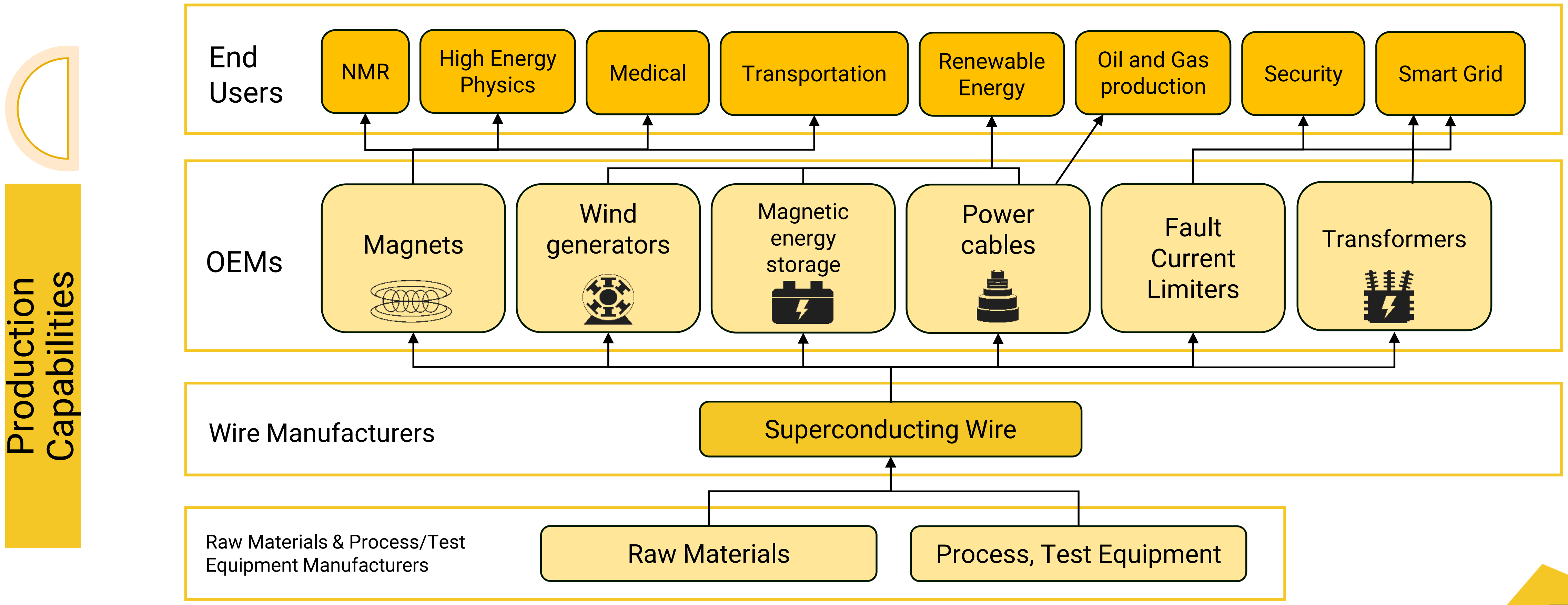
"High throughput, low material cost, High yield is 3 Critical Success Factor"



[9] Venkat Selvamanickam, University of Houston, Recent Advances in High Temperature Superconductors and Potential Applications (2014)

Status Quo of 2G High Temperature Superconductors

ECONOMIES OF SCALE



[10] © 2017 Copyright PI Integral Solutions based on
Venkat Selvamanickam, (2014): Recent Advances in High Temperature Superconductors and Potential Applications, University of Houston

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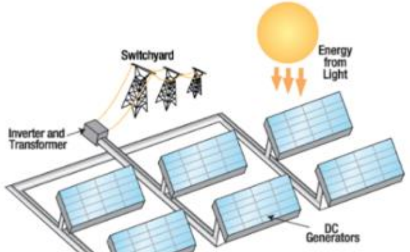
Application Development

ECONOMIES OF SCALE

Industry high current lines

Picture: Vision Electric

Connect renewables

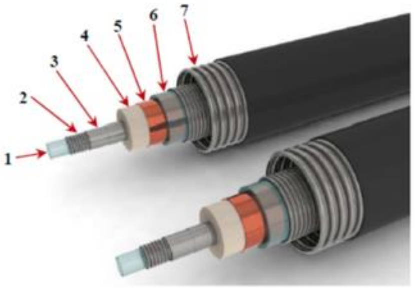


Picture: J. Minervini, MIT

Supply data centers

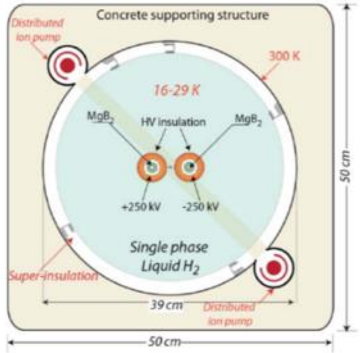
Picture: J. Minervini, MIT

Grounding of HVDC Lines



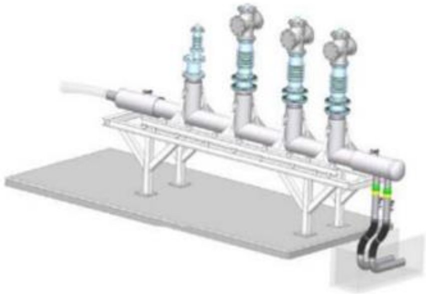
Picture: Nexans

Larger power, long distance transmission



Picture: C. Rubbia, IASS

Degaussing of ships



Picture: B. Fitzpatrick, HTS Peerreview2010

[11] Markus Bauer, Martin Keller, Veit Große, Raphaela Burzler, MT25 Conference 2017, Amsterdam, Ecoswing
[12] EUCAS Short Course Power Applications, Institute for Technical Physics, Superconducting Cables
[13] Mathias Noe, Institut für Technische Physik November 2015, Widerstand zwecklos – Supraleiter erobern Smart Grids

Key Enabling Technology for Naval Applications

Benefits of HTS based in front of Copperbased

- Lower material costs (fewer cables to install)
- Lower volume and weight
- Higher power density

Deg

on Cable

Copper (14)
1,75” OD

=

=

HTS (1)
2,75” OD

Main DC Bus Data from S3D Baseline Design

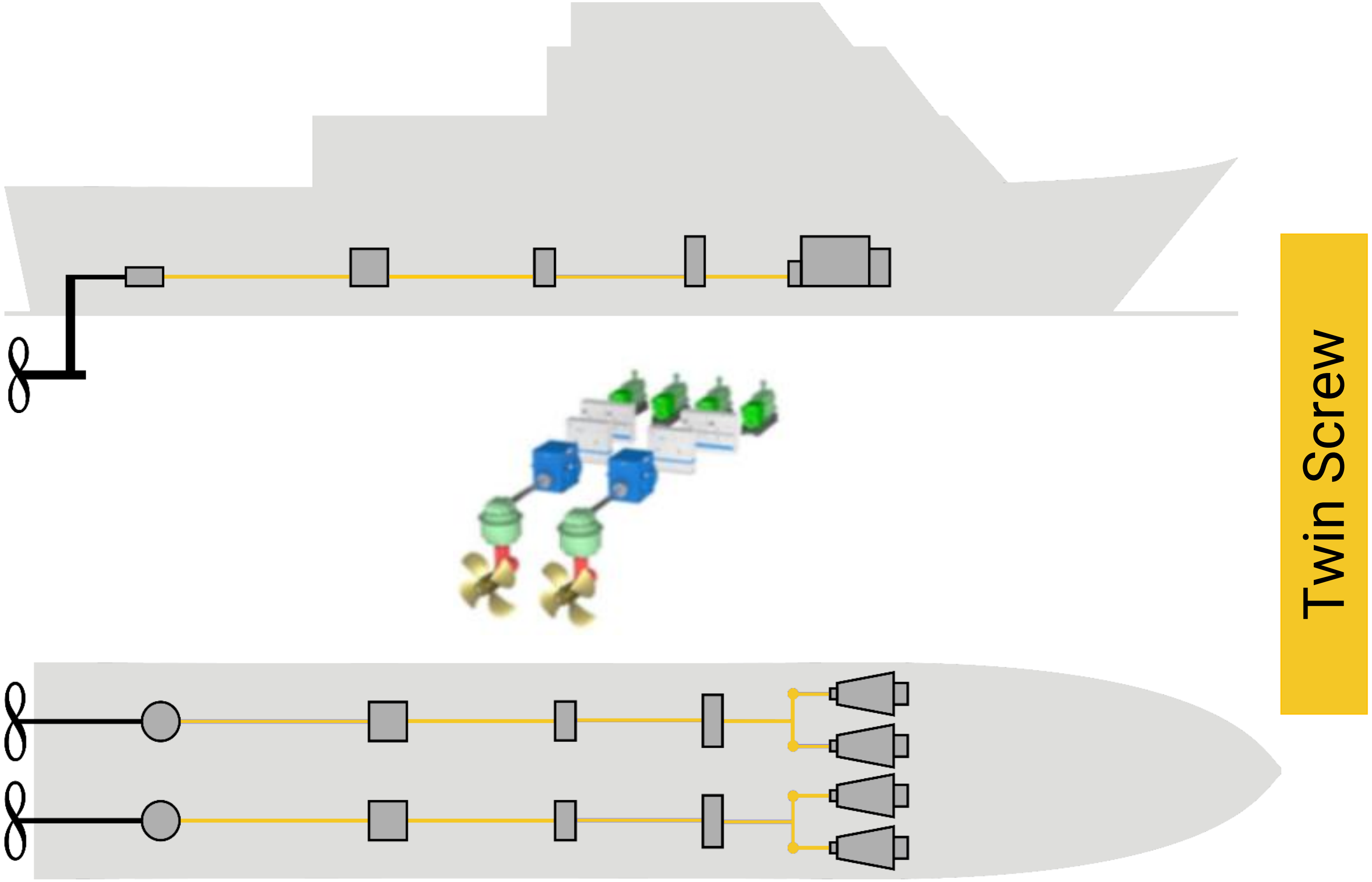
	S3D	New DC Bus
Rated voltage of cable bundle, kV	10	12
Rated current of cable bundle, kA	10	8.3
Total bus length. m	138	138
Number of cable bundle sections	3	3
Average cable bundle length, m	46	46
OD of each cable, mm	57.9	57.9
Number of cables per bundle	6	5
Resistance per unit length, mΩ/m	0.030	0.036
Weight per unit length. Kg/m	50.8	42.3
Number of connections to dc bus	11	11

[14] © 2018 Copyright PI Integral Solutions based on C. E. Bruzek, N. Lallouet, E. Marzahn, and K. Allweins,”Superconducting cables on board a ship A fiction or a reality?”, Seminar on ship building, The Netherlands, 2nd October 2012
[15] R. Hebner, A. Gattozzi, S. Strank, S. Pish, and J. Herbst, Electrical and thermal system considerations for MVDC superconducting distribution on navy ships, Center for Electromechanics, University of Texas at Austin

Key Enabling Technology for Naval Applications

High power electric propulsion

- Higher flexibility on the location of the electric motors
- More compact designs saving weight and volume
- 4.7 MW HTS machine from Siemens (25 % weight reduction)
- 36 MW HTS motor from Northrop Grumman (50 % weight reduction)

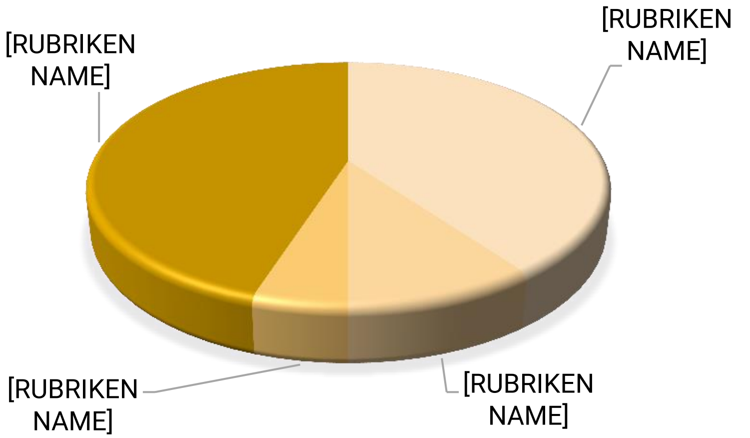


[14] © 2018 Copyright PI Integral Solutions based on C. E. Bruzek, N. Lallouet, E. Marzahn, and K. Allweins,"Superconducting cables on board a ship A fiction or a reality?", Seminar on ship building, The Netherlands, 2nd October 2012

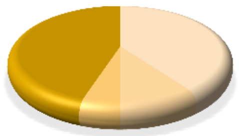
Key Enabling Technology for Naval Applications

Relative weight and cost comparison of copper and HTS based **Degaussing** system for LPL-17

Copper System Weight

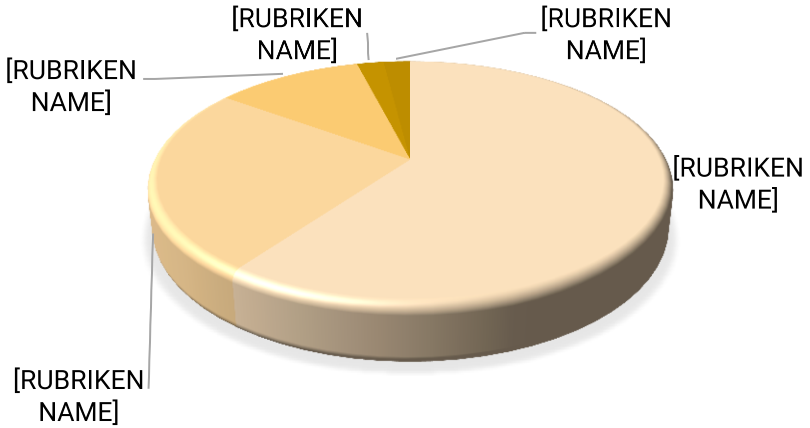


HTS System Weight

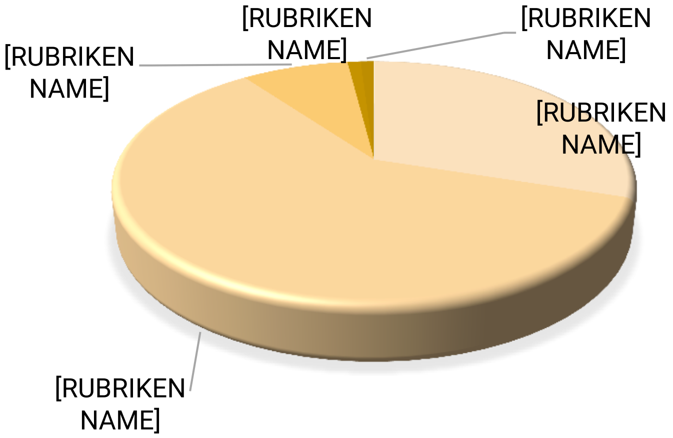


80% Reduction in Weight

Copper System Cost



HTS System Cost



Equivalent Costs Today

J. T. Kephart, B. K. Fitzpatrick, P. Ferrara, M. Pyryt, J. Pienkos and E. M. Golda, "High Temperature Superconducting Degaussing from Feasibility Study to Fleed Adoption," IEEE Transactions on Applied Superconductivity, vol. 21, no. 3, pp. 2229-2232, 2011

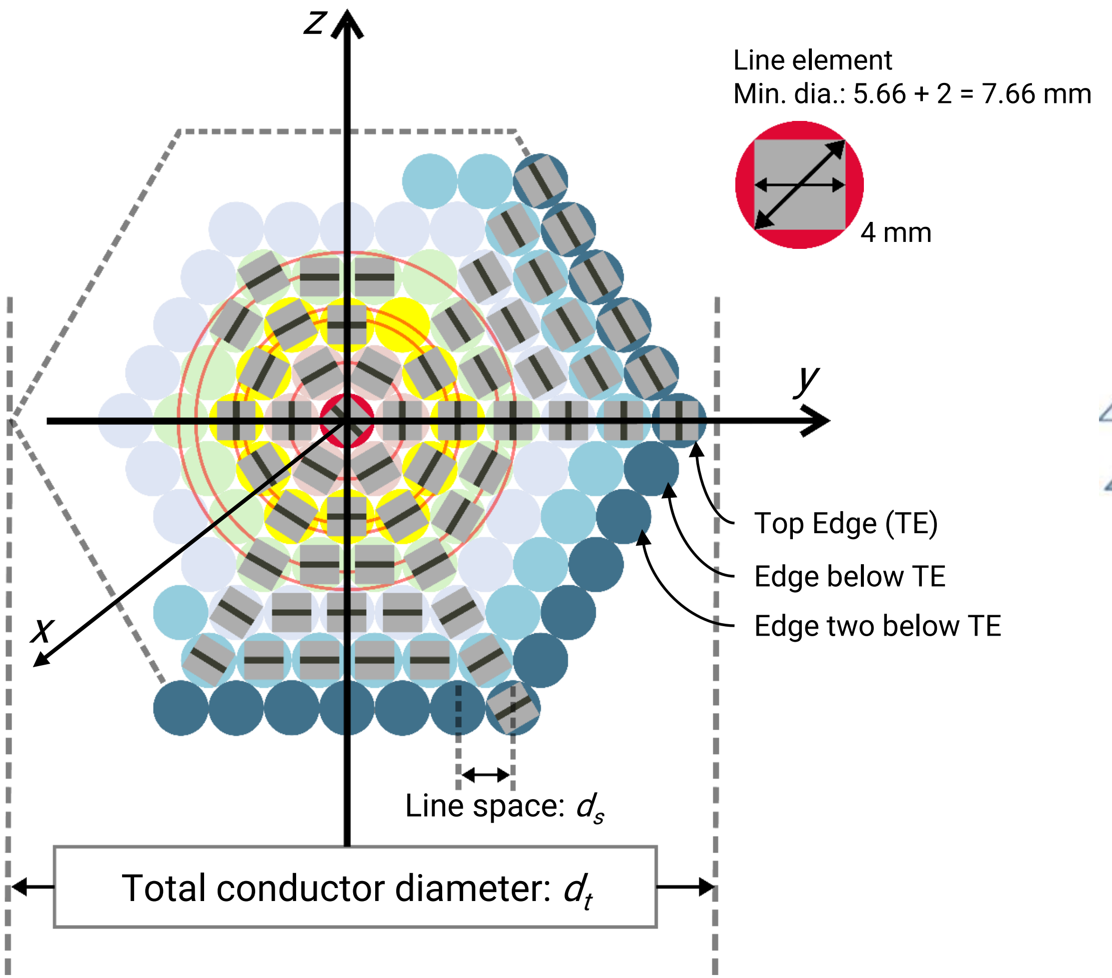
Key Enabling Technology for Naval Applications

Deperming

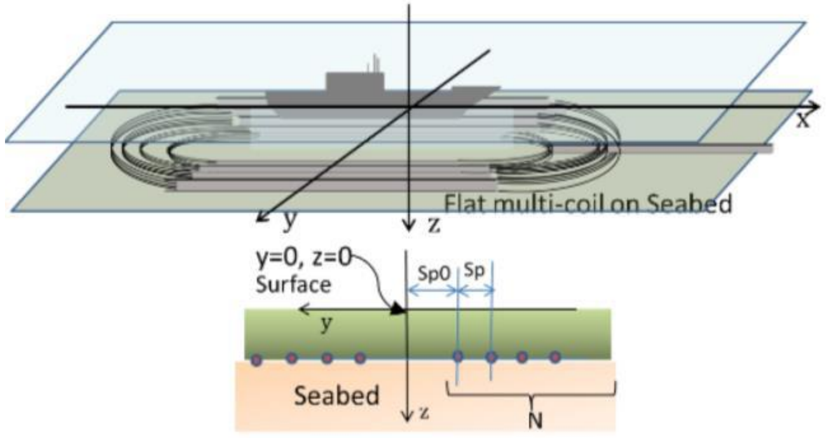
Low heat losses by using HTS technology

Smaller power supply is required

Allow shorter deperming times



Cross section of designed conductor, which is composed of closely packed line elements



Flat multi-turn coils geometry

[17] M. Hirota, "High temperature superconducting cable application to ship magnetic deperming," in Underseas Defence Technology, Bremen, 2017

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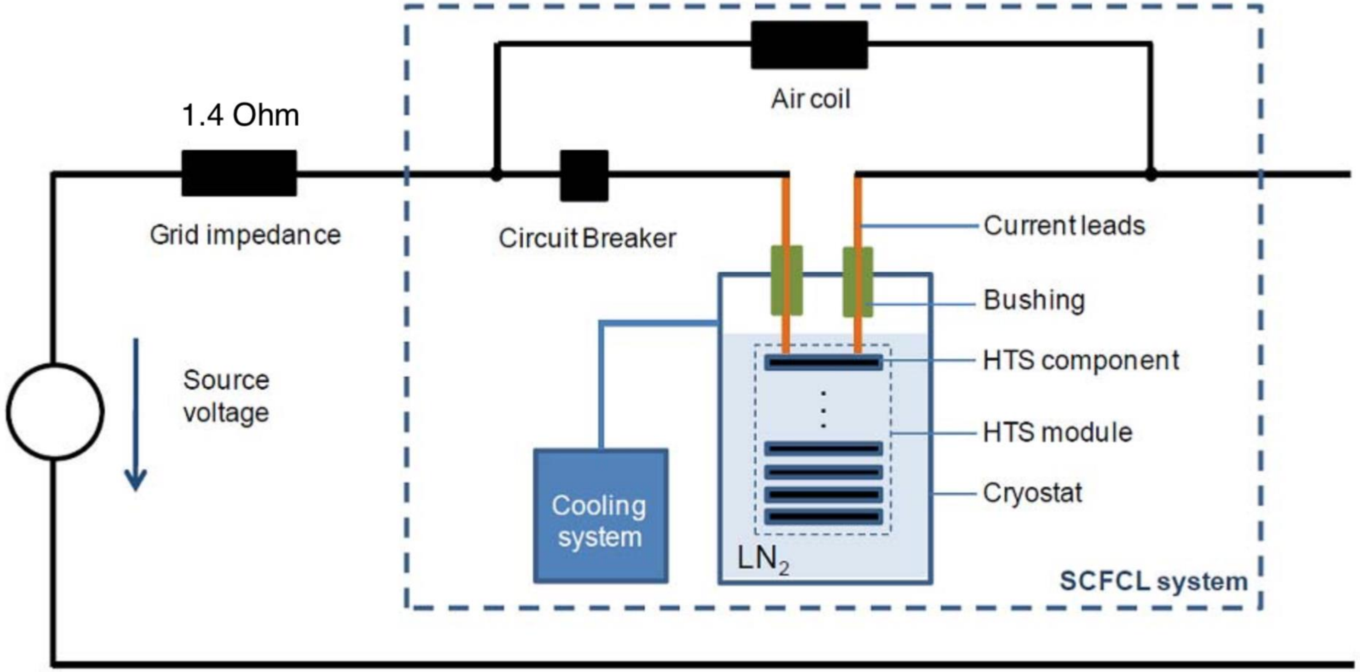
FAULT CURRENT LIMITERS

HTS property of quenching as a FCL Benefits



[18] Mathias Noe, Karlsruhe Institute of Technology Institute for Technical Physics EUCAS Short Course Power Applications, September 17th 2017, Geneva

Key Enabling Technology for Naval Applications

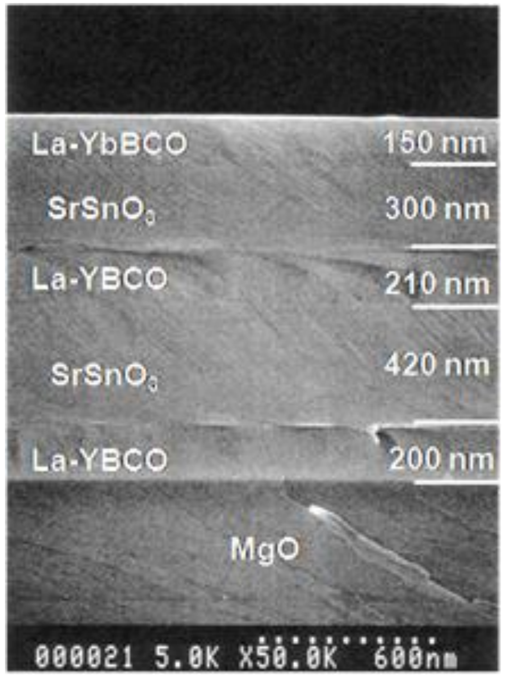
Magnetic Anomaly Detection

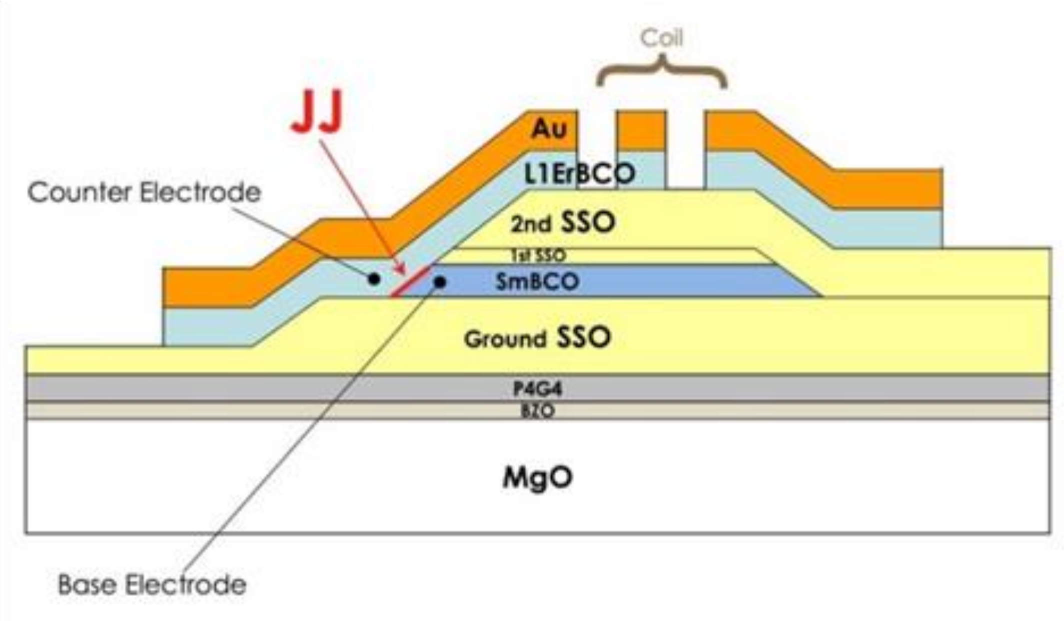
HTS film technology is used in sensor to reduce the ambient noise

High performance in extremely low frequency magnetic field sensors in submarines

HTS technology in SQUID for communication and surveillance in submarines

Development of smooth thin film multilayer structure including five oxide layers and ramp-edge Josephson junctions for HTS integrated circuits and SQUIDs





Cross-sectional SEM image for a smooth oxide multilayer (left) and schematic cross-section of multilayer HTS SQUID (right)
(SSO:SrSn03, L1ErBCO: $La_{0.1}$ $Er_{0.95}Ba_{1.95}Cu_3O_y$)

[19] International Superconductivity Technology Center (ISTEC), Materials/Physics & Electronic Devices Division, url; http://www.istec.or.jp/device/labo-device-E.html, retrieved: June 2018

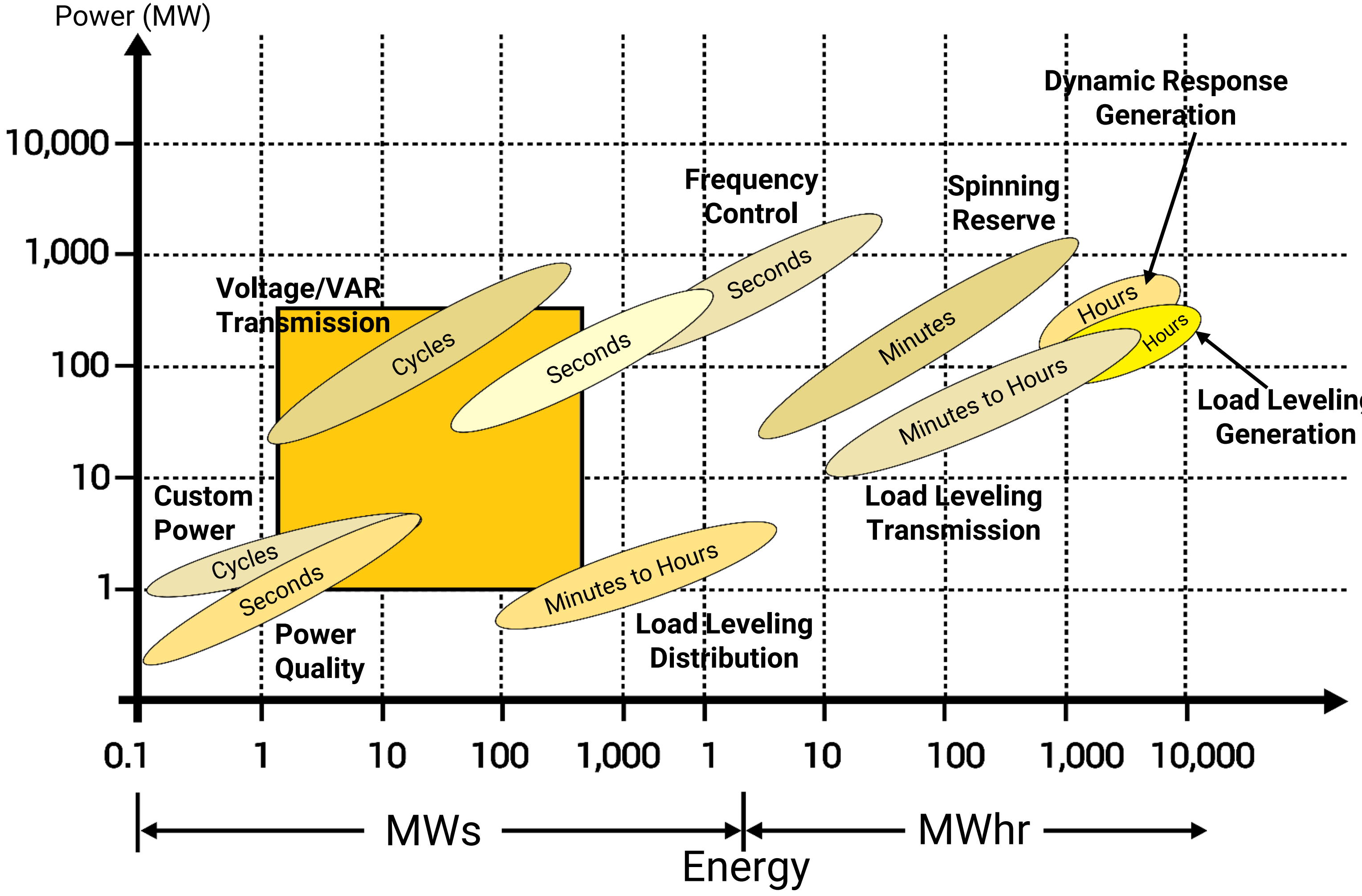
Key Enabling Technology for Naval Applications

SUPERCONDUCTING MAGNETIC ENERGY STORAGE

Superconducting Magnetic Energy Storage

Magnets based on 2G HTS technology has reached a level of maturity that are able to generate magnetic fields as high as the ones produced by low temperature superconductors.

SMES systems exhibit an outstanding performance in power transmission control and stabilization in front of other energy storage solutions



CONCLUSIONS

1

GEO-POLITICAL CHALLENGES

US Navy Technology Leadership on Superconducting Applications

Arctic Territorial and Resources Conflicts

NATO and EU Naval Forces Challenges

2

PROBLEM AND CHALLENGES FOR FUTURE NAVY

Efficiency of high power propulsion systems

Mass and volume reduction of power generation and distribution systems

Noise and electromagnetic signature of vessels

3

STATUS QUO OF 2G HTS TECHNOLOGY

Constant increase in the production of basic elements

Growing number of applications for HTS

4

2G HTS AS KEY ENABLING TECHNOLOGY FOR NAVAL APPLICATIONS

Electric propulsion

Power distribution

Degaussing and Deperming

Advanced Sensors & Defence systems

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Thanks for your attention

References

[1] Tromso, "Cosy amid the thaw," The Economist, March 24th 2012

[2] J. P. Harbour, "Evaluation and comparison of electric propulsion motors for submarines," Master thesis, Departments of Ocean Engineering and Electrical Engineering, Massachusets

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[5] Wasserstraßen- und Schifffahrtsamt Lübeck, New construction of the demagnetization treatment plant of the Bundeswehr in Kiel-Friedrichsort, 2016, url; http://www.wsa-luebeck.wsv.de/aktuelles/baumassnahmen/emb_kiel/index.html, retrieved: June 2018

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[7] Thomas Frey, M. Kleber, H. Kinder, R. Gross Oxidation behavior of RE123 superconductors with time and place resolution. Published on August 2004 at the Technical University of Munich submitted and accepted by the Faculty of Physics on January 2005

[8] Superconductivity Centennial Conference Working around HTS Thickness Limitations – towards 1000+ A/cm – Class Coated Conductors

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