Advancing Microwave-Based Imaging Techniques for Medical Applications in the Wake of the 5G Revolution

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Special Session
CS33 Horizon 2020 research and innovation session (EMERALD): ElectroMagnetic imaging for a novel genERation of medicAL Devices
(http://www.msca-emerald.eu/)

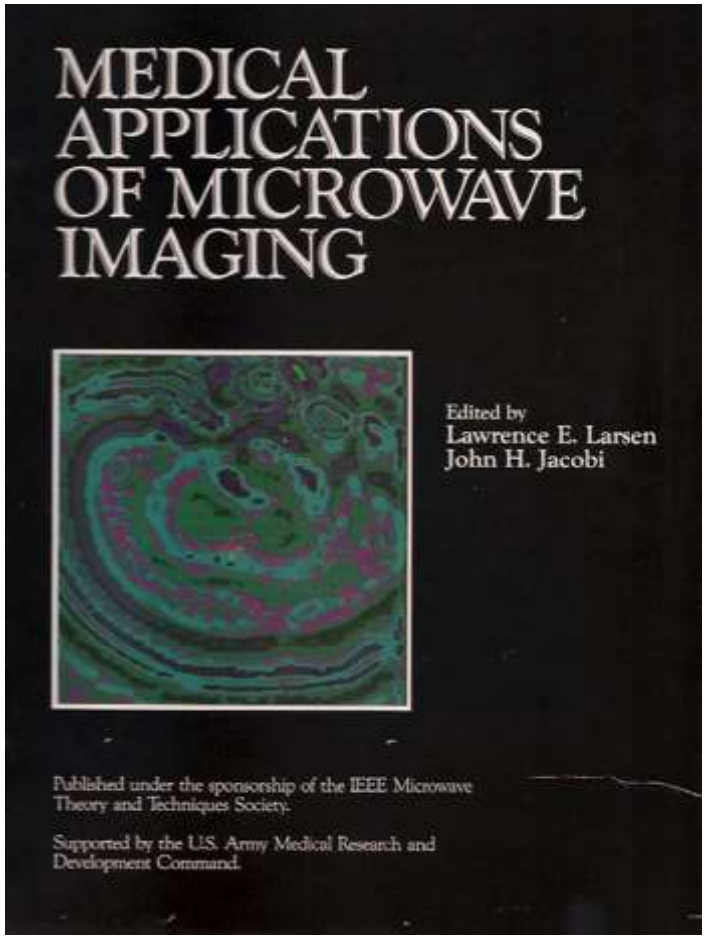
OUTLINE

- FEW QUESTIONS ON MICROWAVE-BASED IMAGING FOR MEDICAL APPLICATIONS
- PART I: WHERE ARE WE ARRIVED ?
- PART II: WHAT COULD BE TRIED/DONE ?
- CONCLUSIONS

Special Session

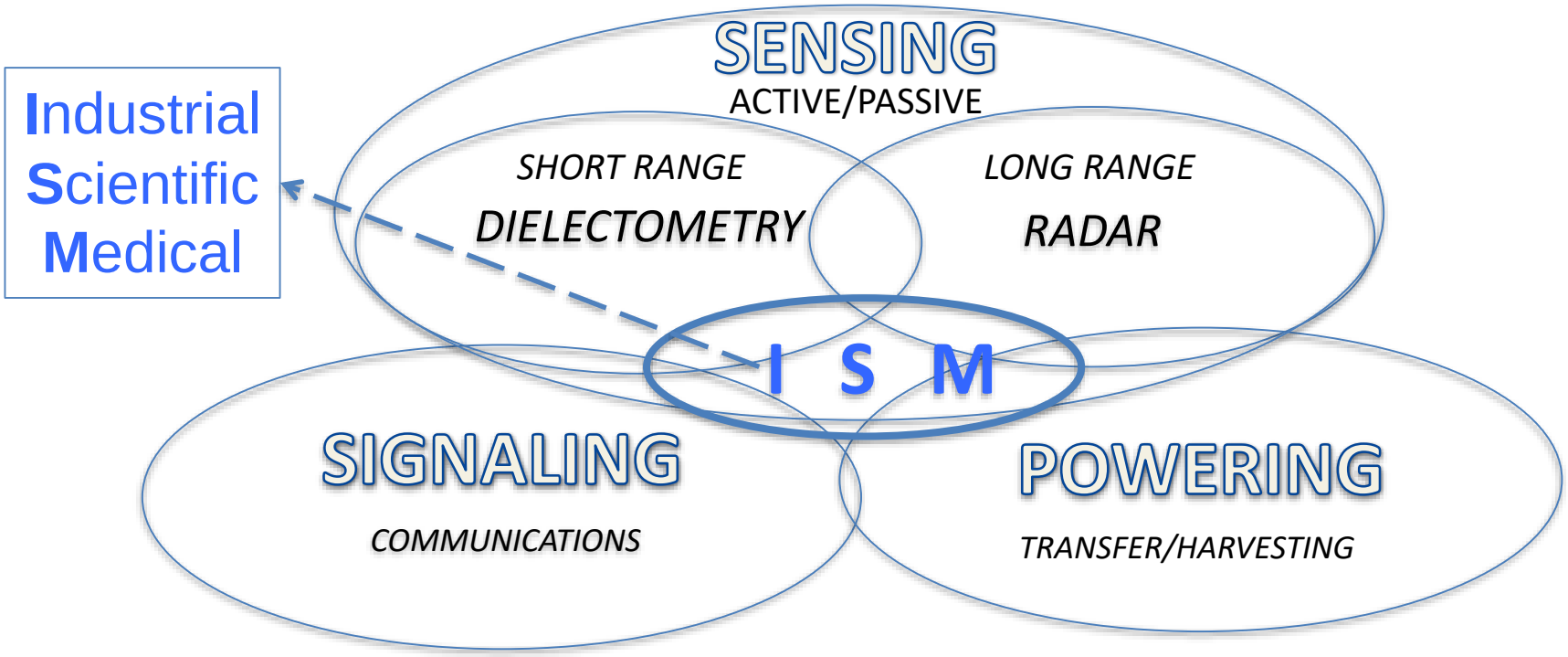
CS33 Horizon 2020 research and innovation session (EMERALD): ElectroMagnetic imaging for a novel genERation of medicAL Devices

MICROWAVE-BASED MEDICAL IMAGING FACTS AND QUESTIONS …



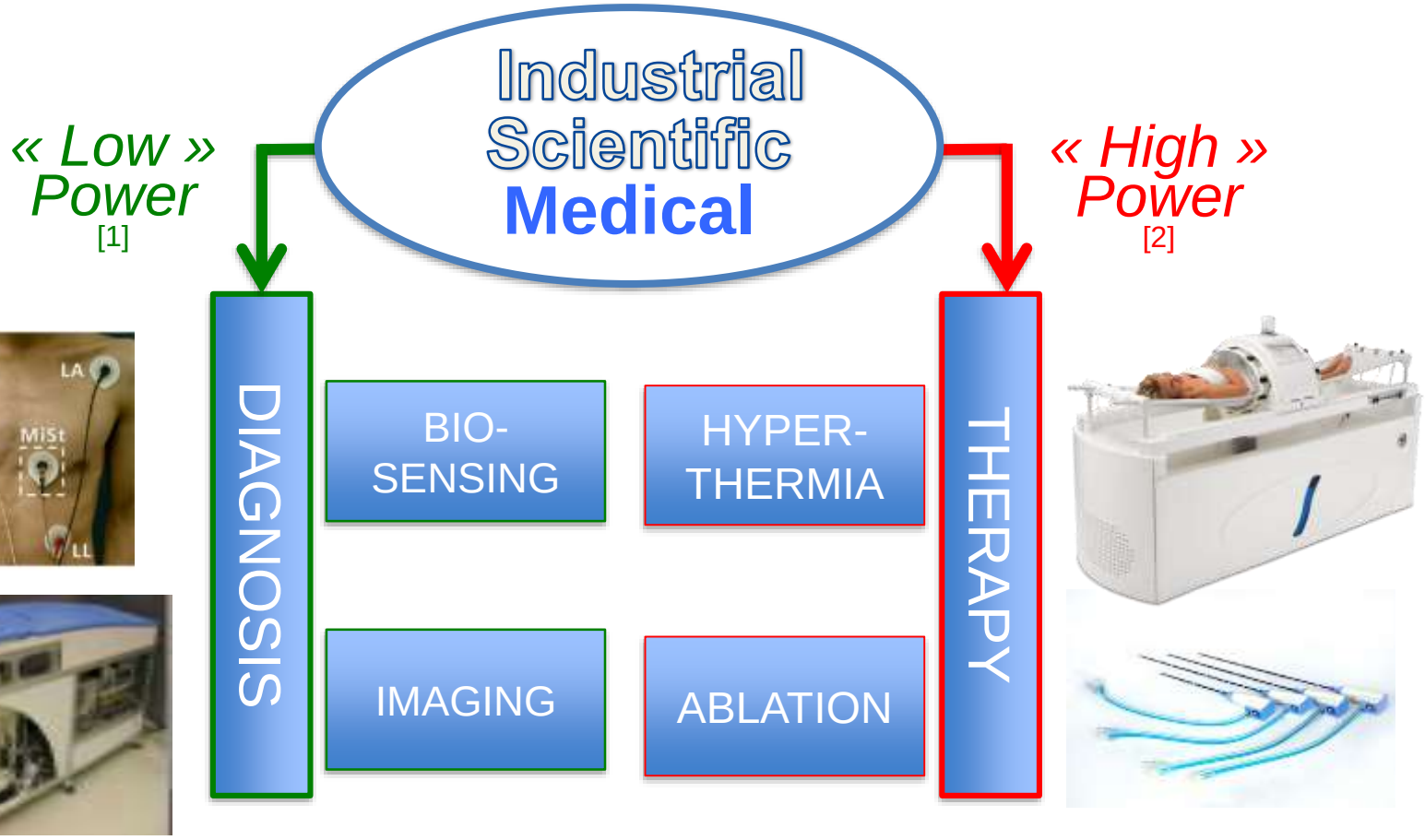
- SINCE EARLY 80's… "MICROWAVES ARE CLAIMED TO OFFER PROMISES AS IMAGING MODALITY"
  L.E. Larsen and J.H. Jacobi
  (*Diagnostic Imaging in Clinical Medicine, **11**, 44-47,1982)*
- WHAT EXACTLY MICROWAVES ARE PROMISING OF ? AND BY WHEN ?
- INDEED, ALMOST 40 YEARS LATER, MICROWAVES ARE STILL CLAIMING TO OFFER PROMISES… BUT ONLY GAINED A MODEST CLINICAL ACCEPTANCE
- IN FACT, THE JOURNEY WAS MORE COMPLICATED THAN EXPECTED BUT THE RESULTS COLLECTED FROM RECENT CLINICAL TRIALS SEEMS SUGGESTING A POSSIBLE EXIT OF THE TUNNEL…

SIMPLIFIED CLASSIFICATION CHART OF MICROWAVE-BASED APPLICATIONS



MICROWAVE ISM APPLICATIONS AT THE CROSS-ROAD OF SIGNALING/SENSING/POWERING TECHNOLOGIES

VARIOUS ASPECTS OF MICROWAVES FOR MEDICAL APPLICATIONS

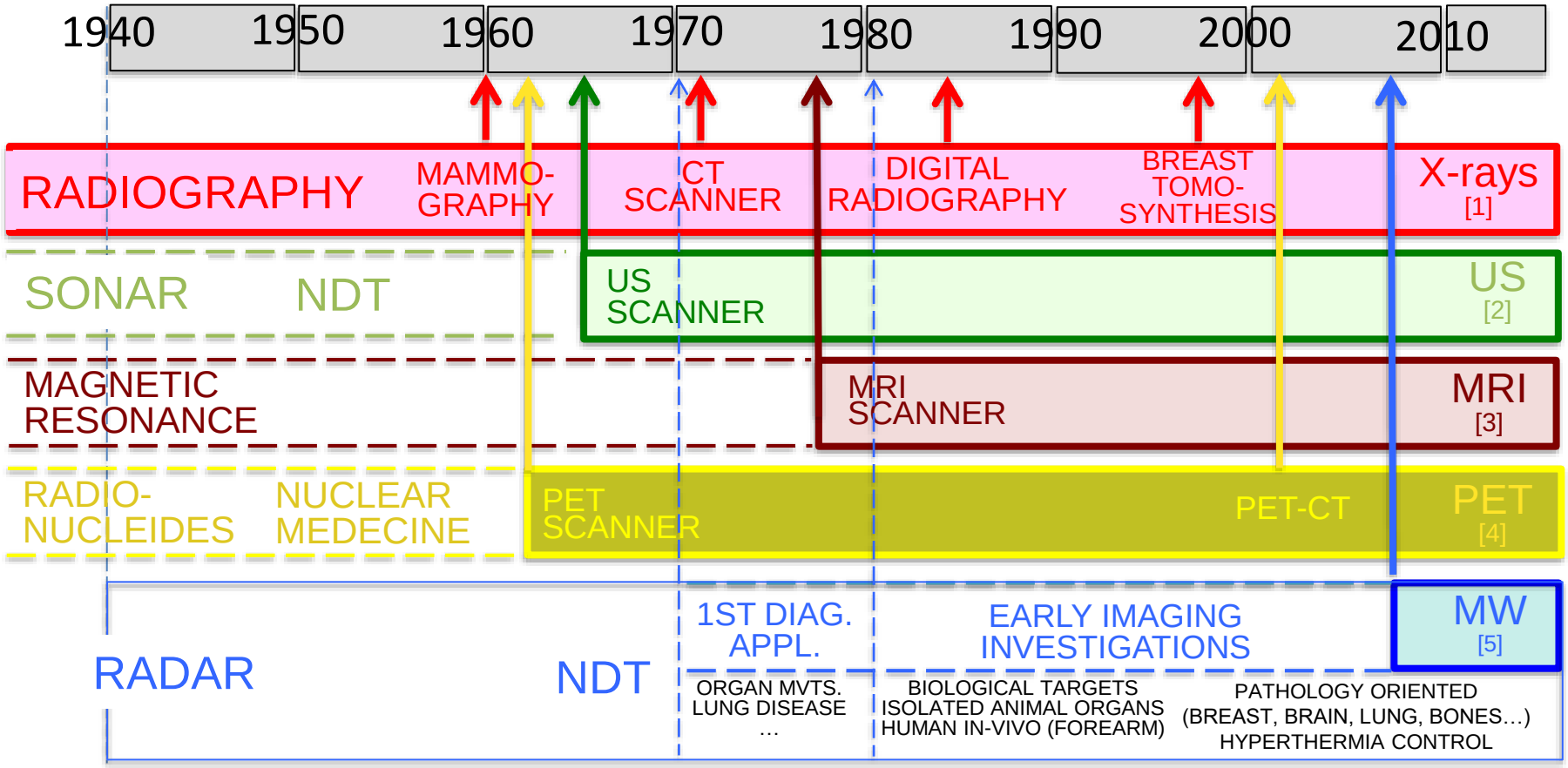


[1] *M.F. Iskander and C.H. Durney, "Electromagnetic Techniques for Medical Diagnosis: a Review", Proc. IEEE, 68, 226-132, Jan. 1980*

[2] *A.W. Guy, "History of Biological Effects and Medical Applications Of Microwave Energy", IEEE Trans. MTT-32, 226-132,Sept. 1984*

MICROWAVE-BASED MEDICAL IMAGING
IS THE "LAST COMER" ISM APPLICATION

TIME LINE OF MAJOR IMAGING MODALITIES MICROWAVES AS "LAST COMER"



[1] R. Ciernak, "X-Ray Computed Tomography in Biomedical Engineering", Springer-Verlag London Limited, 2011

[2] J. Woo, "A short history of the Real-time ultrasound scanner", http://www.ob-ultrasound.net/history-realtime.html

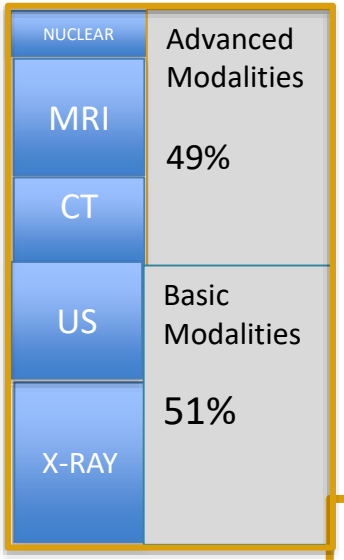
[3] T. Geva, "Magnetic Resonance Imaging: Historical Perspective", Journ. Cardiovascular Magnetic Resonance, 8, 573-580, 2006

[4] G. Bernal, "History of PET scanners", http://large.stanford.edu/courses/2014/ph241/bernal1/

[5] J.Ch. Bolomey, "Crossed Viewpoints on Microwave-based Imaging for Medical Diagnosis: From Genesis to Earliest Clinical outcomes ", in *The World of Applied Electromagnetics,* A. Lakhtakia, C.M. Furse (eds), Springer 2018

GLOBAL VIEW OF MEDICAL IMAGING MARKET
WHAT PLACE FOR MICROWAVES ?

- SALIENT MARKET FEATURES:
  - Global Market size worth 29.48 billions and projected to reach 46.18 by 2024,
  - Market growth supported by the rise of geriatric population and the increased prevalence of CV diseases,
  - Expected Growth Rate: 6.56%, over the forecast period 2016 - 2024
  - X-ray first; fastest growth expected for CT/PET (earlier disease detection),
  - Larger growth expected for emerging markets.
  - Global market shared by only a few big companies.



MEDICAL IMAGING EQUIPMENT MARKET
(*Transparency Market Research, transparencymarketresearch.com*)

GLOBAL MEDICAL IMAGING MARKET
(*Pictures of the Future, Medical Imaging:Facts and Forecasts, siemens.com*)

- KEY GROWTH DRIVERS:
  - Miniaturization and portability,
  - Digitization of measured data,
  - Hybrid imaging systems,
  - Use of non-ionizing modalities,
  - Non-invasive and easy-to-use equipment,
  - Inexpensive, energy saving, ergonomic medical equipment with low maintenance requirements …

A PRIORI MICROWAVES LOOK ALMOST PERFECT

BUT, A POSTERIORI… NOT SO SIMPLE !

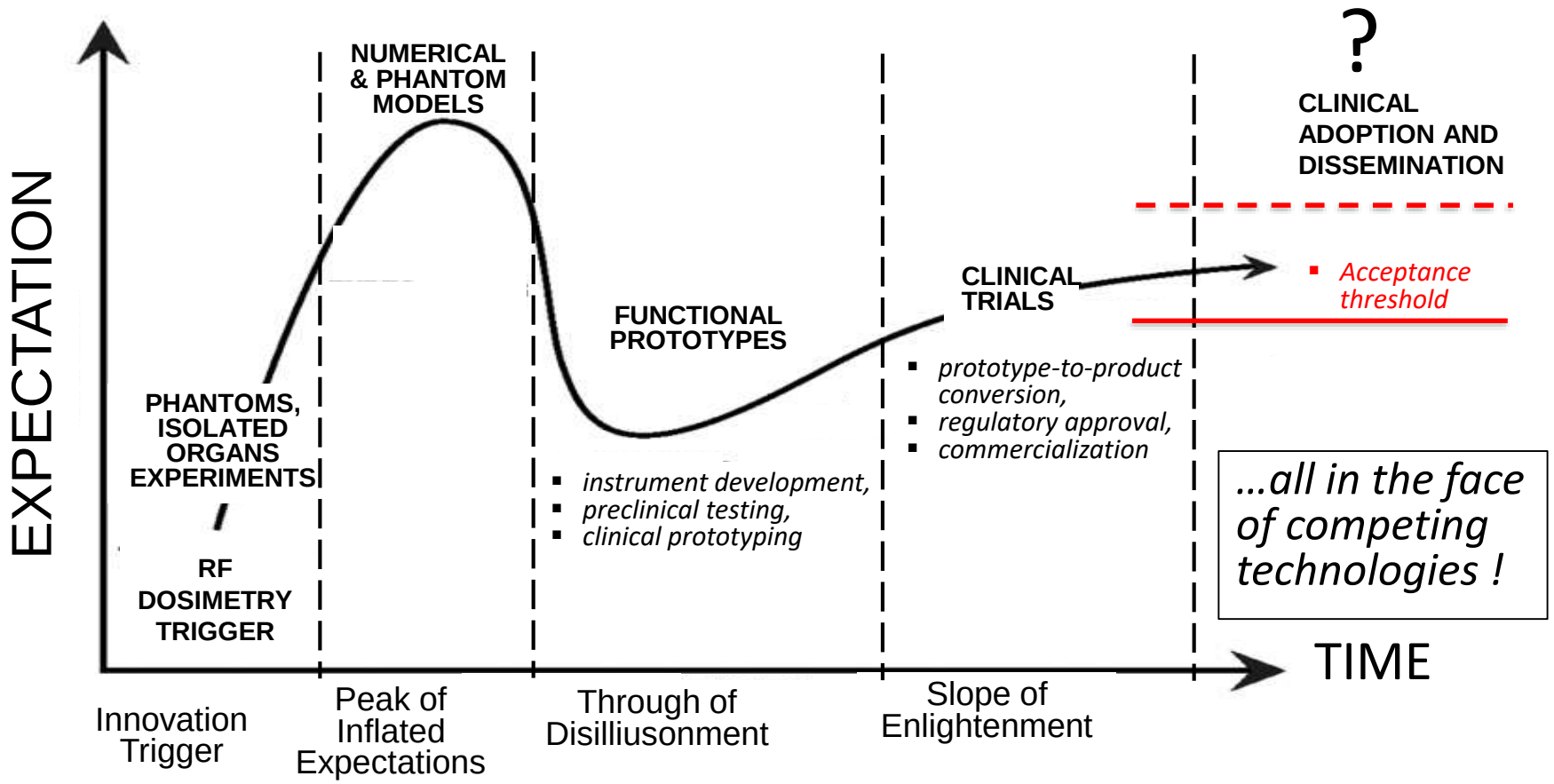
MICROWAVES AS “CHALLENGER” TECH ?

Comparison of 'challenger' breast screening technologies

Measure	DBT	ABUS	MRI	'Challenger' tech
Commercially available in EU	Yes	Yes	Yes	--
Cost of system	200K-275K euros	175K-250K euros	1M+ euros	10K-300K euros
Clinical evidence for screening	Mid/high	Mid/low	Mid	Low
No. of vendors with product	5+	3	5+	< 5 per segment
Maturity of technology	>+++	+	++++	+

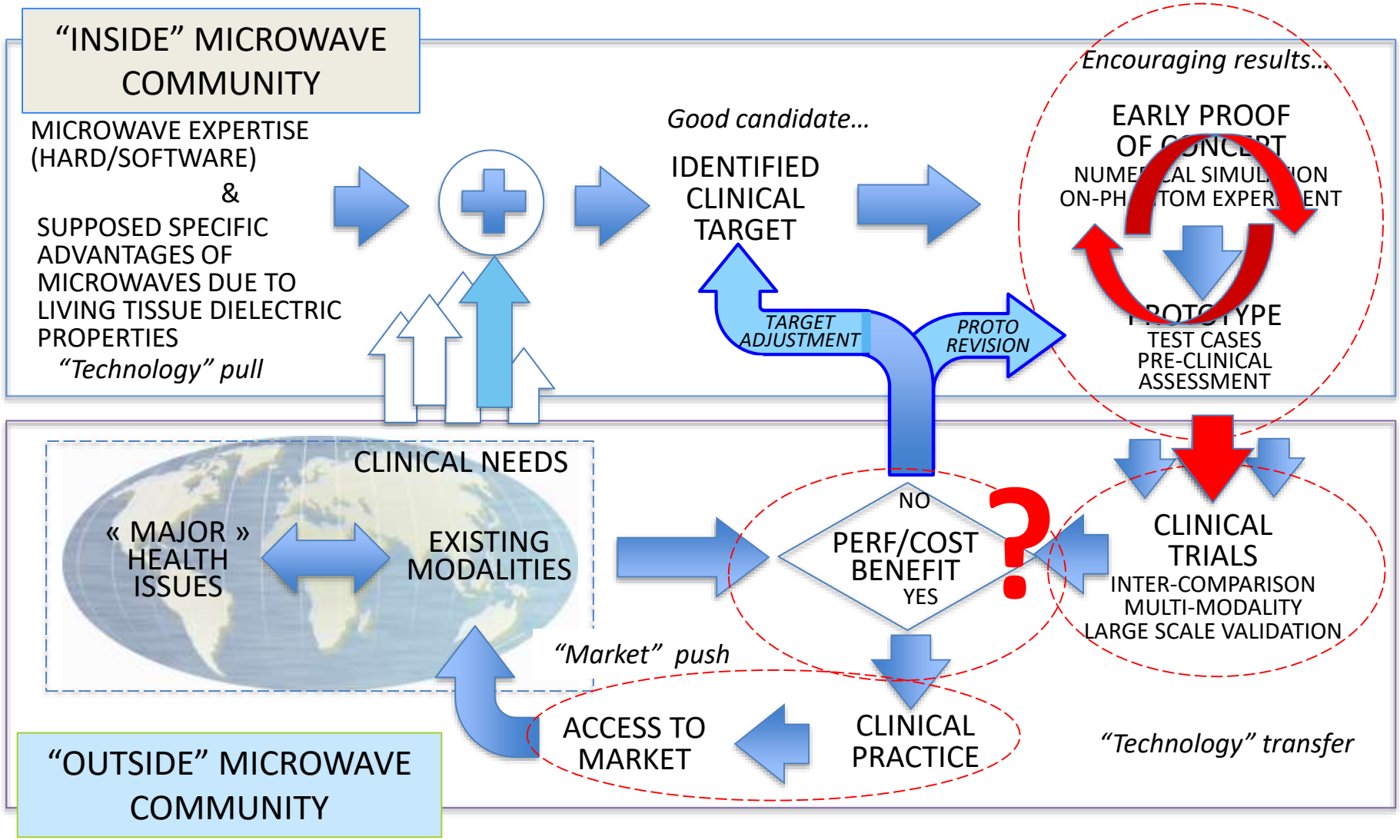
From: Stephen Holloway, AuntMinnie.com contributing writer March 6, 2019
“DBT is well-positioned as successor in European breast screening”
European Congress of Radiology, Vienna, Feb. 27 – March 3, 2019

HYPE CYCLE FOR EMERGING TECHNOLOGIES
APPLICATION TO MICROWAVE-BASED MEDICAL IMAGING

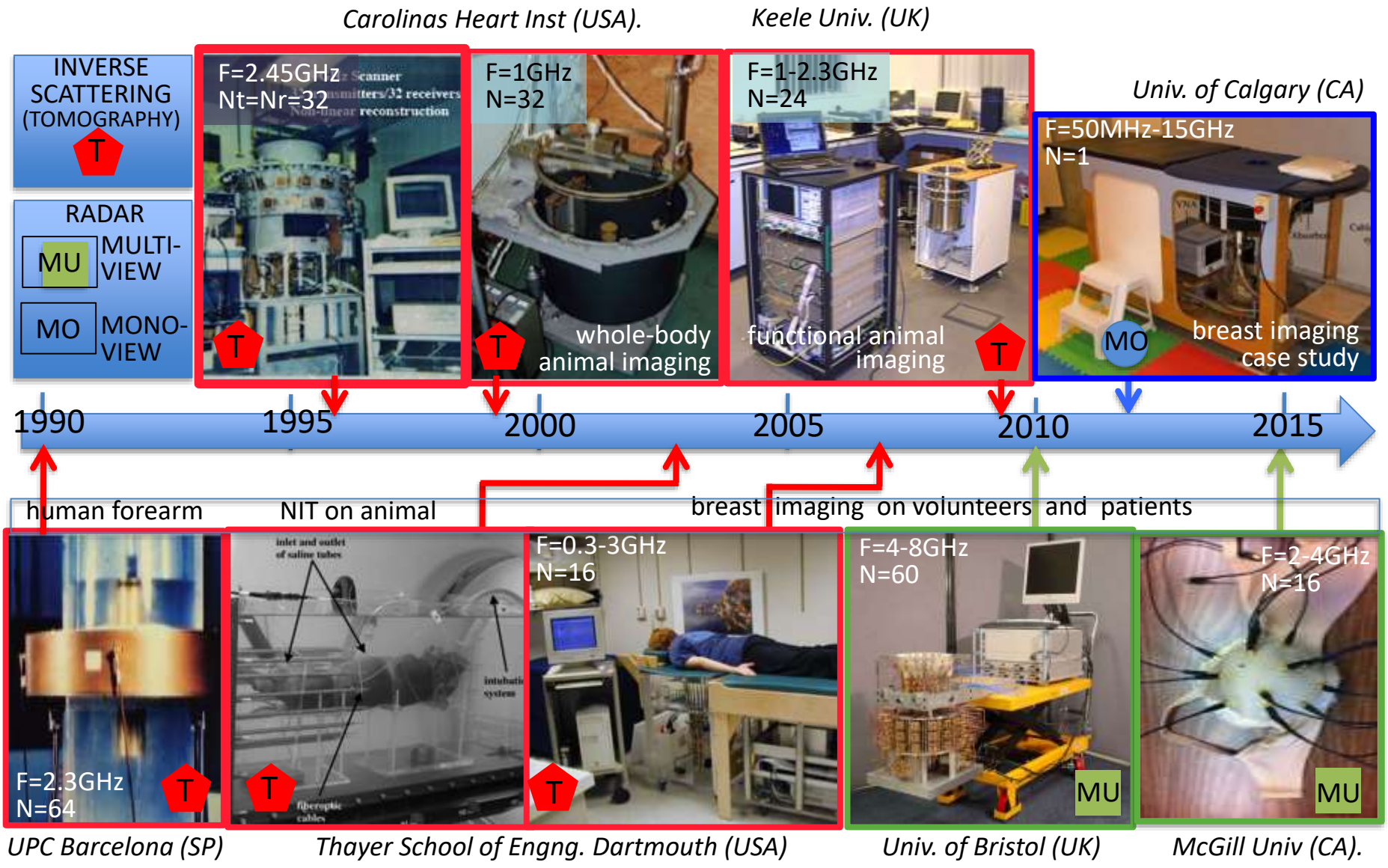


(Adapted from https://www.gartner.com/en/research/methodologies/gartner-hype-cycle)

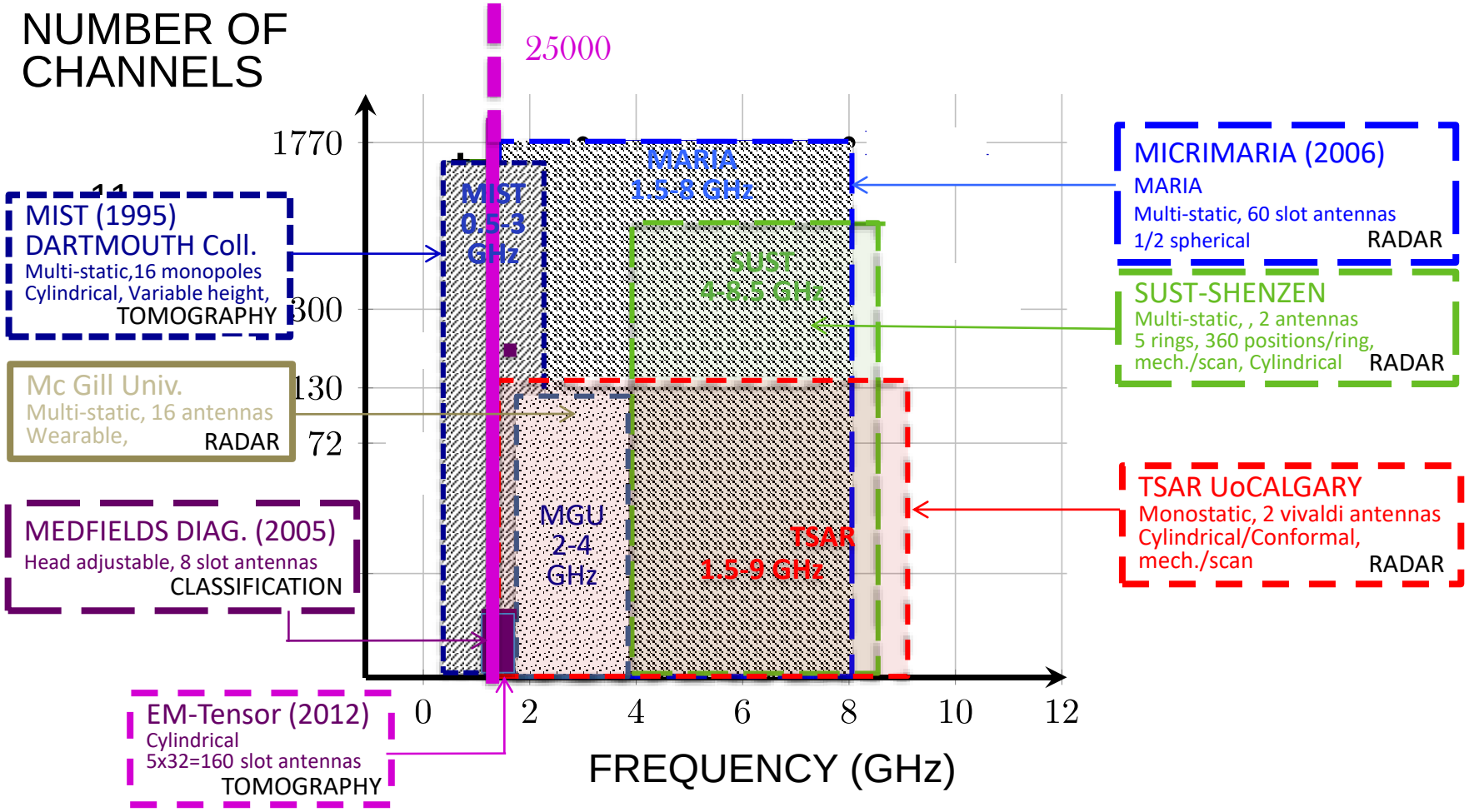
DEVELOPMENT FLOW-CHART FOR MICROWAVE-BASED IMAGING



MICROWAVE SCANNERS FOR EARLY IN-VIVO IMAGING SOME EXAMPLES…

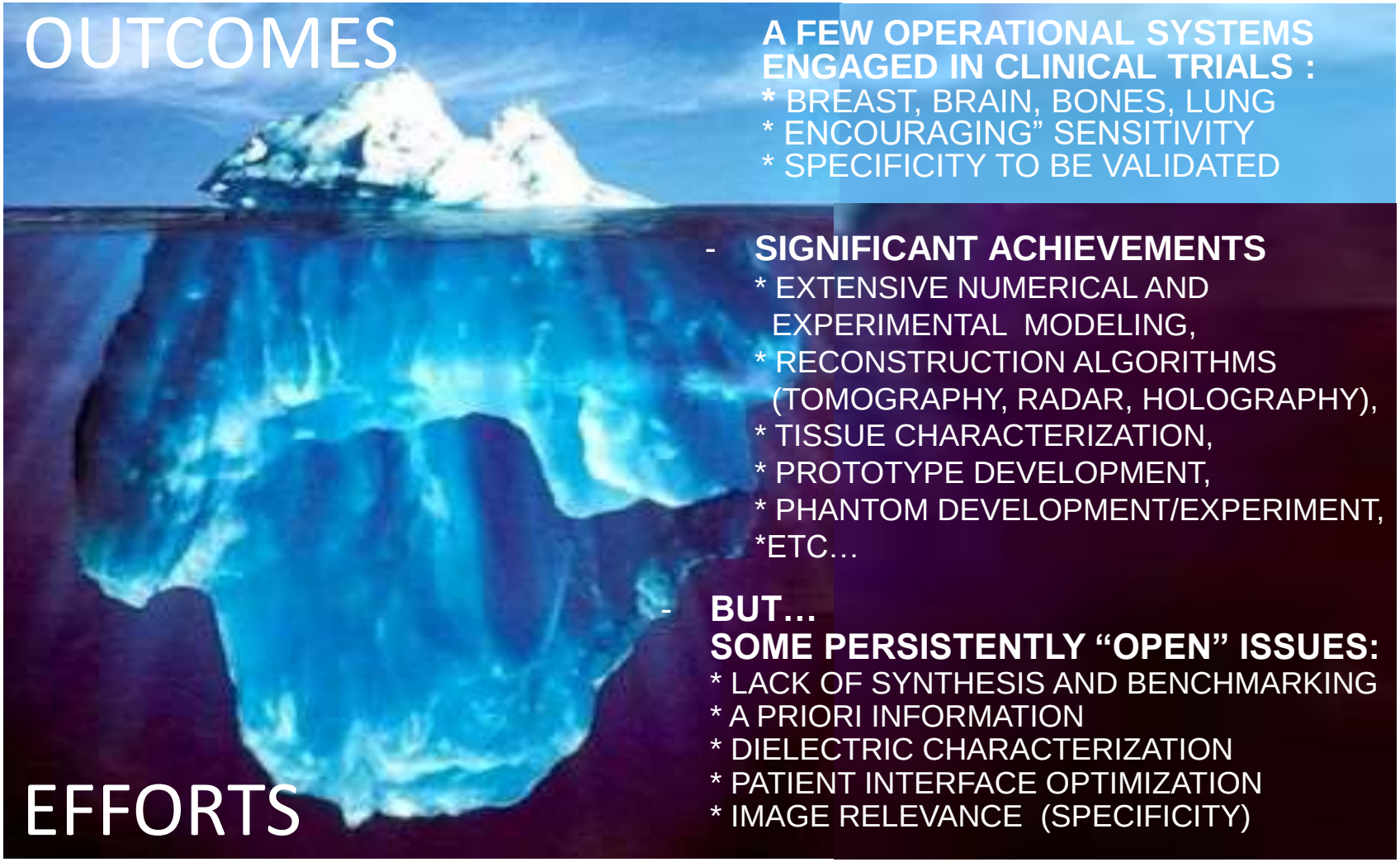


MICROWAVE IMAGING SYSTEMS ENGAGED IN (PRE)CLINICAL TRIALS
MANY DATA ACQUISITION AND PROCESS MODALITIES



Adapted from: "Microwave Breast Imaging: Clinical Advances and Remaining Challenges", D. O'Loughlin, M. O'Halloran, B.M. Moloney et al.; IEEE Transactions on Biomedical Engineering (Volume: 65 , Issue: 11 , Nov. 2018)

WHAT HAS ALREADY EMERGED ?

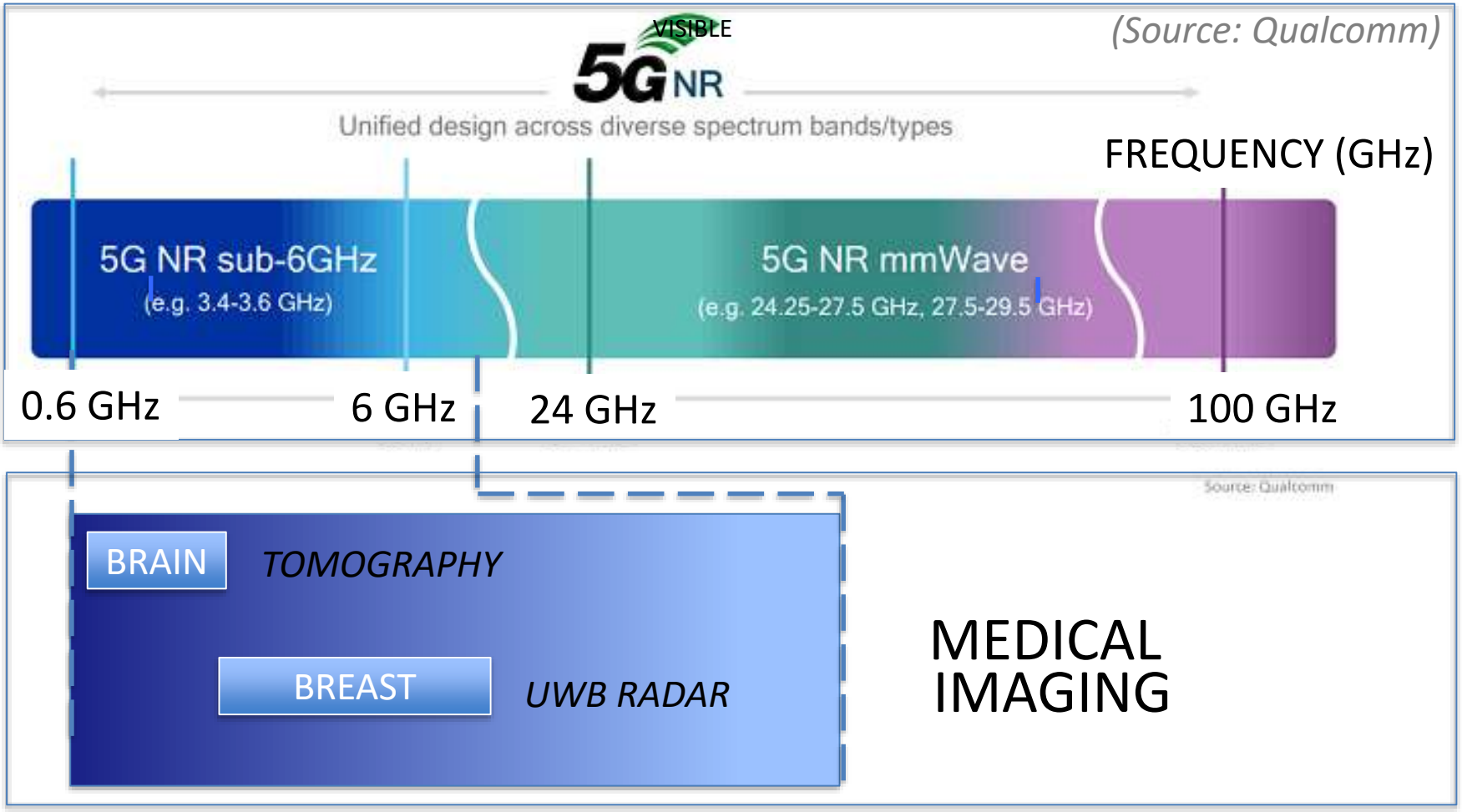


WHAT COULD BE TRIED / DONE ?
LOOK AT EMERAD PROGRAM… AND THREE SUGGESTIONS

"BETTER" DATA ACQUISITION TECHNIQUES

- EXPLOITING ALREADY EXISTING OR SUPPOSEDLY RAPIDLY AVAILABLE MICROWAVE TECHNOLOGIES FOR OBTAINING "BETTER" DATA ACQUISITION TECHNIQUES:
  - INTRODUCING THE BEST OF WIRELESS TECHNOLOGIES USED FOR EXISTING COMMUNICATION, RADAR, SENSOR GRID SYSTEMS (MODULATION/DEMODULATION SCHEMES, OFDN, MIMO PROCESSING,…)
  - APPLICATION-DEDICATED AND/OR PATIENT ADAPTIVE OPTIMIZATION OF THE PROBE ARRAY
  - INCREASING DYNAMIC RANGE TO REDUCE MULTI-PATH CORRUPTION
  - TAKING PROFIT OF 5G, IoT OR IoE DEVELOPMENTS (MINIATURIZATION, ARRAYS OF INTEGRATED PROBES, …)
  - REDUCING FABRICATION/EXPLOITATION/MAINTENANCE COSTS BY MEANS OF APPROPRIATE ARCHITECTURES

MICROWAVES MM-WAVES SPECTRUM MEDICAL IMAGING VS 5G FREQUENCY BANDS

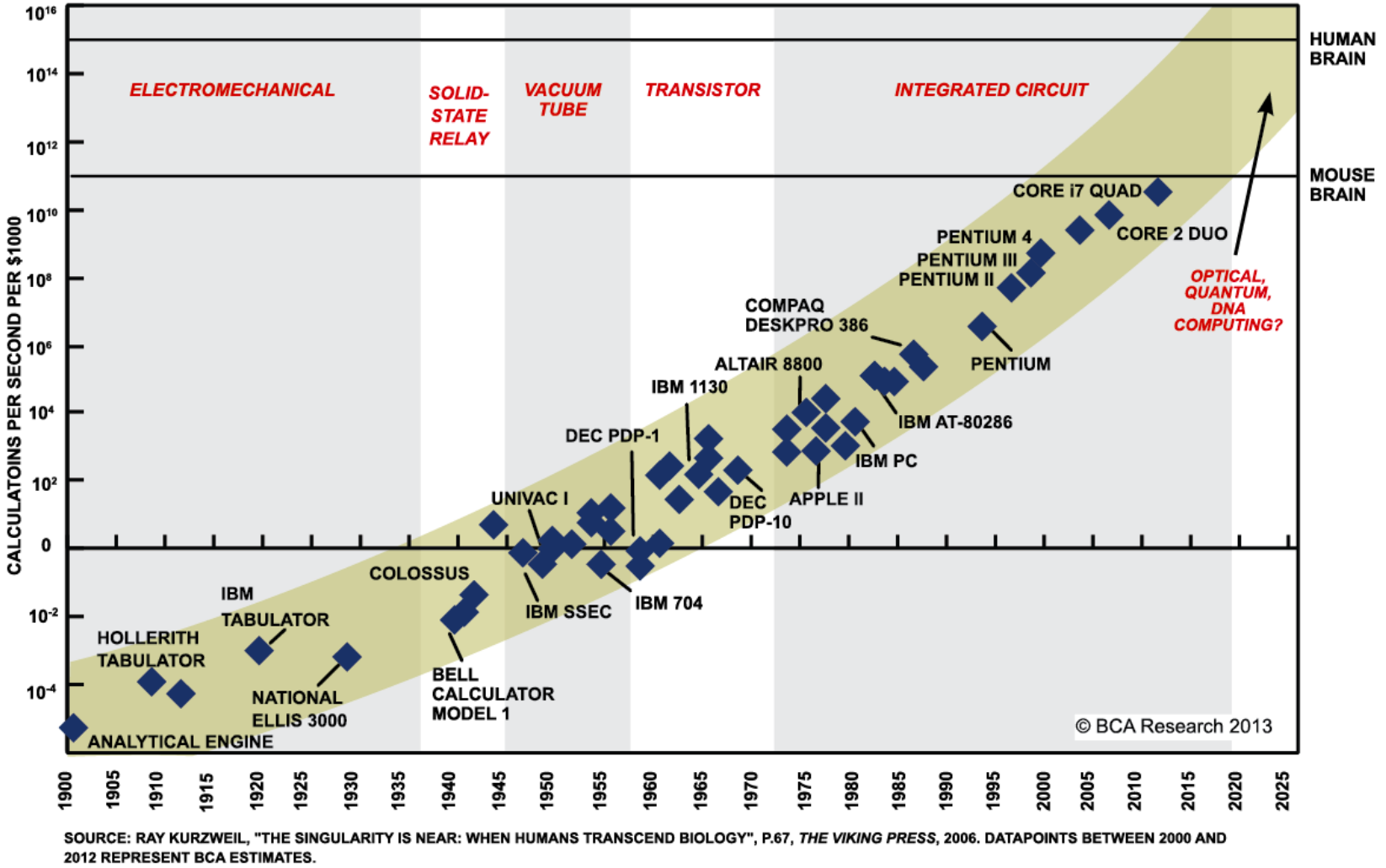


SUGGESTION 2

"BETTER" DATA PROCESSING AND ALGORITHMS

- EXPLOITING/ANTICIPATING GROWING COMPUTING POWER
  - RADAR: TOWARD REAL-TIME, FAST PRE/POST PROCESSING
  - INVERSE-SCATTERING IMAGING: DECREASING MODEL NOISE, FULL 3D ACCURATE MODELING (INCLUDING INTERACTIONS AND MUTUAL COUPLING…)
  - INCREASING AMOUNT OF DATA
  - IMPROVING SPATIAL RESOLUTION
  - QUANTUM COMPUTERS ? BEYOND MOORE's LAW ?
- USING OTHER IMAGING MODALITIES
  - A PRIORI INFORMATION (WHEN NEEDED)
  - MICROWAVE DATA FUSION WITH OTHER MODALITIES FOR AI/ML/DL ALGORITHMS
- CONSIDERING "NON IMAGING-BASED" MICROWAVE SENSING PROTOCOLS (SENSOR NETWORKS GRIDS, ARTIFICIAL/AUGMENTED INTELLIGENCE, MACHINE LEARNING, CLASSIFICATION, NEURAL NETWORKS, ETC.)

MOORE's LAW EXTRAPOLATIONS OF COMPUTATIONAL POWER



SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

SUGGESTION 3

INCREASING INTERACTIONS WITH BIOLOGISTS AND "END-USER" MEDICAL COMMUNITY

- RETURNING TO BASIC MW/BIO INVESTIGATIONS
  - TISSUE DIELECTRIC CHARACTERIZATION (LOCAL PROBE, MRI, SCANNING MICROSCOPY,…)
  - PHYSICAL OR HEURISTIC MODELS FOR FREQUENCY DEPENDENCE
  - FOCUSING ON DIELECTRIC SPECIFICITY AND SENSITIVITY ASSESSMENTS
  - QUANTIFYING DIELECTRIC IMAGES IN TERMS OF BIO-PHYSIOLOGICAL FACTORS
- INCREASING INTERACTIONS WITH "END USER" MEDICAL COMMUNITY
  - IDENTIFYING REAL NEEDS AND LOOKING FOR THE MOST MICROWAVE-FRIENDLY AND CLINICALLY RELEVANT SCENARIOS
  - CASE BY CASE VALIDATION THANKS TO LARGE SCALE /MULTIMODALITY CLINICAL ASSESSMENT CAMPAIGNS
  - GUIDING TECHNICAL ADVANCES BY CLINICAL RETURNS
  - HYBRIDIZING WITH OTHER MODALITIES
  - FOLLOWING UP IMPROVEMENT OF OTHER IMAGING MODALITIES: MAN-PORTABLE MRI, DIGITAL TOMOSYNTHESIS, LOW-DOSE PHASE CONTRAST X-RAYS, ETC.
  - NOT UNDERESTIMATING THE CHANGES IN THE MEDICAL PRACTICE INDUCED BY AI / ML DEVELOPMENTS
  - ATTENDING MEDICAL MEETINGS, LOOKING AT MEDICAL JOURNALS, ETC.

FUTURE MEDICAL IMAGING FACING REVOLUTIONARY AI AND ML CHALLENGES (EXAMPLES)

- "**Look Ahead: The Future of Medical Imaging"**
  James H. Thrall, radiology imaging, August 1, 2015

RSNA News

- **"How Artificial Intelligence Will Change Medical Imaging"**
  D. Fornel, artificial intelligence, February 2017
- **"What is the Future of Medical Imaging Equipment ?"**
  M. Taschetta-millane, radiology imaging, July 2018
- **"Technologies to Watch in Breast Imaging"**
  J. Zagoudis, radioimaging, July 2018

itn IMAGING TECHNOLOGY NEWS

- **"Artificial Intelligence in Radiology: Hype or Hope ?"**
  M.B. Massat, pp. xx-yy, March, 2018
- **"A Promising future for AI in breast cancer screening"**
  M. B. Massat, pp. 22-25, September 2018

APPLIED RADIOLOGY
THE JOURNAL OF PRACTICAL MEDICAL IMAGING AND MANAGEMENT

- **"Demystifying Artificial Intelligence"**
  Part I**, "Simplifying AI and Machine Learning"**, E. Siegel, pp. 26-28, May, 2018
  Part II, **"An Imaging Tool Ready to Explode"**, L.N. Tanenbaum,pp. 26-27, July 2018
  Part III, **"Going Beyond Escape"**, R.B. Shrestha, pp. 8-11, November 2018

- **"Machine (Deep) Learning Methods for Image Processing and Radiomics",** M. H. Latim, C. Parmar, J. Qil, I. el Naqa
  Vol. 3,pp.104-107, March 2019
  SPECIAL ISSUE ON MACHINE LEARNING FOR IMAGE PROCESSING AND RADIOMICS

IEEE Trans. Radiation and Plasma Medical Sciences
IEEE NPSS NUCLEAR & PLASMA SCIENCES SOCIETY
EMB

CONCLUSIONS

- AFTER A LONG MATURATION PERIOD, MICROWAVE-BASED IMAGING SYSTEMS ARE BEGINNING TO PROVIDE CLINICAL RESULTS

- FUTURE DEVELOPMENTS MUST:
  - TAKING PROFIT OF 5G TECHNOLOGY AND DEEP LEARNING ALGORITHMS
  - ACCOUNTING FOR THE EVOLUTION OF THE MEDICAL PRACTICE, MORE PARTICULARLY IMAGING MODALITIESUNDER THE IMPACT OF ARTIFICIAL INTELLIGENCE

- DUE TO THEIR NECESSARY SPECIFICITY, NEW SYSTEMS MUST BE FOCUSED ON REAL CLINICAL NEEDS FOR:
  - COMPLETING/SUPPLEMENTING OTHER IMAGING MODALITIES
  - ADDRESSING SPECIFIC REQUIREMENTS FOR DEVELOPPING COUNTRIES