5G Radio Exposure Measurement

Developing together the solutions that address the actual NEEDS of the Wireless industry and regulation

ART-Fi

2019 March 7th, Tokyo, Japan

Agenda

- Words from the CEO
- About ART-Fi
- Industrial and Regulatory Context
- Updates on ART-Fi solution portfolio for 5G Radio Exposure Testing
- Solution roadmap and feed-back sessions

Words from the CEO

Words from the CEO

"The evolution of the new radio towards the 4.5G and 5G technologies are bringing unprecedented complexity and lengthy compliance testing of the user EMF exposure. Moreover, the saturation of the EMF levels of existing current technologies will require precise and accurate EMF exposure measurements so to achieve the appropriate balance of Exposure level and QoS without sacrificing the user experience.

It is for the sake of developing the best possible solutions that we are proud to invite you to join our working group, from which we incrementally orient the development plans of our disruptive innovation such that we provide you with the solution that addresses our real needs in terms of time-to-market, EMF safety compliance and quality-of-service.

Also, through the same feed-back sessions, we aim to leverage our active contribution to the development of international standards by valuing our partnerships and defining the relevant and accurate, time-efficient and cost-effective standard test-procedures that best foster the wireless industry."

Stephane Pannetrat, CEO of ART-Fi

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About ART-Fi

Leading innovator into the EMF exposure test systems that address the evolving challenges of new radio technologies

ART-Fi's IP & Technology

- 4 international patents protecting the uniqueness of our RF EM-field measurement technology
  1. Time-domain RF-probes and system measuring the Vector electromagnetic fields [WO-2011-080332]
  2. Novel vector E-field probe design [WO-2017-114854]
  3. Broadband single-fluid simulating the dielectric properties of the human tissue for SAR system [WO-2013-079621]
  4. Technique for direct measurement of the amplitude and phase of EM field phasor [EP-2610628]

- Uniqueness of ART-Fi's IP and Technology
  - Planar array of vector RF E-field sensors with electronic scanning - Fastest antenna measurement system
  - Time-domain RF signal measurements – Providing the fundamental measurand for RF performance evaluation
  - Phase-coherent RF signal acquisition – Yields absolute phase and amplitude measurement of the EM-field

- IPs embodied in ART-MAN SAR system and applicable to our mm-Wave PD test solution

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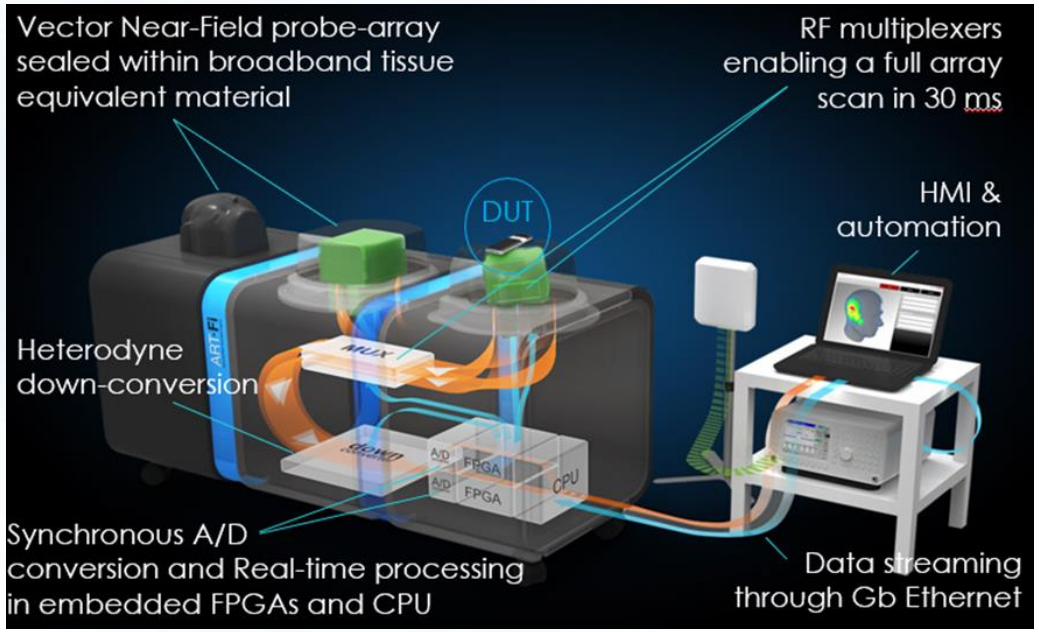
ART-MAN System Overview



- ARTMAN takes direct measurements of the Time-Independent Harmonic E-field Phasor in the Near-Field Region of the device's antenna(s)
  - **Vector Probe-Array** in each Mannequin (1920 sensors in total)
  - 0.7-seconds max for a complete scan thanks to fast electronic scanning of the probes
- Patented Phasor Vector measurement technology enables the measurements of the Complex Vector EM-Field even for Active devices of Multiple-Antennas
  - Without requiring access to the source signal
  - Using synchronous acquisition of probe time-domain voltages in **phase-coherence** with a reference wave provided by the probe-array itself.
- NF-2-VNF 2D tangential E-field Phasor to 3D total E-field Vector using Maxwell's Equations and Physics laws

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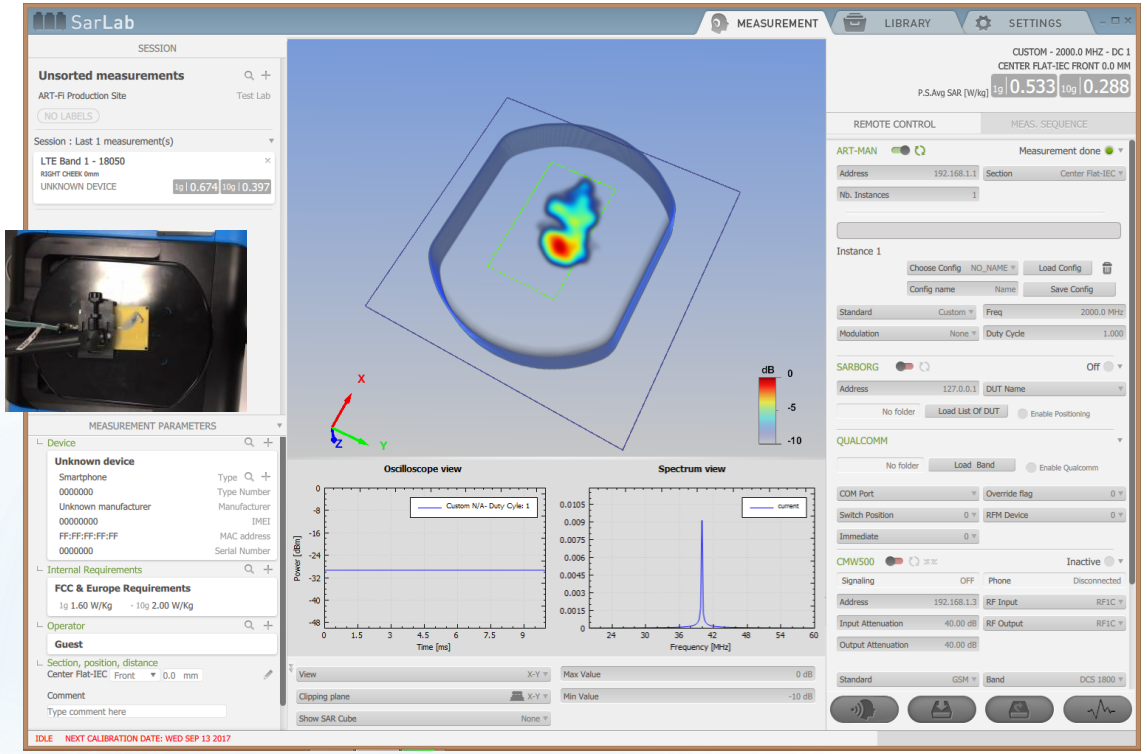
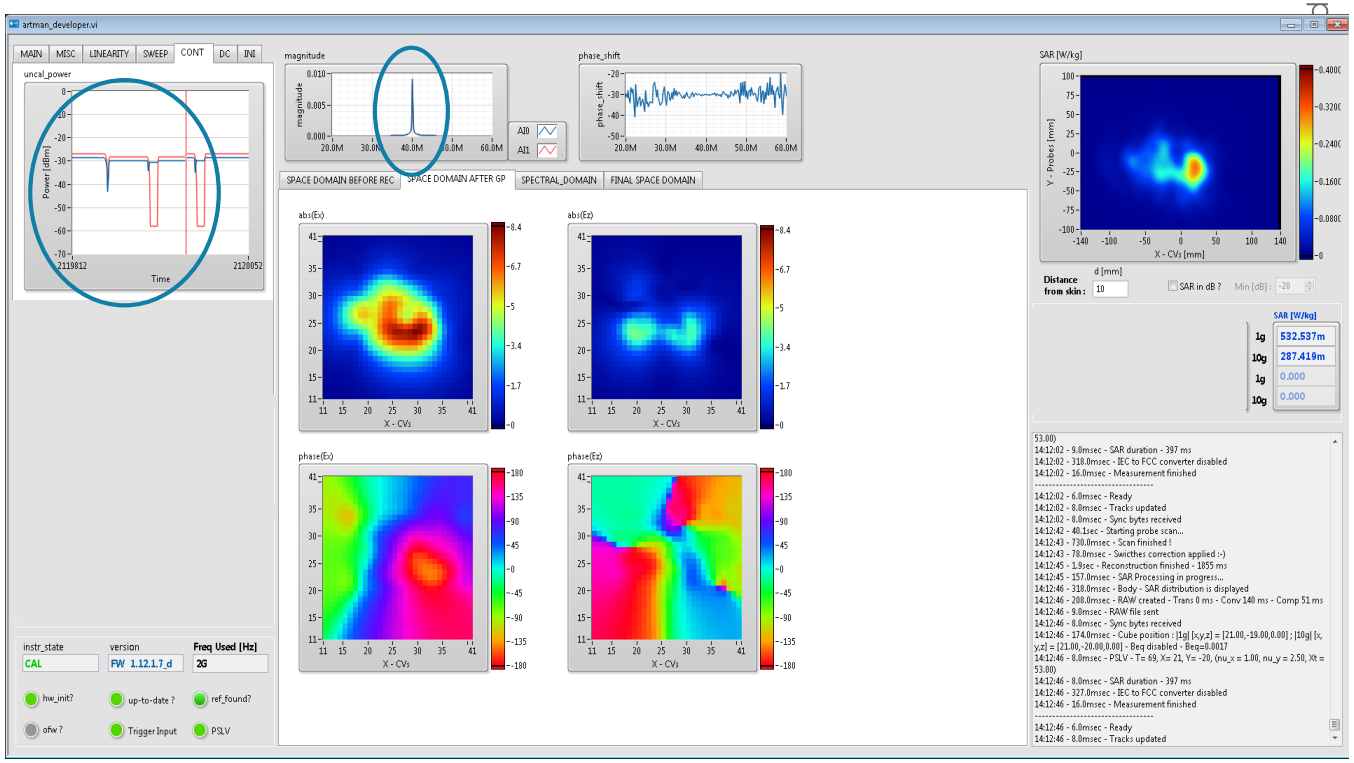
Absolute-Vector RF and E-field Measurements





SARLAB

- System High Level control
- SAR Test Batching and Automation Settings
- SAR and VSA Results Visualization

DEVELOPER FW

- System Low Level Control
- Real-time Power Spectrum and RF Signal Spectrum
- Vector E-field Phasor and Holographic Visualization

Industrial and Regulatory Context

Challenges of new generation radio technologies

- 5G and New Radio Technology Enablers; unprecedented technological complexity
  - Building on all spectrum assets for Wide-band efficient usage of spectrums
    - Up to 800 MHz bandwidth through Technology and Carrier Aggregation (> 8 CA)
  - Exploiting the spatial domain for Spatial multiplexing through Massive-MIMO radio-links
    - Beam forming, Beam steering and Beam tracking in both downlink and uplink

- Saturation of EMF levels already occurring on 2G/3G/4G, will be a challenge for the deployment of 5G(*)
  - Ensuring competitive Quality of Service can only be achieved with physics-based accurate EMF exposure test technology

- **Legacy Scalar-Probe technology** may lead to unpractical and overestimated EMF exposure testing
  - Extremely high number of MIMO beam-forming states can only be tested with conservative overestimations
  - Wide spectrums from technology and carrier-aggregation can't be precisely tested without a frequency-selective probe technology
  - Unpractical and unprecise testing will require trading-off the QoS

- **RF and Vector-Probe Technology**, such as ART-Fi system, is recognized to be the appropriate solution for efficient and rigorous testing of –Wide Spectrum & MIMO- 5G technologies (**)

(*) L. Chiaraviglio et al., "Planning 5G Networks Under EMF Constraints: State of the Art and Vision," in IEEE Access, vol. 6, 2018.
(**) Y. Qi *et al.*, "5G Over-the-Air Measurement Challenges: Overview," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 59, no. 6, Dec. 2017.

ART-Fi Vector Technology Solution

ART-Fi's solution is based in its exclusive and patented Full-Vector technology

- Vector signal analysis of time-domain modulated RF signals
- Intrinsic frequency selectiveness, modulation and technology aggregation independent calibration
- Direct measurement of time-independent complex EM-field phasor-vector
- Maxwell's equation based reconstruction of volume E-field for SAR and the vector H-field for PD

ART-Fi's solution; Fastest test system of the Exact SAR and PD

- Only technical solution to rigorously measure CA and Simultaneous Transmissions
- Only technical solution to rigorously and directly measure ultra-wide band signal
- Reduces to a minimum of (N+1) the number of needed measurements to test all the beam-forming states of a N-antenna MIMO device

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Updates on ART-Fi solution portfolio for 5G Radio Exposure Assessment

ART-Fi is Bringing The Right Test Solution

ART-Fi Timeline for 5G exposure testing

2011-2013
Vecor Probe Array System

2013
Portfolio extension

2015
Automation pack for R&D

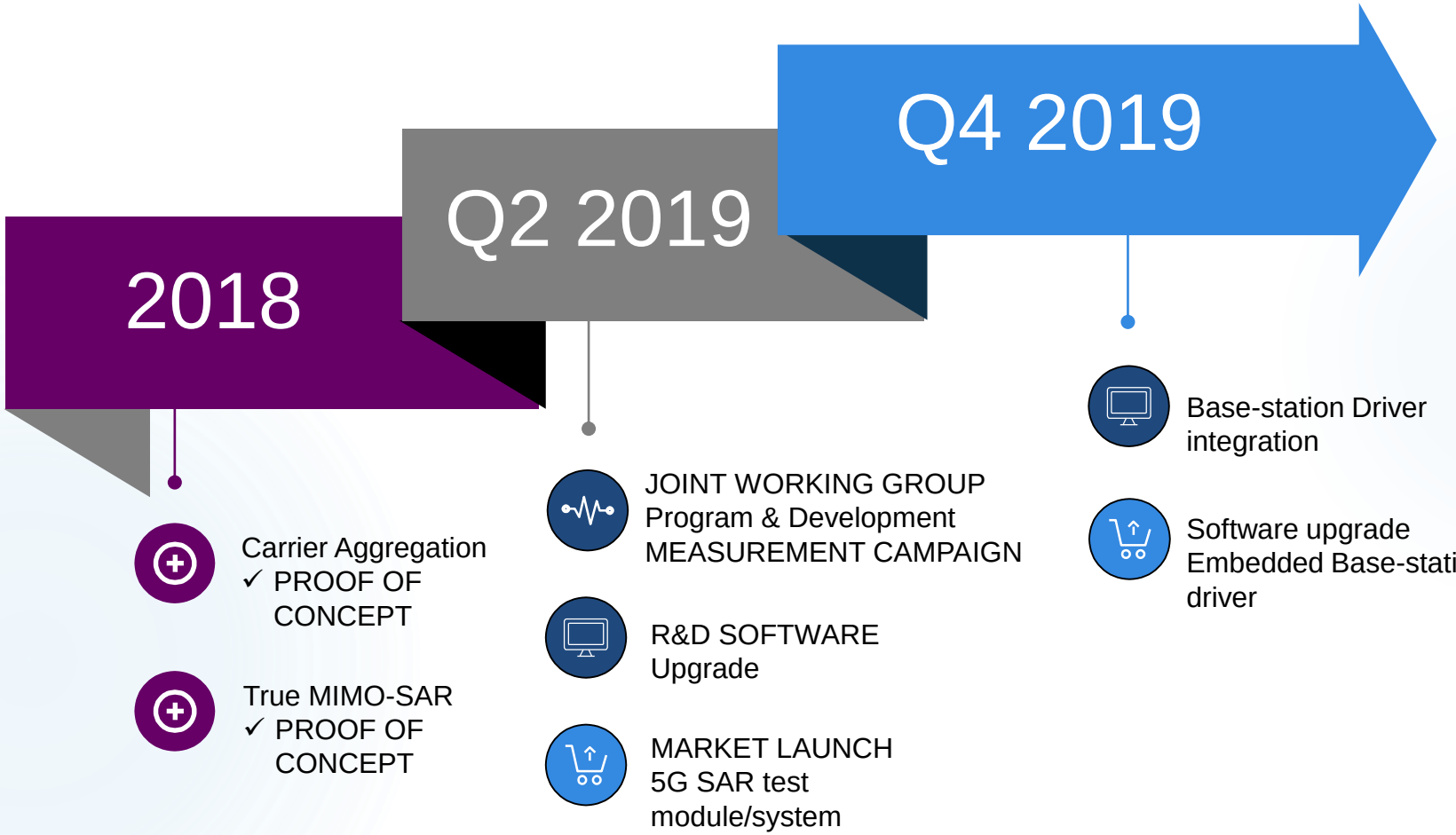
2018
Test in production offer

2018
5G sub-6 GH

2019
mmWaves new releases

Amplitude & phase measurement - Maxwell's heritage

2018-2019 Sub-6 GHz 5G SAR Module Timeline



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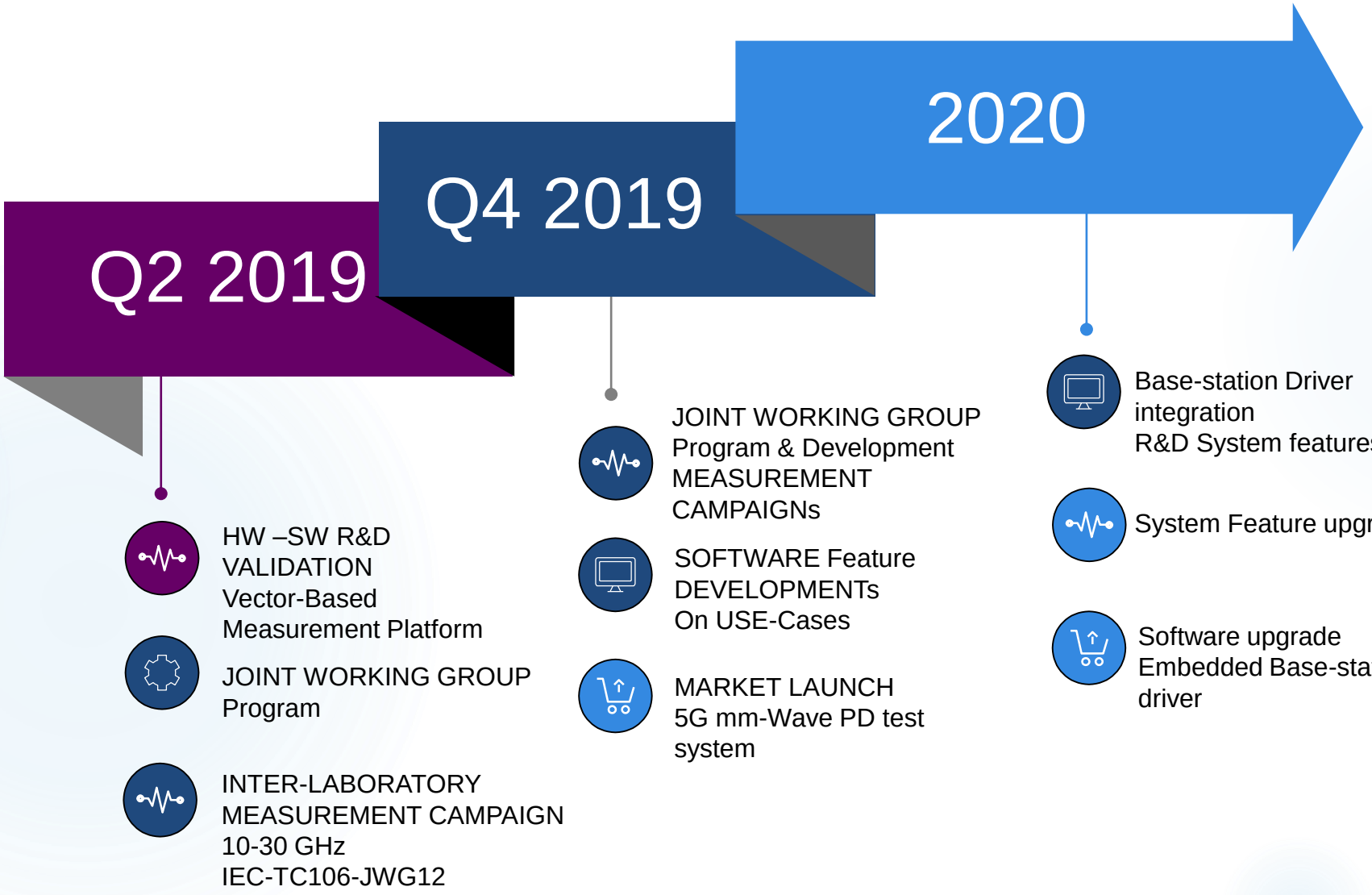
2018-2020 mm-Wave PD System Timeline



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Joint Working Group: Solution Roadmap and Feed-back Sessions

Partnering for Offering you the Right Test Solution

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Summary

- New Radio Technologies
  - 5G is under development progress and its market is not yet mature
  - Mobile makers, Network Operators are still on a R&D stage, with challenges still being identified
  - Ready-made solutions are limited
  - A disruptive technology is needed to achieve EMF test solutions that will not slow down the 5G development
- RF and Vector VNF system is the appropriate test solution
  - ART-Fi is launching a dedicated workgroup to efficiently address the 5G exposure compliance challenges
    - Already involving leading mobile makers, network operators and tests laboratories
  - Soft-ware upgrade for 5G sub-6 GHz
  - New Measurement Platform for mm-Wave
  - All exploiting our exclusive and unique IP's for RF Vector EM-field measurement system
- Join our roadmap sharing and feed-back sessions so to best fit our solution to your needs

ART-Fi

Dynamic and motivated team with a disruptive available technology for making smarter phones with the best QoS

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Annex-I
Fastest and Most Accurate
5G Sub-6 GHz Mu-MIMO Test system

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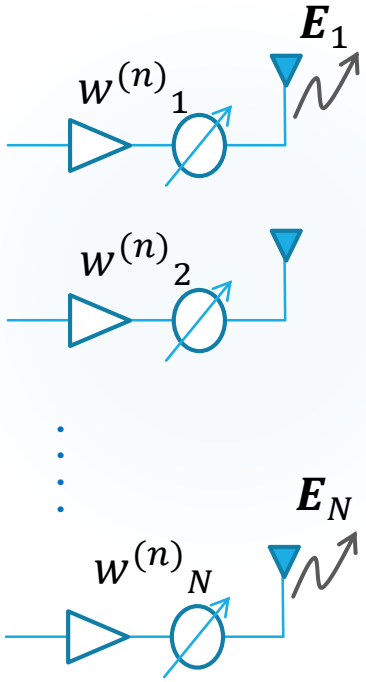
EMF Exposure from MIMO Devices

- Phasor of the E-field vector $\boldsymbol{E}^{(n)}$ of N-antenna array as the vector summation of weighted individual E-field phasors $\boldsymbol{E}_{i=1:N}$ of each antenna

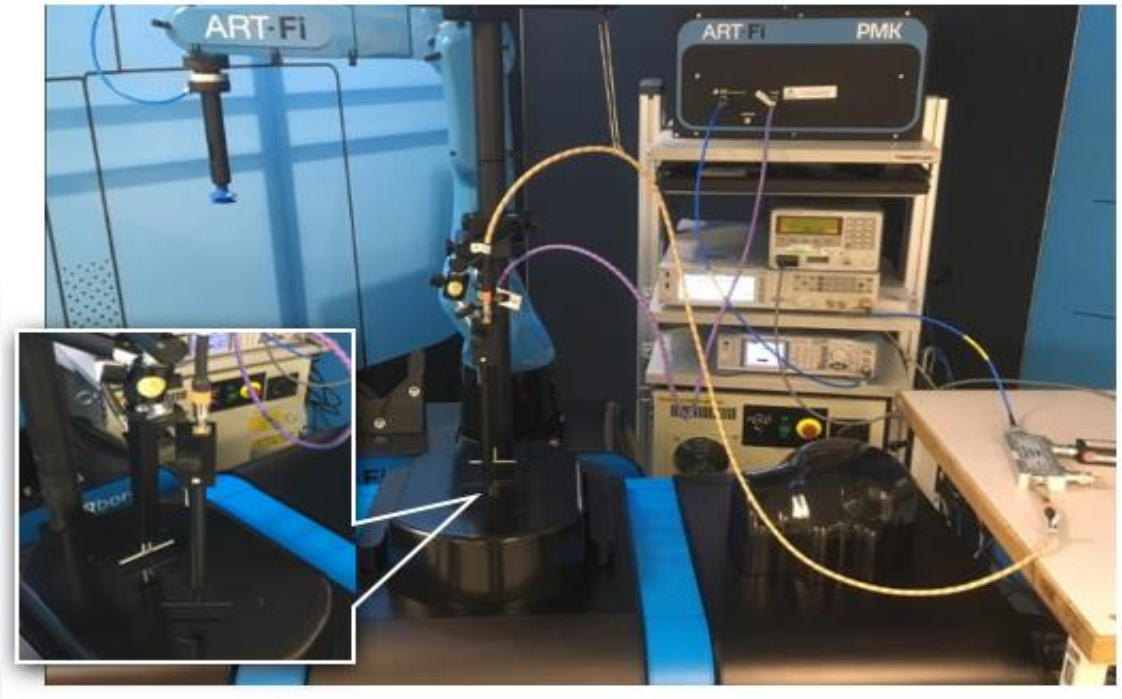
$$\boldsymbol{E}^{(n)}(x,y,z) = \sum_{i=1}^{N} {w^{(n)}}_i \ . \boldsymbol{E}_i(x,y,z) \left[\frac{\mathrm{V}}{\mathrm{m}}\right]$$

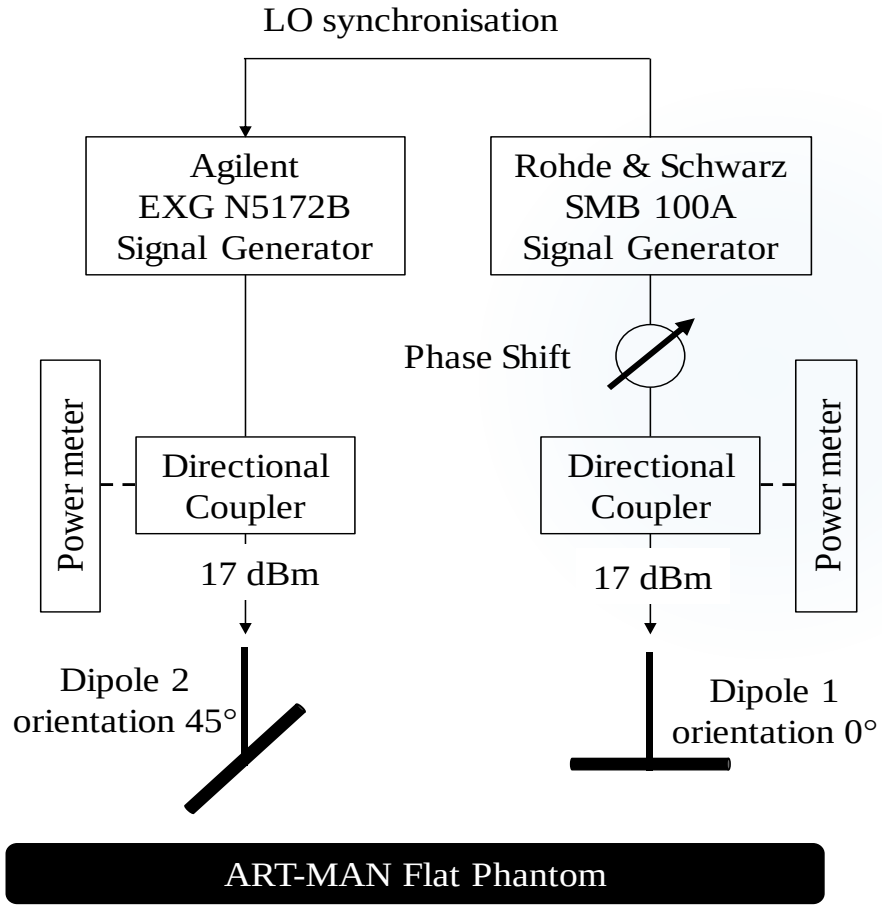


- Unpractical high number (n) of measurements is needed to test all the array interference states for determining the actual peak SAR/PD
- Resulted in the development of reasonably slow, but conservative, procedures for reducing the MIMO-SAR/PD test duration
  - Conservative Overestimate procedures require trading off the OTA performance and Quality-of-Service for ensuring exposure compliance
- ART-Fi's-technology enable practical and most efficient testing of the TRUE SAR/PD
  - Phase coherent measurements using a calibrated vector E-field probe-array
  - Extraction of individual antenna fields from simultaneous excitations of the DUT Phased-Array
  - Reduction by a factor of 6 the number of required measurements w.r.t ad-hoc SAR systems

L. Aberbour, O. Jawad, M. Ramdani, P. Giry, T. Julien, "***Efficient Experimental Assessment of the Specific Absorption Rate (SAR) Induced by MIMO Wireless Communication Devices; Application of Vector near-Field Measurement System***," Proc. of the IEEE 2018-CAMA, Vasteras, Sweden, Sep. 2018.

Demonstration Set-up





Two dipoles operate at 1.9 GHz, distant by 0.5λ and relative orientation of 45°

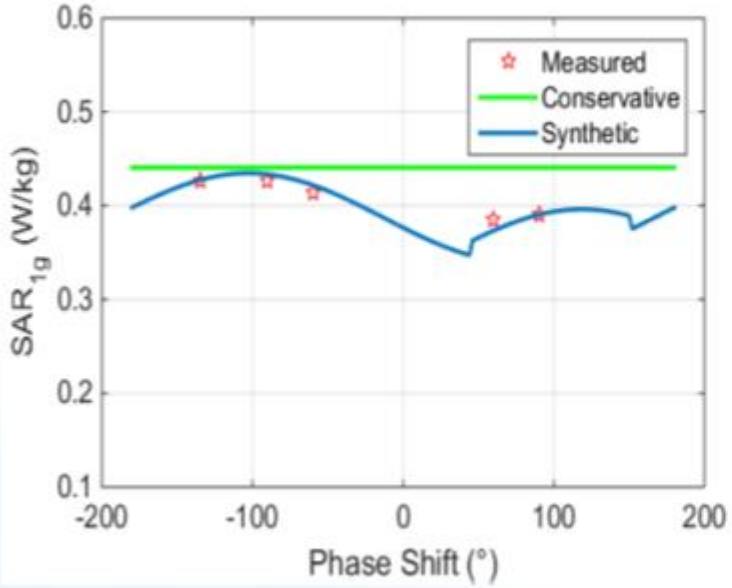
Procedure for Measuring the Vector Field Phasors of MIMO antennas

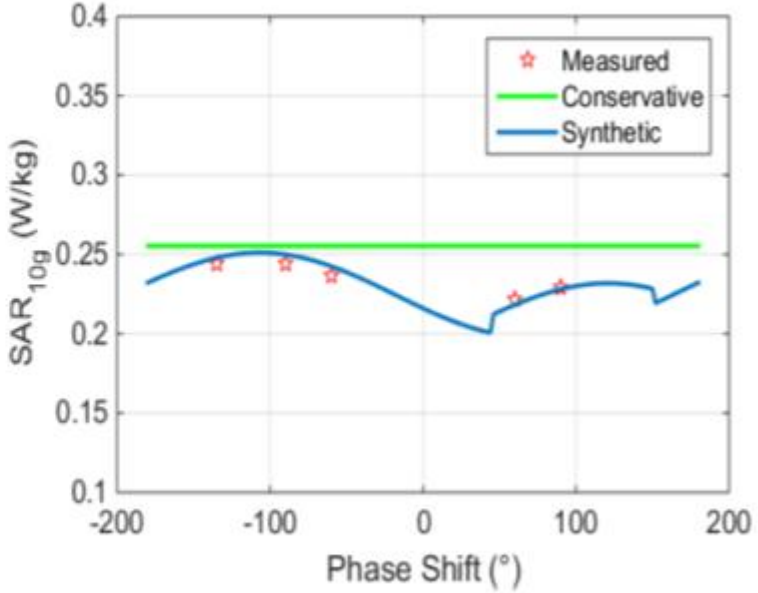
- #1 Vector E-field measurement for sequential excitation of the antenna ports; $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$
- #2 Vector E-field measurement for simultaneous excitation with an enforced phase shift φ_0 on one antenna port; $\boldsymbol{E}_{\mathrm{cmb}}$
- #3 computation of the phase-shift β that minimizes the RMSE on the amplitude of the measured $|\boldsymbol{E}_{\mathrm{cmb}}|$ and superposed $\left|\boldsymbol{E}_1 + \boldsymbol{E}_2 . e^{j(\varphi_0+\beta)}\right|$

$$\min_{\beta} \left\| \sqrt{\sum_{p=x,y,z} \left| E_{1,p}(x,y,z_0) + E_{2,p}(x,y,z_0) . e^{j(\varphi_0+\beta)} \right|^2} - \sqrt{\sum_{p=x,y,z} \left| E_{\mathrm{cmb},p}(x,y,z_0) \right|^2} \right\|$$

- #4 Computation of the total E/H-field for all the array interference states
- #5 Assessment of the maximum SAR/PD of the MIMO device

SAR Results – Applicable to mm-Wave MIMO PD



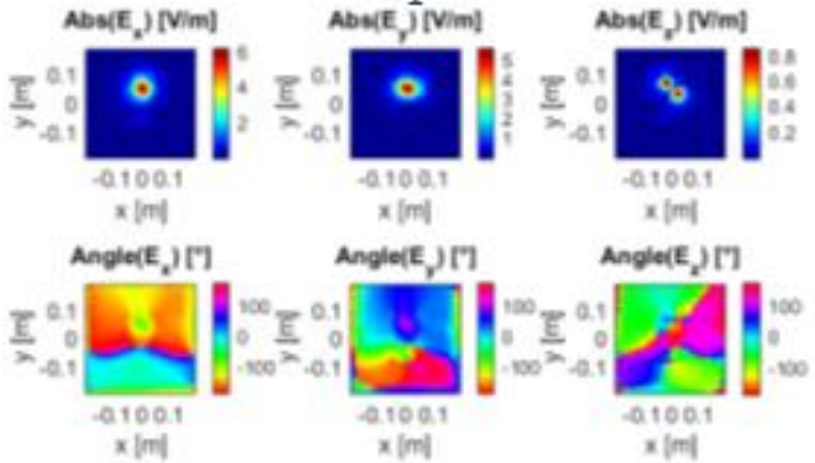


- Measured (*) for simultaneous excitation with known phase shift on the antenna ports
- Conservative (_) from magnitude combining of individual fields from sequential feed
- Synthesized (_) from vector combining of the individual fields form sequential feed and phase-shift compensation

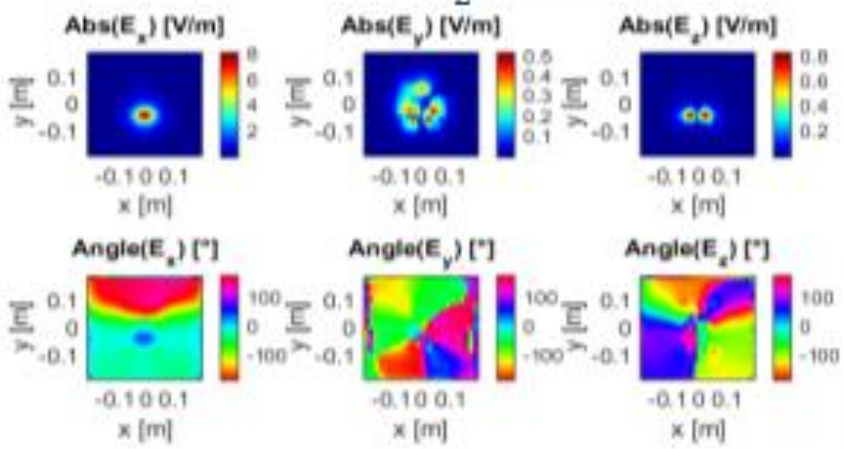
Only N+1 Measurements are needed to evaluate all of the possible N-antenna phase-shifter values
Requiring Phase-Coherent measurements & Calibrated vector E-field probe-array
Our Probe Calibration Measurement Procedure is Applicable to the Calibration of Massive-MIMO Arrays

E-field Phasor Results

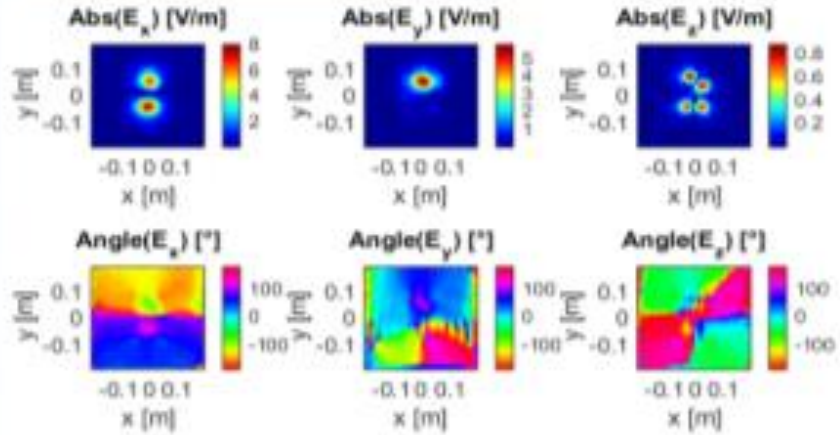
E_1



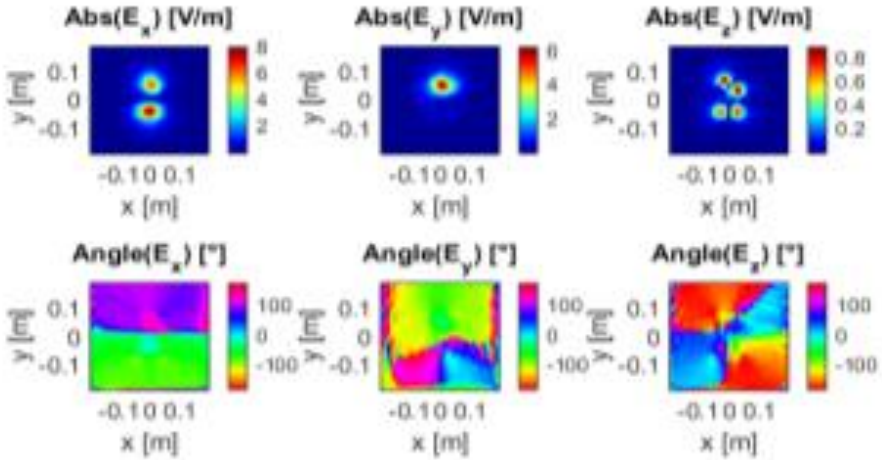
E_2



$$E_{\text{comb}} = E_1 + E_2 . e^{j(\varphi_0)}$$



$$E_1 + E_2 . e^{j(\varphi_0+\beta)}$$



Extraction of individual antenna fields from simultaneous excitations of the DUT Phased-Array
Our Probe Calibration Measurement Procedure is Applicable to the Calibration of Massive-MIMO Arrays

Advances in MIMO-SAR/PD Testing

- Conservative MIMO-SAR determination
  - RMS field based measurements
  - Magnitude field or field-components combining [N. Perentos, *et al.*]
- Vector E-field Phasor Retrieval for true MIMO-SAR/PD
  - RMS field based measurements
  - Enforcing ***N(N-1)+1*** phase-shifts on a ***N*** antenna array
  - Weighted summation of the retried N phasors for MIMO-SAR evaluation [D. T. Le, *et al.*]
- Direct Vector E-field phasor measurement for true MIMO-SAR/PD
  - Requires knowledge of the complex field data
  - Needs only ***N*** measurements for a ***N*** antenna system
  - Vector sum of the measured N complex phasors for MIMO-SAR/PD [D. T. Le, *et al.*]
  - Maximization and optimization methods for balancing PD and TRP [B. Xu, *et al.*]
  - **Vector systems enable fast and true MIMO SAR/PD testing, but involve challenges for active devices**

References

- **L. Aberbour, O. Jawad, M. Ramdani, P. Giry, T. Julien**, "*Efficient Experimental Assessment of the Specific Absorption Rate (SAR) Induced by MIMO Wireless Communication Devices; Application of Vector near-Field Measurement System*," Proc. of the IEEE 2018-CAMA, Vasteras, Sweden.
- **N. Perentos, S. Iskra, A. Faraone, R. J. McKenzie, G. Bit-Babik, and V. Anderson**, "*Exposure compliance methodologies for multiple input multiple output (MIMO) enabled networks and terminals*," *IEEE Trans. Antennas Propag.*, vol. 60, no. 2, pp. 644–653, Feb. 2012.
- **D. T. Le, L. Hamada, S. Watanabe and T. Onishi**, "*A Fast Estimation Technique for Evaluating the Specific Absorption Rate of Multiple-Antenna Transmitting Devices*," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 4, pp. 1947-1957, April 2017.
- **B. Xu, M. Gustafsson, S. Shi, K. Zhao, Z. Ying and S. He**, "*Radio Frequency Exposure Compliance of Multiple Antennas for Cellular Equipment Based on Semidefinite Relaxation*," in *IEEE Transactions on Electromagnetic Compatibility*.
- **T. B. Hansen and A. D. Yaghjian**, "Plane Wave Theory of time Domain Fields", June 1999, Wiley-IEEE Press