BLACK PAPER

HOW TO ACHIEVE FASTER TERMINAL ANTENNA DESIGN & CERTIFICATION WITH SAR SCREENING

Who wrote this?

Benoit Derat, CEO of ART-Fi

Black Paper - SAR "screening"

Before you read: How does "screening" with "probe-array" technology fit into the regulation landscape?

This black paper outlines two ways to make your SAR testing much faster.

* Use SAR "Screening" to reduce the overall quantity of tests you have to perform.
* Use the new amplitude and phase probe-array technology like ART-MAN, because it performs an accurate test in seconds and does not require robotics.

You are probably wondering if these methods are safe to use in the current regulatory landscape. The short answer is yes.

Is amplitude and phase probe-array technology accepted?

In Europe, the certification scheme is different and relies on self-declaration of conformity. Test reports are monitored and reviewed by the Notified Bodies. One of the most advanced Notified Bodies regarding SAR acceptance is the ACB Notified Body, who after making independent tests and technical reviews, is accepting the use of ART-MAN SAR test systems not only for the purpose of "screening" the SAR test cases, but for complete SAR compliance demonstration. This means that patented ART-MAN probe-array technology is now ready for full SAR compliance demonstration for European requirements, and any test labs working to that goal can now upgrade their labs.

The FCC has already reviewed some KDB Inquiries from applicants seeking permission to use vector probe-array SAR test systems for faster screening of dynamic antenna tuners. The FCC is not yet ready to publish an official KDB guidance document on the issue, but are looking for more data comparing the results between amplitude and phase probe-array SAR and legacy SAR systems.

How about "screening" methods in combination with probe-array technology?

The FCC has indicated that on a case-by-case basis, they are ready to review antenna tuner "screening" data measured with ART-MAN, and would accept it to be used as part of a submission if their provisions are filled. The FCC is currently gathering more comparison data both on relative accuracy as well as absolute accuracy. After they gain confidence with the comparison data, they aim to release KDB guidance on the use of these systems. The FCC clearly understands that a) legacy, robotic SAR measurement systems can no longer be expected to deal with the ever-growing set of features requiring SAR testing, and b) the reliance upon legacy SAR measurement systems is becoming a critical issue in product development.

Any news from the SAR test committee?

Also, while the SAR test standards are lagging somewhat behind in pace of the development, the SAR test standard committee have started to work on IEC 62209-3, which is the SAR measurement standard describing the requirements for vector-probe array SAR test systems.

When this standard gets approved and published, the ART-MAN SAR test system is the only SAR test system you will need.

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Why is 'screening" and probe-array technology important?

Unfortunately, it seems that relevant standards are not evolving as fast as the communication industry. Many regulators and certification bodies have already noted that in some cases the measurement times with legacy SAR measurement systems using robotics becomes intolerable when compared to ever shortening device development cycles and the importance of time-to-market.

Slow legacy SAR testing time has recently become a bottleneck for the introduction of new antenna tuning technology to the market, and has begun to inhibit the introduction of new antenna tuning technology for consumers, as manufacturers are reluctant to risk prolonged certification times when they are already racing competitors to the market with each and every device they make.

The overall situation is starting to work against mobile phone users, mobile manufacturers, and network operators. Methods like SAR "screening" for efficient SAR testing must be considered when backed up by technical rationale and good enough evidence and laboratory practices.

How did we get to 2015 in mobile?

The Motorola 8500x is all you need to make a period film.

The technology most commonly used in Specific Absorption Rate (SAR) measurement and testing dates back more than 20 years. In the meantime, the whole concept of a handset terminal has changed, especially the communication capabilities of these devices.

When legacy robotic SAR measurement systems were introduced twenty years ago, a state-of-the art mobile phone featured 1 or 2 GSM or CDMA transmission bands. Robotic SAR measurement taking approximately 20 minutes per measurement scan was adequate to conduct SAR certification tests in a day or two using a single SAR testing system. Similarly, R&D SAR testing for antenna design purposes was relatively easy and fast per each device HW or antenna pattern change.

The Motorola Star TAC 6500 brought vibrating alerts to the world.

Modern mobile handsets may on the contrary possess ~30 different transmission frequency and communication system combinations, making legacy robotic SAR test systems way too slow for both R&D work and certification SAR testing.

Touch screens made tactile keyboards unnecessary for some users.

The radical change we have seen not only includes the complexity of transmission features and protocols, but also the usage scenarios and devices produced. The amount of test cases has multiplied with the introduction of new form factors like tablets.

Ten years ago, the single-band or dual-band handset was common. Since then, the number of transmit/receive frequencies has multiplied, and currently octoband antennas are commonly utilized in modern smartphones as well as tablets and other devices, making antenna design a much more complex task.

Samsung SCH-r900 was
the world's first LTE phone.

The Nokia 6500 slide phone emphasized the quality of the camera.

The ART-MAN SAR measurement system performs a single measurement in seconds.

The number of WWAN communication systems has evolved radically. On top of the initial GSM-only or CDMA-only handsets, modern multi-mode devices may include GSM, CDMA, WCDMA, TD-SCDMA, LTE, TD-LTE, as well the enhanced features of the aforementioned like DC-HSUPA, LTE CA, VoLTE and SV-LTE. Adding local connectivity with BT and WLAN to modern antenna technologies like MIMO results in an enormous test matrix of individual and simultaneous transmission test combinations.

Stringent competition and operator requirements have driven the demand for antenna performance to new levels, while the size and especially the thickness of the devices have radically diminished. Demand for new visual looks has introduced metal covers and decorations, wreaking havoc on the life of antenna designers. New technologies are constantly introduced to meet the contradictory challenges inherent to the modern device. Features like Antenna Switched Diversity (AsDiv) for uplink, Multiple-Input-Multiple-Output (MIMO), "closed-loop" antenna tuners and related control mechanisms like proximity sensors have further multiplied the SAR test matrix.

For example, one can calculate that there are now five times more bands (two is now ten), at least four times as many new communications systems (one is now four), and twice as many antennas (AsDiv or MIMO instead of single antenna). Meanwhile the speed of traditional SAR testing has not gone down 40-fold, unfortunately.

SAR measurement systems have recently undergone a big change

From a ***technical*** point of view, the biggest change in SAR measurement is the manufacture of amplitude and phase probe-array SAR measurement systems. These systems produce an accurate measurement in seconds where legacy systems would need twenty minutes.

Currently, there is only one "physics-based" system that does not rely on statistical analysis and that is accepted for certification testing under European requirements (and can be used on a case-by-case basis with the FCC): ART-MAN SAR measurement system.

Physics-based technology like that of ART-MAN also eliminates the need for robotics in SAR measurement.

ART-MAN SAR measurement system makes SAR testing easier and much faster

SAR Testing concepts have not changed much, but there is much more testing to be done

What has changed if looking at SAR *testing* from a purely technial point-of-view? The shape and location of the SAR pattern for each test position is still dictated only by the device mechanics, its antenna and the transmission frequency. And only by these.

The different communication systems introduced have brought multiple testing rounds per frequency band, once for each communication system, as is required in the SAR testing standards (one may ask if the standards are up-to-date in this sense, but it is just a fact that standards will lag behind innovation). Adding new advanced modulations means just that— one needs to measure more modulations for exactly the same SAR pattern multiple times. For the same frequency, the SAR difference between different communication systems is mostly the difference between time-averaged output powers. Running a whole new robotic scan to distinguish this power difference would seem to be overkill.

In the case of antenna tuners, the screening of the tuner state giving the highest SAR is even easier. The only thing that changes is the through-put power from power amplifier (PA) to antenna varied by tuning circuitry. The SAR pattern does not change by the tuner state when the tuner affects only the feed circuitry and not e.g. the grounding of the radiator. This is really just a “multimeter” measurement, but it’s required when using SAR test systems. The main reason is that a SAR system is the only setup allowing to load the antenna and PA in the appropriate conditions, i.e. accounting for the coupling between standard head or body mannequin and device. However, the number of cases required to be screened may be huge, even practically impracticable.

The most conservative method for the distinction between different modulations and matching conditions is to use modern vector probe-array SAR test systems to do the pre-testing for SAR certification, selecting only those test cases for the official certification testing that make a tangible difference in compliance and the maximum SAR value. Similar approaches can be utilized in antenna R&D work and obviously for antenna designers the measurement time difference speaks for itself.

SAR “Screening” overview

To further elaborate the cases where SAR screening is really beneficial, we give examples with three different usage possibilities as well as combinations of these. We explain in each of these examples the difference between the test cases, what is the same, and what is similar. We also cover how a modern probe-array type fast SAR system can speed up the R&D and certification test time.

In the case of different communication systems (different signal modulations sharing the same frequency band), we already stated above that the SAR pattern scarcely varies depending on the modulation. This is pure physical fact and trivial as such. Typically the required test channel and frequencies are identical or very near to each other for all of the communication systems within a frequency band. As long as the SAR testing system’s response to modulation is linear, basically only power differences are measured when comparing SAR results of a same/similar SAR pattern.

For the purpose of testing different modulations and communication systems, a probe-array fast SAR test system is ideal due to its speed and automated control of communication systems via a base station simulator. If one has N communication systems per frequency band, SAR pre-screening for the communication system giving highest SAR leads to test time of 1/N using traditional robot system as required by the SAR test standards.

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For dynamic antenna tuners or so-called closed-loop tuners, the amount of different tuner states can be huge. As the difference in SAR is only related to forward power in each tuner state, the SAR measurement is just repeated for the same SAR pattern with slightly different power. As an example of a typical antenna tuner commercially available, the transmission band can be divided to 3 sub-bands and further each sub-band can have up to eight different tuner states. Fully measuring this matrix of 24 combinations for each test case with a traditional SAR test system does not make sense.

Instead pre-screening with probe-array, "fast SAR" technology, especially when combined with an internal testing mode on the device capable of scanning through the tuner states, can make such a test really fast. Here the speed difference is directly proportional to the scan times of legacy v.s. modern SAR test systems, as modern systems make measurements in seconds, whereas legacy robotic systems make the same measurements in 20 minutes or more.

From a purely technical point of view, the SAR screening of all possible antenna tuner states is actually counter-intuitive. In SAR test standards, it is required to measure SAR at several frequencies (test channels) to take into account the difference in antenna matching across the transmission bandwidth. The antenna tuner is there partly to minimize the effect of this matching difference and therefore it actually reduces the need for SAR testing for several frequencies. The function of the tuner is to achieve the best possible tuning, in other words matching regardless of used channel or test position to ensure that the antenna is always matched in the best possible way.

This is also the case in practice. The SAR results among different sub-bands and tuner states vary typically very little, less than among the different test channels when traditional antenna design is used. However, as far as the technology is new and partly evolving, it is expected that full SAR screening through the sub-bands and tuner states will be required by the regulators.

Regarding LTE, to date many different sub-modes are required to be tested in certification SAR testing. The SAR pattern stays similar in principle and only power varies because of slightly different matching to antenna due to slightly different frequency of the allocated Resource Blocks (RB). The FCC KDB requirements vary based on conducted power measurements, but typically SAR tests are required for the following highest channel bandwidth sub-modes:

* 1 RB with RB offset at 0%, 50% and 100% within a channel
* 50% RB with RB offset at 0%,50% and 100%
* 100% RB allocations.

The detailed test procedure may vary but this leads to test amounts of at least 7 times to what is required for "traditional" communication systems.

All in all, with tri-mode GSM+WCDMA+LTE handset, the following table demonstrates the time benefit in certification SAR testing when in combination with a probe-array fast SAR system for SAR pre-screening. In this example, it is assumed that 4 test positions are required for Head SAR testing (left cheek, left tilt, right cheek, right tilt).

The number of saved test cases from the full SAR system testing vary from 12 to 480 (384+96) test cases, which assuming 20 minutes saved per test saves 240min to 9600min i.e. 4 hours to 160 hours in test time (up to four weeks).

For the body-worn SAR and FCC's Wireless Router SAR requirements the time saving is of the same order, making total time savings several months.

Table that describes how many tests you 'save" using a screening method

# of frequency bands	Multimode	AsDiv	Antenna Tuner
Saved tests 1 band	12	24	96
Saved tests 2 bands	24	48	192
Saved tests 3 bands	36	72	288
Saved tests 4 bands	48	96	384
Total hours saved at 20 minutes per measurement	Up to 16 hours	Up to 32 hours	128 hours
Total days saved (8 hour work days)	2 days	4 days	16 days

Three approaches to SAR Screening

There are 3 ways to approach the screening issue in practice. Here we use Head SAR testing as an example as it uses four clearly different test positions. Similar screening procedures can be deducted for body-worn and wireless router test requirements.

Procedure 1: fully-tested

In this procedure, all the needed SAR test positions and communications systems are fully tested with a probe-array fast SAR system. This gives the most data but is also the least time saving.

Note: We recommend testing at mid-channel. Do low and high channels at the end.

For the sake of effectiveness, the following order of testing could be recommended:

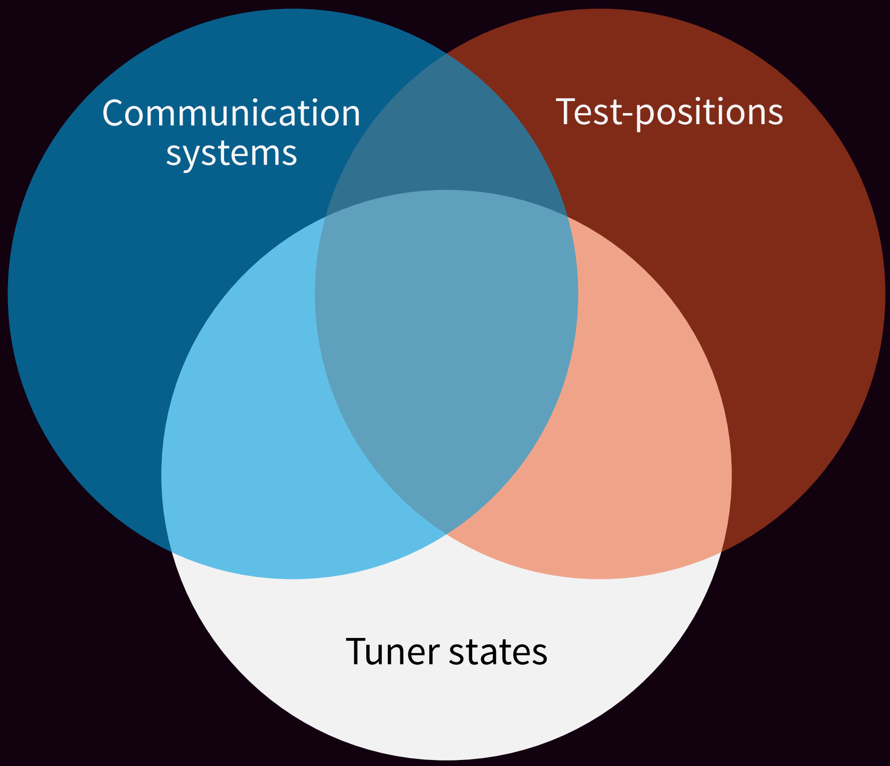
1. Position the DUT to left cheek.
2. Make mid channel measurement in all communications systems e.g. GSM, WCDMA and LTE.
3. Change the device position to left tilt, make mid channel measurement in all communications systems.
4. Repeat steps 2 & 3 for right cheek and right tilt.

This order is selected since the automated base station simulator control can be then utilized and the amount of position changes gets minimized.

This is the fastest way since device positioning typically takes more time than automatic change of the communication system via the base station simulator.

2. Communication system based SAR Screening

Note: We recommend testing at mid-channel. Do low and high channels at the end.



1. Test all tuner states at all communication systems.
2. Identify worst-case tuner state.
3. Test all communication systems at worst-case tuner state at one test position.
4. Identify worst-case communication system.
5. Test worst-case communication system and worst-case tuner state in the remaining three positions.
6. Last, test worst-case at low and high channels.

How many tests did you save?

* 2 communications systems by 3 test-positions
* y tuner states by 4 test-positions

This procedure makes an assumption that power amplifier circuitry behaves reasonably similarly for all the communication systems, i.e. that change in antenna impedance due to different test positions does not affect PA characteristics (e.g. load-pull effect) so that the order of forwarded power gets changed by different test positions. This assumption typically holds well in well-designed DUT since modern power amplifier circuitry is quite immune to small changes in impedance. Overall, these effects are generally small, fractions of dB, and well within overall measurement uncertainty of SAR test systems.

However, not all phone designs are perfect, so you might want to mitigate this minor issue. We recommend fully-screening several communication systems at certain test positions *IF* the SAR difference between communication systems is small in the initial test position. Why? Because if the differences are very small, you are less sure if you have the worst-case communications system.

The benefit of this screening procedure is:

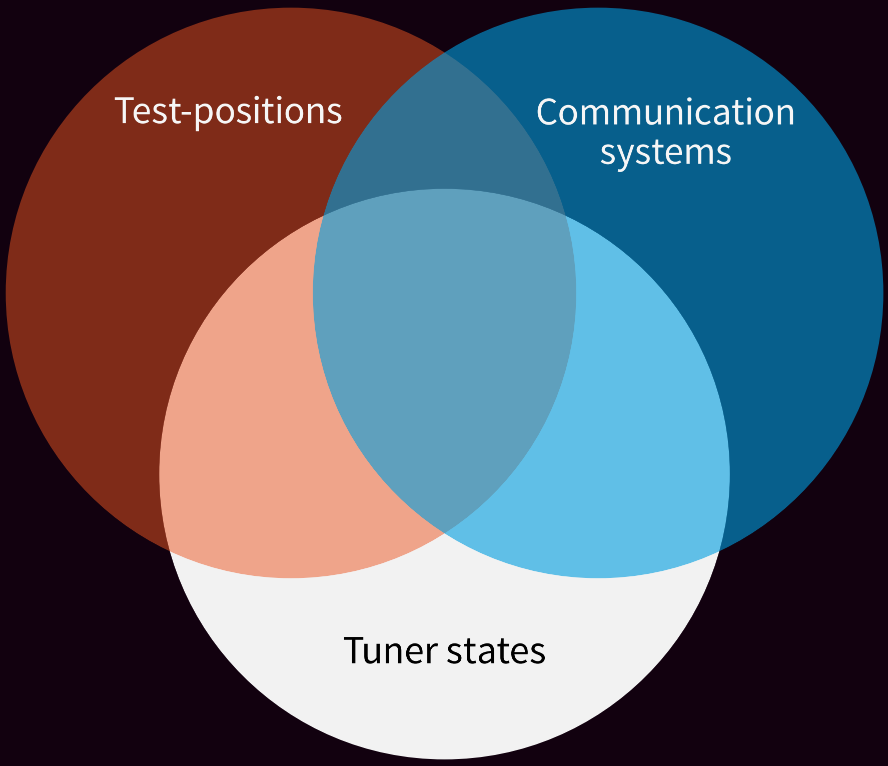
* The minimal amount of screening tests
* The communication system with the highest SAR gets fully-measured for all the required test positions.

This is a clear benefit when assessing simultaneous transmission combinations with other transmitters, e.g. with WLAN.

If you know the worst-case test position beforehand, the initial test position should be the worst case position. All the communication systems are then measured at the worst case position. This leads to a combination of Procedure 2 and Procedure 3 in practice. In other words, the same test cases would be measured in these two.

3. Test position based SAR Screening

Note: We recommend testing at mid-channel. Do low and high channels at the end.



1. Test all tuner states at all communication systems.
2. Identify worst-case tuner state.
3. Randomly select a communication system.
4. Test at all test positions.
5. Identify worst-case test position.
6. Return to the position and communication system with the highest SAR and test both low and high channels.

How many tests did you save?

* 2 communications systems by 3 test-positions
* y tuner states by 4 test-positions

This way, the maximum SAR for the individual antenna gets measured, but the highest SAR for all the test positions is not assessed. This makes a difference if simultaneous transmission exposure in different positions needs to be assessed.

One variation of this procedure could be utilized if the worst-case communication system is known beforehand. Then, the initial test system should be the worst-case communication system and all the test positions are then measured at the worst-case communication system.

This leads to a combination of Procedure 2 and Procedure 3 in practice (the same test cases would be measured in these two).

Add dynamic antenna tuners to your procedure

The procedure for screening closed-loop antenna tuners is simple, but it helps to have an internal mode to automatically cycle through the tuner states.

As the amount of test cases becomes larger and more difficult to manage, a probe-array, fast SAR measurement system is the best path v.s. a legacy SAR system, even with screening practices in place.

What do all these procedures have in common?

Similar SAR patterns are measured again and again, with either different modulations or different antenna matching.

Only the relative accuracy across the different output powers and modulations matter. Therefore, an enormous test matrix can be reduced to a smaller test matrix and screened with a fast SAR system with good confidence.

Screening, Fast SAR, & Standards

As these tests also represent the bulk of test time spent on testing overall, the best balance can be achieved in saving test time while being still compliant with SAR test standards in test cases that matter the most.

The most important factors for the SAR screening to be successful are the SAR test system being linear and independent of the signal modulation.

The ART-MAN system perfectly meets the essential requirements that are needed for succesfull screening through the SAR test matrix.

ART-MAN is actually composed of two main ensembles (see below):

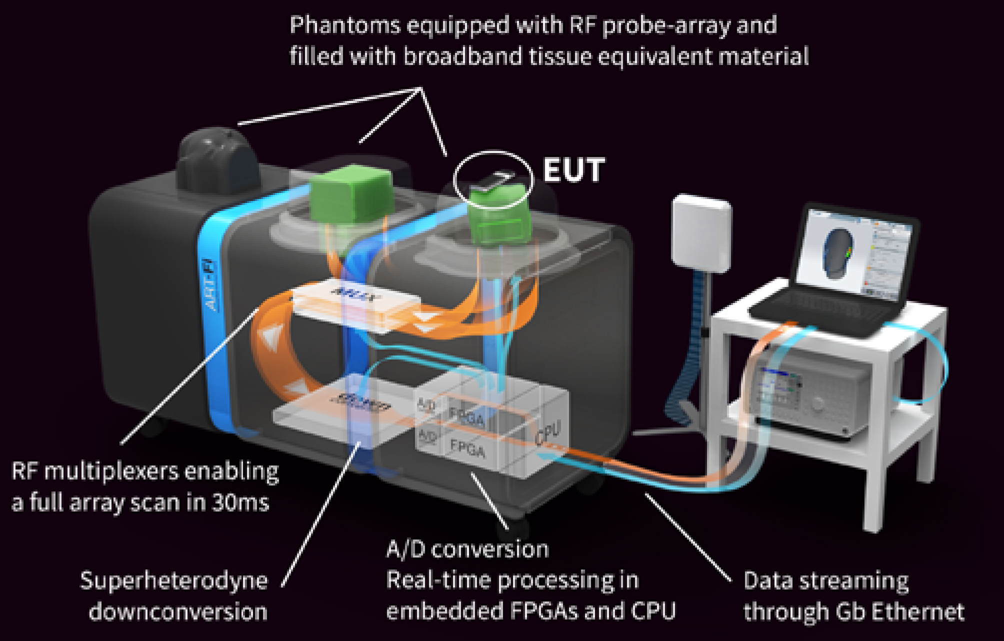


Figure – ART-MAN system overview. Orange lines represent measurement signals and blue lines command signals.

(i) The three instrumented mannequins (the flat body phantom, SAM left and SAM right) containing arrays of RF vector probes capturing the electric field in both amplitude and phase.

(ii) A vector signal analyzer (VSA) chain downconverting the output of the probes in lower frequency time-domain signals, which are then digitized at 250 MSPS and processed through real-time complex spectrum analysis.

The probes patented by ART-Fi [A. Cozza, B. Derat, S. Pannetrat, "System for measuring an electromagnetic field," Patent Application WO 2011/080332.] are made of small capacitive sensors connected to 50 Ohm transmission lines with wideband 690 – 6000 MHz operation. This design is inherently linear and does not contain any detector like traditional diode-based probes. The VSA chain includes some low-noise amplifiers. However, advanced gain control algorithms ensure linear operation of the system over a wide dynamic range from 0.05 to 500 W/kg in 1g SAR. During system calibration, the frequency responses of the signal paths are equalized across the 40 MHz analysis bandwidth of the VSA for each local oscillator frequency of the downconverter. The application of these calibration coefficients then enables a totally flat response of the equipment as a function of frequency. As a result, ART-MAN accurately assesses the complex spectrum of any modulated signal for each measurement acquisition and utilizes this information for evaluating the electric field magnitude and phase. Linearity and independence to modulation are really obtained from the essence of the implemented approach.

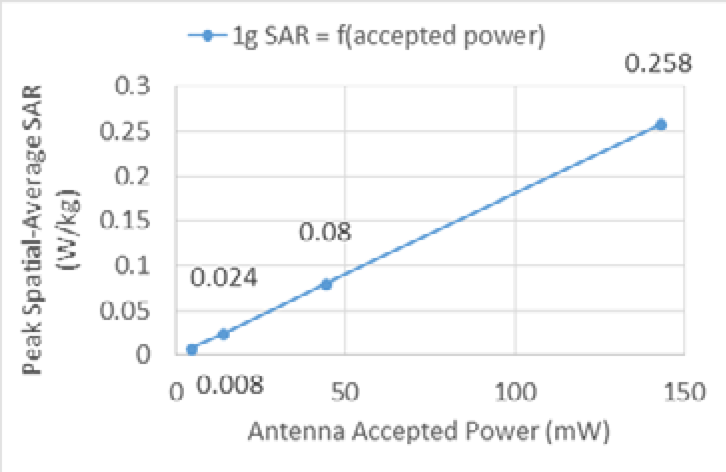


Figure – Linearity of ART-MAN system response. Case of ART100219-03 UWB verification antenna at 10mm from ART-MAN flat phantom filled with FCC compliant body tissue-simulating material. Power accepted fed into the antenna port is varied from 4 to 140 mW for a CW signal at 1920 MHz.

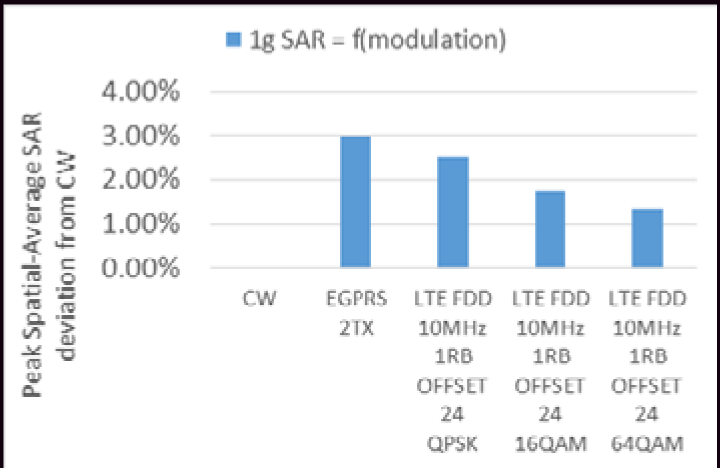
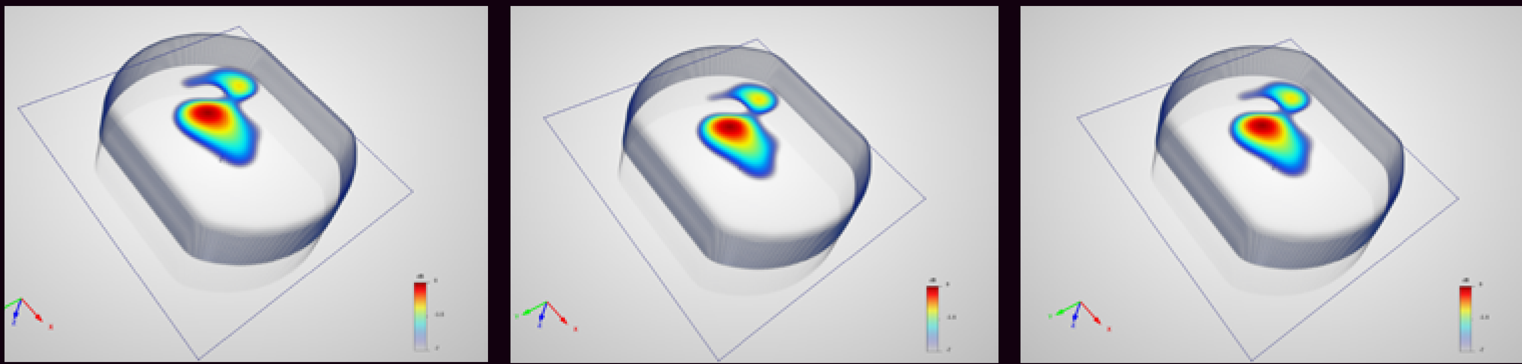


Figure – Independence to modulation – Deviation of SAR normalized to 1W accepted power from CW signal case for ART100219-03 UWB verification antenna at 10mm from ART-MAN flat phantom filled with FCC compliant body tissue-simulating material. Signal generator is set to transmit 25 dBm at 1920 MHz.

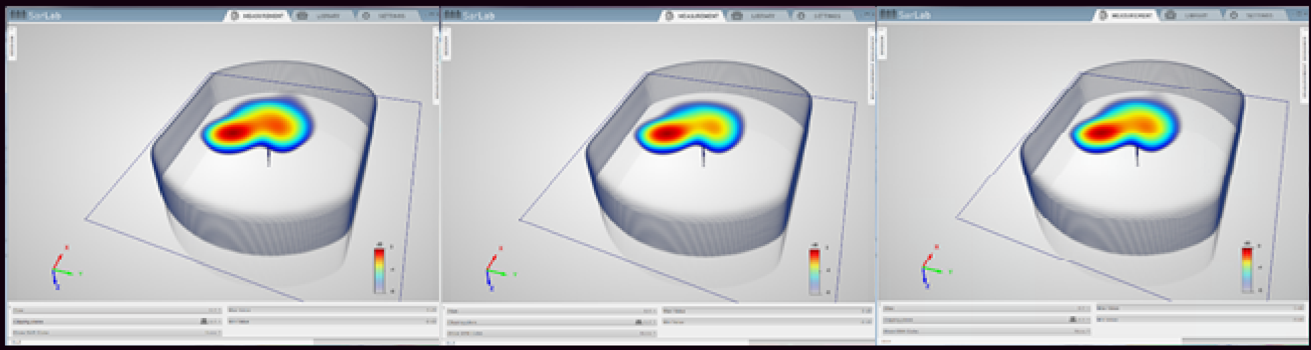
Example screening data with ART-MAN

The following examples include practical demonstration how the SAR patterns are identical/similar across different modulations, as well as across different tuner states of the closed loop tuner.

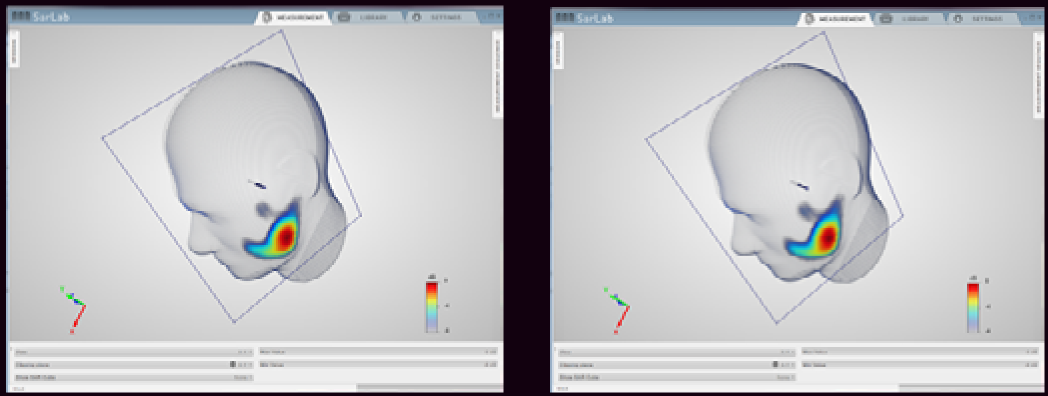
The examples above have demonstrated the similar patterns across the modulations as well as tuner states. These kind of repeated measurements over the same SAR pattern are an excellent example where SAR screening with a probe-array, fast SAR system could be utilized with great benefits when compared to more traditional SAR test systems.



Smartphone measured at WCDMA band 8 mid-channel on ART-MAN flat phantom with FCC compliant body tissue in front 15mm position: from left to right, identical patterns for three different antenna tuner states.



Similar SAR distributions for smartphone measured at LTE band 17 on channel 23790 (710 MHz) with 10 MHz bandwidth on ART-MAN flat phantom with FCC compliant body tissue at flat phantom in rear 10mm position: from left to right, QPSK modulation with RB size 1 and offset 0; 16 QAM modulation with RB size 1 and offset 49; 16 QAM modulation with RB size 50 and offset 0.



Similar SAR distributions for mobile phone tested at ART-MAN SAM left side in cheek position: left – WCDMA band 2 channel 9400 (1880 MHz); right – GSM 1900 voice channel 661 (1880 MHz).

Conclusion

We have shown that SAR “screening” is technically feasible with amplitude and phase probe-array SAR measurement equipment. Furthermore, there is good technical rationale and the results are reliable.