

Safe Online Local SAR Calculation for Transmit Arrays Using Asynchron Data Processing

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Target audience: RF engineers and MR Physicists

Purpose: A safe RF supervision which allows to consider local SAR is an essential pre-requisite for high performance pTX applications. Any safety concept needs to provide at least one online RF supervision component that detects potential violation of local SAR limits in real-time to guarantee patient safety [1-4]. Implementing complex local SAR supervision algorithms on a real-time hardware is a time consuming engineering task involving RF signal reception and processing. Using the MR reception and signal processing unit for RF supervision fails to match the real time requirements. In this study, an online local SAR calculation based on measured RF pulse shapes was implemented on the standard image reconstruction PC of the used 7T MRI system. The local SAR calculation time creates a latency between the application of RF to the patient and its supervision. To overcome this limitation, a simple real-time logic implemented on an FPGA in conjunction with a conventional real-time global SAR supervision unit is used to guarantee patient safety at all times.

Methods: Figure 1 shows the local SAR supervision timing. The upper axis shows RF which is supervised with a latency depicted by red arrows. The dashed vertical line defines the current measurement time. Local SAR occurred within the orange box is not supervised yet at this time, because there is no „SAR OK“ for pulses in time-frame yet. Due to the use of non-real-time hardware to calculate local SAR, the calculation latency is not exactly known. To control local SAR during this period, a maximum calculation latency must be guaranteed and local SAR is supervised based on a worst case assumption within this maximum latency.

To enforce a maximum calculation latency (dt), a simple real-time watchdog logic is implemented in a FPGA as shown in figure 2. This logic uses two one bit inputs and one output to disable the RFPA if necessary. A counter measures the actual delay time. While the RFPA is transmitting RF, it sends true through the “RFPA TX” line. The counter counts up. If the online local SAR calculation has checked another millisecond of RF, it sends a pulse on line “RF check” which decrements the counter by one millisecond. If the counter reaches zero or dt , the RFPA is turned off. Note that this logic supervises RF time, not measurement time.

Local SAR supervision during the maximum delay time is performed by the independent real-time global RF monitor also used for global SAR supervision. The worst case local SAR within the time period dt is calculated based on numerical simulations of the coil and a patient model. The results are compressed using virtual observation points (VOP) [5]. The VOPs are also used for online local SAR calculation. In a worst case scenario, the applied peak local SAR is given by the sum of local SAR already accumulated by the online supervision and local SAR approximated by the global power supervision within dt :

$$SAR_{tot} = SAR_{online} + P_{fwd} \lambda_{max} \Delta t 50\Omega/10s$$

Here, λ_{max} is the biggest eigenvalue of all VOPs and P_{fwd} is the mean forward RF power during dt which is limited at the supervision unit. The window size for worst case local SAR supervision (dt) can be chosen freely. To minimize the second addend in the equation above and thus maximize system performance, dt should be chosen as small as possible.

Results: To choose an appropriate value for the maximum allowed calculation delay time, the mean actual delay time was measured as approximately 1.5ms. During the first millisecond, the online supervision accumulates RF, then peak local SAR is calculated. To be on the safe side in heavily loaded cases, the maximum allowed delay time was chosen to be 10ms. Running a variety of sequences with long RF pulses and/or a high RF duty-cycle for several hours did not cause any watchdog errors. For the watchdog, the clock used for measuring RFPA on time and the clock used by the online local SAR calculation must be precisely matched to avoid false over- or underflows of the watchdog counter. Breaking the connection between local SAR calculation and watchdog caused a RFPA shutdown within 10ms RF time. To guarantee patient safety, the worst case allowed maximum local SAR for a 10s interval was chosen to be 40W/kg as stated for the first level controlled mode of the IEC regulations. For normal scanning (SAR_{online}), 20W/kg peak local SAR should not be exceeded. Putting these values in the equation above yields a maximum allowed mean forward RF power for the 10ms interval of $400W \cdot S/kg / \lambda_{max}$. Simulating a eight transmit channel local body coil at 7T lead to a value for λ_{max} of 0.587S/kg for a male patient. This leads to a maximum allowed mean forward RF power of 7kW within 10ms.

Discussion & Conclusion: The proposed online local SAR supervision allows the use of non-real-time hardware with unknown calculation delays without compromising patient safety. Only a simple real-time logic and the already existing global SAR supervision unit are necessary to achieve this goal. For an eight channel local body coil, a 10ms global forward power limit of 7kW was calculated. This value is high enough to not decrease scanning performance, but lower than the available peak RFPA power. By averaging this power using the global RF supervision unit, peak RFPA power can still be used. Only in case of a system fault, 20W/kg local SAR within 10s may be exceeded during the last 10ms of the scan. 40W/kg are only reached but never exceeded if the RFPA is transmitting at 6.8kW average power within the last 10ms of the scan using the worst case relative transmit phase setting between all channels. This concept is not limited to online local SAR calculation methods, but can also used for pulse comparison techniques shown in [2,3].

References: [1] Graesslin et al., MRM 68:1664-1674 (2012), [2] Graesslin et al. ISMRM 2008, p.74 [3] Gagoski et al. ISMRM 2010, 781 [4] Gumbrecht et al., submitted ISMRM 2013, [5] Eichfelder et al., MRM 66:1468-1476 (2011)

The concepts and information presented in this paper are based on research and are not commercially available.



Fig. 1: Local SAR supervision model.

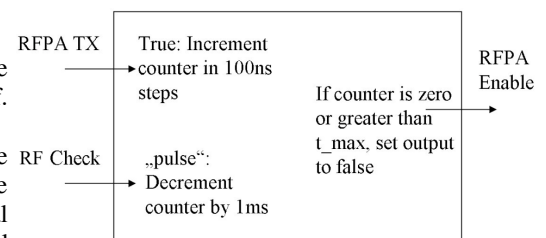


Fig. 2: Local SAR calculation watchdog logic. All I/O lines are one bit connections. The “RFPA TX” line is true during RF transmission. “RF Check” gets a short pulse from the SAR calculation if 1ms RF was successfully checked. The RFPA is turned off if the “RFPA Enable” is false