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**APT report on**

**5G mmWave OTA test methodology for user equipment**

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# Introduction

The 5G mmWave UE RF design is quite different from traditional 2G/3G/4G bands due to several contributing to the increased levels of integration in 5G mmWave UE. These factors are interrelated and are driven by the combination of high frequencies, large numbers of antenna elements, the need to minimize signal path attenuation, and the need to reduce cost. A significant consequence of the resulting integration is that traditional RF connectors are no longer possible to implement. As a result, transceiver systems for 5G mmWave UE will be directly integrated with the antenna arrays, hence there are no longer connectors that might enable conducted tests. Therefore, the 5G mmWave UE test can only be performed by OTA methods.

3GPP developed a series of specifications on the methodologies for 5G mmWave UE OTA test. The challenges of OTA measurement are analyzed. 3GPP continuously addresses the technical challenges with technical solutions.

This report provides a high-level introduction on the test methodologies developed by 3GPP specifications. It will also provide a guidance on how to refer to 3GPP specifications when applying the 5G mmWave UE OTA test methodologies for UE.

# Acronyms

CPE Customer Premise Equipment

DUT Device Under Test

FF Far-Field

FR2 Frequency Range 2 (24.25 - 71GHz)

mmWave Millimeter Wave

MTSU Maximum Test System Uncertainty

NF Near-Field

NR New Radio

OTA Over The Air

RF Radio Frequency

RFIC Radio Frequency Integrated Circuit

RRM Radio Resource Management

RSRP Reference Signal Received Power

Rx Receiver

SI Study Item

TE Test Equipment

TR Technical Report

TS Technical Specification

Tx Transmitter

UBF UE Beam lock Function

UE User Equipment

# Challenges of OTA measurement

Due to high integration of RFIC and RF front end, OTA is the essential method to characterize the performance of mmWave UEs – not only the RF performance, but also the Demodulation and RRM performance. The complexity of OTA test is much higher than the conducted test. The challenges including test time, test uncertainty and the stability of test were analyzed as follows:

* Regarding mmWave OTA test time, the mobile industry has recognized the importance of reducing the testing time of OTA test for mmWave bands. To further enhance the FR2 test methods from TR38.810 adapted in REL-15 through REL-16 3GPP TS38.521-2/-3/-4/TS38.533 specifications, 3GPP Rel-17 starts a SI 850071 “Study on enhanced test methods for FR2 NR UEs”. The SI has an objective of FR2 testability enhancements to improve FR2 testability, increase test coverage, and reduce the test time for RF, RRM and Demodulation test cases. The SI was extended to Rel-18 and has been completed in June 2022, the conclusions from this SI have been incorporated into 3GPP TR 38.884, and further the outcomes are planned to be applied to the FR2 test case design in TS 38.521-2/-4/TS38.533.

Overall the 3GPP test methodologies has multiple options to reduce the test time being proposed and approved including new measurement gird, RSRP(B) based Rx beam peak search, single link polarization measurement, and fast spherical coverage method etc.

For example, in 3GPP TS38.521-2, coarse TRP measurement grid is used in mmWave UE spurious emission test procedure which can significantly reduce the test time. Meanwhile, the certification forum (GCF) is also investigating schemes to further reduce the mmWave test time and test cost, such as modular certification scheme, which would allow the host device to leverage some module test results. The modular certification can balance test time/effort between the module vendors and host device vendors.

* Regarding the test uncertainty and testability enhancements, 3GPP Rel-17 SI 850071 has also addressed improvements to measurement uncertainty issues for applicable test cases, beyond what was incorporated in TR38.903/TR38.810. And the alternative test approach using the combined NF (near field) and FF (far field) method is being studied which can result in typical 10 dB or more pathloss improvement (more details can be found in 3GPP TR 38.884). Further, 3GPP will continue to resolve testability and improve the remaining uncertainty of a few test cases of mmWave OTA test.
* Regarding the stability of test, 3GPP has developed methods like UBF, Tx Diversity disable, Multiple DUT test orientations, which allow full sphere or hemisphere test flexibility. Those functions can greatly minimize stability issues and has been incorporated into FR2 test procedures in TS38.521-2/-3/-4/TS38.533. Connection drops under low signal conditions may occur and it can be further improved by working closely with TE vendor to setup the measurement and link antennas optimally for the DUT.

# OTA test methodology for 5G mmWave UE in 3GPP specifications

3GPP completed a dedicated study item (SI) in Rel-15 to identify the 5G mmWave UE OTA test methodologies. Instead of converging to one single test methodology, the study allows multiple test methodologies with different set up, test procedures and uncertainties. As the outcome of SI, the test methodologies including Direct far field (DFF), Indirect far field (IFF), and Near field to far field transform (NFTF) are specified in 3GPP TR 38.810.

After completion of Rel-15 SI on OTA, 3GPP studied the OTA test method enhancements in Rel-16 and Rel-17. This SI has been completed and the conclusions have been captured into 3GPP TR 38.884 in which the enhanced UE RF test methods using the combined NF(near field) and FF(far field), the approach of reducing the testing time, test method for mmWave inter-band CA and extension of frequency applicability for higher frequency range of mmWave, etc., were incorporated. RAN4 will contribute to study on the OTA test method enhancements in Rel-18 which is to study the test methodology for mmWave UE with multi-panel reception.

## UE RF test methodology

### DFF (Direct far field)

The DFF measurement setup of UE RF characteristics in FR2 is shown in **Figure 1**. Basic DFF RF test method consists of an electromagnetic no-reflection chamber and a far-field probe antenna. The minimum far-field distance (R) for a traditional far field anechoic chamber can be calculated based on Fraunhofer distance criterion (R = 2D²/λ), where D is the diameter of the smallest sphere that encloses the radiating parts of the DUT, and λ represents the wave length.



Figure 1: Configuration of DFF (Direct far field)

### IFF (Indirect far field)

IFF methods creates far field environment using a transformation with a parabolic reflector. This method is also known as the compact antenna test range (CATR). The IFF measurement setup of CATR is shown as **Figure 2**. IFF/CATR system adopts the reflector to transform spherical wave to plane wave in the desired quiet zone. The key aspects of this test method setup include reflector, position/rotation system, feed antenna and link antennas. The advantage of IFF/CATR compared with DFF is that it can shorten the test distance and lower the path loss while still satisfying the Far Field test criteria. Therefore, IFF/CATR test environment with lower path loss will have larger measurement dynamic range compared with DFF.



Figure 2: IFF (Indirect far field) measurement method

### NFTF (Near Field to Far Field Transform)

NFTF is an alternative test method for RF testing in which the requirements for the chamber size are reduced and the results are comparable to DFF achieving with state-of-the-art near-field transformation algorithms. The NFTF measurement setup is shown in **Figure 3**. The method determines the far field of an antenna from a near-field measurement with transformation algorithms which can help to reduce the measurement distance.



**Figure 3: Near Field to Far Field Transform (NFTF) measurement method**

## UE RRM test methodology

The baseline measurement setup of UE RRM characteristics for mmWave is capable of establishing an OTA link between the DUT and a number of emulated gNB sources as shown in **Figure 4**. The key aspects of this test method setup include dual-polarized probe antennas, position/rotation system. The absolute position of the probe antennas is left up to implementation. The relative angular relationship between two angle of arrivals (AoAs) can be achieved using any combination of probe antennas. DFF and IFF are considered as the permitted test setups for OTA RRM testing.



**Figure 4: Baseline measurement setup of RRM characteristics**

## UE Demodulation test methodology

The baseline measurement setup of NR UE demodulation for mmWave is capable of establishing an OTA link between the DUT and a number of emulated gNB sources with one AoA to the UE, which is shown in **Figure 5**. DFF and IFF are considered as the permitted test setups for OTA Demodulation testing.



**Figure 5: Baseline measurement setup of UE demodulation characteristics**

## How to apply 3GPP specifications

This report summarized all the 3GPP RAN4/RAN5 technical specifications (TS) and technical reports (TR) related to mmWave OTA verification of UE performance.

3GPP TSG RAN WG4 (RAN4) works on the Radio Frequency (RF) aspects of 3G/4G/5G and beyond. RAN4 performs simulations and derives the minimum requirements for transmission and reception parameters, Radio Resource Management (RRM), and for channel demodulation and Channel State Information (CSI) reporting. Once these requirements are set, the group defines the test procedures that will be used to verify them. In addition, OTA requirements and testing methods for UE are defined in RAN4. RAN4 specifications and technical reports related to mmWave UE OTA testing are summarized in **Table 1**.

|  |  |  |
| --- | --- | --- |
| TS or TR | Test method study | Requirements aspects |
| TR 38.803 | Initial study on test methodology for mmWave UE. | N/A |
| TR 38.810 | Study on test methodology of RF, RRM, and Demodulation for mmWave UE.Preliminary measurement uncertainty. | See TS 38.101-2, TS 38.101-4, TS 38.133 |
| TR 38.884 | Study on enhanced test methodology of RF, RRM and Demodulation for mmWave UEs.Preliminary measurement uncertainty. | See TS 38.101-2, TS 38.101-4, TS 38.133 |
| TS 38.101-2  | See TR 38.810, TR 38.884 | Specify mmWave UE RF requirements |
| TS 38.101-3 | See TR 38.810, TR 38.884 | Specify mmWave UE RF requirements for mmWave UE RF requirements with FR1 and FR2 interworking operation |
| TS 38.101-4 | See TR 38.810, TR 38.884 | Specify mmWave UE Demodulation requirements |
| TS 38.133 | See TR 38.810, TR 38.884 | Specify mmWave UE RRM requirements |

**Table 1：RAN4 specifications and technical reports related to mmWave UE OTA testing**

3GPP RAN5 works on UE conformance test specifications at the Radio Interface dealing with GSM/3G/4G/5G and beyond based on 3GPP core specifications. The test specifications consist of measurement procedures and conditions, to evaluate the UE requirements defined by other groups such as RAN4 for the radio test cases and RAN2 and CT WG1 for the protocols test cases. RAN5 specifications and technical reports related to mmWave UE OTA testing are summarized in **Table 2**.

|  |  |
| --- | --- |
| TS or TR | Measurement procedures |
| TR 38.903 | Derivation of test tolerances and measurement uncertainty for mmWave UE RF, RRM and Demodulation |
| TS 38.521-2 | Specify measurement procedures and test requirements for mmWave UE RF conformance testing |
| TS 38.521-3 | Specify measurement procedures and test requirements for mmWave UE RF conformance testing with FR1 and FR2 interworking operation |
| TS 38.521-4 | Specify measurement procedures and test requirements for mmWave UE Demodulation conformance testing |
| TS 38.533 | Specify measurement procedures and test requirements for mmWave UE RRM conformance testing |

**Table 2: RAN5 specifications and technical reports related to mmWave UE OTA testing**

The specific examples of test cases defined for mmWave UE RF, RRM, and Demodulation in 3GPP RAN5 are listed in Appendix.

## Test measurement and implementations

###  Example of testing time

In TR 38.884, an example of test time of some mmWave of RF test cases is provided and listed in **Table 3**.

**Table 3: Actual mmWave testing time from one TE vendor (example)**

|  |  |
| --- | --- |
| FR2 test cases based on TS38.521-3/2: | Time/h or min |
| 38.521-2 |  | Tx beam peak direction search | 4h (with 7.5° step) |
| 38.521-2 |  | Rx beam peak direction search | 11h (with 7.5° step) |
| 38.521-3 | 6.2B.1.4.1 | UE Maximum Output Power for Inter-Band EN-DC including FR2 (2 CCs) – EIRP and TRP | 30min |
| 38.521-3 | 6.2B.1.4.2 | UE Maximum Output Power for Inter-Band EN-DC including FR2 (2 CCs) – Spherical Coverage | 1h |
| 38.521-3 | 6.3B.2.4 | Transmit OFF Power for inter-band EN-DC including FR2 | 15min |
| 38.521-3 | 6.5B.2.4.1 | Spectrum emissions mask for Inter-band EN-DC including FR2 (2 CCs) | 35min |
| 38.521-3 | 6.5B.2.4.3 | Adjacent channel leakage ratio for Inter-band EN-DC including FR2 (2 CCs) | 35min |
| 38.521-3 | 6.5B.3.4.1 | General Spurious Emissions for Inter-band including FR2 (2 CCs) | 1h |

Note that the above testing time is varied due to different UE performance, test software version, and detailed parameters setting, etc.

###  Quiet Zone and maximum device size

Generally, the exact antenna size of the DUT is unknown since it depends on many factors such as ground coupling effects, etc. The largest device size (e.g., diagonal) could be used; however, this would lead to very large chambers even for relatively small devices. One of methods to reduce measurement distance is use IFF which has larger Quiet Zone enclosing the DUT with the proper size of the reflector. 3GPP TR 38.903 defines the applicability mapping between minimum QZ size, maximum device size and MTSU. The mmWave devices with max device size <=30cm are currently testable which can cover all type of handheld UEs and most of CPEs. 3GPP will further discuss and specify the test system accommodating larger mmWave device size. Some examples of minimum QZ size and maximum device size are given in **Table 4**.

|  |  |  |
| --- | --- | --- |
| Chamber type | Device size | QZ assumptions for the chamber |
| IFF | <30cm | 20cm, 30cm |
| DFF | <5cm | 20cm, 30cm |

**Table 4: Some examples of minimum QZ size and maximum device size**

# Summary

This report provides a high-level introduction on 5G mmWave OTA test methodology for UE (user equipment), developed by 3GPP. 3GPP has completed a set of specifications and technical reports including test methodology, test procedure and requirements related to mmWave UE testing covering EnDC, NR-DC/CA and SA configurations, which could be used for mmWave certification testing to secure the interoperability and quality/performance of UE. This report also provides the guidance on how to refer 3GPP specifications.

APT/AWG would recommend that the industry consider adopting 3GPP test methodologies and achieve harmonization of test methodology for mmWave UE which will benefit all the APT industry partners and regulators involved in mmWave certification ecosystems due to it being a stable, reliable, repeatable, and optimized state of art test methodologies for the mmWave technology. GCF is validating the required mmWave test cases, which are a subset of 3GPP test cases sufficient for the initial mmWave development. The operators can provide their mmWave certification test case demand to GCF and Test Equipment vendors as early as possible so that they can speed up the validation of 3GPP test cases to meet operators’ demand.

# Reference

1. 3GPP Rel-17 SI 850071 “Study on enhanced test methods for FR2 NR UEs”
2. 3GPP TR 38.884 “Study on enhanced test methods for Frequency Range 2 (FR2) NR User Equipment (UE)”
3. 3GPP TR 38.803 “Study on new radio access technology: Radio Frequency (RF) and co-existence aspects”
4. 3GPP TR 38.810 “Study on test methods”
5. 3GPP TS 38.101-2 “User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone”
6. 3GPP TS 38.101-3 “User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios”
7. 3GPP TS 38.101-4 “User Equipment (UE) radio transmission and reception; Part 4: Performance requirements”
8. 3GPP TS 38.133 “Requirements for support of radio resource management”
9. 3GPP TR 38.903 “Derivation of test tolerances and measurement uncertainty for User Equipment (UE) conformance test cases”
10. 3GPP TS 38.521-2 “User Equipment (UE) conformance specification; Radio transmission and reception; Part 2: Range 2 standalone”
11. 3GPP TS 38.521-3 “User Equipment (UE) conformance specification; Radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios”
12. 3GPP TS 38.521-4 “User Equipment (UE) conformance specification; Radio transmission and reception; Part 4: Performance”
13. 3GPP TS 38.533 “User Equipment (UE) conformance specification; Radio Resource Management (RRM)”

Appendix

**Table 5: RAN5 mmWave UE RF test cases**

|  |  |  |  |
| --- | --- | --- | --- |
| **Area** | **TS** | **Clause** | **Title** |
| RF Rx Tx | 38.521-2 | 6.2.1.1 | UE maximum output power - EIRP and TRP |
| RF Rx Tx | 38.521-2 | 6.2.1.2 | UE maximum output power - Spherical coverage |
| RF Rx Tx | 38.521-2 | 6.2.2 | UE maximum output power reduction |
| RF Rx Tx | 38.521-2 | 6.2.3 | UE maximum output power with additional requirements |
| RF Rx Tx | 38.521-2 | 6.2.4 | Configured transmitted power |
| RF Rx Tx | 38.521-2 | 6.3.1 | Minimum output power |
| RF Rx Tx | 38.521-2 | 6.3.2 | Transmit OFF power |
| RF Rx Tx | 38.521-2 | 6.3.3 | Transmit ON/OFF time mask |
| RF Rx Tx | 38.521-2 | 6.3.4 | Power control |
| RF Rx Tx | 38.521-2 | 6.4.1 | Frequency error |
| RF Rx Tx | 38.521-2 | 6.4.2.1 | Error vector magnitude |
| RF Rx Tx | 38.521-2 | 6.4.2.2 | Carrier leakage |
| RF Rx Tx | 38.521-2 | 6.4.2.3 | In-band emissions |
| RF Rx Tx | 38.521-2 | 6.5.1 | Occupied bandwidth |
| RF Rx Tx | 38.521-2 | 6.5.2.1 | Spectrum Emission Mask |
| RF Rx Tx | 38.521-2 | 6.5.2.3 | Adjacent channel leakage ratio |
| RF Rx Tx | 38.521-2 | 6.5.3.1 | Transmitter Spurious emissions |
| RF Rx Tx | 38.521-2 | 6.5.3.2 | Spurious emission band UE co-existence |
| RF Rx Tx | 38.521-2 | 6.5.3.3 | Additional spurious emissions |
| RF Rx Tx | 38.521-2 | 6.6.1 | Beam correspondence - EIRP |
| RF Rx Tx | 38.521-2 | 7.3.2 | Reference sensitivity power level |
| RF Rx Tx | 38.521-2 | 7.3.4 | EIS spherical coverage |
| RF Rx Tx | 38.521-2 | 7.4 | Maximum input level |
| RF Rx Tx | 38.521-2 | 7.5 | Adjacent channel selectivity |
| RF Rx Tx | 38.521-2 | 7.6.2 | In-band blocking |
| RF Rx Tx | 38.521-2 | 7.9 | Spurious emissions |

**Table 6: RAN5 mmWave UE RRM test cases**

|  |  |  |  |
| --- | --- | --- | --- |
| **Area** | **TS** | **Clause** | **Title** |
| RRM | 38.533 | 5.3 | RRC\_CONNECTED state mobility |
| RRM | 38.533 | 5.3.2 | RRC connection mobility control |
| RRM | 38.533 | 5.4.1 | UE transmit timing  |
| RRM | 38.533 | 5.4.2 | UE timer accuracy |
| RRM | 38.533 | 5.4.3 | Timing advance |
| RRM | 38.533 | 5.5.1 | Radio link monitoring |
| RRM | 38.533 | 5.5.2 | Interruption |
| RRM | 38.533 | 5.5.3 | SCell activation and deactivation delay |
| RRM | 38.533 | 5.5.4 | UE UL carrier RRC reconfiguration delay |
| RRM | 38.533 | 5.5.5 | Link recovery procedures |
| RRM | 38.533 | 5.5.6 | Active BWP switch delay |
| RRM | 38.533 | 5.5.8 | Active TCI state switch delay |
| RRM | 38.533 | 5.6.1 | Intra-frequency measurements |
| RRM | 38.533 | 5.6.2 | Inter-frequency measurements |
| RRM | 38.533 | 5.6.3 | L1-RSRP measurement for beam reporting |
| RRM | 38.533 | 5.6.4 | CLI measurements |
| RRM | 38.533 | 5.6.6 | L1-SINR measurement for beam reporting |
| RRM | 38.533 | 5.7.1 | SS-RSRP |
| RRM | 38.533 | 5.7.2 | SS-RSRQ |
| RRM | 38.533 | 5.7.3 | SS-SINR |
| RRM | 38.533 | 5.7.4 | L1-RSRP |
| RRM | 38.533 | 5.7.5 | SRS-RSRP |
| RRM | 38.533 | 5.7.6 | L1-SINR measurement for beam reporting |
| RRM | 38.533 | 7.1 | RRC\_IDLE state mobility |
| RRM | 38.533 | 7.1.1 | NR cell re-selection |
| RRM | 38.533 | 7.2 | RRC\_INACTIVE state mobility |
| RRM | 38.533 | 7.3 | RRC\_CONNECTED state mobility |
| RRM | 38.533 | 7.3.1 | Handover |
| RRM | 38.533 | 7.3.2 | RRC connection mobility control |
| RRM | 38.533 | 7.3.3 | Conditional handover |
| RRM | 38.533 | 7.4 | Timing |
| RRM | 38.533 | 7.4.1 | UE transmit timing |
| RRM | 38.533 | 7.4.2 | UE timer accuracy |
| RRM | 38.533 | 7.4.3 | Timing advance |
| RRM | 38.533 | 7.5 | Signalling characteristics |
| RRM | 38.533 | 7.5.1 | Radio link monitoring |
| RRM | 38.533 | 7.5.2 | Interruption |
| RRM | 38.533 | 7.5.3 | SCell activation and deactivation delay |
| RRM | 38.533 | 7.5.4 | UE UL carrier RRC reconfiguration delay |
| RRM | 38.533 | 7.5.5 | Link recovery procedures |
| RRM | 38.533 | 7.5.6 | Active BWP switch dela |
| RRM | 38.533 | 7.5.7 | PSCell addition and release delay |
| RRM | 38.533 | 7.6 | Measurement procedures |
| RRM | 38.533 | 7.6.1 | Intra-frequency measurements |
| RRM | 38.533 | 7.6.2 | Inter-frequency measurements |
| RRM | 38.533 | 7.6.3 | L1-RSRP measurement for beam reporting |
| RRM | 38.533 | 7.6.4 | CLI measurement |
| RRM | 38.533 | 7.6.6 | L1-SINR measurement for beam reporting |
| RRM | 38.533 | 7.7 | Measurement performance requirements |
| RRM | 38.533 | 7.7.1 | SS-RSRP |
| RRM | 38.533 | 7.7.2 | SS-RSRQ |
| RRM | 38.533 | 7.7.3 | SS-SINR |
| RRM | 38.533 | 7.7.4 | L1-RSRP |
| RRM | 38.533 | 7.7.5 | SRS-RSRP |
| RRM | 38.533 | 7.7.6 | L1-SINR |
| RRM | 38.533 | 8.2 | RRC\_IDLE state mobility  |
| RRM | 38.533 | 8.2.1 | Inter-RAT cell re-selection  |
| RRM | 38.533 | 8.2.2 | E-UTRA - NR Inter-RAT Early Measurement Reporting |
| RRM | 38.533 | 8.4.2 | Inter-RAT measurements |
| RRM | 38.533 | 8.5.2 | Inter-RAT measurement accuracy |

**Table 7: RAN5 mmWave UE Demodulation test cases**

|  |  |  |  |
| --- | --- | --- | --- |
| **Area** | **TS** | **Clause** | **Title** |
| Demod/CSI reporting | 38.521-4 | 7.2.2.2.1\_1 | 2Rx TDD FR2 PDSCH mapping Type A performance - 2x2 MIMO with baseline receiver for SA and NSA |
| Demod/CSI reporting | 38.521-4 | 7.2.2.2.1\_2 | 2Rx TDD FR2 PDSCH mapping Type A performance - 2x2 MIMO with enhanced type 1 receiver for SA and NSA |
| Demod/CSI reporting | 38.521-4 | 7.3.2.2.1 | 2Rx TDD FR2 PDCCH 1 Tx antenna performance for both SA and NSA |
| Demod/CSI reporting | 38.521-4 | 7.3.2.2.2 | 2Rx TDD FR2 PDCCH 2 Tx antenna performance for both SA and NSA |
| Demod/CSI reporting | 38.521-4 | 7.5.1 | FR2 Sustained downlink data rate performance for single carrier |
| Demod/CSI reporting | 38.521-4 | 8.2.2.2.1.1 | 2Rx TDD FR2 periodic wideband CQI reporting under AWGN performance for both SA and NSA |
| Demod/CSI reporting | 38.521-4 | 8.2.2.2.2.1 | 2Rx TDD FR2 aperiodic wideband CQI reporting under fading performance for both SA and NSA |
| Demod/CSI reporting | 38.521-4 | 8.3.2.2.1 | 2Rx TDD FR2 Single PMI with 2TX TypeI-SinglePanel codebook for both SA and NSA |
| Demod/CSI reporting | 38.521-4 | 8.4.2.2.1 | 2Rx TDD FR2 RI reporting for both SA and NSA |