API - SP - E01 - A

Standard Practice in EMI Measurement -
on Shielding Effectiveness (SE) Evaluation Test v4.0

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It is a recent trend of controlling RE/RFI issues in relatively small hand-held devices, like smartphones and notebook computers, by screening out components (IC's) from suppliers whose components show relatively high emission before they are assembled.

This documentation provides guideline of standard procedures for EMI shielding effectiveness evaluation (SEE) using near-field scanning at API. Technical details such as evaluation of SEE test set-up, setup verification, measurement, system factor extraction, data summary, etc. are given in this documentation. Overall flow for customers to follow-up from handling an initial scan request to sending out final reports is given by a separate documentation, API-MSP-E01-A.

In this document, "customer" is the main owner of a project. A "supplier" is the provider of the DUT/component.

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1. Overview

The purpose of this API internal standard practice documentation is to define the standard procedures of the EMI shielding effectiveness evaluation (SEE) using near-field scanning. Shielding configurations that suppliers provide include; no shield (NS), self-shield (SS), shield can (SC), self-shield plus shield can (SP), and/or other supplier specific configurations. This test procedure can be applied to any integrated chip (IC) mounted on an evaluation circuit board that is accessible by the scanning probe.

Depend on the types of device under test (DUT), the operation of the DUT is monitored through the peripheral apparatus connected to the DUT, and provided by the supplier. The measurement frequency range based on the capability of the measurement system (probe/ amplifier/cables/connectors/instrument/shielding tent/etc.), can be covered from 100 kHz to 40 GHz.

2. Test Equipment

2.1. Probe Positioning System

This measurement requires a precise probe positioning system to hold the probe close to the IC surface for detecting the emission pattern of the radio frequency (RF) sources from the operating IC.

2.2. RF Amplifier

In the case of weak signals that cannot be detected directly by instruments, external RF amplifiers are required for the measurement. Such specifications of amplifiers as, frequency range, gain, maximum input power level, NF, VSWR, etc., have to be carefully checked to select proper amplifiers.

2.3. Cables

This measurement requires well shielded coaxial cables such as double shielded and triple shielded cables. It is recommended to test the shielding capabilities of the cables before their first use. Additionally, the connector's shielding capability and performance need to be checked on regular basis. It is recommended that a known and controlled RF-structure is utilized when characterizing the capability of the coax-cable.

2.4. Connectors

Connectors used for this measurement need to be checked before use. User shall check if the connector type is appropriate for the required frequency range.

2.5. Spectrum Analyzer (SA)

A spectrum analyzer is used to measure the frequency characteristics of the signals, for instance amplitude vs. frequency. Parameters of the measured signal required for the data collection are controlled from the spectrum analyzer. Depending on the required measurement frequency of the DUT, a SA with proper frequency range should be selected.

3. EMI Near Field Probe

An EMI near-field probe is used for surface scanning to detect the near-field above the DUT. It measures the signals emitted from the DUT and sends the data to the recording center. Different probes are used under different circumstances depending on the frequency of interest, the type of field components to be measured, and the spatial resolution of the measurement required. Various types of probes are available to detect the magnetic (H) field and the electric (E) field in directions of X, Y, and Z coordinates.

It is highly recommended that each probe is analyzed using a full-wave simulation for better understanding of its behavior during a measurement.

A thorough characterization of each probe used in the measurement is required before and after the measurement.

3.1. Magnetic (H) Field Probe

Magnetic field probes can be used to detect magnetic field radiation from the DUT. Usually, an H field probe has a single-turn and miniature shielded loop, and can be made of printed circuit board (PCB) traces, coaxial cable, wire or other appropriate materials. A magnetic field probe should have high sensitivity to a magnetic field in the direction of interest while rejecting the magnetic field in the unwanted direction; it should also reject electric field in all three X, Y, and Z directions.

3.2. Electric (E) Field Probe

Electric field probes can be used to detect electric field radiation from the DUT. Usually, an E-field probe has a disc or a trace, and can be made of printed circuit board (PCB) traces, coaxial cable, wire or other applicable materials. An electric field probe should have high sensitivity to electric field in the direction of interest while rejecting electric field in the unwanted direction, as well as rejecting magnetic field in all three X, Y, and Z directions.

4. Setup

Set up for this shielding effectiveness evaluation consists of 2 parts, the hardware set up and the software set up.

4.1. Instrument Setup

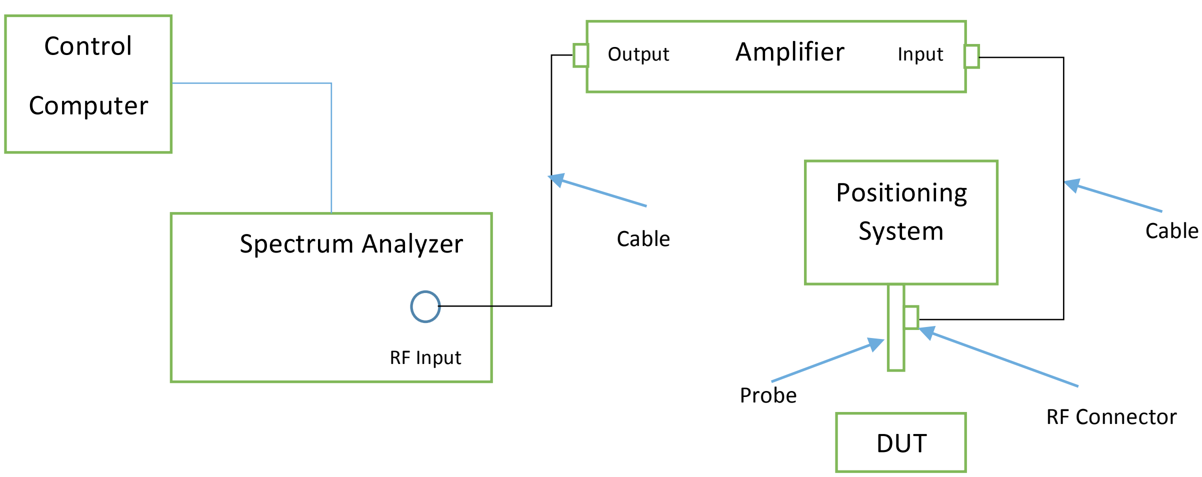

Figure 1: Block diagram of measurement set up.

Figure 1 shows the setup of an EMI measurement. A probe is attached to a positioning system for a precise movement. The input of the RF amplifier is connected to the SMA connector of the probe to amplify the weak signal captured at the tip of the probe. The output of the RF-amplifier is connected to the spectrum analyzer to measure the signal. Also, the spectrum analyzer is connected to a control computer to read and store the scanned data.

The setting of the spectrum analyzer is based on the requirements of a specific scanning project. SA mode, start frequency, stop frequency, RBW, number of sweeps, number of sweep points, internal attenuator, internal amplifier (if applicable), and peak detector shall be defined for each measurement.

Table 1 is an example of the settings of the spectrum analyzer.

Table 1: Measurement setting example.

SA Parameters	SA Settings
Start frequency	100 kHz
Stop frequency	3 GHz
RBW	20 kHz
VBW	200 kHz
Number of sweeps	1
Number of freq. points	8001

4.2. Software Setting

A software package needs to be used along with the probe positioning system for a precise movement. This software should allow user to set scanning area parameters, create test scenario, identify coordinates, number of test points, control data collection, and visualize scanning result.

Scan software has to be configured for the desired scan parameters after the DUT has been set up. Scanning step, probe orientation, and probe height above DUT should be defined in software according to the test request. Table 2 is an example of the software settings.

Table 2: Software setting example.

Scanning step	0.5 mm for Hx/y; 1 mm for Hz
Probe orientation	0, 90 degree for Hx/y; 0 degree for Hz
Probe height above DUT	0 mm above shielding can for Hx/y; 0 mm above PCB for Hz

5. Apparatus and Environment Verification

5.1. Apparatus Verification

5.1.1. System Performance

The performance of the scanning system shown in Figure 1 needs to be checked before the measurement starts. Place the probe on top of a known RF structure such as coplanar waveguide (CPW) or a micro-strip line (MSL), and check the overall S21 shape to make sure there is no unexpected behavior. Wanted and unwanted field separation over the measurement frequency range also needs to be checked.

5.1.2. Amplifier and SA

The DUT shall be in operation during the checkup procedures. Hand scan is strongly recommended for detecting the general emission level/pattern of the DUT. Manually move the probe to the DUT's surface and find the highest emission point. Change the input power of the DUT and check if the output response is as expected, also make sure that the SA is not over-loaded.

5.2. Scan Condition Verification

5.2.1. Scan Steps

The scan step size is assigned depending on the DUT size, desired spatial resolution, user preference and any additional conditions necessarily.

5.2.2. Resolution Bandwidth

Resolution bandwidth (RBW) can be defined based on the scanning time, noise floor, desired resolution etc. Recommended RBW for this shielding effectiveness evaluation is 20 kHz.

5.2.3. Noise Floor Level

Compare the noise floor to previous similar setups to make sure there is no abnormality in noise floor that may affect the scanning result.

5.3. Scan Environment Verification

5.3.1. Environment Noise

It is necessary to shield both expected and unexpected environmental noise from the scanning results. Unexpected sources of noise can include but are not limited to: Wi-Fi signals and or FM radio station radiation.

5.3.2. RF Noise

Check RF noise levels from all equipment such as the DC power supply and the DUT controller which are required for normal operation of the DUT. These pieces of equipment should be as isolated from the shielding environment as possible. If it is needed to place such equipment inside the shielding environment, the noise they generate should be known, controlled and/or isolated.

5.3.3. Cable Routing

Cables routed from the positioning system to the instrument might move during the measurement. Check cable length and cable routing capability before the measurement.

5.3.4. DUT Temperature

The operating condition of the DUT might change as a function of temperature. It is recommended that a cooling system is used to stabilize the temperature of the DUT's working environment. It is also recommended that the DUT condition is monitored on a regular basis during the measurement.

6. API SmartScan EMC Scanning System

6.1. Hardware

The main role of the electromagnetic interference (EMI) scanner is to measure near-field electromagnetic signals emitted from a DUT, and to display the signal data with the accompanied SmartScan software. Probe movement and data display are fully automated with proprietary hardware and software.

Figure 2 shows the block diagram of the EMI scanner hardware set-up. It is necessary that the DUT is operating under normal conditions for the duration of the emission scanning procedure. Movement of the probe can be achieved through manual operation or automated via a four-axis scara robot, or a six-axis robot controlled by SmartScan software. Collected data is displayed on a monitor superimposed on the DUT picture or PCB layout showing relative intensity of emissions from all scanned areas. A PC display shows collected data reflecting the relative intensity of emissions from all scanned areas superimposed on a picture of the DUT. The displayed map is then used to identify circuit components that are emitting the potentially interfering signals.

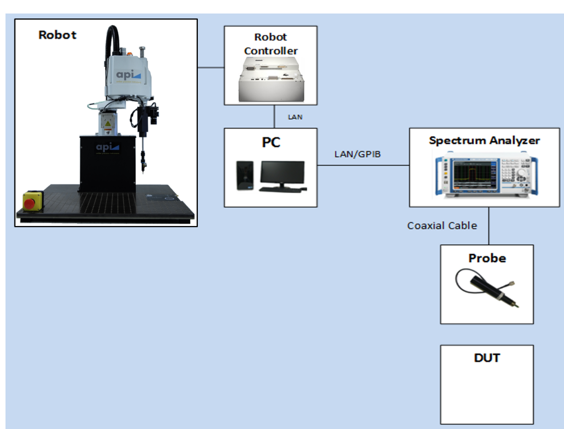

Figure 2: Block diagram of EMI scanning system.

A probe is moved to user-specified positions by the scanning system. Rotation of the probe is also accommodated by the robot ϕ axis. The robot allows 4 degrees of movement: along X, Y, Z, and 360° ϕ rotation (both clockwise and counterclockwise).

6.2. Software

SmartScan is the proprietary software that controls all hardware components and processes the collected data. It is a software package that is capable of defining the scanning area parameters, creating a test scenario, identifying the location and number of test points, controlling data collection, controlling the measurement instrument, controlling the robotic system, interpolating and visualizing the data, post processing of the data, and analyzing the data, and utilizing its built-in capability for report generation.

7. Procedures

7.1. Operation verification of SmartScan EMI System

Once the instrument set up is established, the performance of the SmartScan EMI system should be checked. The forward transmission coefficient (S21) of the system is measured by a vector network analyzer (VNA). A through calibration needs to be performed before measuring the S21 of the system. The block diagram of the calibration setup is shown in Figure 3, the block diagram of the S21 measurement setup is shown in Figure 4, and an example of the system S21 is shown in Figure 5.

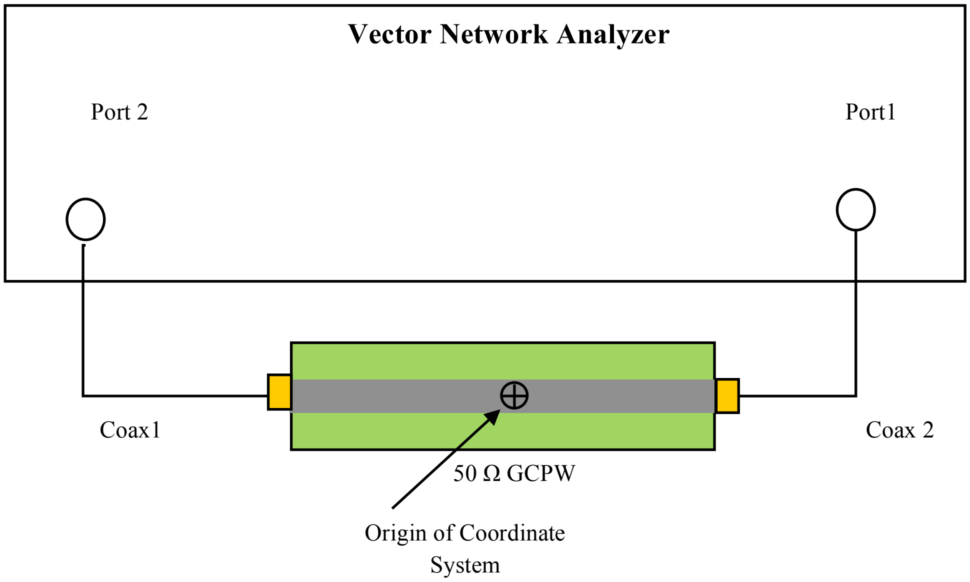

Figure 3: Block diagram of the calibration setup.

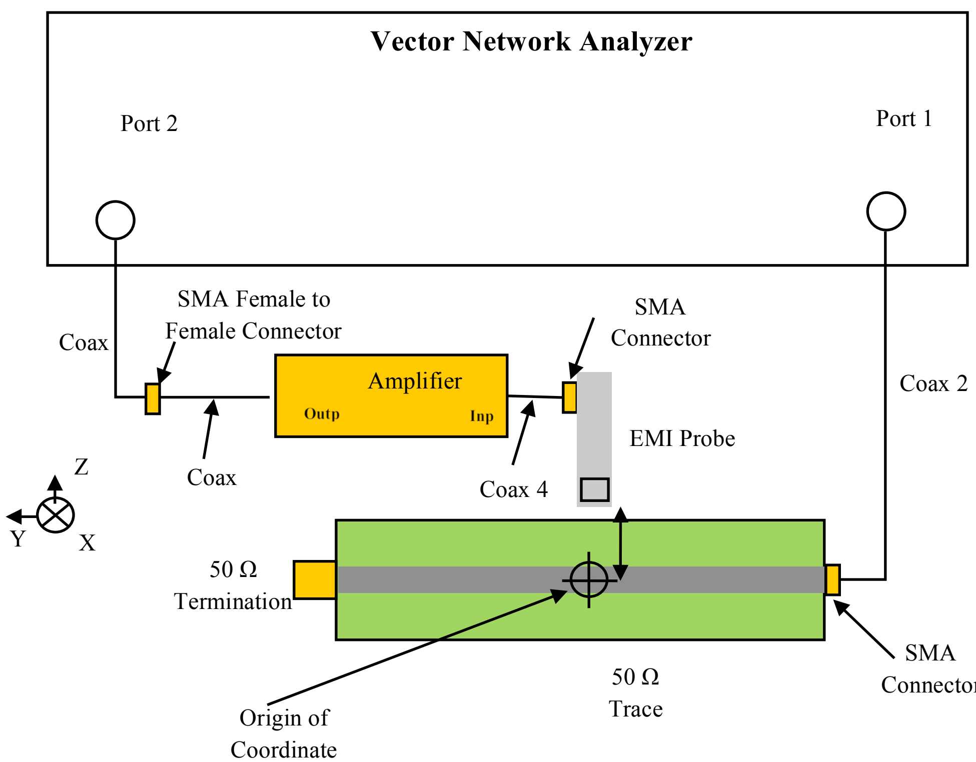

Figure 4: Block diagram of the S21 measurement setup.

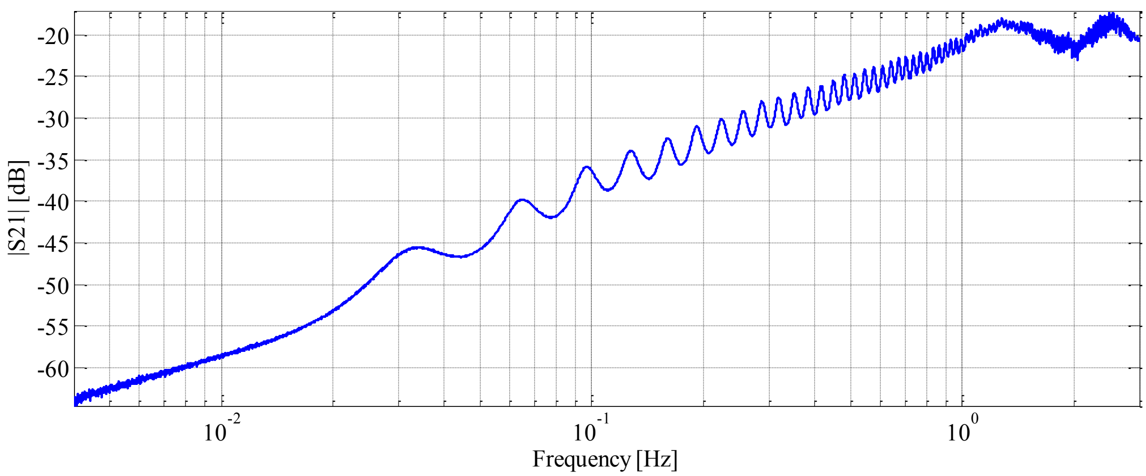

Figure 5: Example of the S21 of the system.

An example of S21 and rejection of the probe used along with the SmartScan system is shown in Figure 6, and the probe factor is shown in Figure 7.

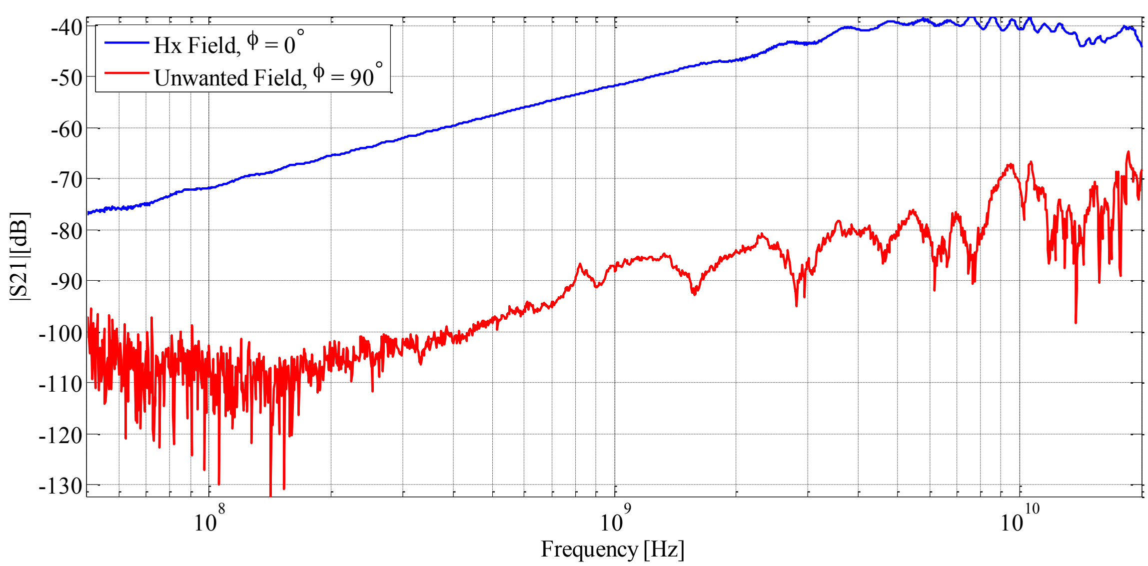

Figure 6: Example of S21 of EMI Hx1 mm probe.

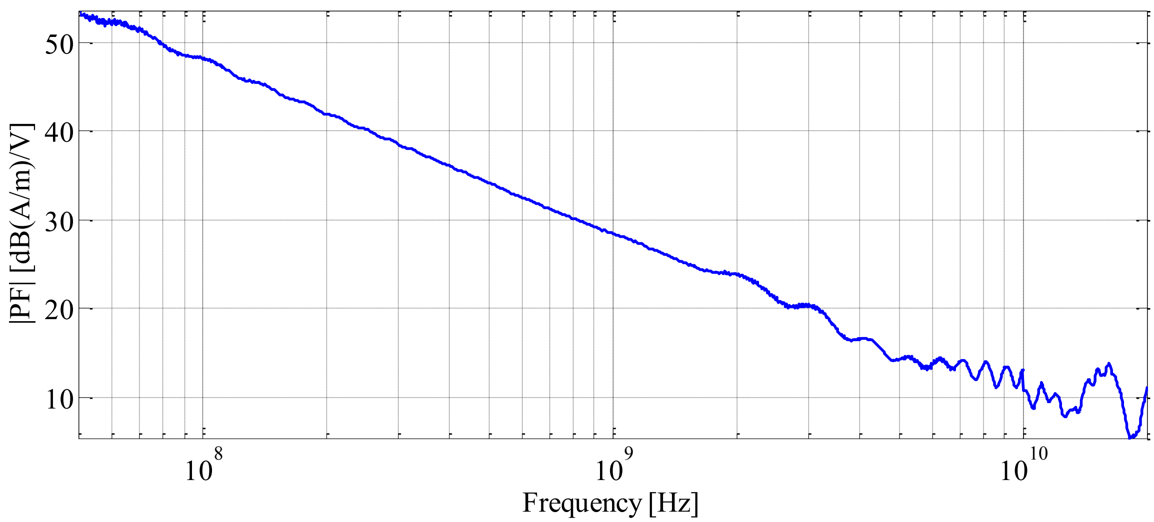

Figure 7: Example of probe factor of EMI Hx1 mm probe.

7.2. Check Shielding Environment

The SmartScan EMI system is placed inside a shielding tent to isolate from the room noise which may affect the DUT measurement. The common signals like FM radio frequencies and 2.4 GHz Wi-Fi signal are either isolated or reduced to at least 30dB when the tent is fully closed. In some cases, the tent cannot be fully closed due to the setup of a DUT from suppliers. In this case, environmental noise may be detected by the EMI system, and may be shown on the final plot. Under such circumstances, all possible measures must be tried in order to isolate the interferences as much as possible.

7.3. SA Setting

Once the DUT is operating normally, the user should place the probe on top of the DUT manually and read the data from the spectrum analyzer to check if the settings of the SA are appropriate for the scanning project. The user shall see clear peaks at fundamental and harmonic frequencies of the operating DUT. For DUTs that produce broadband signals, user should check the sensitivity of the probe and should see an obvious broadband signal on the screen of SA.

7.4. Create Scanning Project in SmartScan

The minimum procedures required to set up an SEE scan are described in this section. For other features and more detailed information, refer to the SmartScan_V5.0 Operation Manual.

A SmartScan workspace needs to be created first, shown in Figure 8. Multiple scanning projects can be created with different names under the same workspace. Projects hold all the information required to run a test: the shape and size of the tested area, the number of scanning points, the type of probing device etc. The project Wizard is the test setup sequence checkup window that navigates user to complete a scanning project, shown in Figure 9.

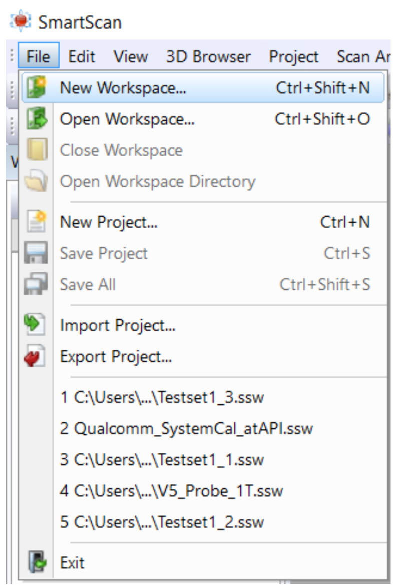

Figure 8: Create a Workspace.

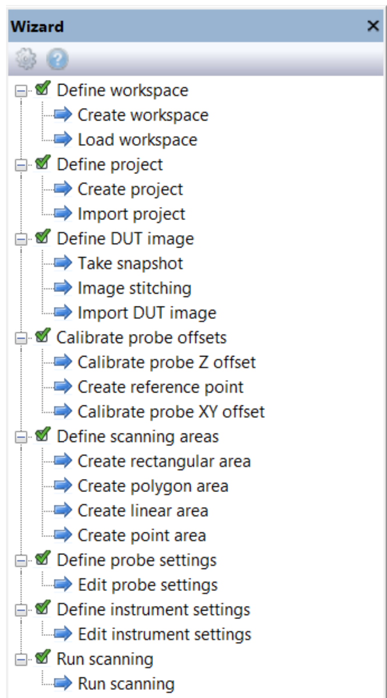

Figure 9: SmartScan Wizard.

Define DUT image, Calibrate probe offsets, and Define scanning areas can be achieved in the Scan Area Settings window. The user is required to take a picture of the DUT with the system's integrated camera, define the height of the DUT, select the scanning area, and set the scanning distance.

Define probe settings can be done in the Probe Settings window. The user is required to define the type of probe, the Z offset and the XY offset of the probe. Probe Z offset is a physical distance adjustment from the tip of the probe to the surface of the scanning table. The XY offset is used to align the center of the probe with the desired scanning points on the DUT.

In the Instrument Setting window, the user is required to define and set the parameters that will be sent to the Instrument. User can either define the start and stop frequencies, or define the center frequency and the span. Resolution bandwidth, video bandwidth, number of sweep points, number of sweeps, and number of averaging can all be defined in this window.

The setting windows can be found under the Workspace Explorer, an example is shown in Figure 10. Testset1_3 is the name of the workspace; SF_0p8_3 to GCPW_1p2_3 are the projects under the same workspace. For each scanning project, user can define different scan area, probe and instruments settings.

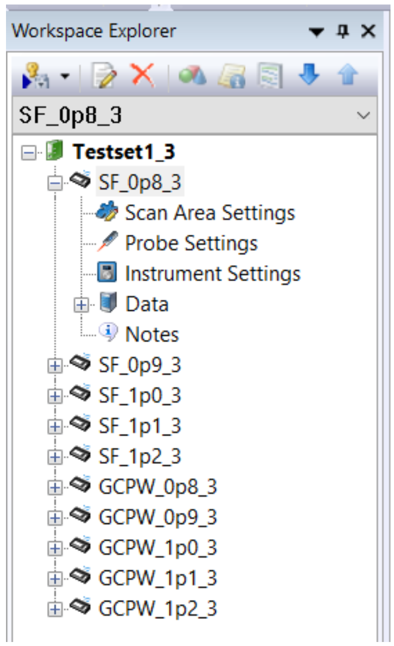

Figure 10: Settings window.

7.5. Run a Project

After all the setups are defined, the user should make sure the DUT is operating normally, then close the tent and click the run bottom to start the scan. Hx, Hy and Hz will be scanned in the shielding effectiveness measurement for each DUT and each corresponding fundamental frequency. E field components might be measured based on customer's requirements.

8. System Characterization

Measured near field data using SA (in dBm) can be converted to field values (in dB mA/m or dB mV/m) by applying a system factor that includes the probe, cables, connectors and amps. A VNA or an SA with a tracking generator can be used for system factor extraction.

8.1. System Factor Measurement Setup

Through calibration needs to be performed before measuring the S21 of the system. Please refer to the Figure 3 for the calibration setup diagram.

An example of the settings of VNA is shown as follows:

- Start and stop frequency: any range that covers the SE test frequency range (e.g. 50 MHz to 10 GHz)
- IF bandwidth: 300 Hz
- Number of sweep points: e.g. 5000 points
- Log-magnitude and log-freq setting
- Source power: 0 dBm or the maximum that the VNA can support

After the through calibration, connect the VNA to the system. Please refer to Figure 4 for the setup block diagram.

8.2. SmartScan Software Setup

The steps for the SmartScan software setup are as follows:

- Create a project in SmartScan
- Define X, Y and Z offset of the probe in probe setup
- Define a scan line across the GCPW trace (step size 0.1mm)
- Copy the instrument setting from the measurement setup during SE measurement
- Run the scan

8.3. System Factor Calculation

A built-in function 'Probe Factor Calculation' in SmartScan can be used to calculate the system factor, shown in Figure 11. The system includes probe, cables, connectors and amps.

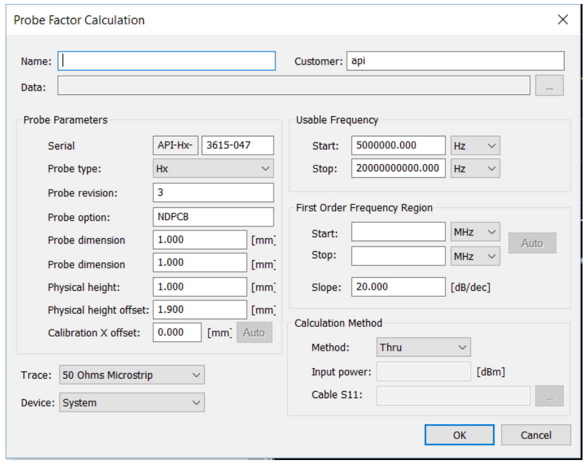

Figure 11: Probe Factor Calculation in SmartScan.

Once filled in all parameters in the window above, the user shall click on the OK button. Thus, the calculated probe factor will be saved in the library and will be shown in the SmartScan as shown in Figure 12.

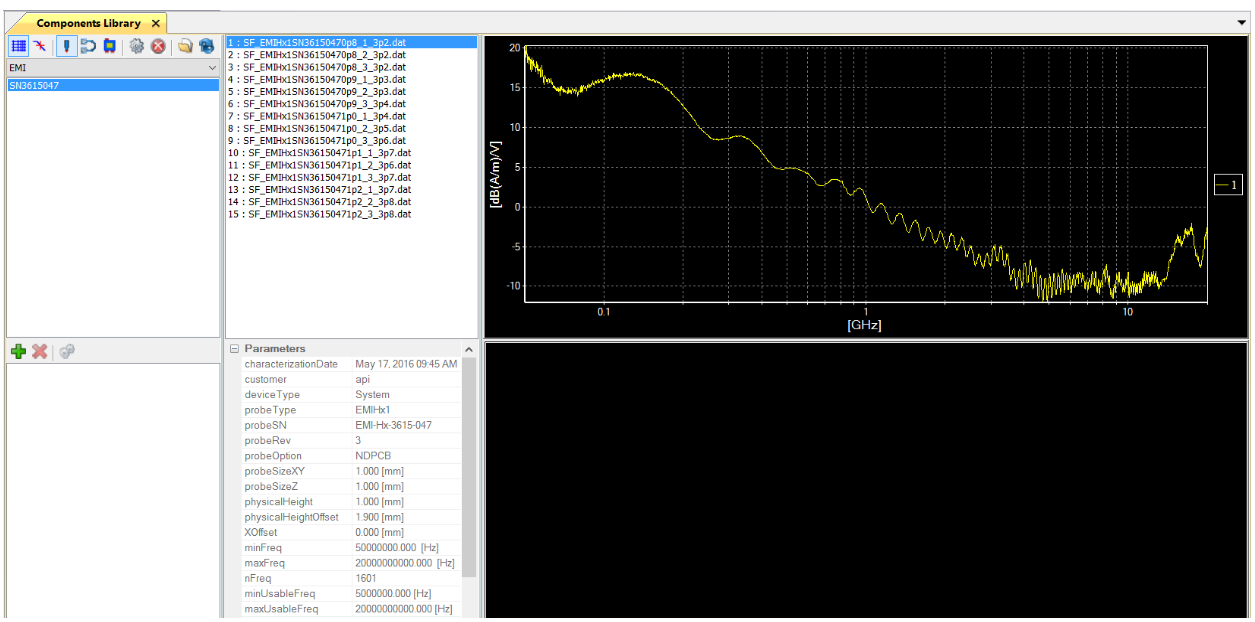

Figure 12: Probe factor in SmartScan.

8.4. Field Calculation

Measured near field data can be converted to field by applying a system factor that includes the probe, cables, connectors and amps. Field calculation is done by selecting "Apply Probe Factor" from the drop-down menu under Post Processing drop-down list. Software converts the power measured (in dBm) to H-field at the tip of the probe (in dB mA/m or dB mV/m).

9. Report

The data presented in the report is based on processed data (H-field), i.e., field values.

9.1. Data Analysis

SE can be defined in various ways, and several types of shielding effectiveness (SE) can be defined in each measurement. One peak value from each measurement is compared in this SE evaluation. Depending on the shielding enclosure type the vendor provides, the number of configurations will be different. The data should be exported from the SmartScan software, and be stored in the excel file.

- SE_SS = NS – SS
- SE_SC = NS – SC
- SE_SP = NS – SP
- d_SE = SE_SC – SE_SS = SS – SC

NS, SS, SC and SP are defined as the maxhold of all scanned points for a certain harmonic frequency.

The highlighted results in the excel file are the worst case value for each case of SE across all harmonics. For each DUT, the worst case across all frequency bands and across all harmonics is selected for plotting the scan area. An example of SE excel file format is shown in Figure 13.

API	500MHz												
		NS		SS		SC							
	Harmonics [MHz]	Hxy [dBmA/m]	Hz [dBmA/m]	Hxy [dBmA/m]	Hz [dBmA/m]	Hxy [dBmA/m]	Hz [dBmA/m]	SE_SS = NS - SS [dB] Hxy	Hz	SE_SC = NS - SC [dB] Hxy	Hz	d_SE = SE_SC - SE_SS = SS - SC [dB] Hxy	Hz
f1	500.00	25.00	24.00	15.00	10.00	-20.00	-18.00	10.00	14.00	45.00	42.00	35.00	28.00
f2	1000.00	15.00	10.00	6.00	-10.00	-25.00	-20.00	9.00	20.00	40.00	30.00	31.00	10.00
f3	1500.00	-10.00	-15.00	-32.00	-30.00	NAN	NAN	22.00	15.00	NAN	NAN	NAN	NAN
f4	2000.00	20.00	4.00	-48.00	-30.00	-39.00	-30.00	68.00	34.00	59.00	34.00	-9.00	0.00
f5	2500.00	-15.00	-28.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f6	3000.00	-20.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f7	3500.00	-30.00	-25.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f8	4000.00	-10.00	-15.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f9	4500.00	-40.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f10	5000.00	-28.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f11	5500.00	-39.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f12	6000.00	-10.00	NAN	-30.00	NAN	NAN	NAN	20.00	NAN	NAN	NAN	NAN	NAN
f13	6500.00	-41.00	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
f18													
							Defines worst:	Min	Min	Min	Min	Max	Max
							Worst value:	9.00	14.00	40.00	30.00	35.00	28.00
							Freq of worst value:	1000.00	500.00	1000.00	1000.00	500.00	500.00
							# Freq of worst value:	f2	f1	f2	f2	f1	f1
							Defines worst:	Min	Min	Min	Min	Max	Max
							Worst value of all freqs:	9.00	4.00	35.00	11.00	36.00	33.00
							Freq of worst value of all:	1000.00	3000.00	800.00	3000.00	500.00	1000.00
							# Freq of worst value of all:	f1	f3	f3	f1	f1	f1

Figure 13: Example of SE excel file format.

9.2. Full Test Report

The following contents should be included in the SE test report:

- DUT information
- Shielding configuration
- List of abbreviations in SmartScan projects
- Instruments used in the test
- Measurement settings
- Software settings
- System characterization
- Measurement results
- Data summary and shielding effectiveness