Electromagnetic Compatibility Testing Handbook

AcubeSAT-COM-G-026

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Contents

Appendices

Changelog

Date	Version	Document Status	Comments
28/12/2020	2.0	INTERNALLY RELEASED	Added dimensions and more specific information about the tests based on standards
2/12/2020	1.1	INTERNALLY RELEASED	• Conducted emission tests' equipment updated • Suggestions for the choice of the appropriate, low-cost but sufficient LISN • Set-up for the conducted emission tests updated • New reference added for the conducted emission tests • Earth cable of the ESD simulator connection to ground plane added • Burst tests deleted, because they refer to external interference which is irrelevant for the CubeSat • Reference for designing DYI testing (LISN, probes) and in general EMC equipment added • Typos fixed
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The AcubeSAT project is carried out with the support of the Education Office of the European Space Agency, under the educational Fly Your Satellite! programme.

Acronyms

ADCS Attitude Control & Determination Subsystem

COMMS Communications

DC Direct Current

DUT Device Under Test

DYI Doing Yourself In

EMC Electromagnetic Compatibility

EMCCP Electromagnetic Compatibility Control Plan

EMI Electromagnetic Interference

ESD Electro-Static Discharge

EUT Equipment Under Test

LISN Line Impedance Stabilization Network

LSF Libre Space Foundation

OBC On-Board Computer

PA Power Amplifier

PCB Printed Circuit Board

SU Science Unit

TCXO Temperature Compensated Crystal Oscillator

1 Introduction

The third phase of Electromagnetic Compatibility Control Plan (EMCCP), after Characterization of all the components as Sources or Victims of Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) Design is EMC *Testing*. In this report, all EMC tests that are going to be applied to the AcubeSAT spacecraft, both at a system and at a subsystem level, are described. More specifically, the appropriate equipment needed for every test, the limits required according to EMC standards, as well as the procedure from the beginning until the end of every test are examined.

2 Pre-compliance tests

Pre-compliance testing is an affordable method of testing components at an early stage. More specifically, the basic purpose of this method is to prevent any compliance problems when almost all design modifications are feasible to happen in order to increase the probability of the components fully passing every future EMC compliance test. The affordable pre-compliance test set-up mimics the expensive compliance test set-up within an acceptable margin.

2.1 Emission tests

Emission tests are a required part of EMC testing. The name of this type of test originates from the fact that the Device Under Test (DUT) (or the Equipment Under Test (EUT)) emits EMI during nominal operation. In Annex A of [1], it is stated that there must be special concern on having low-emission equipment, particularly for small spacecrafts with scientific purpose that have highly-sensitive detectors like AcubeSAT. This highlights the importance of emission tests, especially at a subsystem level. Depending on the methodology of testing, emission tests can be divided into *Conducted* and *Radiated* emission tests. According to 5.2.9.1 paragraph of [1], the measurement receiver bandwidths, along with the minimum measurement time that shall be used for emission testing, are mentioned in Table I.

Frequency Range	**6db Bandwidth**	**Min. measurement time (analog meas. receiver)**
30 Hz - 1 kHz	10 Hz	0,015 s/Hz
1 kHz - 10 kHz	100 Hz	0,15 s/kHz
10 kHz - 150 kHz	1 kHz	0,015 s/kHz
150 kHz - 30 MHz	10 kHz	1,5 s/MHz
30 MHz - 1 GHz	100kHz	0,15 s/MHz
Above 1 GHz	1 MHz	15 s/GHz

Table I: *Bandwidth and measurement time*

2.1.1 Conducted emission tests

The **equipment** that is used for these tests apart from the DUT (which is generally a PCB) consists of:

- 2 Line Impedance Stabilization Networks (LISNs)
- 1 spectrum analyzer (or a general purpose receiver capable of conducting EMC tests)
- 1 or 2 thin metal (aluminum) plates acting as the ground plane(s) (optional)
- 1 wooden table (optional)
- 2 or more ferrite beads
- 1 DC power supply
- 1 50 Ω matching load.

At this point it is crucial to explain the function of the LISN and the spectrum analyzer in order for the testing procedure to be more understandable.

Line Impedance Stabilization Network (LISN)

A *LISN* is essentially a low-pass filter. Its schematic is generally quite simple, consisting of only fundamental components like resistors, capacitors, coils and sometimes diodes. An example of a LISN schematic is shown in Figure 1.

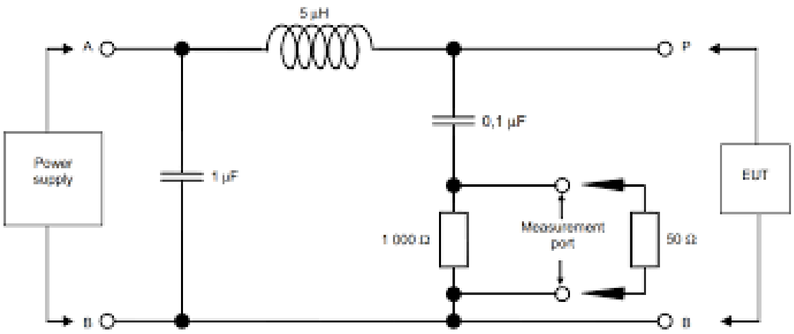

Figure 1: *An example of a LISN schematic [2].*

This circuit provides a stable output complex impedance whose amplitude and phase depend on the working frequency. However, most of the times there is a frequency range provided in the datasheet where impedance amplitude is **50 Ω** and phase is zero simultaneously. In this way, a perfectly-matched measurement port that can be connected to spectrum analyzer is created, because the input impedance of virtually all modern spectrum analyzers is 50 Ω. Moreover, as a low-pass filter, a LISN prevents high-frequency noise generated by the power supply from entering and contaminating the system. This helps to achieve a reliable measurement, using a spectrum analyzer, of the high-frequency EMI produced only by the DUT. A LISN is shown as a black box with its ports and RF connector in Figure 2.

Some indicative examples of appropriate LISNs for an in-house EMC, pre-compliance conducted emission test can be found in these links: TEKBOX, The EMC Shop, SCHWARZBECK Mess-Elektronik. It is a fact that coupling via power cords (conducted

Figure 2: *LISN as a black box. BNC connector and ports are shown. x,y,z values depend on the type and the quality of LISN. Especially x is chosen based on the type of measurement. In [3], for example, it is stated that when voltage is the most crucial physical quantity for the conducted emission test, x is usually 50 µH. Another common value for x is 5 µH. Extra sources: [4], [5].*

emission coupling) is predominant up to 150 MHz. That is why **no LISN** can cover above 150 MHz. This means that the conducted emission tests are significant and necessary only for components that do work at a frequency lower than 150 MHz. Based on table VI with all components' working frequencies in [6] and taking into account the 150 MHz - limit, **AcubeSAT team must choose a LISN with at least 100 MHz (for the NAND Flashes of the SU and OBC subsystems) frequency coverage.** Special focus in the datasheets must also be given on **the type of power supply** of the devices that a LISN can handle, because the PCBs of AcubeSAT use batteries (DC voltage) for their function, and on **the impedance level** (usually 50 Ω). Figs. 3 and 4 are examples of LISNs that can be used for the in-house conducted emission test. Last but not least, a typical LISN costs **from 250$ up to 1000$.** Videos [7], [8] and most significantly [12] provide a lot of information on the use and the connection of a LISN, as well as information about the test procedure that is going to be described.

Figure 3: *Batronix TEKBOX 5 µH LISN. Characteristics: DUT max. 10 A, SOURCE max. 200 V, DC Power Supply, frequency range: 100 kHz-110 MHz. Datasheet.* ***This 5 µH LISN has very close input impedance curve as the ECSS [1] LISN, so it is sufficient for AcubeSAT project.***

Figure 4: *TEKBOX 50 μH LISN. Characteristics: DUT max. 16 A, SOURCE max. 250 V, DC/AC Power Supply, frequency range: 9 kHz-100 MHz. Datasheet.* ***This LISN can also be used for testing the DUT used with AC power input and can be used for testing wider range of DUT.***

Spectrum analyzer

A *spectrum analyzer* measures the spectral power density produced by the device/system connected to it. This means that the power produced by the system in every frequency is known. A typical spectrum analyzer does have settings which enable the user to measure and watch the power at a specific range of frequencies and use a lot of measurement units (dBuV, dBmV etc.). There is also the opportunity to create a horizontal line as a limit, above which power may be probably undesirable, in the screen of the spectrum analyzer. Most spectrum analyzers have **50 Ω** input impedance. That is why it is required for a perfect matching the LISNs or in general any device connected to the spectrum analyzer to have an output impedance of 50 Ω. Like every electronic device, there is an allowable amount of input power that a spectrum analyzer can tolerate **(often 20-30 dBm)**.

Tests' set-up and procedure

The tests' set-up are shown in Figure 5 and Figure 6 where all the equipment which is mentioned in the beginning of this subsection is depicted, except for the ferrite beads. It is worth mentioning that there is **no need of an anechoic chamber** to run this test. It can be simply done in the laboratory. The LISNs should be placed either on the ground or the table, but it is important to use **short** and **low impedance** ground leads for better grounding. The ground planes made of aluminium reduce the capacitive coupling from other devices in the room to mimic the structure of the satellite. The vertical one can be eliminated if there is not enough space, or due to cost etc. The horizontal one is sufficient for this test. The table is suggested to be wooden and not metallic by specific standards in order to avoid reflections. Standards also determine the length and the height of the table the thickness of the aluminium planes and provide very specific instructions on how to run a conducted emission test. According to these standards, the dimensions of the **wooden table** must be 160 cm x 80 cm x 80 cm. The **floor aluminium ground plane** must be **at least** 50cm larger than all sides of the wooden table, so an estimated size is 260 cm x 180 cm, with a thickness larger than 0.25 m. The **horizontal and the vertical ground plane** must be 160 cm x 80 cm and 50 cm x 50 cm respectively, with a thickness larger than 0.25 mm. Finally, the distance between the DUT and the vertical ground table must be 10 cm. However, this test is, as already mentioned, a pre-compliance test. At this point the test procedure is going to be described, and more specifically, two slightly different assemblies - measurements (for the battery line and for the ground line) are going to be presented, because in this way conducted emission tests are complete and both differential and common mode noise coupling are measured.

For the battery line measurement:

Firstly, DC power supply is connected to the SOURCE port of LISN 1 (right red wire). The voltage must be lower than y, that the LISN can tolerate, and of course appropriate for the DUT (PCB) to function properly. For example, if the OBC/ADCS board is the DUT and works properly with 12 V input voltage, then the power supply must provide 12 V voltage. Secondly, the DUT is connected to the DUT port of LISN 1 (left red wire). Again, the maximum current of the PCB must be lower than z, which the LISN can tolerate. Thirdly, the other (black) wire of the DUT is connected to the DUT port of LISN 2. After that, LISN 1 is connected to spectrum analyzer and a 50 Ω load is connected to the respective port of LISN 2 for matching purpose. Then, black ports of the Line Impedance Stabilization Networks (LISNs) are connected to the ground and finally, DC Power Supply is connected to the SOURCE port of LISN 2 (black wire).

For the ground line measurement:

The only change in comparison with the battery line measurement is that LISN 2 is connected to spectrum analyzer and the 50 Ω matching load is connected to LISN 1 spectrum analyzer port.

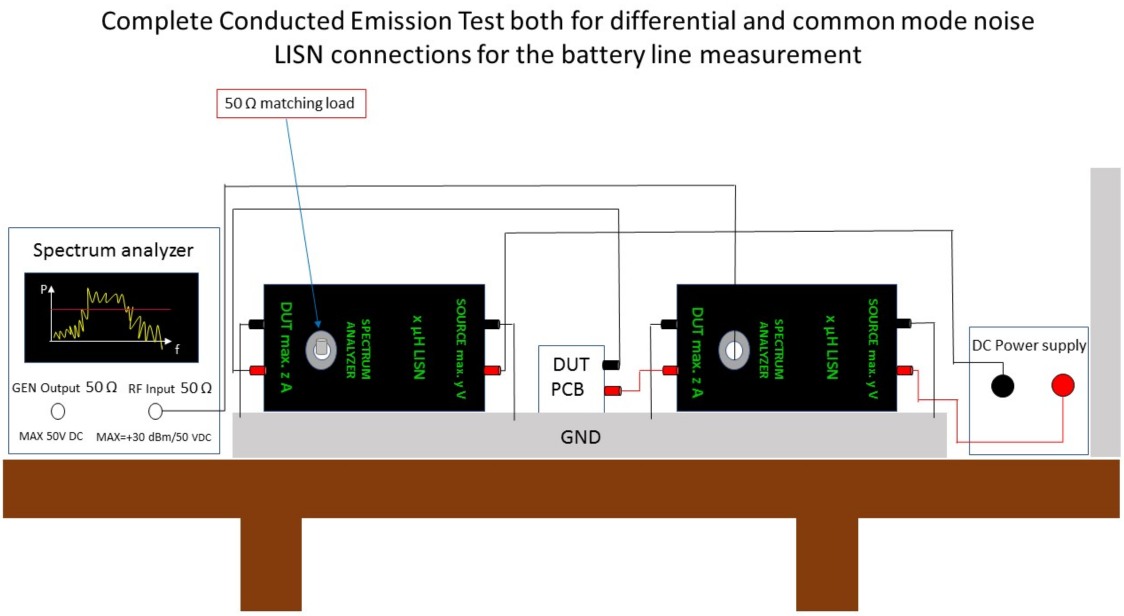

Figure 5: *Pre-compliance complete conducted emission test set-up for both differential and common mode noise. LISN connections for the* ***battery line*** *measurement. Let the LISN near the DC Power supply be* ***LISN 1*** *and the other one* ***LISN 2****.*

Power emitted at a specific frequency range appears in the spectrum analyzer's screen. The frequency range that can be examined depends on the LISN's type and the frequencies that it can "cut" as a low-pass filter. For example, if the LISN's highest and

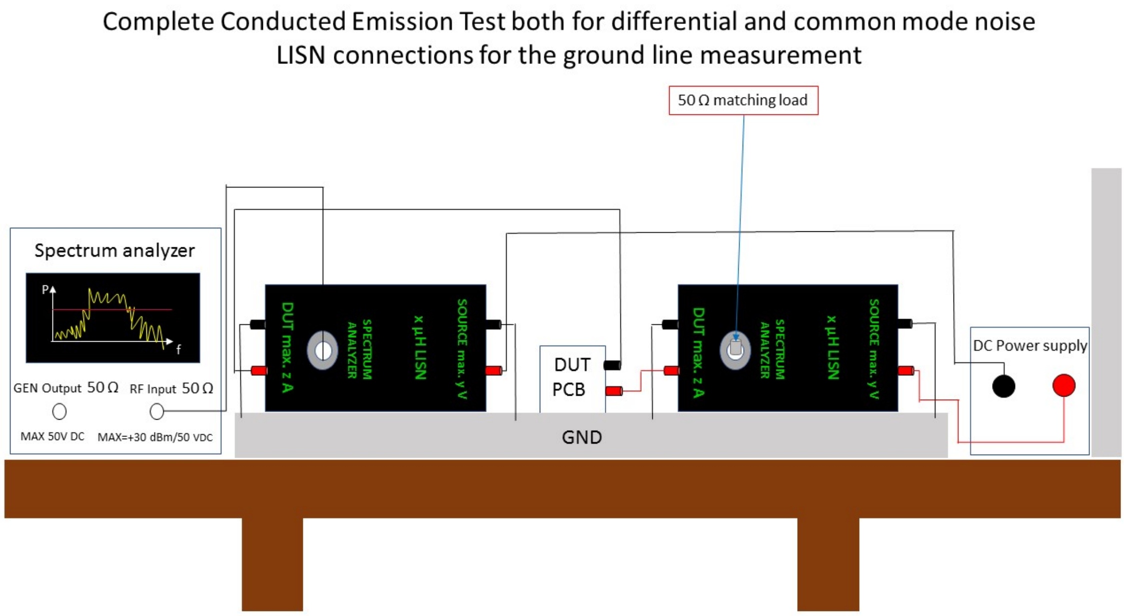

Figure 6: *Pre-compliance complete conducted emission test set-up for both differential and common mode noise. LISN connections for the* ***ground line*** *measurement. Let the LISN near the DC Power supply be* ***LISN 1*** *and the other one* ***LISN 2****.*

lowest working frequencies are 100 MHz and 9 kHz respectively, all frequencies until 100 MHz can be examined with the spectrum analyzer. It is expected that there are going to be peaks at the working frequencies and their harmonics of the components of the PCB in the spectrum analyzer. For example, if the OBC/ADCS board, with components that work at a frequency less or equal to 100 MHz like crystal oscillator (32.678 kHz), Temperature Compensated Crystal Oscillator (TCXO) (12 MHz), NAND flash (100 MHz), is the DUT, then the power peaks are expected to appear at 32 KHz, 12, 100 MHz and their harmonics (integral multiples of the frequencies) in the spectrum analyzer. The **pink horizontal line** in the spectrum analyzer's screen can be manually put by the user spectrum analyzer as the highest limit that power must not exceed. If the yellow peaks in the screen are higher than the pink line, then test is considered as a fail. If not, it is considered as a pass. After being able to define these limits, several horizontal, with different color, lines for each case can represent them in the screen of the spectrum analyzer. The only thing that remains to be done is to check whether the power exceeds the horizontal line at a specific frequency. If this happens, then this means that the DUT failed the EMC conducted emission test and probably needs to be redesigned. Otherwise, the DUT passes the test and can continue with other EMC tests at a subsystem level. Before redesigning a PCB which has failed to pass this test, it is worth a try to put some **ferrite beads** outside the wires between the DUT and the Line Impedance Stabilization Networks (LISNs) and repeat the tests. The ferrite beads are used for **debugging** purpose in this case. More specifically, they are used to confirm the location of a noise. If the noise is mitigated when a ferrite bead is inserted outside a specific wire, this means that the redesign of the PCB is necessary for the input/output circuit parts related to this wire and consequently the problem is pinpointed.

2.1.2 Radiated emission tests

The **equipment** that is used for these tests apart from the DUT, which is usually a PCB, consists of:

- 1 Spectrum analyzer (or a general purpose receiver capable of conducting EMC tests)
- Software for saving and post-processing of the data of the spectrum analyzer
- Near E-field and H-field probes (at least 1 E-field and 1 H-field).

At this point software and probes are going to be better explained.

Software for spectrum analyzer

If there is a need of post-processing and keeping the data from a test with the spectrum analyzer, there is a need of a software. In general, there is a lot of software for this purpose, but every spectrum analyzer is often compatible with a different one. More specifically, some companies which manufacture spectrum analyzers provide the respective software for them and their devices are compatible only with that software. However, sometimes spectrum analyzers provide data at a very common format and as a result even a custom created software can handle the data. Data can be transported from a spectrum analyzer to a computer via an **Ethernet or a USB port**, but this depends obviously on the device. AcubeSAT team should find out the model of the spectrum analyzer which is going to be used for the radiated emission tests and manage to find a way to collect the data.

E-field and H-field probes

Probes are usually thin, quite long rods with a sharp edge or a circle edge and a small concentric hole, which are used to measure the electric and the magnetic field respectively. An example of a probe set can be seen in Figure 7. E-field probes measure the electric field produced by voltage changes and they are **insensitive** to orientation. This means that they measure E-field correctly independently from the way they are placed on a component. On the contrary, H-field probes end with a small loop which measures the magnetic field produced due to current changes and they are **sensitive** to orientation. This means that the loop must be placed both horizontally and vertically to the component under test in order all magnetic field components to be pinpointed and measured. An important parameter of probes to pay attention to is the **frequency range** that they can measure. Taking into account the PCB with the highest frequency (COMMS board, S-band PA and transceiver work at 2.45 GHz) a frequency range of a few kHz up to 2.5 GHz would be sufficient for AcubeSAT team. A typical set of 3-5 such probes (both types) **cost between 250$ and 1000$.**

Figure 7: *Instrument Center, RF Near Field Probe Set.*

Test set-up and procedure

The test set-up is shown in Figure 8. At this point the test procedure [9] is going to be described in different steps.

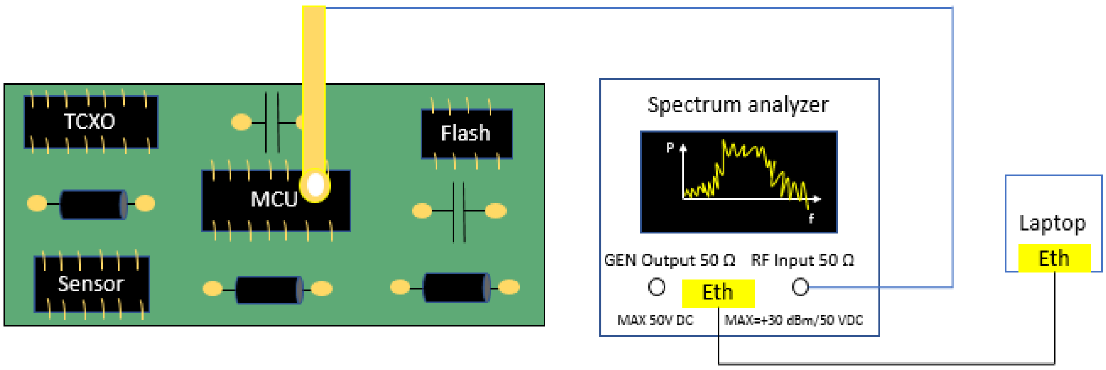

Figure 8: *Pre-compliance radiated emission test set-up.*

Step 1 - Spectrum analyzer

- AMPT→ Input Attenuator: 0 dB→ RF Preamp: On
- FREQ→ Stop Freq: 400 MHz or 2.5 GHz (depends on the PCB that is being tested and the working frequencies of its components).

Step 2 - Connections

Connect the yellow probe (Figure 8) to the spectrum analyzer via an N-type connector.

Step 3 - Actual measurement

- Turn on the PCB under test
- Pass the probe over the components of the PCB (each one separately)
- Find a way to keep the probe stable above the component without using hands
- Connect spectrum analyzer to a laptop, usually via an Ethernet port (it depends on the spectrum analyzer as it was mentioned before)
- Save the waveform and check whether it exceeds the limits or not.

Again **limits are not defined by standards**, so it is necessary to ask an EMC expert or make an educated guess based on similar missions that succeeded to understand whether the test is a pass or failure.

As it is already mentioned, E-field probes are insensitive to orientation, which means that there is nothing to care for when electric field is measured. On the contrary, the same test for the magnetic field with the H-field probes has to be run 2 times. The first time, the H-field probe should have the circle edge *in parallel* to the PCB's plane, whereas the second time the circle loop should be *vertical* to the PCB's plane. In this way, both magnetic field created by current that flows horizontally and magnetic field created by current that flows vertically in the PCB is measured. More information about the use of probes can be found in [10]. Furthermore, it should be taken into account that modern spectrum analyzers provide a lot of opportunities to make the measurement quicker and more precise. For example, the waveform can be holded in the screen. This means that we can test 2 versions of the same PCB, one shielded and one not shielded, and notice if shielding is indeed effective by comparing the waveforms. Moreover, there is a chance to do a time domain measurement and choose the "period" to be almost infinitesimal. However, these facilities depend on the spectrum analyzer and that is why research should be done in the laboratories throughout the university to find which of them is going to be used based on its appropriateness and availability. More information about this clever use of a spectrum analyzer are presented in [9].

2.2 Immunity tests

Some useful remarks regarding the **immunity / susceptibility** testings, according to paragraph 5.2.10.1 of [1], are the following:

1. During susceptibility testing, the EUT shall be placed in its **most susceptible** operating mode.
2. For susceptibility measurements, the **entire frequency range** for each applicable test shall be scanned.
3. Stepped scans shall dwell at each tuned frequency for the **greatest of three seconds** or the EUT response time.
4. Step sizes shall be decreased such to permit observation of a response.

2.2.1 Electro-Static Discharge (ESD) tests

This type of standardized tests is **hazardous** for the test personnel and that is why they take place at suitable, specialized for high-voltage laboratories and is also mandatory to take necessary precautionary steps to assure safety. At this point, an equivalent pre-compliance ESD test that can be run in a common laboratory is going to be described. This test is also **very dangerous**, so the test personnel must be **very careful!**

The **equipment** that is used for this test apart from the DUT consists of:

- 1 ESD simulator (as in Figure 9, typical **cost 500-1000**, for more info check these products - ESDGuns)
- 1 wooden table **(mandatory at this test)**

- 3 thin metal, aluminium plates as ground planes **(mandatory at this test)**
- 1 MΩ cable.

Figure 9: *emtest Electro-Static Discharge (ESD) simulator.*

The test set-up is shown in Figure 10.

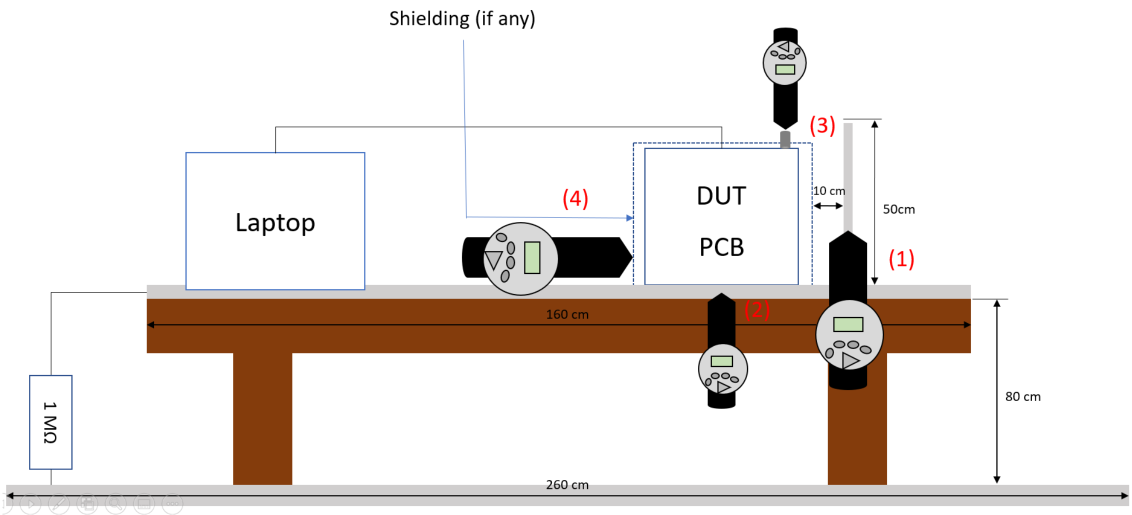

Figure 10: *Pre-compliance Electro-Static Discharge (ESD) test set-up.*

As it can be noticed, the dimensions of the wooden table must be 160 cm x 80 cm x 80 cm. The floor aluminium ground plane must be **at least** 50cm larger than all sides of the wooden table, so an estimated size is 260 cm x 180 cm, with a thickness larger than 0.25 m. The horizontal and the vertical ground plane must be 160 cm x 80 cm and 50 cm x 50 cm respectively, with a thickness larger than 0.25 mm. Finally, the distance between the DUT and the vertical ground table must be 10 cm. In addition, the horizontal aluminium ground plane is connected via a **1 MΩ cable** to an aluminium plane on the floor. Also, the **earth cable** of the ESD simulator (it is not depicted in Figure 10) should be connected to the horizontal ground plane above the table and the created **loop** should be as **large** as possible. This test consists of 4 measurements (4 positions of the ESD simulator in Figure 10). First of all, ESD is created to the vertical aluminium plane by the ESD simulator. Secondly, the simulator produces ESD to the horizontal aluminium plane over the table. Thirdly, ESD is created to the shielding of the connector of the DUT (PCB). Finally, the simulator produces ESD to the shielding of the PCB or to a screw on the shielding (if any). During all these 4 measurements, the DUT is connected to a laptop with an appropriate software that presents waveforms of the DUT's function, based on which someone can understand whether the DUT works well or not. The DUT passes this test if it continues working correctly after all these 4 ESD productions. If not, then the DUT fails this test and probably needs to be redesigned. More information about this test is provided in [11]. The respective standardized test, which is described in 5.4.12 paragraph of [1] is much more complex and requires very special equipment.

3 Other useful parameters

- The **tolerance** for EMC testing, according to 5.2.1 paragraph of [1], shall be as follows:
  1. Distance: ±5 %
  2. Frequency: ±2 %

3. Amplitude, measurement receiver: ±2 dB
4. Amplitude, measurement system (includes receivers, transducers, cables, connectors): ±3 dB
5. Time (waveforms): ±5 %
6. Resistors: ±5 %
7. Capacitors: ±20 %

- Remaining cable lengths should be routed to the back of the setup and placed in a zigzagged arrangement.
- When the setup includes more than one cable, individual cables shall be separated by 2 cm measured from their outer circumference.

4 Conclusion - Next steps

1. **COMMS board** is maybe the most difficult PCB of the AcubeSAT to test due to its high frequency components that the equipment (i.e. a LISN) **cannot** cover. Taking into account that the COMMS board is being designed by Libre Space Foundation (LSF), maybe these tests will have been applied to the board before it is delivered to the AcubeSAT team. However, if these tests are not part of the LSF's design plan, the AcubeSAT team will be responsible for running them.

2. LISN's schematic is generally quite simple as it can be noticed in this report. After research it can also be noted that there are many free tutorials of how to design and manufacture a **Doing Yourself In (DYI) LISN.** This means that the AcubeSAT team's members can manufacture their own LISN in order to reduce the cost of the conducted emission tests. The same can also happen with **the probes.** Their design seems simpler than the LISN's one. More info on how to make a DYI LISN, probe and in general EMC, low-cost testing equipment can be found in [13].

3. The equipment for the immunity tests and the spectrum analyzer are **very expensive.** This may lead the team to search for these devices in the university and ask for permission to use them. Otherwise, a better solution is obligatory (probably a sponsorship) to be found.

4. AcubeSAT members, especially COMMS ones, should gain more experience in the use of the spectrum analyzer before using it for the tests, because probably some more **advanced settings of the spectrum analyzer** might be necessary for the tests as it is already mentioned in this report. Additionally, a good use of **the software** that handles data from spectrum analyzer is required. However, this software depends on the spectrum analyzer so first of all, the team has to know exactly the model of the spectrum analyzer that is going to be used for the EMC tests. The same should happen for all the equipment that is going to be used.

5. AcubeSAT team should be **very careful during the procurement** of the devices needed for the tests. Focus should be given on the **working frequency range**, **the voltage and current** limits that each device can tolerate and compare them to the respective ones of the components of the PCBs that are going to be tested. Moreover, extensive search should take place to find out if a device does already

exists in the university and is available for the team to use.

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[9] Radiated Emissions Testing (Video)

[10] Basics of Near Field RF Probes | E-Field & H-Field | How-to use (Video)

[11] Introduction to EMC (Part 4/4): Radiated and Conducted Immunity Tests (Video)

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A Document-ID reference

AcubeSAT - COM - G - 026 2.0

- 2.0 → Version number
- 026 → Document number
- G → Category:
  - E: Experimentation & Development
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  - COL: Collaboration
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