INTERNSHIP PROJECT REPORT ON

ELECTROMAGNETIC COMPATIBILITY (EMC) AND

ELECTROMAGNETIC INTERFERENCE (EMI) TESTING

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ABSTRACT

This report provides a comprehensive overview of Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) testing within the Defence Research and Development Organization (DRDO). The objectives of EMC/EMI testing include ensuring operational integrity, compliance with standards, safety, and reliability of defence systems. DRDO's approach encompasses state-of-the-art facilities such as anechoic chambers, reverberation chambers, open area test sites, and shielded enclosures. The testing phases range from design review to post-compliance monitoring, adhering to standards like MIL-STD-461. Detailed testing procedure for emissions and susceptibility, as well as specialized tests like RE102,RS103,CE102, CS114, CS115,CS116,CS118 are covered .Briefing on the topics such as Field calibration,Spectrum analyzer, ambient measurement, attenuation measurement ,Controllling VNA through SCPI commands, conversion of dBm to dBµV ,S parameters, radiation pattern of antennas ,USDS and experimental images of tests performed at CVRDE. This report underscores DRDO's commitment to ensuring the reliable performance of its systems in complex electromagnetic environment.

Defence Research and Development Organisation (DRDO)

The Defence Research and Development Organisation (DRDO) is the research and development (R&D) wing of India's Ministry of Defence. DRDO's mission is to develop and produce state-of-the-art weapon systems, defense equipment, and sensors for the Indian Armed Forces. DRDO also aims to achieve self-reliance in critical defense technologies and systems, and to equip the armed forces with cutting-edge defense technologies.DRDO has a network of 52 laboratories that work in various fields, including aeronautics, armaments, electronics, land combat engineering, life sciences, materials, missiles, and naval systems. The organization employs around 5,000 scientists and 25,000 other scientific, technical, and supporting personnel. DRDO has achieved many successes since its inception, including developing major systems and critical technologies such as aircraft avionics, UAVs, small arms, artillery systems, EW systems, tanks and armored vehicles, sonar systems, command and control systems, and missile systems

CONTENTS

1. INTRODUCTION TO MIL STD 461F:

This standard establishes interface and associated verification requirements for the control of the electromagnetic interference (EMI) emission and susceptibility characteristics of electronic, electrical, and electromechanical equipment and subsystems designed or procured for use by activities and agencies of the Department of Defence (DoD)

Emission and susceptibility designations. The emissions and susceptibility and associated test procedure requirements in this standard are designated in accordance with an alphanumeric coding system. Each requirement is identified by a two-letter combination followed by a three-digit number. The number is for reference purposes only. The meaning of the individual letters is as follows, (C = Conducted, R = Radiated, E = Emission, S = Susceptibility)

a. Conducted emissions requirements are designated by "CE"

b. Radiated emissions requirements are designated by "RE"

c. Conducted susceptibility requirements are designated by "CS"

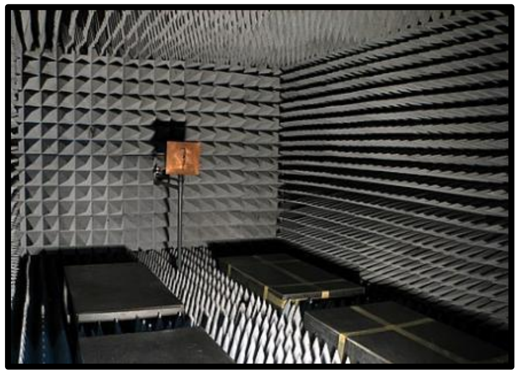
d. Radiated susceptibility requirements are designated by "RS"

2. ANECHOIC CHAMBER

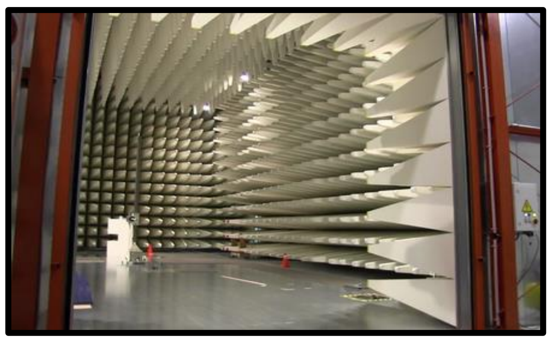
An-echoic meaning “non-reflective” or “without echoes” is a room designed to stop reflections or echoes of either sound or electromagnetic waves. They are also often isolated from energy entering from their surroundings. This combination means that a person or detector exclusively hears direct sounds (no reflected sounds), in effect simulating being outside in a free field.

An F-16 Fighting Falcon in the anechoic test chamber at Eglin Air Force base

Fully Anechoic Chamber:



Semi Anechoic chamber:



An anechoic chamber is a shielded room designed to suppress sound and/or electromagnetic energy. It is designed to suppress the electromagnetic wave energy of echoes such as reflected electromagnetic waves from the internal surfaces and to provide effective isolation from the acoustic or RF noise present in the external environment. Anechoic chambers are also used to accurately measure an antenna's gain, efficiency, and radiation patterns. These antennas are vital components for communication of almost all devices ranging from satellites, military vehicles, aircrafts, mobile phones, etc. The chambers are also used to test radiations for medical devices such as X-ray, MRI, CT-scan machines, etc.

2.1.Types of anechoic chamber :

1.Acoustic anechoic chambers

2.RF anechoic chambers

The one we visited in drdo CVRDE avadi emi EMC testing facility was an RF anechoic chamber.

2.2.Construction of anechoic chamber :

In order to make the anechoic chambers free of reflection, the interior surfaces of the RF anechoic chamber are covered with radiation absorbent material (RAM). The most common absorber is made of carbon loaded foam shaped like a pyramid. Sharp tips on the absorbers help to absorb RF waves without letting them from bouncing off. Due to its shape, the amount of RF that bounces off anechoic chamber walls is often 0.1% to 1% (-30 to -20 dB) of the original wave. The one in the EMI EMC testing facility was constructed by ETS Lindgren, an ESCO testing company.These anechoic chambers have a high-performance wall panel system that provides the low-noise environment required to test today's low-noise products

2.3.Materials used in anechoic chamber construction:

- Foam RF Absorber.
- EMC Chamber Filters.
- RF Shielded Doors.
- EMC Shielded Cameras.
- EUT Transient Monitors.
- Data Transmission.

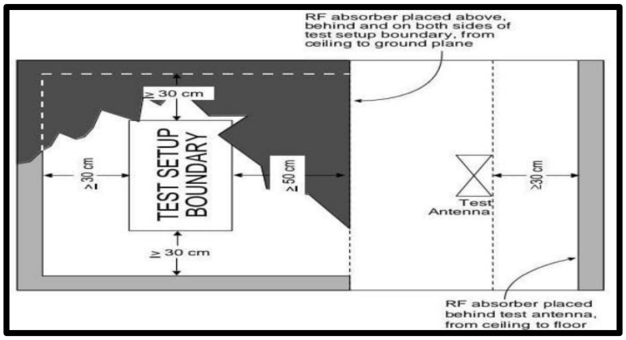
Shielding Enclosures:

To prevent interaction between the EUT and the outside environment, shielded enclosures will usually be required for testing. These enclosures prevent external environment signals from contaminating emission measurements and susceptibility test signals from interfering with electrical and electronic items in the vicinity of the test facility.

Radio Frequency (RF) absorber material:

RF absorber material (carbon impregnated foam pyramids, ferrite tiles, and so forth) shall be used when performing electric field radiated emissions or radiated susceptibility testing inside a shielded enclosure to reduce reflections of electromagnetic energy and to improve accuracy and repeatability. The RF absorber shall be placed above, behind, and on both sides of the EUT, and behind the radiating or receiving antenna as shown in the below figure. Minimum performance of the material shall be as specified in Table I. The manufacturer's certification of their RF absorber material (basic material only, not installed) is acceptable.

Frequency	Minimum absorption
80 MHz - 250 MHz	6 dB
above 250 MHz	10 dB



Faraday Cage: The chamber is built inside a Faraday cage, which is a structure, made of conductive material (such as metal mesh or plates) that blocks external electromagnetic fields. This prevents external RF interference from entering the chamber and affecting the tests.

Grounding: The Faraday cage must be properly grounded to ensure it effectively shields against electromagnetic interference.

Structural Foundation:

Foundation: Similar to acoustic anechoic chambers, RF anechoic chambers have a solid, vibration-free foundation, often isolated from the rest of the building to minimize external noise and vibrations.

Absorber Panels: The interior surfaces (walls, floor, and ceiling) are lined with RF absorber materials, typically made from foam or rubberized materials impregnated with carbon or ferrite. These materials absorb RF energy, preventing reflections and creating a non-reflective environment.

2.4.Applications of Anechoic chamber :

EMI Testing: Testing devices for electromagnetic interference to ensure they do not emit excessive RF energy that could interfere with other devices.

EMC Testing: Ensuring that devices can operate correctly in their intended electromagnetic environment without being affected by external RF interference.

Antenna Testing: Measuring the radiation patterns and performance of antennas in a controlled environment.

Wireless Communication Testing: Evaluating the performance of wireless devices such as mobile phones, Wi-Fi routers, and other RF communication equipment.

In summary, the construction of an RF anechoic chamber involves creating a shielded environment using a Faraday cage and lining the interior with RF absorber materials. This combination ensures that the chamber is free from external RF interference and internal reflections, providing a reliable space for EMI/EMC testing and other RF measurements.

3.VECTOR NETWORK ANALYSER

Vector Network Analysers (VNA) are versatile instruments for RF test and measurement applications, combining generators and receivers in a single box. They work in a wide frequency range and have powerful computers for fast data processing and controlling external equipment. The combination of VNAs and external switch matrices increases flexibility in RF test applications, allowing simultaneous testing of multiple test objects, complex digitally controlled RF modules, and simultaneous connection of prototypes as indicated in Fig1.

3.1.VNA vs Spectrum Analyzer

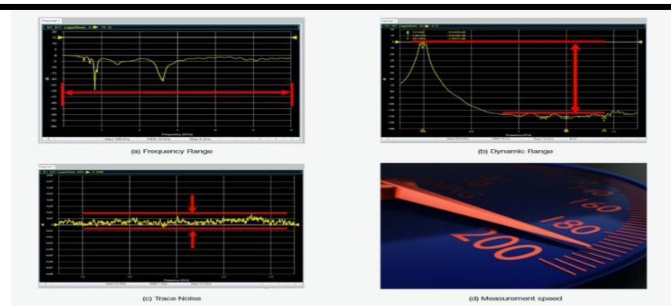


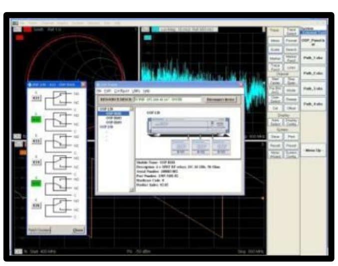
FIGURE 5. VNAs contain both a stimulus source and receivers to provide a very accurate closed loop for evaluating DUTs.

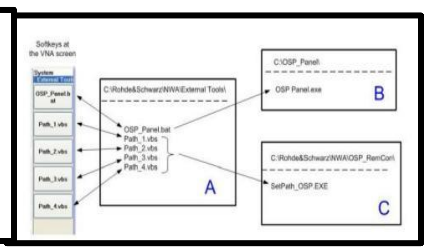
The OSP switch matrix can be set and its effects observed simultaneously at the VNA. The entire configuration can be stored permanently using "paths" with appropriate pathnames.

The OSP panel software can be closed once all paths are defined and stored. This solution is useful for a Spectrum Analyzer (SA) in 2-port analysis, especially when switching RF paths or modifying DC bias values using digital outputs.

3.2.Need of VNA

Wireless solutions, including smartphones, WiFi networks, connected cars, and IoT devices, use transmitters and receivers with RF and microwave components. VNAs are used to test component specifications and verify design simulations, ensuring system functionality. They are commonly used by R&D engineers and manufacturing test engineers at various stages of product





development, component designers, system designers, manufacturing lines, and even in field operations to verify and troubleshoot deployed RF and microwave systems.

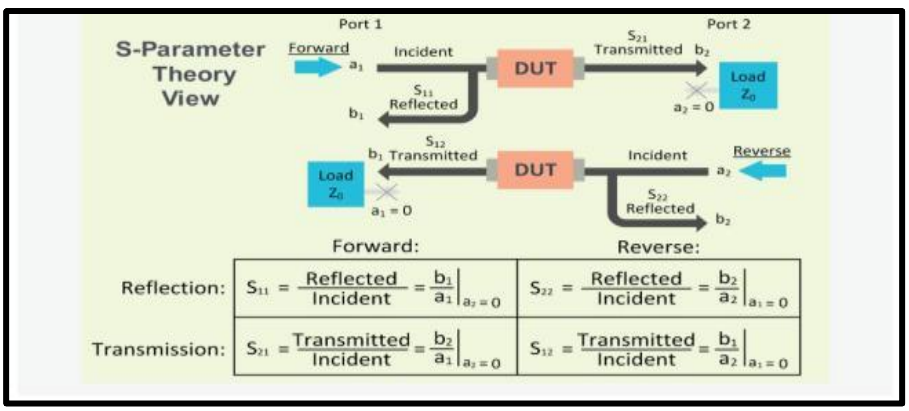
3.3.Key specifications :

To select a VNA, consider four top-level specifications: frequency range, dynamic range, trace noise, and measurement speed. Frequency range is crucial, considering both immediate and future needs. Active components may need to be tested at their harmonic frequencies, which can be a cost driver. Dynamic range is the measurable attenuation range from max to min for a specified frequency range. Most VNAs offer good dynamic range (~120 dB), but high-performance components may require more expensive solutions.

3.4.Understanding S-Parameters:

Scattering parameters or S-parameters are used to characterize the electrical properties or performance of an RF component or network of components. They are related to familiar measurements such as gain, loss, and reflection coefficient. A VNA (Visual Network Analyzer) is used to characterize a DUT by using incident and reflected waves as excitations at each port. The S-parameters are constants that characterize the network under these conditions.

In the Forward case, the S-parameters correspond to the reflection coefficient at Port 1 and the forward transmission coefficient through the DUT. In the Reverse case, the S-parameters



correspond to the reflection coefficient at Port 2 and the reverse transmission coefficient through the DUT.

4.MIL-STD-461 CE102:

4.1.Purpose:

This requirement is applicable from 10 kHz to 10 MHz for all power leads, including returns, which obtain power from other sources not part of the EUT.This test procedure is used to verify that electromagnetic emissions from the EUT do not exceed the specified requirements for power input leads, including returns.

4.2.Test Equipment:

The test equipment shall be as follows:

1.Measurement receiver

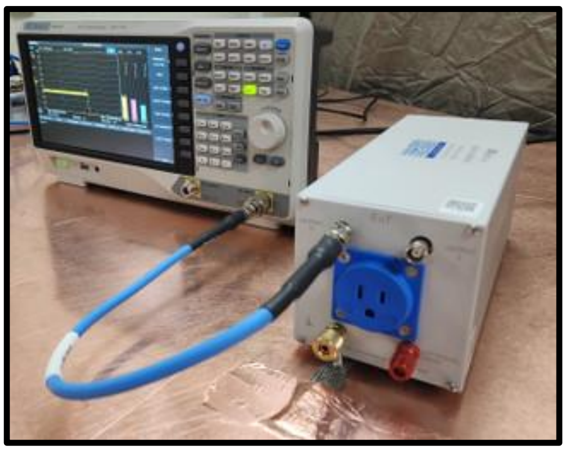
2.Data recording device

3.Signal generator

4.Attenuator, 20 dB, 50 ohm

5.Oscilloscope

6.LISNs



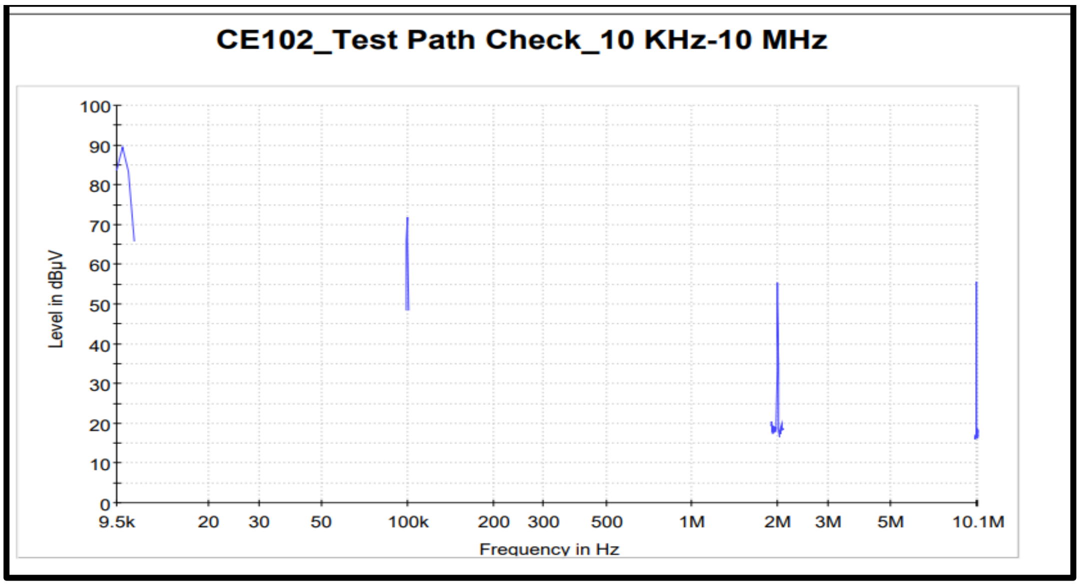
Rohde & Schwarz ESRP3 EMI Test Receiver per CISPR 16-1-1

4.3.Test Procedure :

EMI test receiver and signal/spectrum analyzer combined in one box Resolution bandwidths in line with CISPR

Weighting detectors: max. peak, min. peak, average, RMS, quasi-peak, average with meter time constant, and RMS in line with current CISPR 16-1-1 version

Very fast FFT-based time domain scan as an option,Automatic test routines

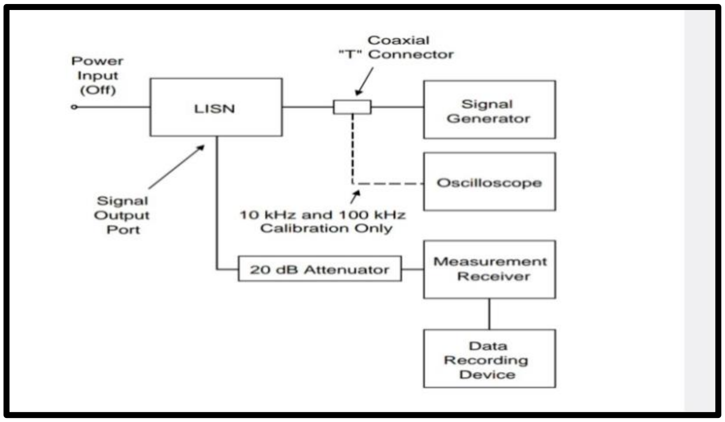


4.4.Test Setup :

The test setup shall be as follows:

Maintain a basic test setup for the EUT as shown below

A. **Calibration.**



Configure the test setup for the measurement system check and ensure that the EUT power source is turned off.

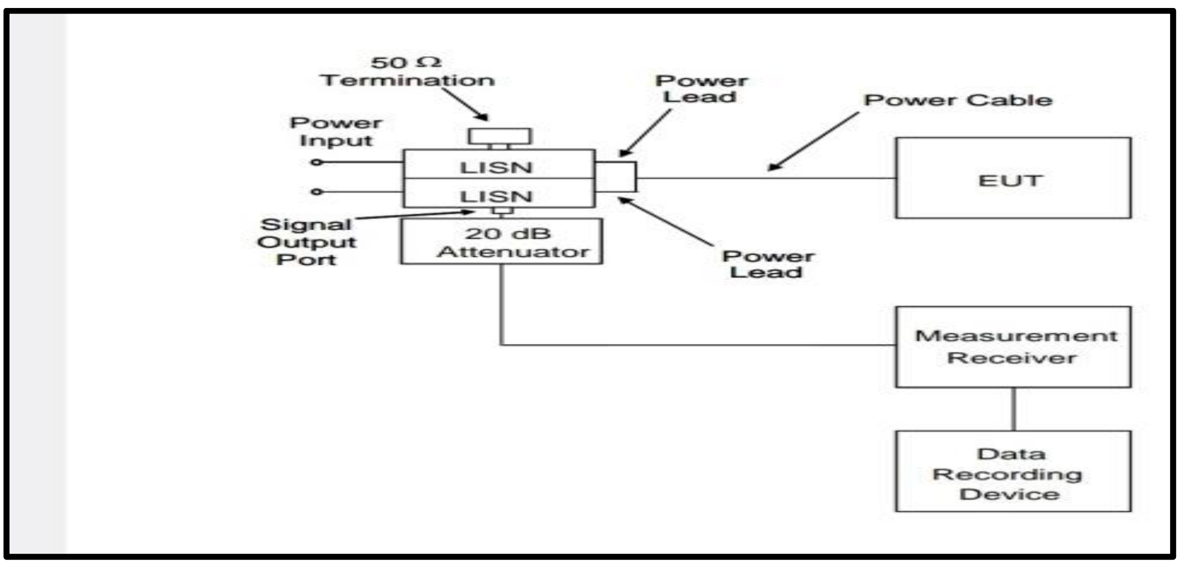
(1) Connect the measurement receiver to the 20 dB attenuator on the signal output

Port of the LISN.

B.EUT testing.

(1) Configure the test setup for compliance testing of the EUT as shown below.

(2) Connect the measurement receiver to the 20 dB attenuator on the signal output



C.Data presentation.

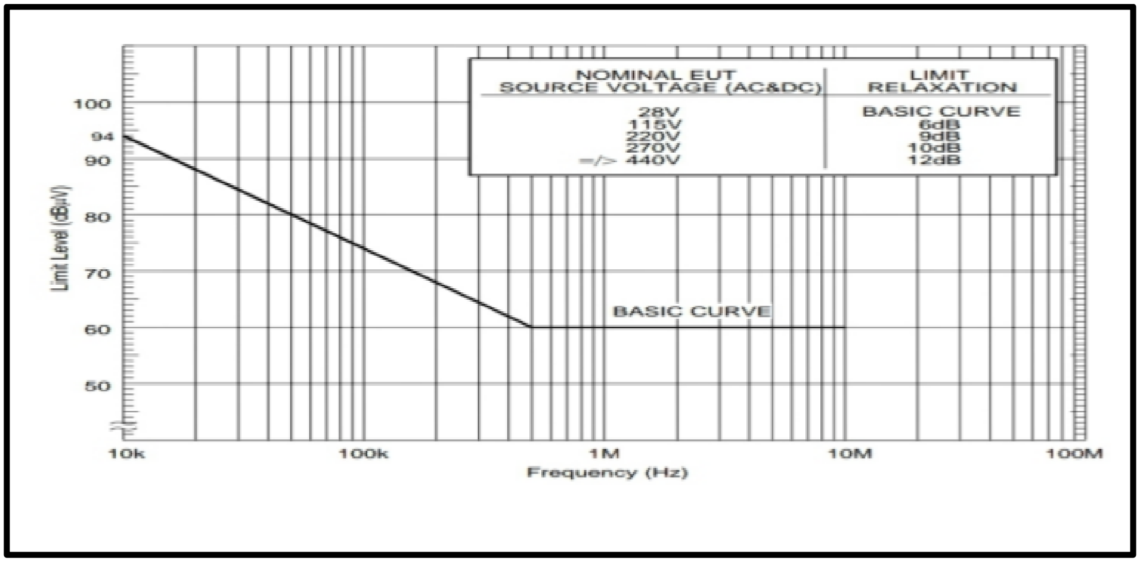
Data presentation shall be as follows:

a.Continuously and automatically plot amplitude versus frequency profiles on X-Y axis outputs. Manually gathered data is not acceptable except for plot verification.

b.Display the applicable limit on each plot.

c. Provide a minimum frequency resolution of 1% or twice the measurement receiver bandwidth, whichever is less stringent, and a minimum amplitude resolution of 1 dB for each plot.

d.Provide plots for both the measurement system check and measurement portions of the procedure.



5.RADIATED EMISSION-RE102:

5.1.Purpose:

RE102 is a military testing standard that is part of the MIL-STD-461 standard, which covers radiated emissions. The test measures unwanted signals emitted into the air from the device and its cables. It involves simulations of potential disturbances from magnetic sources, radio frequency sources, electrostatic discharge (ESD) sources, and electromagnetic pulse (EMP) sources.

5.2.Requirement:

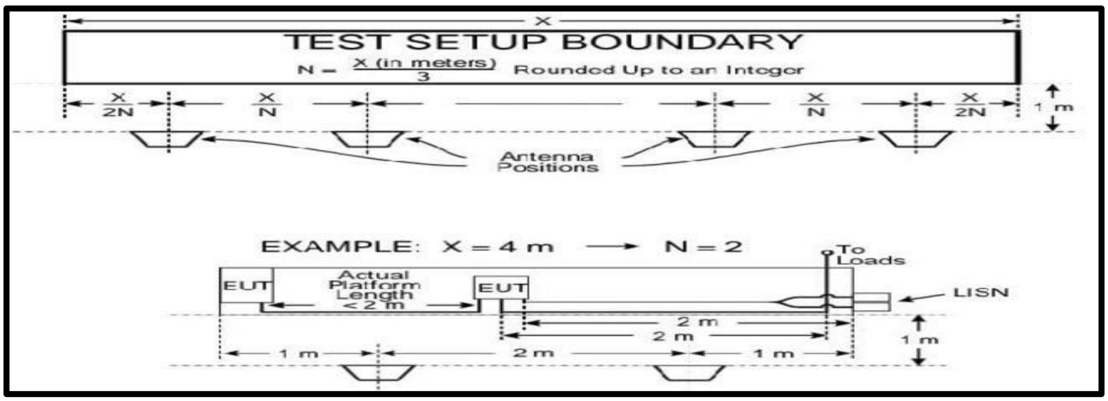
MIL-STD 461 EMC testing standard RE102 refers to radiated emissions from equipment and subsystem enclosures, and all interconnecting cables. This standard military testing requirement does not apply to permanently mounted antennas.

This EMC MIL-461 test applies as follows:

- Ground 2 MHz to 18 GHz
- Ships, surface 10 kHz to 18 GHz
- Submarines 10 kHz to 18 GHz

- Aircraft (Army and Navy) 10 kHz to 18 GHz

5.3.Test Setup:



5.4.Test equipment:

1. Measurement receivers
2. Antennas ranging from 10 kHz to 18 GHz
3. Signal generators
4. Stub radiators

5.5.Testing Procedures:

- Ambient requirements must be verified and met. Plots are taken when required.
- The measurement equipment is turned on and allowed sufficient time for stabilization.
- Using the system check path, an evaluation of the overall measurement system from the coaxial cable end used at each antenna is performed. For rod antennas that use passive matching networks, the evaluation is performed at the centre frequency of each band. System check path verification is performed near the upper end of the affected frequency band. If readings are obtained that deviate by more than three dB, the source of the error is located and must be corrected.

- An evaluation for each antenna to demonstrate that there is electrical continuity through the antenna is conducted. This is done by visually inspecting each antenna for damage.
- After, each EUT is turned on and allowed sufficient time for stabilization.

Using the measurement path, the radiated emissions are finally determined from the EUT and its associated cabling. Lastly, measurements are taken for each antenna position.

6.Radiated susceptibility-RS103:

6.1.Purpose:

This test procedure is used to verify the ability of the EUT and associated cabling to withstand electric fields.

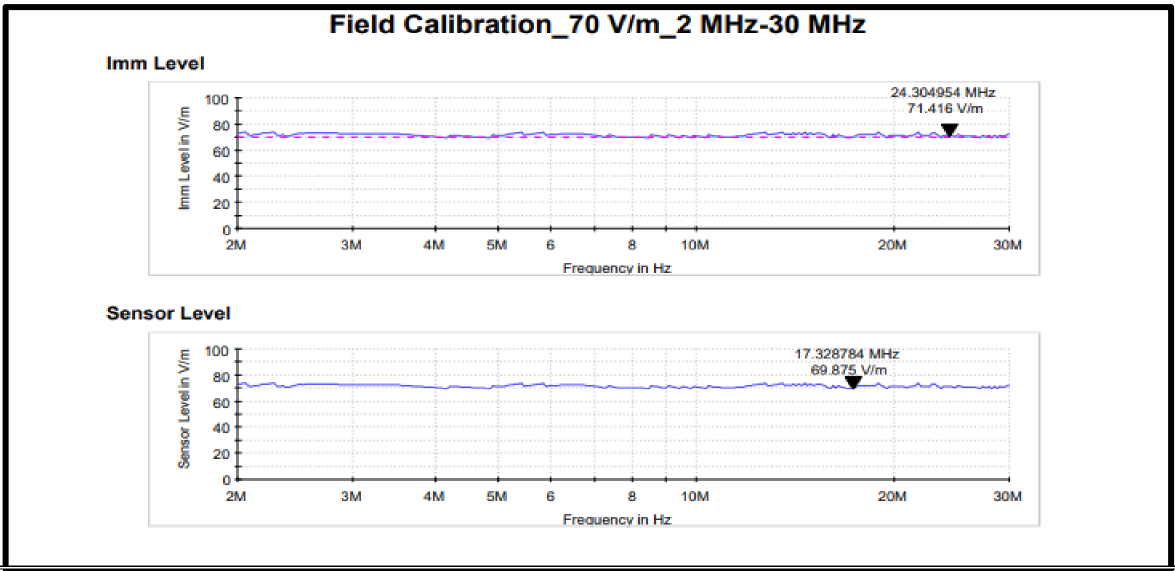
6.2.Requirement:

The MIL-STD-461 lab testing requirement is applicable for equipment and subsystem enclosures. The EMC compliance test is also applicable to all interconnecting cables.

- 2 MHz to 30 MHz – Army, Navy and optional* for all others
- 30 MHz to 18 GHz – All
- 18 GHz to 40 GHz – Optional* for all

The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem specification.

6.3.Test equipment



The test equipment shall be as follows:

a. Signal generators

b. Power amplifiers

c. Receive antennas

(1) 1 GHz to 10 GHz, double ridge horns

(2) 10 GHz to 40 GHz, other antennas as approved by the procuring activity

d. Transmit antennas

e. Electric field sensors (physically small - electrically short)

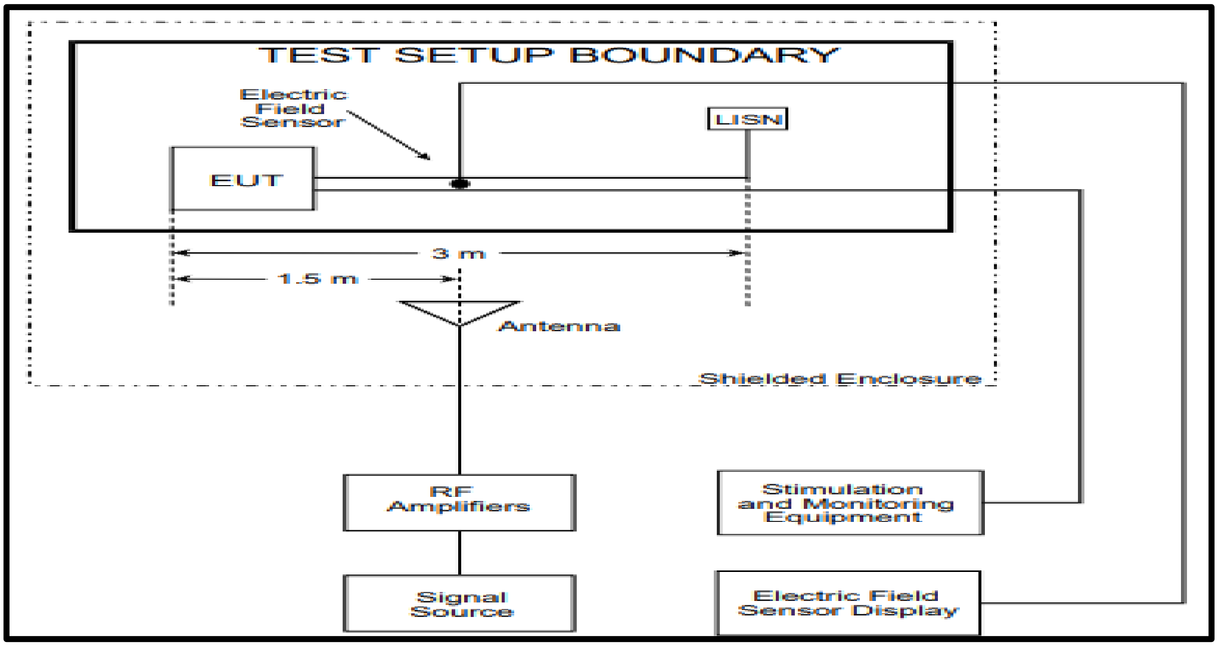
f. Measurement receiver

g. Power meter

6.4.Test procedure:

- First, the measurement equipment and EUT is turned on and allowed ample time for stabilization.
- After, the test area is assessed for potential RF hazards. The testing engineers take necessary precautions to assure the safety of all personnel.
- Subsequently, the EUT test is performed. This is done over the required frequency ranges. The transmit antenna must be vertically polarized. The signal source is set to 1 kHz pulse modulation and 50% duty cycle.
- An electric field is established at the start frequency. It is gradually increased until it reaches the applicable limit. The required frequency ranges are scanned. These must be in accordance with specified rates and durations.
- If susceptibility is noted, the threshold must be determined. These steps are repeated above 30 MHz with the transmit antenna horizontally polarized. The test is also repeated for each transmitted antenna position.

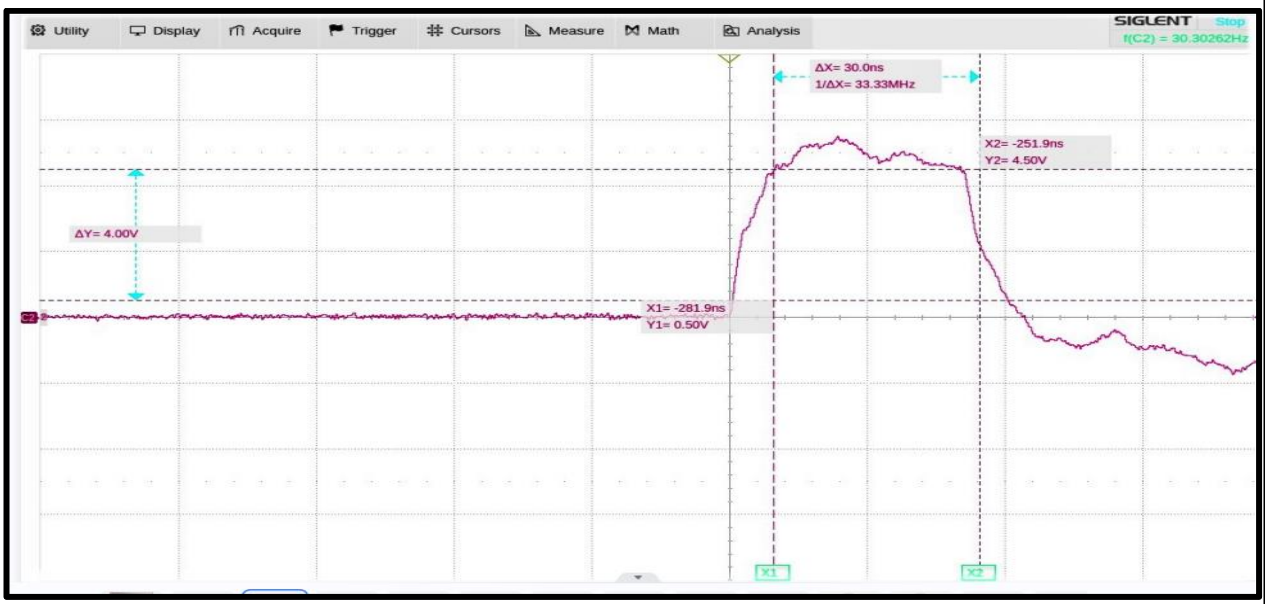
6.5.Test Setup:



7.MIL-STD-461 CS115 IMPULSE EXCITATION:

7.1.Purpose :

The purpose of CS115 testing is to evaluate the ability of a device to tolerate electromagnetic energy from switching transients that could couple into the device wiring. Test parameters establish the waveform simulating the coupling and device performance determines the acceptance criteria. The device performance specification should establish a quantifiable pass/fail deviation from the standard operation of the device that is considered acceptable or not acceptable.



7.2.Test Setup:

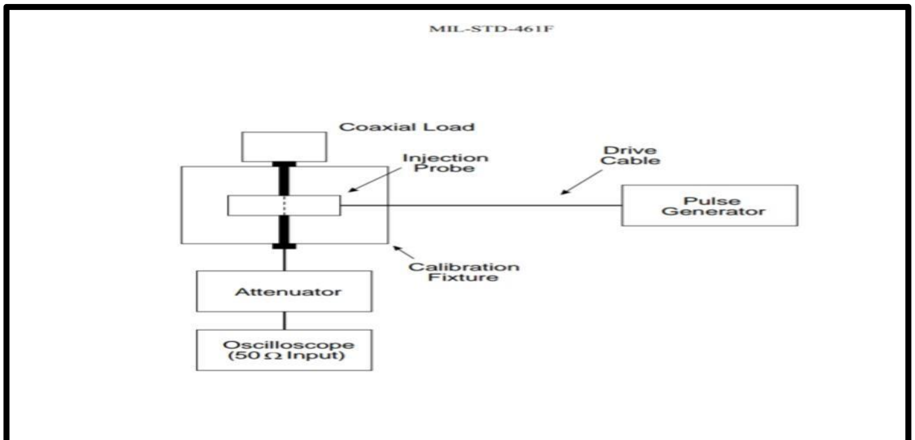
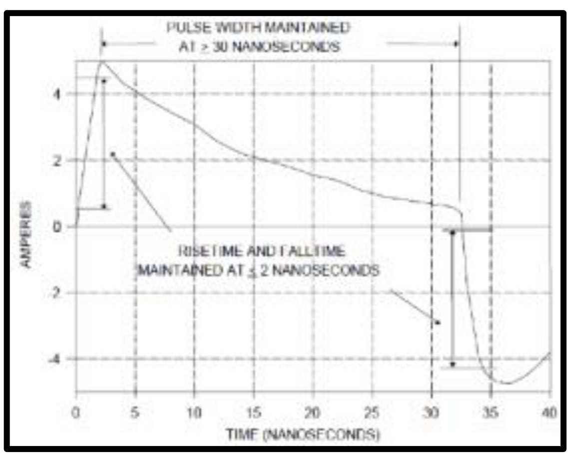


FIGURE CS115-2. Calibration setup.

7.3.Test Equipment:

A coaxial charged line pulse generator is used to generate the specified waveform where an open circuit coaxial cable will acquire a charge and then discharge into the output circuit connected to a current probe when switched connecting the charged line. Switching is controlled by a pulse rate controller and relay. The waveform goal is seldom attained because of inductive coupling so expect to see something like the acceptable waveform.Note that waveform parameters are met during the calibration process and highly distorted when testing a cable.

A current Injection probe rated for at least 500 MHz is used as the coupling transformer and a current monitoring probe is used during testing. The high-frequency performance is necessary to meet the required 2 nS transition time.



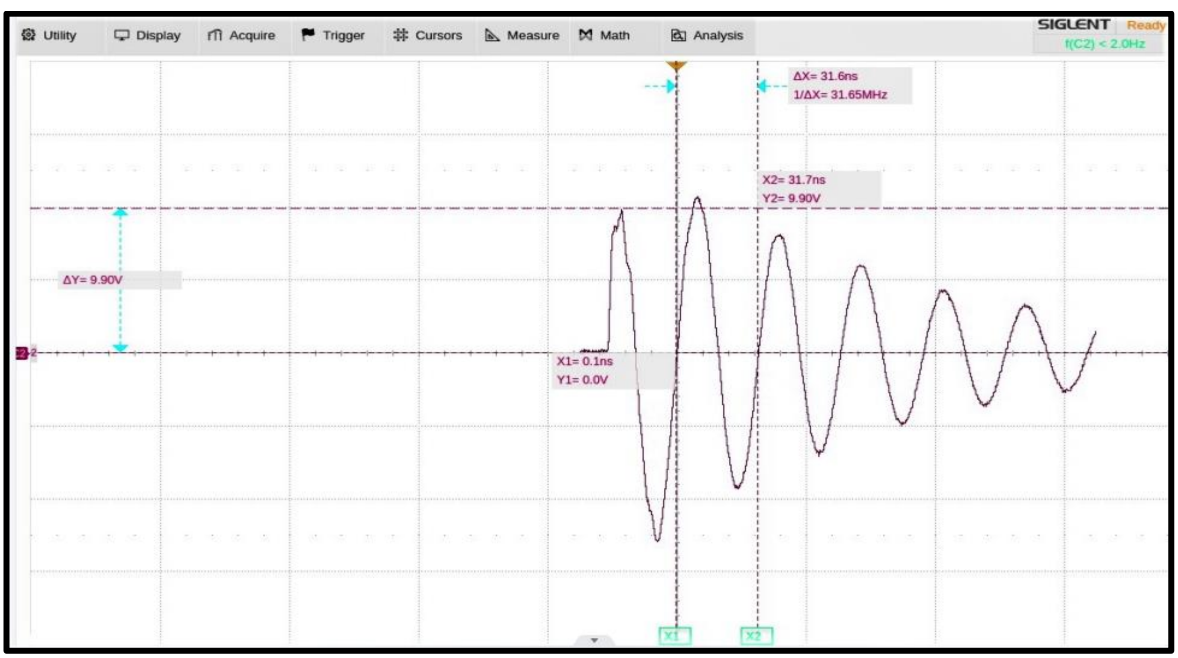
7.4.Test Procedure:

An oscilloscope with the bandwidth necessary to display the transition time without altering the waveshape. The current monitoring probe and the calibration fixture depend on a measurement impedance of 50 Ω, so provide the correct impedance by oscilloscope selection or an external terminator but NOT both simultaneously.Attenuators, coaxial loads, LISNs and other assorted hardware will likely be needed to accomplish the testing.The attenuator noted in the calibration process is not in the test configuration figure because it is not likely to be required for the monitor probe. However, should the signal overdrive the oscilloscope, an attenuator is used instead of a 10X probe to maintain the 50 Ω termination.Note that power cables are tested on the bundle, power with neutral and ground and phase leads without neutral or ground. Based on this a 3-phase power cable would test phases A-B-C simultaneously but not individually.

8.MIL-STD-461 CS116 Damped Sinusoidal Transients, Cables and Power Leads:

8.1.Purpose:

MIL-STD-461 assigns applicability to a broad variety of applications and states the purpose is to verify the ability of the EUT to withstand damped sinusoidal transients coupled onto EUT associated cables and power leads.



8.2.Test Procedure :

Since the beginning, the overall procedure has evolved as discussed (many details were not included above). So, let's recap the current process – after all this discussion is about the testing.Calibration for CS116 has multiple aspects including all the details associated with waveform parameters and the additional target of establishing the drive level to produce the test current via the calibration fixture.

8.3.Test Equipment:

1. Damped Sinusoid Generator
2. Wave Recording Device
3. Current Injection Probe
4. Attenuators (50 Ohm)
5. Calibration Fixture
6. Measurement Recievers
7. Oscilloscope
8. Coaxial Load (50 Ohm)
9. Current Probes
10. LISNs

8.4.Test Setup:

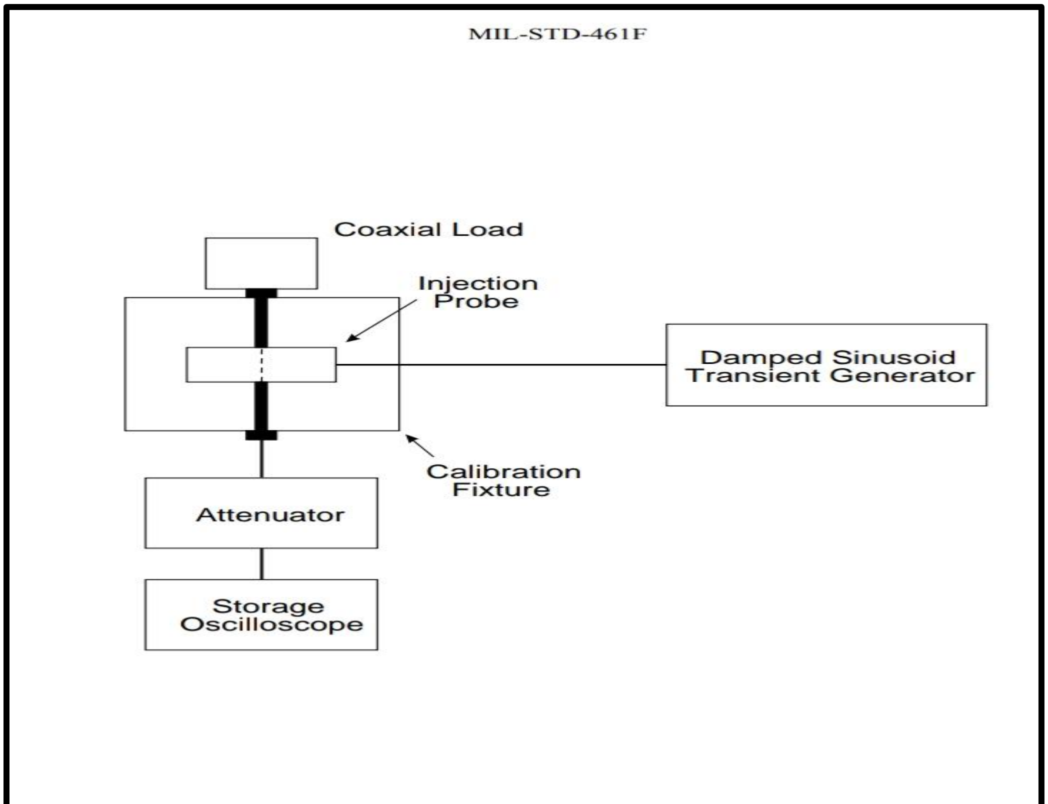
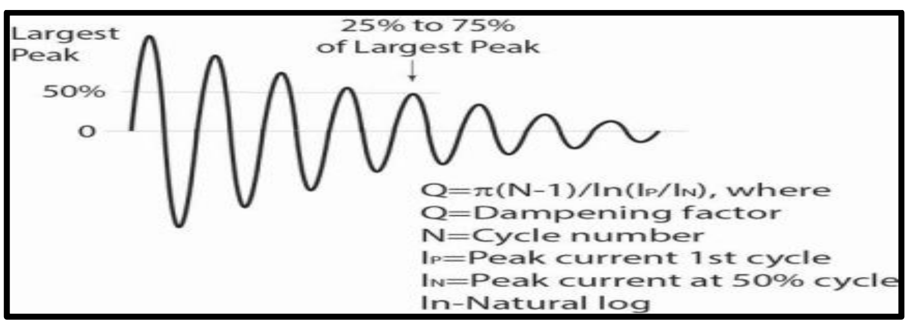


FIGURE CS116-3. Typical test setup for calibration of test waveform.

Part of the calibration is to assess the "Q" or the dampening factor. MIL-STD-461 requires a Q of 15 ±5 as calculated by the formula. The peak current at the 50% cycle is not 50% or peak current – it is the peak current of the cycle nearest the 50% current point. In the figure, N = 5.



Once the EUT is operating correctly, increase the transient generator amplitude until the test current is flowing but don't exceed the calibration drive level for that test frequency. As with all MIL-STD-461 tests, planning is an essential element and planning includes defining the hardware necessary to accomplish the testing. Make sure you are aware of reporting requirements, so you will capture the necessary information during the test.

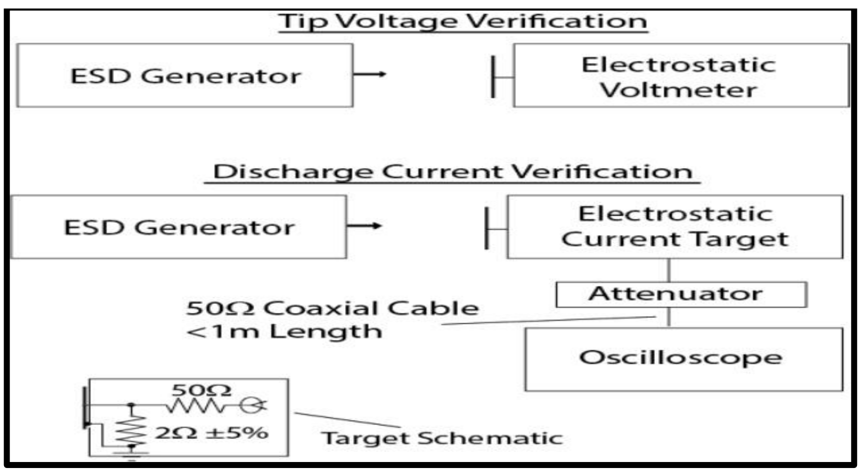
9.MIL STD-461G Test Method CS118 Personnel Borne Electrostatic Discharge:

9.1.Purpose:

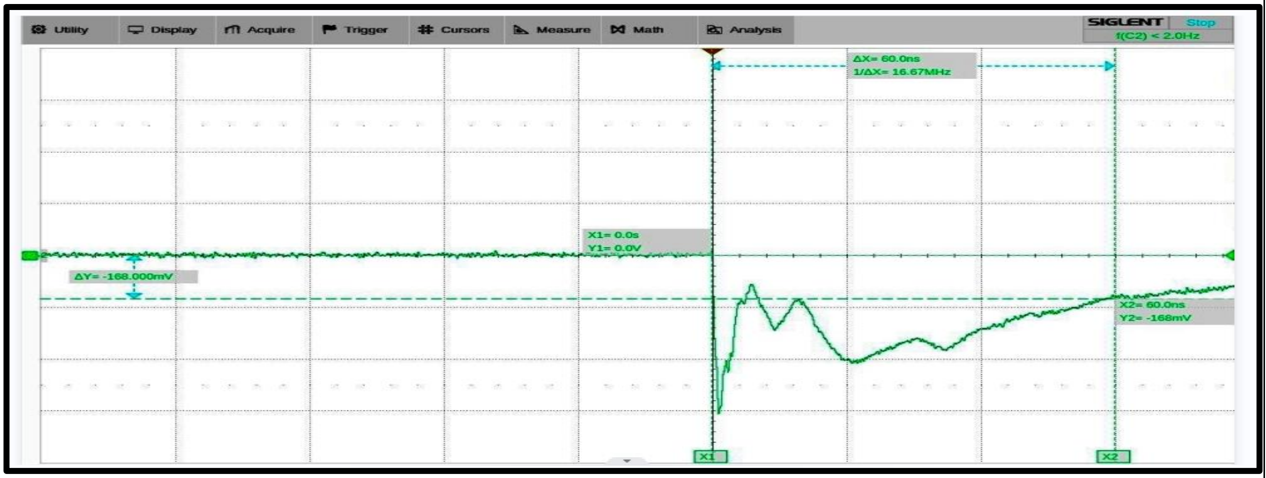
This MIL-STD 461 compliance testing method is applicable to electrical, electronic, and electromechanical subsystems and equipment that have a man-machine interference. The MIL-461 CS118 test is not applicable to ordnance items.

This immunity test procedure is used to verify the ability of the EUT to withstand personnel-borne electrostatic discharge (ESD) in a powered-up configuration.

9.2.Test Setup:



The equipment under testing (EUT) cannot show any signs of malfunctioning or degradation of performance. The EUT must not show signs of deviation from specified indications when subjected to values while discharging from a 150 picofarad capacitor. This includes beyond the tolerances indicated in the individual equipment or subsystem specifications.
Contact discharge at 8 kV is required for conductive surfaces. Air discharge is only required where contact discharge cannot be applied.
The test is set up specifically as follows:



The electrostatic discharges are applied to points and surfaces of the EUT which are accessible to the operator during normal use.

9.3.Test Equipment:

1. ESD Simulators/Guns

2. Air & Contact Discharge Tips

3. Resistance Capacitance (RC) Module/Network

9.4.Test procedures :

The test procedures are carried out as follows:

The ESD Generator is ground to the EUT chassis ground point in the setup.The EUT is powered and operated during this test in a manner sufficient to verify its operation.The ESD generator's tip voltage is set to the selected test level.Five positive discharges and five negative discharges are applied to each EUT test point.The discharges are applied directly on the test point. For air discharges, the tip starts at a distance and is moved closer to the EUT slowly until the discharge occurs or until the tip physically contacts the test point.The EUT is monitored for degradation of performance during testing,Lastly, the MIL 461-test is repeated for each applicable level of voltage.

Electrostatic discharge testing for automotive applications is different from commercial based in a variety of ways. The largest variations stem from voltages, test setups, standards, number of discharges, and resistance/capacitance (RC) networks. The voltages of these applications can be in excess of 25kV and often require several RC networks.

10.ANTENNA:

Antennas are essential components in wireless communication, including mobile phones and televisions. They convert electric power into electromagnetic waves, such as radio waves, and vice versa. Wireless devices like routers, wireless modems, game controllers, and Bluetooth devices also have antennas. Antennas are structures that help bridge the transition between guided waves and free space, converting electric power into electromagnetic waves. Infrared communication is an exception, but both devices rely on antennas.Antennas convert signals from transmission lines or guiding devices like co-axial cables into electromagnetic energy for transmission through free space. They can be used for both transmission and reception of radiation, collecting electrical signals and accepting radio waves from space.

10.1.Antenna beam width:

Antenna beam width determines the expected signal strength given the direction and radiation distance of an antenna. The beam width will vary given a number of different factors such as the antenna type, design, orientation and radio frequency. Understanding beam width and how it influences a test environment is critical to accurate and repeatable tests.

10.2.How beam width is measured:

To calculate an antenna beam width, it is first important to understand directional antennas and antenna gain. Gain is more than increased signal strength. It is directly associated with antenna directionality: increased signal strength in one direction is obtained by reducing signal strength in another. Antenna gain is referenced against a theoretical, pure omnidirectional antenna that radiates power equally in all directions, in the shape of a perfect sphere. Gain is measured in decibels (dB), which is a logarithmic scale since radio frequency (RF) power drops logarithmically with distance. All of these components of gain are important to consider during product testing to ensure that tests are correct, accurate and repeatable. The half-power value, also called the -3 dB point, which is represented by the red lines in below figure determines and defines the main RF lobe and its width, or beam width.

10.3.Accounting for different antenna and frequency:

Antennas have a specific beam width pattern, but this pattern is not consistent across all frequencies. When testing, consider the frequency of operation to account for beam width differences. Higher frequencies have a narrower beam width and are more directional. The divergence of the beam is related to frequency by a formula, making it easy to account for these effects. A typical test setup in an anechoic chamber with a log periodic antenna, where its beamwidth at 1 m covers 0.536 m2 of testing area. This demonstrates the necessity of calculating the required testing distance relative to beamwidth and antenna.Antenna design plays a crucial role in selecting the best antenna for each test, considering factors like resonant frequency, bandwidth, polarization, and gain. Log periodic antennas have wide-frequency bandwidth and directionality, and their beamwidth is used for half-power testing. The half-power beamwidth and distance to the device under test provide necessary information for setting up a test environment.

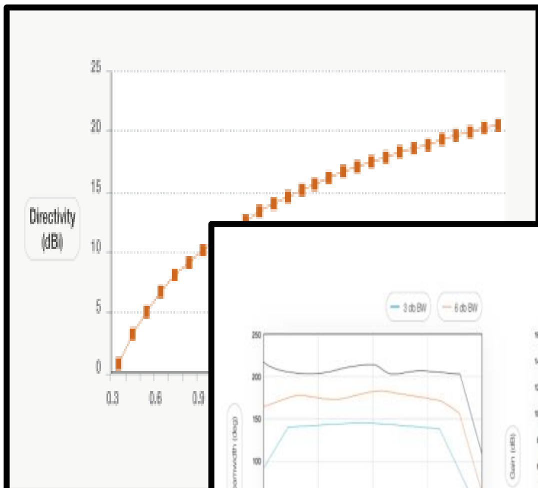
10.4.Gain:

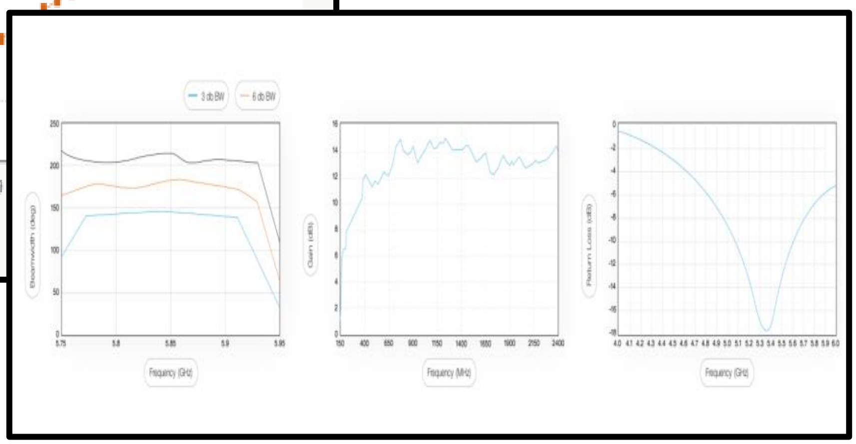
Gain / Directivity: The extent to which an antenna focuses energy. In general gain is measured and directivity is calculated

Efficiency (dB) = Directivity (dB) – Gain (dB)

10.5.Antenna measurements:

An isotropic radiator is a theoretical point source of electromagnetic energy that radiates



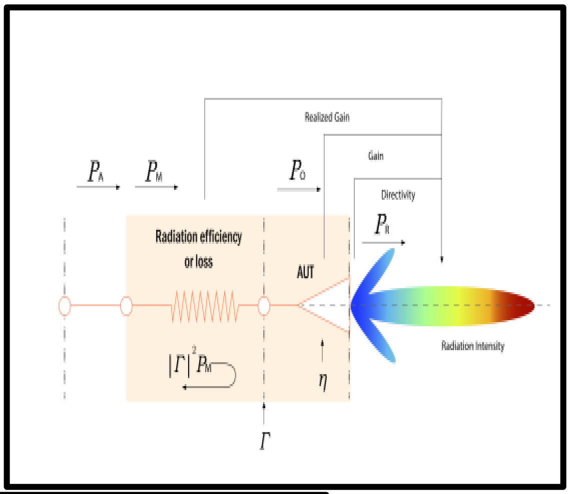


uniformly in all directions. The absolute power used is an isotropic radiator, and the measured gain relative to it is expressed in dBi. Directivity, calculated using antenna pattern or design parameters, should always be greater than the actual measured gain.

10.6.Antenna impedance:

The antenna impedance (in ohms) is the impedance value seen at the antenna terminals. This does not mean the DC resistance, but the radiation resistance (whose job is to convert the incoming signal to radiation) which varies with the frequency. As a result, using the antenna outside of its designed frequency will change its feed point impedance to an incorrect value. An incorrect value will cause the antenna to reflect some of the RF signal back and produce high VSWR.

10.7.Universal spectral dipole source:



Applied Electromagnetic Technology, LLC (AET) offers the Universal Spherical Dipole Source (USDS), a broadband electric field comb generator RF source with Quasi-Peak detector test functionality. The USDS is traceable to the Precision Spherical Dipole Source (PSDS) design, developed by NIST. It is ideal for RF emission site comparisons, shielding measurements, quasi-peak detector verification, and verification of RF laboratory equipment. The USDS's spherical dipole antenna offers a highly uniform radiation pattern, easy use, and a small, 10 cm size for shielding effectiveness tests.

11.Controlling of VNA through SCPI Commands:

SCPI is a Python-based collection of mathematical algorithms and convenience functions, offering high-level commands and classes for data manipulation and visualization. It rivals systems like MATLAB, IDL, Octave, R-Lab, and SciLab.

Basing SCPI on Python allows for sophisticated programming and specialized applications, including parallel programming, web and database subroutines, and classes, making it a powerful tool for Python developers.

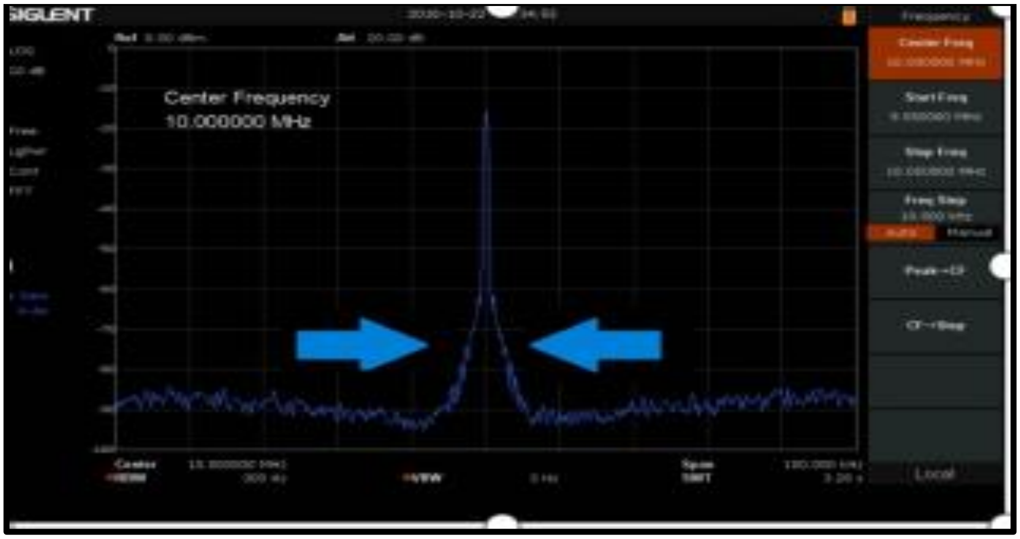
12.EMI Receiver :

12.1.Resolution bandwidth (RBW):

Spectrum analyzers are useful tools for broadcast monitoring, RF component testing, and EMI troubleshooting. There are a number of common adjustments available with many modern analyzers that can optimize performance for a particular application. In this application note, we will introduce resolution bandwidth (RBW) and video bandwidth (VBW) and how they affect measurements.Bandwidth is defined as the span of frequencies that are the focus of a particular event. For example, the bandwidth of the transmission signal is the span of frequencies that the transmission occupies. The bandwidth of a measurement defines the range of frequencies that were used for the measurement.Ideally, you would like to set this bandwidth as narrow as possible, as that would give you the finest frequency resolution. The tradeoff is sweep time. The narrower the resolution bandwidth, the longer the sweep time, but if you sent the RBW too wide, you won't see signals that are close to one another.In spectrum analysis, the resolution bandwidth (RBW) is defined as the frequency span of the final filter that is applied to the input signal. Smaller RBWs provide finer frequency resolution and the ability to differentiate signals that have frequencies that are closer together.

12.2.Phase Noise:

Another factor that affects the frequency resolution of an analyzer is the phase noise. This is observed as a widening and increase in the noise amplitude near the center frequency of the signal. It is caused by the random thermal fluctuations of the oscillator used as a timing reference in the spectrum analyzer circuitry. These fluctuations cause the phase of the output clock signal to vary with time, very similar to jitter in a time-based system. This widening can cover up any small signals that may be near the frequency of interest. For meaningful measurements, select an instrument with lower phase noise than the signal source you are measuring.



13.Conversions related to Power and dB :

$$P_{dB} = 10log_{10}\left(\frac{P}{P_{ref}}\right)$$

$$\text{Because } P = \frac{V^2}{R}$$

$$P_{dB} = 10log_{10}\left(\frac{\frac{V^2}{R}}{\frac{V_{ref}^2}{R_{ref}}}\right)$$

$$P_{dB} = 10log_{10}\left(\left(\frac{V}{V_{ref}}\right)^2\left(\frac{R_{ref}}{R}\right)\right)$$

$$P_{dB} = 10log_{10}\left(\left(\frac{V}{V_{ref}}\right)^2\right)$$

$$P_{dB} = 20log_{10}\left(\frac{V}{V_{ref}}\right)$$

[dB] Unit Conversion - [V], [dBV], [dBμV], [A], [dBA], [dBμA], [dBm]		
To	Calculation	Remark
V	$[\mathbf{V}] = 10^{\left(\frac{[\mathbf{dBV}]}{20}\right)}$	
V	$[\mathbf{V}] = 10^{\left(\frac{[\mathbf{dB\mu V}]-120}{20}\right)}$	
dBV	$[\mathbf{dBV}] = 20\log_{10}(\mathbf{V})$	
dBV	$[\mathbf{dBV}] = [\mathbf{dB\mu V}] - 120$	
dBμV	$[\mathbf{dB\mu V}] = 20\log_{10}(\mathbf{V}) + 120$	
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dBm}] + 10\log_{10}(Z) + 90$	Z = system impedance
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dBm}] + 107$	50Ω system impedance
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dB\mu A}] + 20\log_{10}(Z)$	Z = system impedance
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dB\mu A}] + 34$	50Ω system impedance
A	$[\mathbf{A}] = 10^{\left(\frac{[\mathbf{dBA}]}{20}\right)}$	
A	$[\mathbf{A}] = 10^{\left(\frac{[\mathbf{dB\mu A}]-120}{20}\right)}$	
dBA	$[\mathbf{dBA}] = 20\log_{10}(\mathbf{A})$	
dBA	$[\mathbf{dBA}] = [\mathbf{dB\mu A}] - 120$	
dBμA	$[\mathbf{dB\mu A}] = 20\log_{10}(\mathbf{A}) + 120$	
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dBm}] - 10\log_{10}(Z) + 90$	Z = system impedance
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dBm}] + 73$	50Ω system impedance
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dB\mu V}] - 20\log_{10}(Z)$	Z = system impedance
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dB\mu V}] - 34$	50Ω system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu V}] - 10\log_{10}(Z) - 90$	Z = system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu V}] - 107$	50Ω system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu A}] + 10\log_{10}(Z) - 90$	Z = system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu A}] - 73$	50Ω system impedance

14.Insertion Loss Measurement of Direction Coupler using VNA:

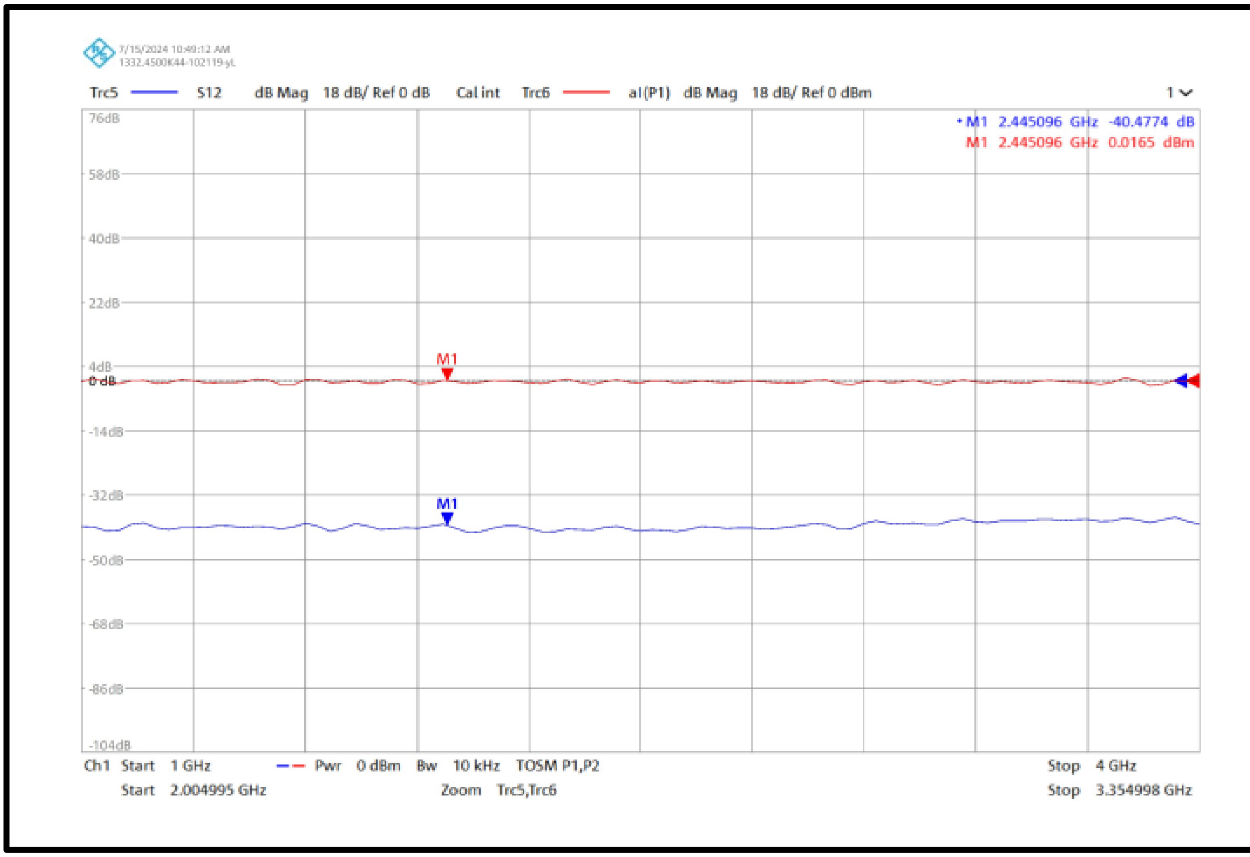
Insertion loss, also known as attenuation, is a measure of how much signal power is lost as it passes through an EMI/EMC filter. It is expressed in decibels (dB) and is typically a negative value because the filter's primary function is to reduce or attenuate unwanted signals.The relationship between insertion loss and frequency for several different filter circuit configurations with a full load in a balanced 50 Ω system.Insertion loss is a critical performance metric that determines how effectively the filter attenuates unwanted EMI signals and reduces their impact on sensitive electronic components.

14.1.Directional Coupler:

Directional couplers are versatile aids when measuring RF/microwave power levels. Directional and bi-directional couplers provide the means to sample a small portion of the RF / microwave signal power through a transmission line with minimal disruption to the main line. Teamed with RF / microwave test instruments such as spectrum analyzers or electromagnetic-interference (EMI) receivers, couplers can provide sampled signals as part of better understanding the electromagnetic compatibility (EMC) of a new electronic design and whether it generates excess EMI. To qualify for sale in many markets, electronic products must pass rigorous EMC / EMI compliance testing and many developers of high-frequency components and systems have adopted EMC / EMI pre-compliance testing in preparation for a new product's EMC / EMI compliance testing. Directional and bidirectional couplers can simplify EMC/EMI pre-compliance test efforts.

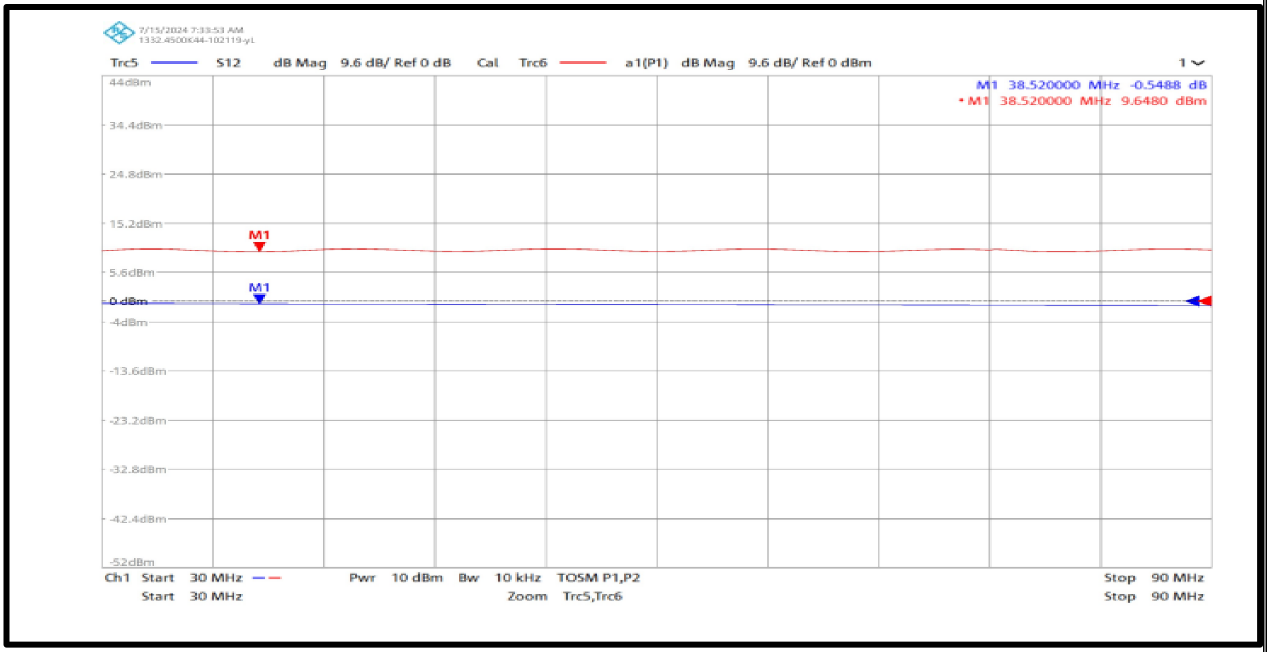
14.2.What is VSWR?

We continue the explanation by ignoring the Voltage and Ratio parts for now and examine how a Standing Wave is created.



14.3.How to Measure VSWR Using a Directional Coupler:

A directional coupler is used in RF systems as a power divider. Directional couplers can be designed to sample power from a microwave circuit and measure it with an inductive probe, microwave ADC, or receiver. A directional coupler can be used to sample some power in a standing wave, which can be used for a voltage standing wave ratio measurement. In order to ensure high transmission of radiation between a source and a downstream device over the air, antennas need feed lines to be carefully matched to the antenna impedance. Impedance matching for antennas is a fundamental subject in RF design, but new designs also need to be evaluated to ensure the matching technique provides desired power transfer. The goal is to ensure the antenna has low return loss and insertion loss at the interface between the feed line and the radiating element. Impedance matching is also important in RF devices beyond antennas, and there is a metric that can be used to evaluate antennas on a finished PCB. The voltage standing wave ratio (VSWR) is one convenient metric that is linked to impedance matching within the desired antenna bandwidth.



One useful way to evaluate antenna impedance matching is to measure VSWR using a directional coupler. If you plan to use a directional coupler to measure VSWR, here's how to analyze your coupler design and the measurement results for your system.

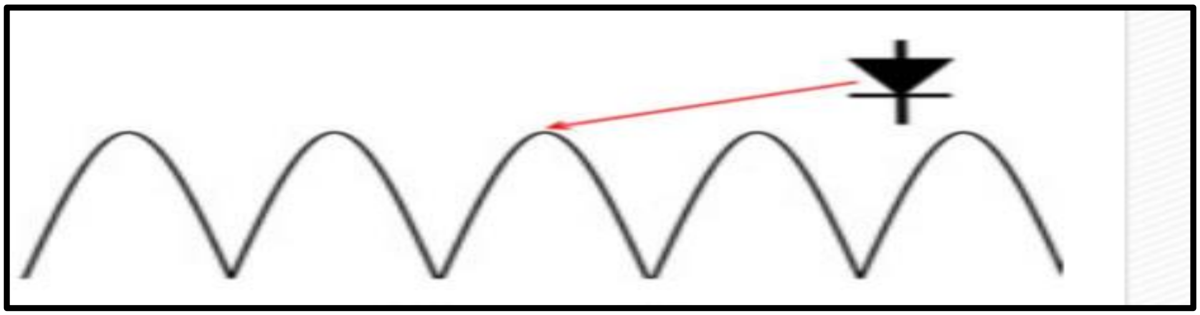
$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$\left| \frac{V_D}{V_C} \right|_{\substack{\max \\ \min}} = \frac{|\Gamma| \pm \frac{1}{D}}{1 \mp \frac{|\Gamma|}{D}}$$

With this equation, you can plug in the value of D and the measured voltages, and finally solve the above equation for the reflection coefficient. You can then use the result to calculate VSWR.

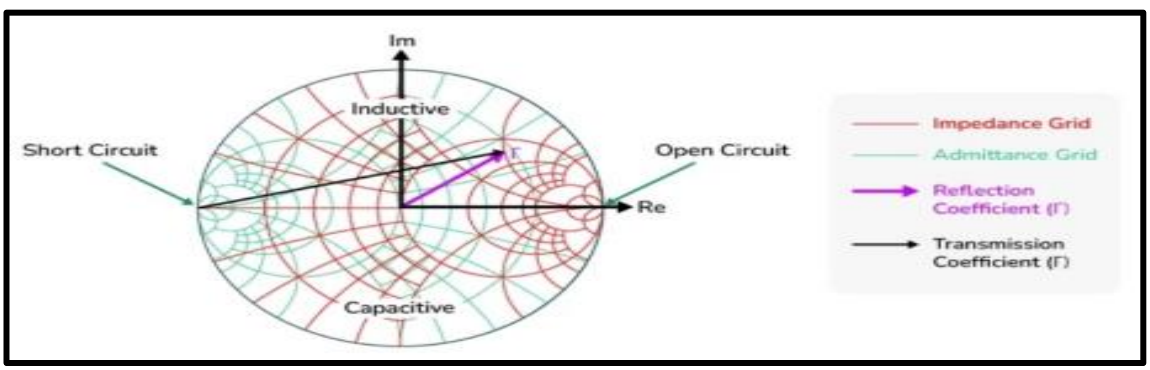
14.4.VSWR of Transmitting Antennas using VNA:

VSWR Stands for 'Voltage Standing Wave Ratio' and is used in EMC to specify the effect of mismatch presented to a test system signal.At microwave frequencies slotted lines became a way of accurately determining the ratio of the maximum voltage to the minimum voltage (the VSWR, symbol 's'), and because of the simplicity of measurement and the easy math associated with it, VSWR became an everyday parameter. As the name suggests, a slotted line is a length of waveguide with a slot along the top. A probe is moved along the slot and a detector gives the voltage at any point on the line. Once you have obtained the two extremes of voltage you can determine the ratio of the two. Once you have this ratio it is easy to calculate the reflected power coefficient, symbol rho. The reflected power coefficient is the amount of power reflected back compared to the incident power.

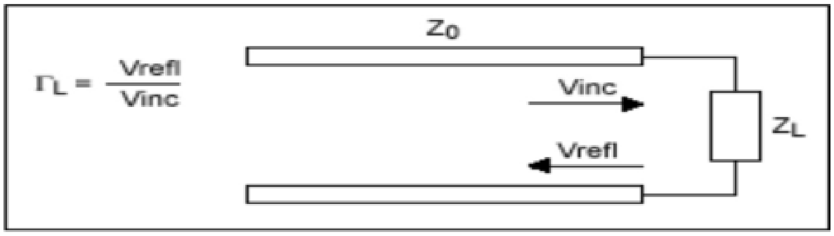


15.SMITH CHART:

A Smith chart is a circular plot with a lot of interlaced circles on it. When used correctly, matching impedances, with apparent complicated structures, can be made without any computation. The only effort required is the reading and following of values along the circles.The Smith chart is a polar plot of the complex reflection coefficient (also called gamma and symbolized by Γ). Or, it is defined mathematically as the 1-port scattering parameter s or s11.



A Smith chart is developed by examining the load where the impedance must be matched. Instead of considering its impedance directly, you express its reflection coefficient ΓL, which is used to characterize a load (such as admittance, gain, and transconductance). The ΓL is more useful when dealing with RF frequencies. We know the reflection coefficient is defined as the ratio between the reflected voltage wave and the incident voltage wave:



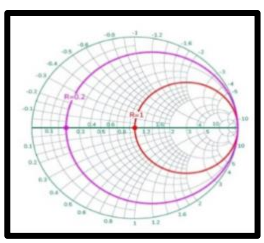
The amount of reflected signal from the load is dependent on the degree of mismatch between the source impedance and the load impedance. Its expression has been defined as follows:

$$\Gamma_L = \frac{V_{refl}}{V_{inc}} = \frac{Z_L - Z_0}{Z_L + Z_0} = \Gamma_r + j\Gamma_i$$

15.1.Components of Smith Chart:

While understanding the Smith chart, we need to understand its components. There are various components depending on the type of Smith Chart which is as follows:

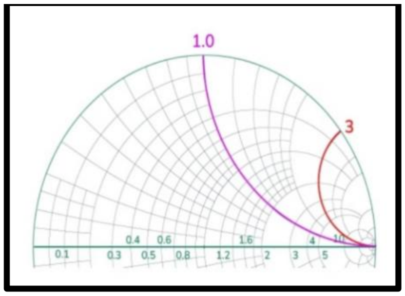
Constant R Circles:



The figure given above represents the constant resistance circle. The horizontal line represents the resistance axis. It is used to represent the complex impedances of the resistive part of circuit. The center having the normalized resistance R=1. A circle (red color) tangent to the right side of the chart which passes through the prime center represents the constant normalized resistance circle with the constant resistance of 1. A similar circle (pink color) which passes through the resistance axis at R=0.2 represents the normalized resistance of 0.2 at every point on that circle.

Constant X Circles

It is known as the constant reactance circle. The reactance axis lies across the the circumference of the Smith Chart. The figure given below represents the constant reactance circle.



Every point along the curve (either pink or red) has the same value of reactance or imaginary part. The points lying on the pink curve have the normalized reactance of 1.0 while the points lying on the red curve have the normalized reactance of 3.0. The upper half of the Smith Chart have the positive reactance value (inductive) while the lower half of the Smith chart have the negative reactance value (capacitive).

15.2.Advantages of Smith Chart:

1.Smith chart helps find the complex impedance and reflection coefficients. It makes the analysis of RF circuits easier.

2.It helps in finding the matching impedance of the network which helps in the maximum transfer of the power.

3.The reflection coefficients can be easily found with the help of Smith Charts. It helps in analyzing and visualizing the impedance mismatches. This helps prevent the signal reflections.

4.With the help of the Smith Chart, we can find the admittance of the circuit easily. It provides additional information about the circuit which enhances the flexibility in the circuit design.

15.3.Applications of Smith Charts:

1.Transmission Line Analysis: Smith charts help in understanding and correcting issues in transmission lines, such as impedance mismatches and signal reflections, critical in high-frequency applications.

2.Antenna Design: Engineers use Smith charts to design and tune antennas for optimal performance by matching the antenna’s impedance to the transmission line’s impedance.

3.Filter Design: In the field of microwave and RF filter design Smith Charts play a role in attaining desired frequency response characteristics by manipulating component values and impedance transformations.

4.Amplifier Design: Engineers utilize Smith charts to optimize input output matching networks of amplifiers in order to maximize gain while minimizing noise levels and distortion.

5.S-parameter Analysis: These charts find application in vector network analyzers where they display S parameters providing information on how electrical signals propagate through a system.

16.POWER MEASUREMENT USING USB POWER SENSORS:

16.1.Average Power:

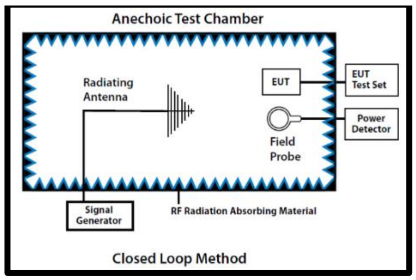
Average power formula is $P=\Delta W/\Delta T$, and P = VI for electric circuits. There is no difference between power and average power. Thus, average power is commonly known as power only.Power has magnitude, but no direction and hence is known to be a scalar quantity. A system's average power is directly proportional to the work done by the energy used and is inversely proportional to the time consumed to complete the work. As per average power definition, it is the total quantity of work done over a specific period.The average amount of energy utilised or work done per unit of time is known as average power. In specific cases, the average power is represented as power only. For example, when the work done over time increases, the average power also increases.

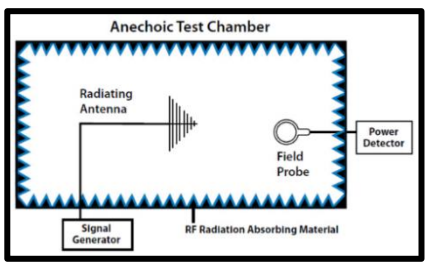
However, if there is no change in the quantity of work done over a continuously increasing time, the average power decreases. Thus, work that can be finished within a short-term duration demands higher average power, and the work done for an extended period has comparatively less average power requirement. You can read about it in a detailed average power definition. The SI Unit of average power is Watt and is represented as 'w' where Watt is Joules per second.

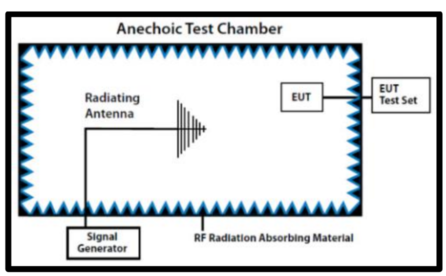
16.2.Average Power Measurement:

Average power is the quantity of work carried out over a specific period. The dimensional formula of average power is L^2MT^{-3}. In the SI units, Watt measures average power. Therefore, the symbol for Watt is 'W'. According to the International Systems Unit, for a total time of one second, if the total quantity of work done or the energy consumed is one joule, the average power is one Watt. Various other units used to measure average power are as follows: Horsepower, Foot pounds per minute, Ergs per second, BTU per hour, dBm, Tons of refrigeration, Calorie per hour (Cal/h).The above units of measuring average power are area-specific.

16.3.Power sensors in Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) testing:





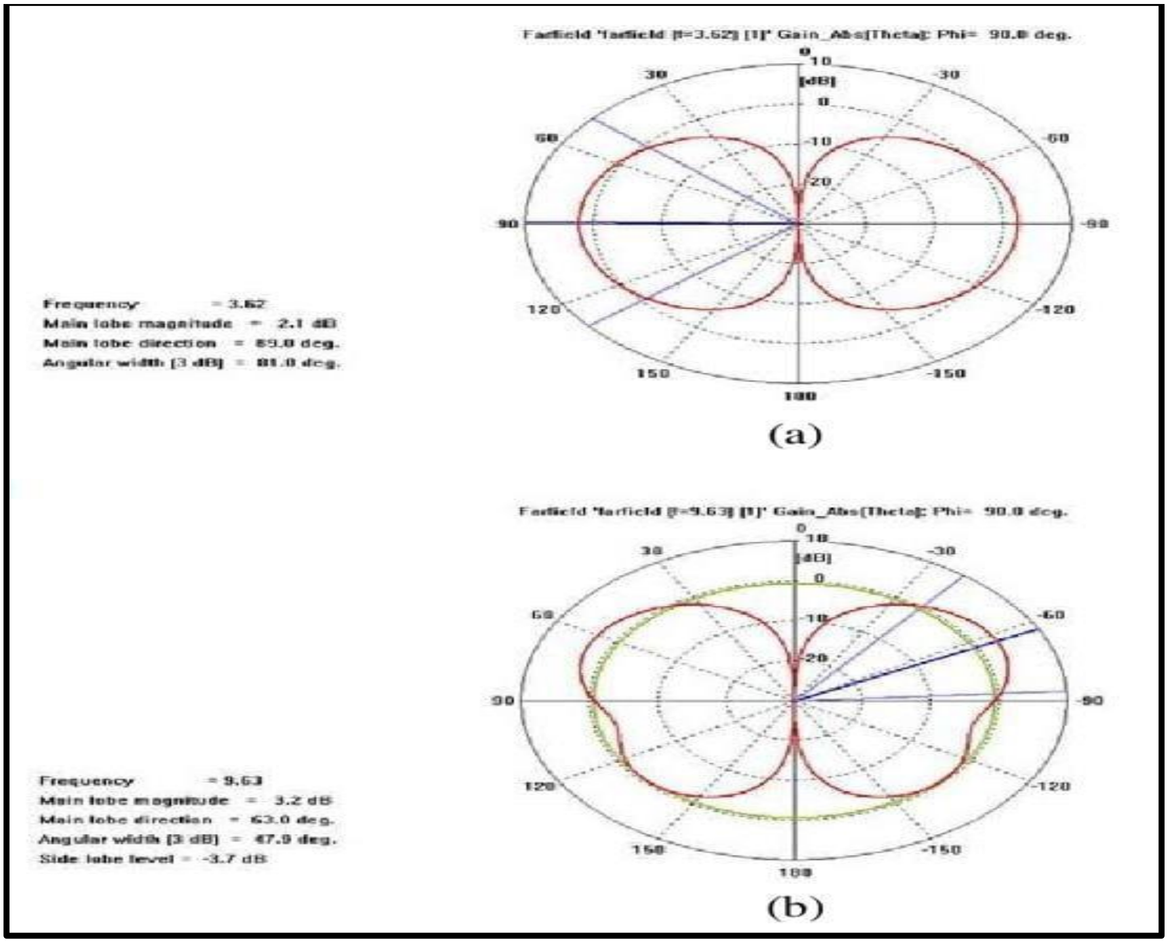


Power sensors are critical components in Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) testing.

17.Performance checking of Biconical Antenna:

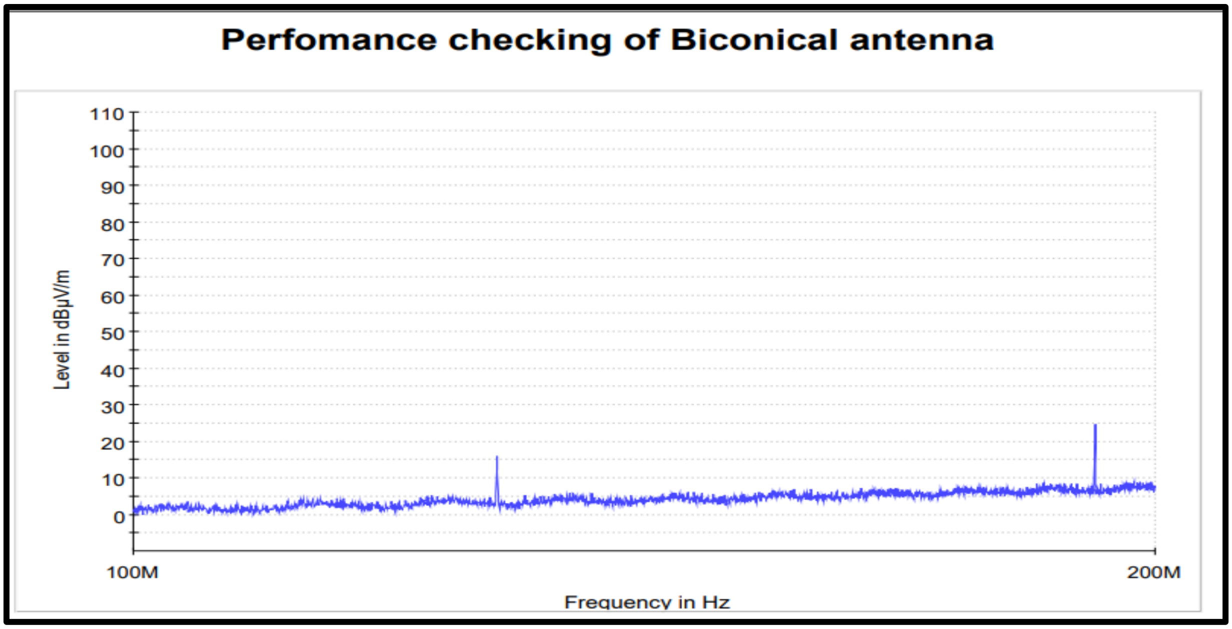
Radiation patterns are a crucial characteristic of antennas, describing how they distribute energy in space.The radiation pattern is a visual representation of the radiation emission from an antenna. Depending on the application, antennas may need 360-degree coverage or in the case of fixed point to point links, the antenna only needs to transmit in front. Below are the radiation patterns for dipole, yagi and parabola.

17.1.Radiation Pattern of Biconical Antenna:



The radiation pattern of a wire biconical antenna is similar that of a half-wave dipole antenna. The wire biconical antenna displays an omnidirectional pattern (circular shape) in the H-plane and a bidirectional (eight-shaped) pattern in the E-plane. The antenna is used in field surveillance and spectrum monitoring applications because of its H-plane beam width.

The wire biconical antenna plays a major role in testing applications due to its advantages over other antennas. Its chief advantages are compact size and broadband characteristics along with omnidirectional radiation pattern. Regardless of the type of test (standard compliance test or simple field monitoring test), the antenna displays efficient performance characteristics



18.CONCLUSION:

This internship has been an enriching experience, providing us with invaluable insights and practical knowledge that will undoubtedly shape our future careers.Throughout our time here, we had the privilege of working alongside talented and dedicated professionals who have generously shared their expertise and guidance. Their mentorship has not only enhanced our technical skills but also instilled in us the importance of collaboration, innovation, and continuous learning. The supportive and nurturing environment of the Vehicle Communication Division has made our journey enjoyable and valuable. We are thankful for the friendships we have formed and the sense of belonging we felt throughout our internship.As we move forward, we carry with us the lessons learned, the skills acquired, and the inspiration to achieve more. This internship has been a pivotal chapter in our professional development, and we are excited to apply what we have learned to future endeavors.

19.REFERENCES:

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