...us·1

ns·1 The most effective measures fall into categories of shielding, filtering, grounding/bonding and system/layout optimization.

1- Shielding

- Shielding involves using conductive or magnetic materials to contain electromagnetic fields (emission) or prevent them
- Enclosures - Use shielded metal enclosures for high-EMI source like the inverter and motor as well as for sensitive electronic control units (ECU's) and sensors These enclosures act as Faraday cages to contain radiated emission
- Cables - Utilize shielded high voltage (HV) cables for the connections between the battery, ~~inverter~~ and motor. The shield must be properly terminated (grounded) to the chassis.
- Gaskets and Seals - Use conductive gaskets or seals at the seams and joints of shielding enclosures to maintain shield continuity, especially around access panels and connectors.

2- Filtering

Filters are used to attenuate or block conducted EMI noise on power and signal lines.

- EMI filters - Implement EMI filter (eg. passive LC, Torl...) on the power supply lines of the inverter and other high power components to suppress both Common Mode (CM) and differtial mode (DM) noise.

- Common Mode Chokes - Uses common mode chokes on high frequency lines and power cable to block common-mode noise, which is a major source of radiated EMI.

- Capacitors: Use decoupling capacitors close to power pins on PCB to suppress high frequency noise and voltage spikes.

- Feed-through filter - Used feed-through capacitors or filters at the point where power or signal lines enter or exit a shielded enclosure to prevent noise from propagating

3- Grounding and Bonding

A robust, low impedance grounding system is fundamental for EMC.

- Low-Impedance Grounding - Ensure all enclosures, shields & grounding points connect to the vehicle chassis with a low-impedance path, typically via short, wide conductor or braids to safely sink EMI current.

- Single-Point Grounding - Strategically design the grounding topology to avoid ground loops, which can create large area current loops that act as efficient antennas for noise.

- Bonding: Ensure good electrical bonding between all metallic structure and components to prevent potential differences that can drive unwanted noise current.

System

- Miti

System and Layout Optimization

- Mitigating EMI often starts with intelligent design and placement of components and wiring harnesses.

- Cable routing separate noisy high-power cables (like those for motors/inverters) from sensitive low voltage LV signal/data cables. When they must cross, ensure they cross at right angles to minimum inductive and capacitive coupling (crosstalk).

- Twisted pair wiring: Use twisted-pair cables for sensitive signal lines (like CAN bus) to ensure the magnetic fields induced by noise currents cancel each other out, significantly reducing noise susceptibility and emissions.

- Minimise Loop Areas: Keep the loop area between the forward and return conductors for power and signal lines as small as possible to minimise the area available for noise coupling, for example by running supply and return lines in close proximity or using laminated bus structures.

- Component placement - Increase the physical distance between the main EMI sources (inverters, motors) and the most susceptible 'victim' ECU's (like the main vehicle control unit).

- PCB Design: Optimize printed circuit Board (PCB) layout for sensitive components by.
  - Using solid ground planes to provide a low impedance return
  - Minimise trace length, especially for high speed switching components.

⇒ Design and Selection Considerations

Ans.2

- The design or robust EMI filter for EV power electronics involves separating and measuring the DM and CM noise components to determine the required attenuation at specific frequencies.

- Common Mode chokes - These are key for CM suppression. They are designed so that the desired differential signal currents create opposing magnetic fluxes that cancel each other out, allowing the signal to pass with low impedance. The unwanted common mode currents create additive fluxes, resulting in a large impedance to the noise

- Capacitors -
- X- capacitor (for DM) are placed across the power lines to shunt differential noise.
- Y- capacitors (for CM) are placed between the power line and the chassis / ground to provide a low impedance return path for common-mode currents.

- Filter topology - LC (inductor-capacitor) filters are common, but CLC filters (capacitor-inductor-capacitor). are often used when high attenuation for both DM and CM is required

Ans. 2

Ans. 2 Relialele satellite communication in the harsh space enviromental requires a multi-faceted approach to reduce EMI from sources like solar radiation and other disturbances. The design strategies focus on three core principles.

- Shielding
- Filtering
- Hardening

- These strategies create physical barriers and controls to prevent interference from entering or being generated within the system.

- Electromagnetic shielding (~~Faraday Cages~~)
- Enclose all sensitive electronics (receivers, signal processing units) in metallic enclosure (like aluminium or copper) that act as Faraday cages to absorb or reflect external electromagnetic waves.
- Use conductive coatings on the satellite's exterior surfaces to block and dissipate incoming radiation.
- Employ EMI gaskets and conductive seals at the seams and openings of shielded enclosures to maintain a continous low-impedance barrier against leakage.

- Optimal Grounding and Bonding
- Ensure a single-point, low impedance chassis ground to prevent voltage differences that can turn the structure into an unintended radiating antenna.
- Use proper bonding between all metallic parts to establish a continuous stable electrical reference and eliminate potential ground loops.

- Cables and Harness Management
- Utilize shielded and twisted pair cables for power and signal lines to reduce electromagnetic coupling prevent cables from acting as antenna for radiated noise.
- Implement optical isolation (fibre optics) for critical data links where possible, as optical lines are immune to electromagnetic interference.

- Low-Noise Power System
- Select and design low-noise power converters (eg - soft-switching power supplies) to minimize the high-frequency switching transients that are major source of EMI.

ystem Hardening and Communication Robustness

To address the specific challenges of solar and cosmic radiation, strategies involve radiation hardening and robust communication protocals.

- Radiation Hardening (Rad-Hard) Electronics

→ Utilize Radiation Hardened (Rad-Hard) components for all mission-critical electronics, which are specially designed and manufactured to withstand the effects of cosmic rays and Solar Particle Events (SPE's).

- Implement Redundancy such as Triple Modular Redundancy (TMR) in critical digital circuits where three identical platform a task and a majority vote logic masks any temporary failure (Single Event Upset and SEU) caused by single high energy. particle strike.

- Advance Communication Techniques

→ Employ spread-spectrum or frequency-hopping techniques which make signal more resistant to interfrence by. disturbing the power over a wider bandwidth or constantly changing the carrier frequency.

- Use of Error Correction Codes (ECC) to detect and correct data corruption caused by noise, ensuring reliable data transfer even with poor signal to noise ratio.

- Circuit and Component-Level Migration

These techniques actively suppress of filters noise at circuit board and component level.

→ EMI filtering components

- Integrate LC filters (inductor-capacitor networks), ferrite beads / chokes, and common chokes on power and signal lines to attenuate high frequency conducted noise.

- Place decoupling capacitor close to the power pins of all integrated circuits to filter out high frequency voltage spikes and ensure clean power delivery.

→ Printed Circuit Board (PCB) best practices

- Design PCB's with solid ground planes to provide a stable electrical reference and minimize common mode emissions.

- Use controlled impedance and employ proper routing (eg. keeping high frequency traces short, separating signal layers from power layers) to minimize crosstalk and radiated emissions.

- Low Noise Power System

→ Select and design low-noise power converters to minimize to high frequency switching transients that are a major source of EMI.

ysical Radiation Shielding

use physical shielding materials (like alumenium, plastics with high hydrogen content, or composite laminates) arous sensetive components to attenuate high energy particles

→ Advanced Materials and Techniques

- In addition to traditional shielding materials, stallelites designers employ advance composite laminates and graded Z sheelding techniques.

- Graded Z-shielding involves layering materials of successively lower atomic numbers (Z). This method is crucial because high Z efficiency materials efficiently stop premiory high energy particles but can generate secondary, lower energy x-rays.

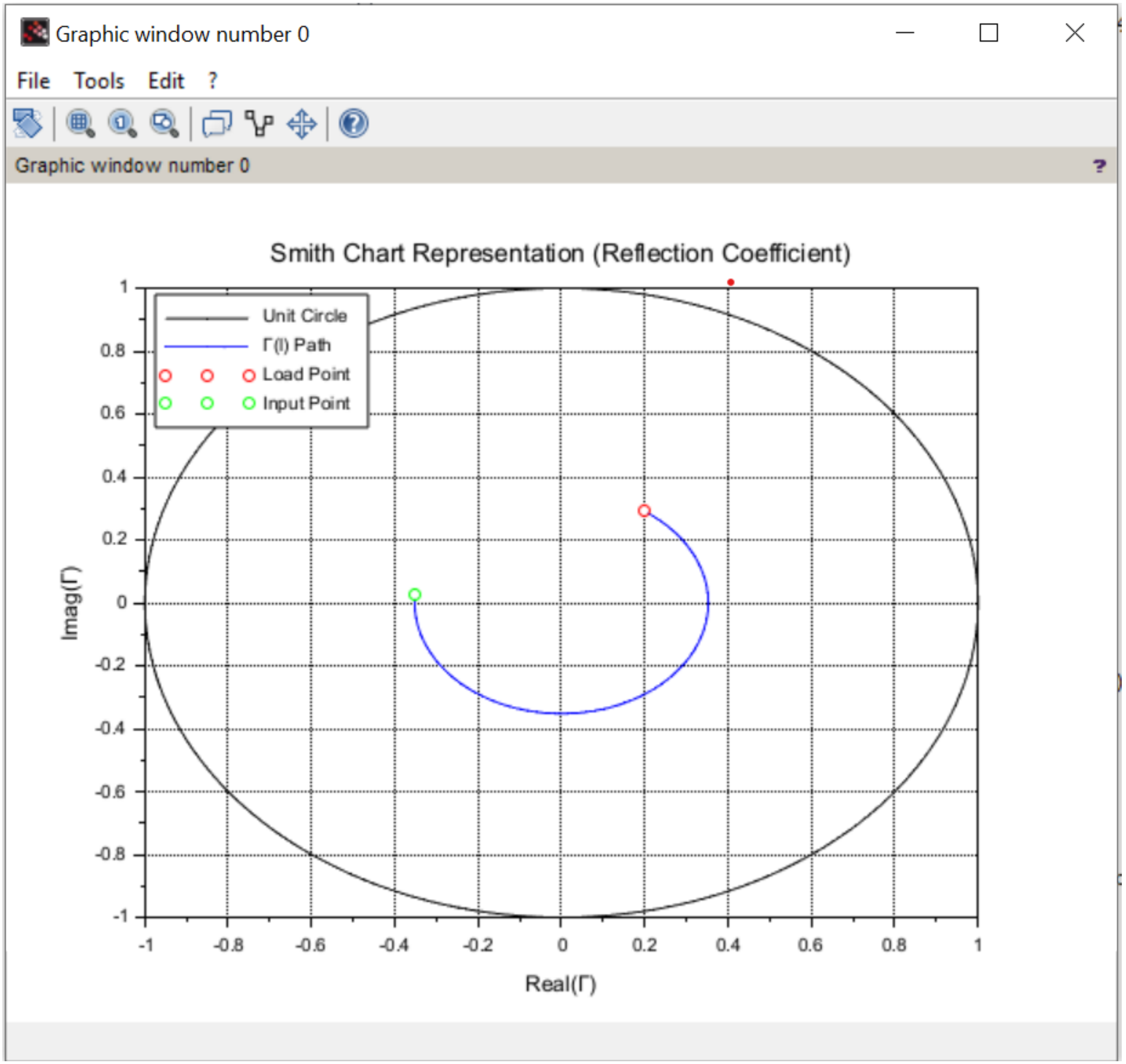
- Placing a low-Z materials like polythylene or other hydrogen rich plastics behind the high Z layer effectively absorbs these lower energy secondary particles, offering superior overall protection the overall weight compared to using a single, thick sheeld.

Scilab 2026.0.0 Console

```
--> Zo = 50;

--> ZL = 60 + %i*40;

--> f = 2e6;

--> c = 3e8;

--> u = 0.6 * c;

--> l = 30;

-->

--> lambda = u / f;

--> beta = 2 * %pi / lambda;

-->

--> GammaL = (ZL - Zo) / (ZL + Zo);

--> Gamma_mag = abs(GammaL);

--> Gamma_phase = atan(imag(GammaL) / real(GammaL));

--> SWR = (1 + Gamma_mag) / (1 - Gamma_mag);

-->

--> n = 200;

--> d = linspace(0, l, n);

--> Gamma_in = GammaL .* exp(-%i * 2 * beta * d);

--> Zin = Zo * (ZL + %i*Zo*tan(beta*d)) ./ (Zo + %i*ZL*tan(beta*d));

-->

--> disp("Reflection Coefficient at Load (ΓL) = " + string(GammaL));
```

Scilab 2026.0.0 Console

```
  "Reflection Coefficient at Load (ΓL) = 0.1970803+%i*0.2919708"

--> disp("Standing Wave Ratio (SWR) = " + string(SWR));

  "Standing Wave Ratio (SWR) = 2.0876619"

--> disp("Input Impedance at l = 30m = " + string(Zin($)));

  "Input Impedance at l = 30m = 23.972955+%i*1.3515496"

-->

--> theta = linspace(0, 2*%pi, 360);

--> x_circle = cos(theta);

--> y_circle = sin(theta);

-->

--> clf;

--> plot(x_circle, y_circle, 'k-');

--> plot(real(Gamma_in), imag(Gamma_in), 'b');

--> plot(real(GammaL), imag(GammaL), 'ro');

--> plot(real(Gamma_in($)), imag(Gamma_in($)), 'go');

--> xlabel('Real(Γ)');

--> ylabel('Imag(Γ)');

--> title('Smith Chart Representation (Reflection Coefficient)');

--> xgrid();

--> axis('equal');
Undefined variable: axis

--> legend(['Unit Circle','Γ(l) Path','Load Point','Input Point'], 2);
```

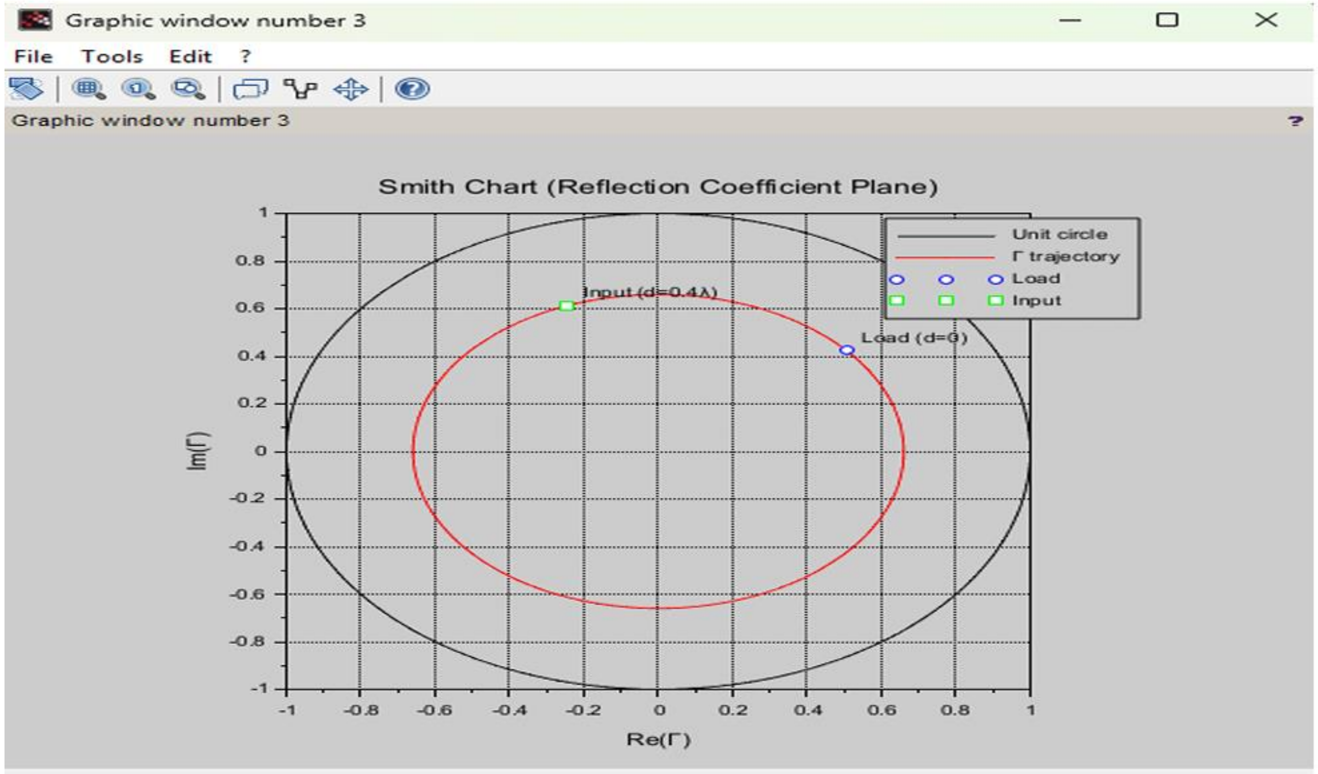

Graphic window number 0
File Tools Edit ?
Graphic window number 0
Smith Chart Representation (Reflection Coefficient)
Unit Circle
Γ(l) Path
Load Point
Input Point
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Imag(Γ)
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Real(Γ)

Scilab 2026.0.0 Console

```
Startup execution:
  loading initial environment

--> Zo = 75;

--> ZL = 100 + %i*150;

--> l = 0.4;

--> lambda = 1;

--> beta = 2 * %pi / lambda;

-->

--> GammaL = (ZL - Zo) / (ZL + Zo);

--> Gamma_mag = abs(GammaL);

--> SWR = (1 + Gamma_mag) / (1 - Gamma_mag);

--> Gamma_in = GammaL * exp(-%i * 2 * beta * l);

--> Zin = Zo * (ZL + %i*Zo*tan(beta*l)) / (Zo + %i*ZL*tan(beta*l));

-->

--> disp("Reflection Coefficient at Load (ΓL) = " + string(GammaL));

  "Reflection Coefficient at Load (ΓL) = 0.5058824+%i*0.4235294"

--> disp("Standing Wave Ratio (SWR) = " + string(SWR));

  "Standing Wave Ratio (SWR) = 4.8783458"

--> disp("Input Impedance at 0.4λ = " + string(Zin));

  "Input Impedance at 0.4λ = 21.964531+%i*47.60816"

-->
```

Scilab 2026.0.0 Console

```
--> disp("Standing Wave Ratio (SWR) = " + string(SWR));

  "Standing Wave Ratio (SWR) = 4.878345815468326"

--> disp("Input Impedance at 0.4λ = " + string(Zin));

  "Input Impedance at 0.4λ = 21.96453113544101+%i*47.6081596723411"

-->

--> theta = linspace(0, 2*%pi, 360);

--> x_circle = cos(theta);

--> y_circle = sin(theta);

-->

--> clf;

--> plot(x_circle, y_circle, 'k-');

--> plot(real(GammaL), imag(GammaL), 'ro');

--> plot(real(Gamma_in), imag(Gamma_in), 'go');

--> xlabel('Real(Γ)');

--> ylabel('Imag(Γ)');

--> title('Smith Chart Representation (Reflection Coefficient)');

--> xgrid();

--> axis('equal');

Undefined variable: axis

--> legend(['Unit Circle','Load Point','Input Point'], 2);
WARNING: Mouse moving picker ON => Console LOCKED
On a figure: Click left to get and set. Click middle to QUIT...
-->
```



Graphic window number 3
File Tools Edit ?
Graphic window number 3
Smith Chart (Reflection Coefficient Plane)
Unit circle
Γ trajectory
Load
Input
Input (d=0.4λ)
Load (d=0)
Im(Γ)
Re(Γ)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1