ELECTROMAGNETIC THEORY AND INTERFERENCE

LLT-1 (Case Study & Simulation)

CASE-STUDY

Q.1) An Electric Vehicle is facing Electronic control system malfunctions caused by EMI from its high-power drive systems. What measures can be taken to Enhance Electromagnetic compatibility among the Vehicle's Electronic components?

Introduction

Electric Vehicles (EVs) use multiple Electronic control systems such as the Battery Management system (BMS), Motor control Unit (MCU), and On-Board Charger (OBC) to Ensure smooth performance. However, these systems often face disturbances caused by Electromagnetic Interference (EMI) from high power drive Systems. EMI can lead to unstable sensor readings, Malfunctioning of controllers, or dirupted communication between components. As EVs depend heavily on Electronics, Ensuring Electromagnetic compatability (EMC) among all components is crucial for safe, reliable operation

Sources of Electromagnetic Interference in EVs

The main sources of EMI in Electric Vehicles are high-power switching devices like MOSFETs and IGBTs used in inverters and DC-DC converters. These components operate at high frequencies, producing sudden voltage and current transitions (dV/dt) and (dI/dt) that generate noise. Additional sources include on-board chargers, power converters, and wireless communication systems. EMI spreads through two primary paths:

* Conducted EMI - Noise transmitted through power lines, affecting connected systems.

* Radiated EMI - Electromagnetic waves Emitted into the Environment, disturbing near Electronic circuits.

Without proper suppression, these interferences can propagate throughout the vehicle and affect sensitive control units.

Effects of EMI on Vehicle Electronics

* ECU Malfunctions - The Electronic unit may interpret inputs or reset unExpectedly.
* Sensor Signal distortion - Noise can corrupt readings from Temperature, speed, or Voltage sensors

* Communication disruptions- EMI can interfere with data transmission on CAN, LIN, or Flex Ray buses.

These issues not only affect performance but can also compromise the safety of Vehicle functions like braking, steering assistance, and Energy Management.

Measures to Enhance Electromagnetic Compatibility

To Reduce EMI and Enhance EMC, both hardware and design-based approaches are Essential.

1.) Shielding and Grounding

Shielding blocks Electromagnetic fields from reaching sensitive components. Using metal closures, conductive coatings, or shielded cables miniatures radiation. Proper grounding Ensures unwanted current flow safely to the chassis or Earth, avoiding interference.

2.) Filtering Techniques:-

Installing EMI filters, LC Networks, ferrite beads, or common-mode chokes on power lines can suppress conducted interference. These filters block high-frequency noise without affecting the desired signals, providing cleaner power.

3.) PCB Design Optimisation :-

Effective PCB design is Key to EMC performance.

* Keeping high-power and low-signal circuits physically seperated.
* Using continuous ground planes to minimize impedance
* Adding decoupling capacitors near integrated circuits.

4.) Cable Management and Routing :-

Cables carrying large currents should be routed seperately from low-voltage signal-lines. Using twisted pairs helps cancel magnetic fields, and shielded cables prevent radiation leakage. Proper cable termination at both Ends is crucial for Effective noise suppression.

5.) Isolation Techniques :-

Galvanic Isolation seperates high-power and low-power circuits, preventing direct EMI transfer. This can be achieved using optocouplers, isolation transformers or digital isolators. Isolation Ensures that noise in one subsystem doesn't affect another.

6.) Use of Ferrite Components :-

Ferrite beads and cores are widely used to suppress high-frequency noise on signal and power lines. They are simple, cost-effective solutions to limit EMI propagation through cables and harnesses.

7.) Software and Control-Based Techniques :-

Software techniques can complement hardware solutions. Spread-spectrum modulation spreads EMI energy over a wider frequency range, reducing peak emissions.

8) Component Selection :-

choosing automotive-grade components with built-in EMI control features - such as snubber circuits and controlled slew rates - can greatly improves system robustness. Proper component selection reduces susceptibility to noise and improves overall system reliability.

Testing and Validation

* Conducted Emission Testing to measure noise on power and ground lines.
* Radiated Emission Testing to assess Electromagnetic field strength.

* Immunity Testing to confirm that Electronic modules operate correctly under interference.

Conclusion :-

Electromagnetic compatibility is Essential for the reliable and safe performance of Electric Vehicles. With increasing system complexity and power levels, EMI management becomes even more critical. By combining shielding, grounding, filtering, isolation, optimized PCB design, and robust component selection, Engineers can achieve Effective EMC. Regular Validation through standard tests ensures long-term reliability. Integrating EMC practices from the design phase Ensures that modern Electric Vehicles remain Efficient, safe, and interference-free.

Q.2) A Satellite Communication system is encountering interference from solar radiation and other Electro-magnetic disturbances in Space. What design strategies can be adopted to Ensure reliable communication and reduce EMI?

Introduction :-

Satellite Communication systems are an indispensable part of global infrastructure, supporting telecommunications, broadcasting, navigation, and remote sensing. These systems operate in the challenging environment of outer space, where they are constantly exposed to solar radiation, cosmic rays, and other electromagnetic disturbances. Unlike terrestrial systems, satellites lack atmospheric shielding, which makes them more valuable to Electromagnetic interference (EMI). Such disturbances can result in degraded signal quality, transmission errors, and even complete loss of communication links. Therefore, ensuring electromagnetic compatability (EMC) through careful design and engineering is essential for maintaining stable and reliable communication between satellites and ground stations.

Nature of Electromagnetic Interference in Space

Electromagnetic interference in space is primarily caused by solar flares, cosmic background radiation, and interactions with charged particles in the magnetosphere. Solar atoms emit high-energy particles that can induce strong electromagnetic pulses, affecting both analog and digital satellite circuits. Additionally, electronic subsystems within the satellite - such as transmitters, processors, and switching power supplies - can generate internal EMI.

Impact of EMI on Satellite communication :-

EMI affects satellite systems in multiple ways. It can lead to data corruption during transmission, reduce signal-to-noise ratios, and cause fluctuations in carrier frequencies. Prolonged Exposure to radiation can also degrade the performance of onboard sensors and communication Transponders.

Design Strategies to reduce EMI and Improve Reliability :-

1.) **Shielding and Grounding :-**

Shielding is one of the most Effective methods to block Engagement of Electromagnetic fields from penetrating sensitive components. Conductive closures are commonly used to protect. Proper grounding Ensures that Excess charge is safely discharged, preventing unwanted current loop that cause noise.

2.) **Frequency Management and Filtering :-**

Proper frequency allocation minimizes overlap between communication channels. Using narrow band-pass filters and digital notch filters isolate the required frequencies and suppress noise signals. Frequency hopping techniques can further reduce vulnerability to persistant interference.

3.) Error Correction and Modulation Techniques :-

Adopting robust modulation schemes such as QPSK (Quadrature phase shift Keying), QAM (Quadrature Amplitude Modulation), and OFDM (orthogonal Frequency Division Multiplexing) ensures better noise resistance.

4.) Antenna Design and Placement Optimization :-

Antenna design plays ~~a critical~~ role in EMI mitigation. High-gain directional antennas limit unwanted signal reception, while polarization diversity minimizes reflection-based interference. Placing antennas strategically away from noise-generating components.

5.) Radiation-Hardened Components :-

Radiation-hardened semiconductors are designed to tolerate high doses of radiation without mal-functioning. These components maintain functional integrity during solar storms, protecting key communication and control subsystems.

6.) Redundant Communication Links :-

Redundancy Ensures reliability. Multiple transponders, duplicate communication channels, and alternate frequency bands can maintain data flow even if one system Experiences interference or failure.

7.) Thermal & Power Management :-

Thermal Variations in space can affect Electronic stability and EMI susceptibility. Efficient thermal control systems and regulated power supply prevent voltage fluctuations that can generate noise or distort communication signals.

8.) Signal Isolation and PCB design :-

The physical layout of circuit boards significantly influences EMI performance. Techniques like seperating analog & digital ground planes, using shielded cables, and routing high-speed traces carefully reduce cross-coupling and internal interference.

9.) Advanced Materials and Coatings :-

Using composite materials that absorb Electro-magnetic waves Enhances EMI protection. Special coatings can deflect solar radiation and prevent static charge buildup, ensuring better surface conductivity and heat dissipitation.

10.) AI-Based Monitoring and Adaptive Control :-

Artificial Intelligence can analyze real-time inter-ference patterns and adapt signal parameters dynamically. By predicting EMI Events and adjusting transmission power of frequency, AI systems improve communication Efficiency and stability.

System-Level Design Considerations :-

Electromagnetic Compatibility Testing :-

Before deployment, ~~satellites~~ undergo rigorous EMC testing in controlled Enviroments. Tests such as radiated Emission, susceptibility, and conducted interference help verify that all components function harmoniously without mutual disruption.

Software-Based Error Mitigation

Apart from hardware, software-level countermeasures are implemented to detect and correct transmission anomalies.

Ground Station Collaboration

Ground control stations play an active role in mitigating EMI effects by monitoring space whether data, and adjusting communication parameters accordingly.

Conclusion :-

In the hostile Electromagnetic Environmental of space, EMI poses a serious a threat to the performance and longevity of satellite communication systems. To Ensure reliability. Engineers must integrate a comprehensive mix of shielding, grounding, adaptive modulation, radiation tolerance, and intelligent monitoring. Each design strategy, from antenna optimization to AI-Based interference prediction, contributes to strengthning Electro-magnetic compatability. As satellite networks Expand with mega constellations and higher data demands, the focus on EMI mitigation will continue to evolve—blending material innovation, intelligent control systems, and advanced testing methodologies to achieve seamless, interference-free communication across the vastness of space.

Q.3) A lossless 30 m long transmission line with Zo=50Ω is established between two ground stations which operate at 2 MHz. The line is terminated with a load ZL = 60+j40Ω. If u = 0.6c on the line. Write a Scilab code to plot the reflection coefficient (Γ), standing wave ratio (S) and input impedance in smith chart.

Source Code:

```
// Scilab script for Q3
// Plots: |Gamma| vs distance, SWR vs distance, and Smith-chart (Gamma plane)

clc;
clear;
close;

// Given
Z0 = 50;            // ohms
ZL = 60 + %i*40;        // load
f = 2e6;            // Hz
c = 3e8;            // m/s
u = 0.6 * c;        // propagation velocity
L = 30;             // line length in meters

// Derived
lambda = u / f;
beta = 2 * %pi / lambda;

// Reflection coefficient at load
Gamma_load = (ZL - Z0) / (ZL + Z0);
Gamma_load_mag = abs(Gamma_load);
```

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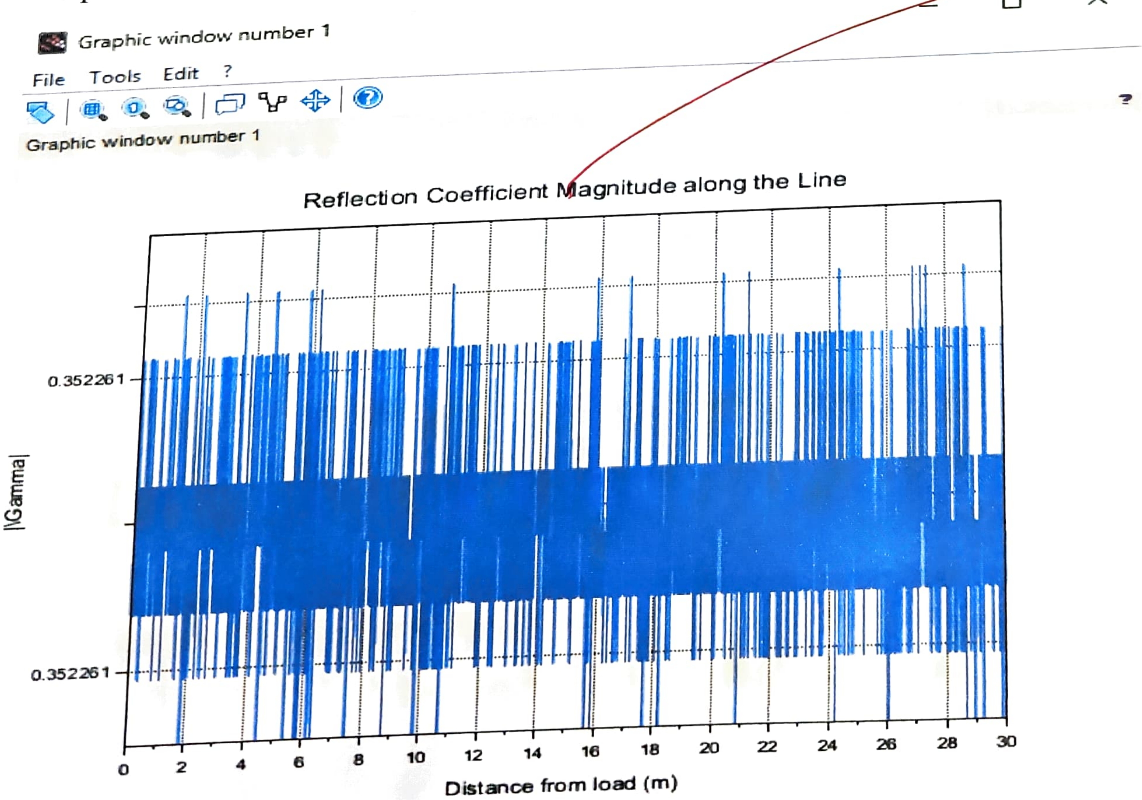
```
Gamma_load_phase_deg = atan(imag(Gamma_load)/real(Gamma_load)) * 180
/ %pi; // approximate angle
SWR_load = (1 + Gamma_load_mag) / (1 - Gamma_load_mag);

// Print numeric checks
disp("Gamma at load: " + string(Gamma_load));
disp(" |Gamma| at load: " + string(Gamma_load_mag));
disp(" Phase (deg) approx: " + string(Gamma_load_phase_deg));
disp(" SWR at load: " + string(SWR_load));

// Sample points along line (0 -> L)
d = 0:0.01:L; // meter resolution (adjust if needed)

// Input impedance along line (lossless)
Zin = Z0 * (ZL + %i*Z0 .* tan(beta .* d)) ./ (Z0 + %i*ZL .* tan(beta .* d));

// Reflection coefficient along line
Gamma_d = (Zin - Z0) ./ (Zin + Z0);

// Plot |Gamma| along the line
figure(1);
plot(d, abs(Gamma_d));
xlabel("Distance from load (m)");
ylabel("|\Gamma|");
xtitle("Reflection Coefficient Magnitude along the Line");
xgrid();

// Plot SWR along the line
```

```
SWR_d = (1 + abs(Gamma_d)) ./ (1 - abs(Gamma_d));
figure(2);
plot(d, SWR_d);
xlabel("Distance from load (m)");
ylabel("SWR");
xtitle("Standing Wave Ratio along the Line");
xgrid();

// Smith chart (Gamma plane)
// Unit circle
theta = 0:0.01:2*%pi;
cx = cos(theta);
cy = sin(theta);

// Prepare points for overlay: Gamma trajectory
realG = real(Gamma_d);
imagG = imag(Gamma_d);

// Compute Gamma at input end (d = L) for annotation
Gamma_input = (Zin($) - Z0) / (Zin($) + Z0); // Zin($) = last element
// (Gamma_load already computed for d=0)

// Plot unit circle and Gamma trajectory on same axes
figure(3);
plot(cx, cy, 'k'); // unit circle
// Overlay trajectory and key points in one plot call
plot(cx, cy, realG, imagG, 'r-', real(Gamma_load), imag(Gamma_load), 'bo',
real(Gamma_input), imag(Gamma_input), 'gs');
```

```
xlabel("Re(\Gamma)");
ylabel("Im(\Gamma)");
xtitle("Smith Chart (Reflection Coefficient Plane) - Trajectory of \Gamma(d)");
xgrid();
// keep equal axis scale
a = gca();
a.isoview = "on";
legend(["Unit circle", "Gamma trajectory", "Load (d=0)", "Input (d=30 m)"], 1);

// Optionally annotate numeric values near points
// (Simple text annotations)
xstring(real(Gamma_load)+0.03, imag(Gamma_load), "Load (d=0)");
xstring(real(Gamma_input)+0.03, imag(Gamma_input), "Input (d=30 m)");
```

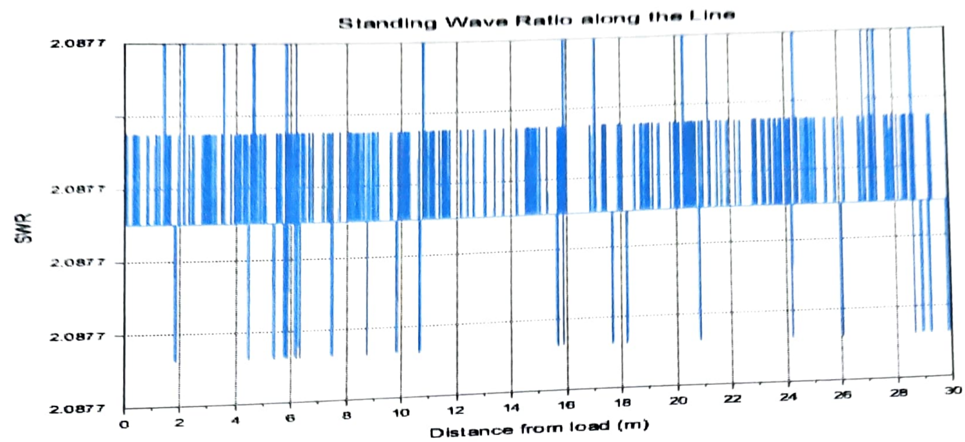
Output:



Graphic window number 2

File Tools Edit ?

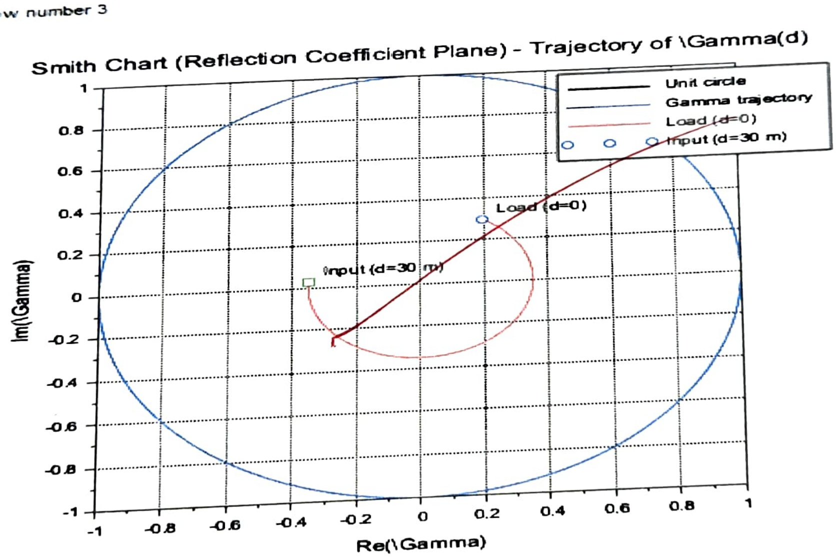
Graphic window number 2



Graphic window number 3

File Tools Edit ?

Graphic window number 3



Scilab 2026.0.0 Console

File Edit Control Applications ?

Scilab 2026.0.0 Console

```
"Gamma at load: 0.1970803+%i*0.2919708"
" |Gamma| at load: 0.3522607"
" Phase (deg) approx: 55.98065"
" SWR at load: 2.0876619"

-->
```

Q.4) In a satellite base station, a load of 100 + j150 Ω is connected to a 75Ω lossless line. Write a Scilab code to plot the Reflection coefficient (Γ), SWR value and input impedance (Zin) at 0.4λ from the load.

Source Code:

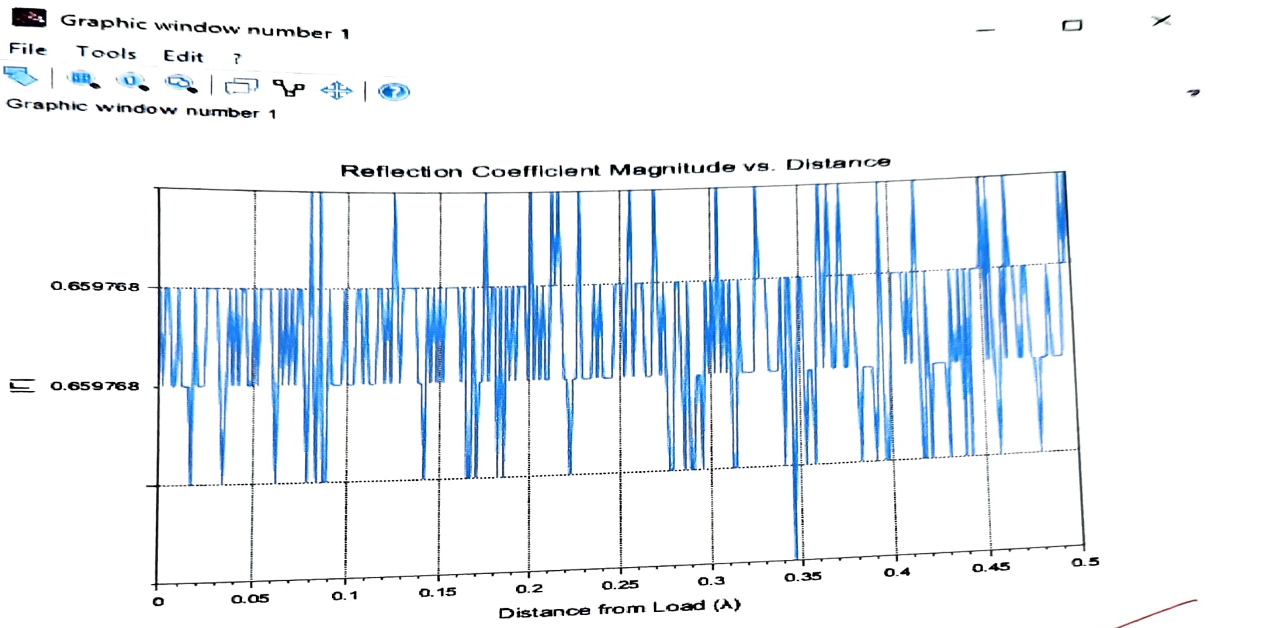
```
// Q4 - Electromagnetic Theory and Interference

// Satellite base station simulation

// Compute and plot Reflection Coefficient, SWR, and Zin at 0.4λ


clc;

clear;

close;


// Given data

Z0 = 75;            // Characteristic impedance (ohms)

ZL = 100 + %i*150;  // Load impedance (ohms)

lambda = 1;         // Normalized wavelength (unit value)

d = 0.4 * lambda;   // Distance from load (in wavelengths)


// Reflection Coefficient at Load

Gamma_L = (ZL - Z0) / (ZL + Z0);

Gamma_mag = abs(Gamma_L);

Gamma_phase_deg = atan(imag(Gamma_L)/real(Gamma_L)) * 180 / %pi;


// Standing Wave Ratio

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


// Input Impedance at distance d = 0.4λ
```

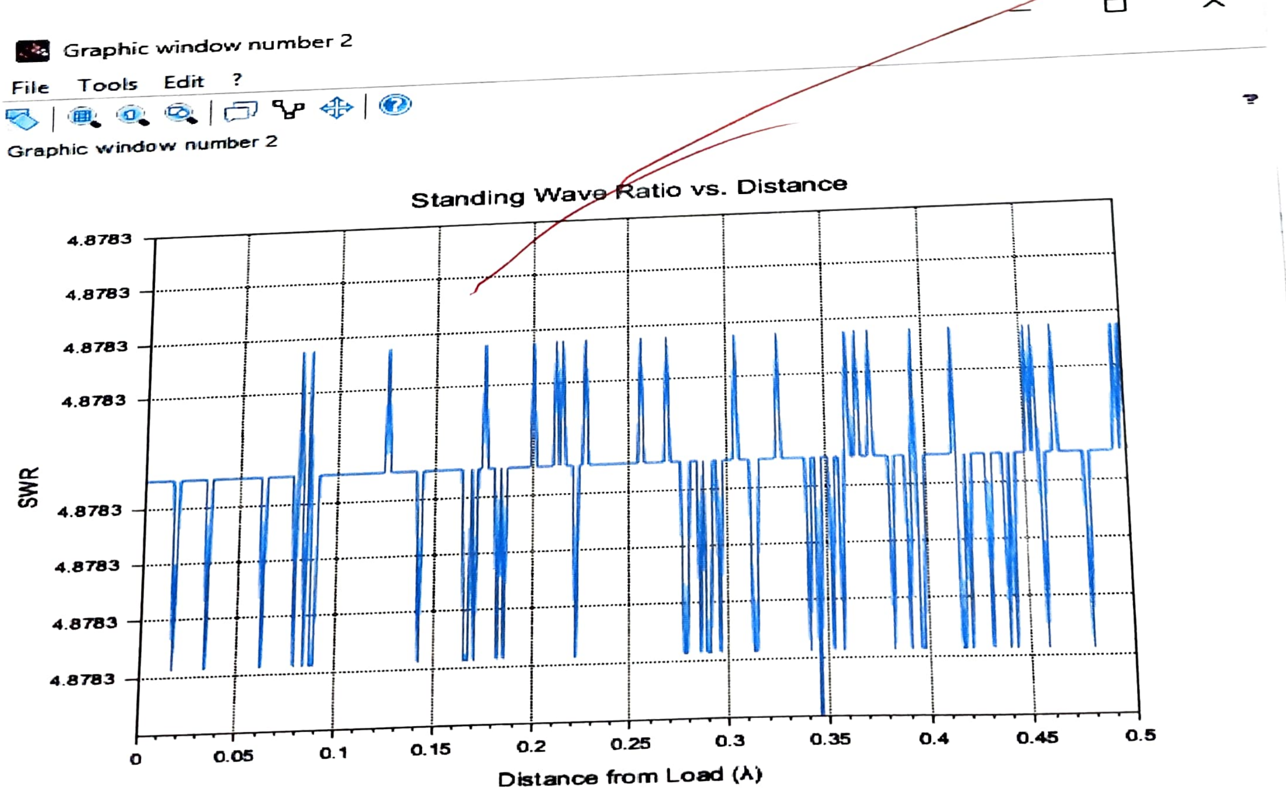
```
beta = 2 * %pi / lambda;          // Phase constant (rad/m)
Zin = Z0 * (ZL + %i*Z0 * tan(beta*d)) / (Z0 + %i*ZL * tan(beta*d));

// Display results
disp("--------------------------------------------------");
disp("Reflection Coefficient (Γ_L): " + string(Gamma_L));
disp("|Γ_L| : " + string(Gamma_mag));
disp("Phase of Γ_L (degrees): " + string(Gamma_phase_deg));
disp("Standing Wave Ratio (SWR): " + string(SWR));
disp("Input Impedance at 0.4λ (Zin): " + string(Zin));
disp("--------------------------------------------------");

// For visualization, sweep along 0 to 0.5λ for Γ and SWR variation
d_values = linspace(0, 0.5*lambda, 300);
Zin_values = Z0 * (ZL + %i*Z0 .* tan(beta .* d_values)) ./ (Z0 + %i*ZL .*
tan(beta .* d_values));
Gamma_d = (Zin_values - Z0) ./ (Zin_values + Z0);

// Plot |Γ| vs. distance
figure(1);
plot(d_values, abs(Gamma_d));
xlabel("Distance from Load (λ)");
ylabel("|Γ|");
title("Reflection Coefficient Magnitude vs. Distance");
xgrid();

// Plot SWR vs. distance
SWR_d = (1 + abs(Gamma_d)) ./ (1 - abs(Gamma_d));
```

```
figure(2);
plot(d_values, SWR_d);
xlabel("Distance from Load (λ)");
ylabel("SWR");
title("Standing Wave Ratio vs. Distance");
xgrid();

// Smith Chart (Γ plane)
theta = 0:0.01:2*%pi;
cx = cos(theta);
cy = sin(theta);
realG = real(Gamma_d);
imagG = imag(Gamma_d);

figure(3);
plot(cx, cy, 'k'); // unit circle
plot(realG, imagG, 'r-');
xlabel("Re(Γ)");
ylabel("Im(Γ)");
title("Smith Chart (Reflection Coefficient Plane)");
xgrid();
a = gca();
a.isoview = "on";

// Mark important points
plot(real(Gamma_L), imag(Gamma_L), 'bo');
Gamma_input = (Zin - Z0) / (Zin + Z0);
```

```
plot(real(Gamma_input), imag(Gamma_input), 'gs');
xstring(real(Gamma_L)+0.03, imag(Gamma_L), "Load (d=0)");
xstring(real(Gamma_input)+0.03, imag(Gamma_input), "Input (d=0.4λ)");
legend(["Unit circle", "Γ trajectory", "Load", "Input"], 1);
```

Output:

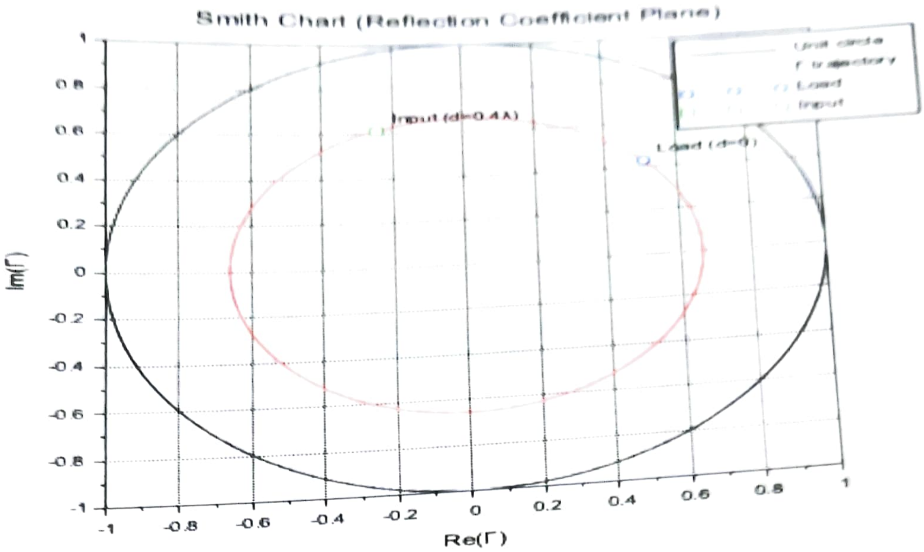




Graphic window number 3

File Tools Edit ?

Graphic window number 3



Scilab 2026.0.0 Console

File Edit Control Applications ?

Scilab 2026.0.0 Console

```
"-------------------------------------------------------"
"Reflection Coefficient (Γ_L): 0.5058824+%i*0.4235294"
"|Γ_L| : 0.6597682"
"Phase of Γ_L (degrees): 39.936383"
"Standing Wave Ratio (SWR): 4.8783458"
"Input Impedance at 0.4λ (Zin): 21.964531+%i*47.60816"
"-------------------------------------------------------"

-->
```