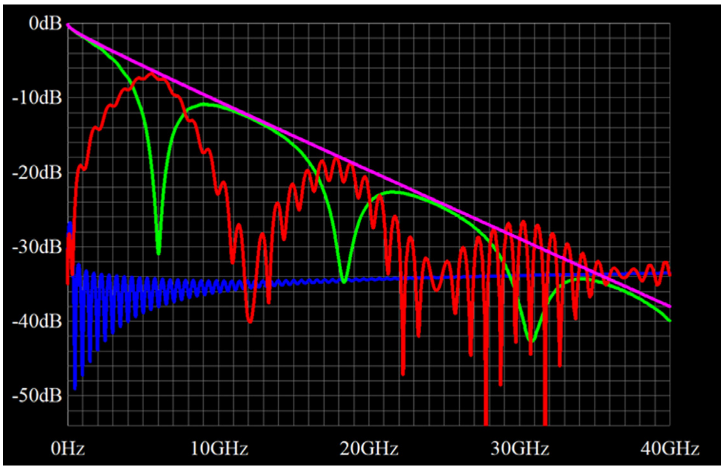
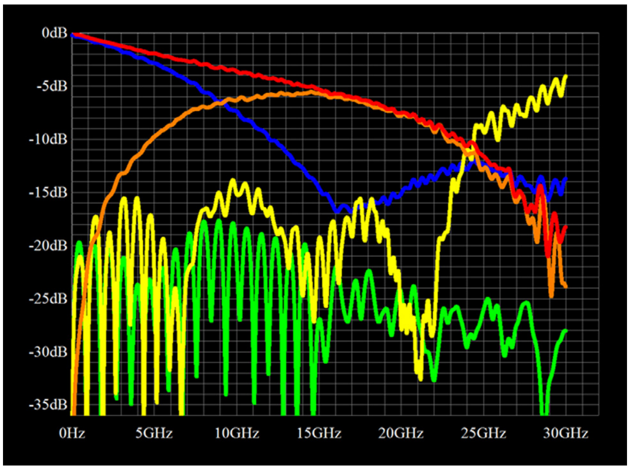
INTERLLIGENT
RF & Microwave Solutions

S parameters

for Broadband Analog/High-Speed Digital Designs

4-day (36 study hours) course





RF is our Business... Signal us!

S parameters for Broadband Analog/ High-Speed Digital Designs

Background

Scattering parameters (S-parameters) carry fundamental importance in RF, microwave and high-speed digital designs. Their mathematical properties, such as magnitude, phase and combined matrix representation, provide the designer essential insights for the analysis and design of broadband devices, PCBs and packages. The concept of S-parameters originated from microwave network theory and distributed systems. Yet, with the rising data rates of today's digital interfaces, S-parameters analysis becomes not only the property of microwave engineers, but also for high-speed digital engineers.

In this course, the fundamental properties of scattering parameters will be studied, both single-ended as well as mixed mode, differential and common. The study will include their mathematical derivation, properties and their use in PCB and package analyses such as attenuation, reflections, crosstalk, mode conversion, dispersion, ground bounce and others. The aim of the course is to provide the course participants with extensive practical and theoretical knowledge in order to understand and use S- parameters in their designs.

Due to the dual use of S-parameters in microwave and high-speed digital applications, this course can be suitable for both microwave engineers as well as high-speed digital designers and signal integrity engineers.

The topics include:

- Extensive S parameters practice and theory
- Design, analysis and measurement of PCB and package high-speed elements using S parameters
- Dozens of examples from simulations and network analyzer measurements
- Proof of design and failure investigation using S parameters
- Familiarizing with S parameters simulation and measurement tools.
- Defining how much reflection, attenuation, xtalk and mode-conversion is too much by using S parameters
- Briefing on data sheets and common specifications

Presenter

Dror Haviv received his Master of Science (M.Sc) degree in electrical engineering with honors from the Electromagnetic and Microwave program at Ben-Gurion University (Beer-Sheva, Israel). He is one of Israel's leading Signal and Power Integrity (SI/PI) engineers and has years of design, analysis, measurement, and teaching experience in the signal integrity field behind him.

Today, Dror serves as a Technologist at the Signal and Power Integrity team at Western Digital ASIC platform engineering organization. His job duties include flash controllers' signal and power integrity design, silicon die and package co-design, modeling, system level signal and power integrity simulations and correlation analysis of die/package SI/PI parameters between simulation and measurement results.

From 2010-2019, Dror served as signal integrity focal point and architect with Rafael's R&D division. As a signal integrity architect, he designed, analyzed, simulated, and measured dozens of systems and PCBs for high-speed interfaces. As focal point, he has qualified, educated, trained, and supervised many engineers in the signal integrity field. Simultaneously, he served as a senior signal integrity cooperate researcher and has conducted several research projects in the field. His research has been presented in conferences on signal integrity, both in Israel and abroad.

Target audience

All professional engineers that are involved in design, qualification and manufacturing of products that contain high-speed frequencies/interfaces, such as: RF, microwave, board design, signal integrity, layout, verification, integration, system and process manufacturer engineers.

Course Duration

4 days (36 hours) from 8:30-17:30

Course Structure

The course includes extensive practical and theoretical background, examples from simulations and measurements, open discussions, briefing on common specifications and etc.

Course Syllabus * Subject to changes *

1. Introduction to S Parameters

- Electromagnetic theory vs microwave network analysis
- What are Scattering parameters (S parameters)
- Sources for S parameters
- Introduction to S parameters
- Sine waves properties in LTI systems
- Two ports device Return Loss - S11
- Two ports device Insertion Loss - S21
- The TouchStone file - SnP
- S, Z and Y parameters relationships
- S parameters passivity, reciprocity, symmetry and causality
- The balance equation
- Dispersion
- The digital signal band-width
- Lumped vs distributed systems and the critical length
- Introduction to transmission lines.
- The signal and return conductive currents in transmission lines
- Local (Instantaneous) vs Characteristic impedance
- The edge zone and the edge spatial resolution
- The Time Domain Reflectometer (TDR) - T11, T22
- Examples from simulations and measurements

2. Principles of Return Loss and Insertion Loss

- Maxwell equations principles
- The skin effect and skin depth
- The proximity effect
- The smooth copper model for attenuation
- Models for surface roughness: Hammerstad, hemispherical, Hurray
- Low loss approximation for conductor loss attenuation
- Dielectric loss, displacement current, dissipation factor
- Low loss approximation for dielectric loss attenuation
- The total attenuation – S21
- Insertion loss S21 vs attenuation
- The Return loss S11 and Insertion loss S21 ripples – single discontinuity
- The connection between the discontinuity electrical length and S11,S21 ripple spacing
- The connection between the discontinuity value and S11,S21 ripple intensity
- Connecting the DUT directly to the Source Ports
- The impact of the coaxial connector on S11 return loss
- Source impedance ZS re-normalization
- Inter Symbol Interference (ISI) due to S11 and S21
- How much S11 return loss is too much?
- Examples from simulations and measurements

3. Return Loss and Insertion Loss of Typical Resonators

Transmission line stub

- T topology vs topology with stub
- The quarter wave stub 1D resonator: S11 and S21 patterns, the resonance frequencies, Q factor
- Thinking about interconnect as 1D resonator
- The stub length vs the data rate

via stub

- vertical interconnect access (via) stub
- via and via stub - 2.5D model
- via stub - S11 and S21 patterns, the resonance frequencies, Q factor
- Minimizing the via stub effects

High-Q 3D cavity Resonator

- Coupling to high-Q 3D resonator
- 1D vs 3D cavity resonator

- 3D Cavity resonator: S11 and S21 patterns, the resonance frequencies, Q factor
- ISI, GND noise, power noise and jitter due to coupling to high-Q 3D resonator
- Ways to reduce coupling to high-Q 3D resonator and the impact on S11 and S21

The impedance of 1D and 3D cavity resonators in the frequency domain

Coaxial Connectors

- Resonances in coaxial connectors and the impact of the return path vias
- Coaxial connectors - rectangular and cylindrical resonances and the impact on S11 and S21
- Single-ended via matching, shielding and radiation, the impact on S11 and S21
- Coaxial via structure - the circular cavity resonator, S11 and S21 patterns, the resonance frequencies
- Coaxial connectors – from SMA (12 GHz) to 1 mm (110 GHz) evolution
- Examples from simulations and measurements

4. Obtaining Circuit Characteristics with S Parameters

- 1 port impedance analyzer
- Obtaining transmission line (TL) Z0, capacitance and inductance with S parameters
- 2 ports impedance analyzer: first and second order approximation
- Dynamic range of a vector network analyzer (VNA)
- Measuring and simulating the impedance of PDN, resistors, vias and capacitors with 2 ports impedance analyzer
- Obtaining the TL dielectric constant with S parameters
- The skin effect dispersion
- Dispersion artifacts due to high S11 return loss
- Types of inductances: Self Loop Inductance (SLI), Mutual Loop Inductance (MLI), Self-Partial Inductance (SPI) and Mutual Partial Inductance (MPI)
- The influence of the skin and proximity effects on the loop inductance
- The physical meaning of the partial inductances
- The relationship between loop and partial inductances
- Different types of port connections in S parameter simulations
- The impact of the port connection type on the S parameter results
- The influence of the inductance on each port connection type
- Examples from simulations and measurements

5. Mixed Mode S Parameters

- The superposition of differential and common signals
- Pure differential signal vs mixed signal (differential + common)
- The even and odd modes of the interconnects
- The effects of coupling on TL properties (characteristic impedance and velocity) in even and odd modes – Zodd and Zeven
- The differential and the common impedances – Zdiff, Zcom
- 4 ports S parameters
- The Mixed Mode S parameters matrix
- Principles of conversion single-ended S parameters to Mixed Mode S parameters
- The “M Matrix”
- The convenient vs the confusing single-ended S parameters port assignment
- The Mixed Mode source impedance
- The balance equation for 4 ports DUT
- Principles of Differential Return Loss – SDD11
- How much differential return loss SDD11 is too much?
- Using SDD11 for impedance matching
- How Much differential insertion loss SDD21 is too much?
- Tightly vs loosely coupled differential pair SDD21 attenuation
- The impact of Ground Bounce on the Insertion loss
- SDD21 and SCC21 of differential pair coupled to Hi-Q cavity resonator
- Summary of typical SDD21 and SCC21 insertion loss patterns
- De-embedding
- Cascading S-parameters, T-parameters
- The principles of de-embedding
- Ways to obtain the fixture’s S-parameters
- De-embedding using TRL and SOLT calibration types
- Time domain Gating - port extension, impedance peeling
- Examples from simulations and measurements

6. Cross-talk (XTALK) S Parameters

- The return current distribution in microstrip and stripline
- The return current and xtalk
- Coupling by mutual inductance and capacitance
- Near End xtalk (NEXT) S31 and Far End xtalk (FEXT) S41
- NEXT and FEXT - single-ended and Mixed-Mode S parameters
- Ripples in NEXT pattern - S31, SDD31

- Differential SDD11,SDD21 vs single-ended S11,S21 due to coupling
- Tightly vs loosely coupled differential stripline
- S31,S41 coupling in differential microstrip
- Calculating the resonance frequencies for S41 FEXT
- Analyzing the xtalk location along the interconnect
- Differential xtalk SDD31, SDD41 - tightly vs loosely coupled differential pairs
- Investigating the differential xtalk SDD31 ,SDD41 with single-ended S parameters
- Simplifying large S parameter models
- Xtalk by cavity resonators – S31,SDD31 and S41,SDD41 patterns
- The Hybrid S parameters matrix
- How much xtalk is too much?
- ICR – insertion loss to Cross-talk ratio
- Xtalk in connectors
- Examples from simulations and measurements

7. Mode Conversion S Parameters

- What is and what causes Mode Conversion – SCD, SDC
- Mode Conversion – why do we care?
- Termination of the odd and the even modes
- Differential to common (SCD) and common to differential (SDC) S parameters
- Investigating mode conversion SCD and SDC with single-ended S parameters
- Resonance frequencies in SCD and SDC
- How much Mode Conversion SCD and SDC is too much?
- Summary of typical differential insertion loss SDD21 and common insertion loss SCC21 patterns due to mode-conversion SCD,SDC
- Serpentine – principles of operation, where to place and how to design
- Serpentine in tightly vs loosely coupled differential pair
- The impact of the serpentine on the differential return and insertion loss SDD11, SDD21 and on SCD21 and SCD11
- Coupling within the serpentine
- Analyzing the Mode Conversion location along the interconnect
- Examples from simulations and measurements