EMCT
Electromagnetic Compatibility Tutorial ®

OVERVIEW

What is the EMCT?

The EMCT: Electromagnetic Compatibility Tutorial is a PC-based EMC educational tool available via download or on a CD-ROM. It combines the best qualities of a classroom instructor, a seminar, and a book in one extremely convenient and very powerful teaching medium.

What do the Experts Say?

Howard Johnson, Ph.D., in an article in Electronic Design News said:

"… Let me tell you about a CD-ROM tutorial I saw this week that flipped my bits. The CD-ROM is written by my favorite EMC guru, W. Michael King … If you can't get King to personally train you, the next best thing is to check out his CDROM… EMCT Tutorial is a very high-quality offering."

IEEE Peer Review Process: The EMCT has successfully completed the IEEE Peer review process. That's two thumbs up from EMC professionals in the field, assuring you that the EMCT meets the highest quality standards.

PC-based Educational Program for EMC

With seminars, you tend to get information that quickly fades. With the EMCT, you work with the tutorial at your own pace and retain the material much more effectively. In addition, you don't have to give up your prime work time or disrupt your schedule to go off to a class. Lastly, you will have the ability to easily revisit and brush up on any information that has faded from memory.

Benefits of The EMCT

The EMCT provides over 1600 images in dazzling color using mixed media. There are 3-D animated graphics, photographs, plots, schematics, and block diagrams. All the images are in vivid color. Some of EMCT's images are even animated, 3-Dimensional graphics depicting radiating fields (books can't show you moving images). Remember the old saying "a picture is worth a thousand words"? You'll learn EMC faster because you'll remember the images you've seen – they will help cement the concepts in your mind.

EMC is a complex subject. In this tutorial, the author masterfully weaves the concepts of EMC into a powerful understanding of complex systems – one simple layer at time. The teaching method is both conceptual and intuitive. Throughout the tutorial, you're provided with numerous design examples and design rules. And, what's most important – you're not just blindly learning a bunch of rules. Always, you're learning the core concepts, so you'll know when and where to apply the design rules.

Would you like to be able to "drill down" for more information on topics that are of particular interest to you? Many topics contained in the EMCT provide additional screens to clarify and further explain key concepts.

The EMCT is self-paced. You can move along at a tempo that suits your needs. Seminars and classes move along at a predetermined pace and you are forced to keep up, even when a key concept has not been made clear to you and instructors can sometimes run out of time, forcing them to shorten their presentation or truncate important topics. Not so with the EMCT. You will always be able to go back as often as you like to absorb the key information at your own pace and on your own schedule.

New to EMCT Version 3.0

Along with the new content in the Propagation Module and the new Troubleshooting module which contains 3 sections including Concepts, Conducted Emissions, and Radiated Emissions troubleshooting, several graphical and usability enhancements have been implemented and in total 270 screens have been added in this latest version of the EMCT. The screen resolution has been increased. This means there's more room for the graphics images and less "page" turning on your part. The screen navigation options have also been expanded. You are now able to jump to a selected topic directly from the table of contents. In addition, a comprehensive and unified index allows you to jump to topics anywhere in the tutorial – try doing that in your seminar or class notes!

Would you rather navigate with your keyboard? In addition to using your mouse, the new release of the EMCT allows you to use your arrow keys to quickly navigate through the content. Perhaps you just want to jump to a particular page? Just use the navigation bar over to page 46 and you're there instantly. And now when you detour off the main path, the sub-tier slides are numbered as well, making it easy for you to keep track of where you are on the alternate path. We have done everything possible to make the EMCT as functionally convenient and easy to use as possible.

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Upgrade Pricing - Customers who have purchased previous versions of EMCT are eligible for special upgrade pricing options. Please contact us at info@emctutorial.com for more information.

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Propagation from Devices, Circuit Boards, and Chassis (454 screens)

With the Propagation Module, we're introduced to the primary mechanisms that create EMI from active circuit boards. Using a layered teaching approach, we first learn about the fields that are created by a single device. Then, building on those concepts, we can understand the more complex fields that emanate from several devices, including how circuit boards couple EMI currents to attached wires or cables and form radiating antenna structures. Along the way, we learn the Fourier approach–that digital waveforms are comprised of many higher frequency sine waves. By a careful progression through important EMC design concepts, we're brought to the heart of the Propagation Module: Circuit Board Layout Considerations. In this all-important section, we learn how circuit boards create distributed transmission lines with respect to chassis structures and surface planes. We learn how to control EMI propagation using the reflection losses and null formations that form within the distributed transmission lines that are setup between the boards and the chassis. Then, we learn how to minimize losses by flux and inductive cancellation using transmission-line methods in the stack-up of circuit boards and individual traces. Finally, we study the techniques we'll need to reduce EMI coupling by partitioning the circuitry.

Introduction to EMC (43 Screens)

- Blocked and Lumped Equivalent Models
- Coupling Interrelationships to Chassis Structure
- Interface Connections as Antenna Equivalents
- Overview of Conductive-Case Shielding Containment
- Initial Susceptibility "Intrusions" Presented by ESD
- Interface Role as Antennas for "Exit and Entry Currents" in Susceptibility - Immunity Performance
- Overview of common-mode and Architectural Considerations

Section A - Logic Devices and Circuit Boards

- Logic Drivers and Cross-Conduction Currents
- Spectral EMI Characteristics of Various Signal Waveforms
- Spread Spectrum Approaches
- Common-mode Structures Within Circuit Boards
- Significance of Propagation Through an Imperfect Plane
- Peak Currents and Repetitive Impulse Surges
- Coupling of Common-mode Potentials to Heat Sinks and Heat Sink Arrays with resulting currents
- Storage Capacitors: Layout Locations, Methods, Rationale and Resonances
- "Array" Effect of Multiple Circuit Devices
- Interface Wires and Cables as Antenna Structures

Section B - Field Transfers To Structures from Circuit Boards

- Concept of Distributed Common-mode Transmission Lines
- Relationship and Modes of Field Transfers to Chassis Planes (adjacent conductive mechanical structures)
- Chassis Planes as Common-mode Image Returns: in Distributed Line and Surface Patch Modes
- Spectral Profile Alterations Derived from Imposition of Chassis Planes
- Multi-Mode Propagation Arrays
- Equivalent "Antenna Radial Propagation" of Common-mode Currents in Interface Wires and Cables
- Use of "Ground Nulls"
- Common-mode Field Displacements and Transfer Impedances to Chassis Structures
- Susceptibility Effects with "Ground Null" Implementations
- Concepts of Common-mode Regional Partitioning Through "Moats" and "Isolation Zones" to Increase Signal-noise Ratios

Section C - Circuit Board Layout Considerations

- Concept Review of Transmission Lines in Signal and Power
- Flux Linkage; Flux and Inductance Cancellation
- Dichotomous "Breaks" in Transmission Lines, and Occurrences of "Break-equivalents" in Circuit Boards
- Descriptions of Return Images in Relationship to Flux Linkage
- Reviews of Transmission Lines:
  - o Micro-Stripline, Stripline, Embedded Micro-Stripline; Asymmetrical Stripline, Edge-Coupled Differential Line; Broadside Coupled Differential Line
- Transmission Line Impedance Characteristics
- Power Plane Configurations and Impedances with Signal Imaging
- Circuit Board "Stack-up" Considerations for Power and Signal
- Power Planes and Edge Impedance Terminations
- Undercut Power Planes
- Multiple Dielectric Separations
- Skin Effect and Skin Depths
- Flux Linkage Patterns- "6-H" Rule
- "3-W" and "10-W" Trace Width Rules for Flux Boundaries of Traces – Derivations from "6-H" Rule
- Signal and Power Imaging for Various Board Layer Stack-ups
- Transmission Line Image Return Skew with Layer-Jumping Through Vias
- Skew Route Patch for Layer-jumping
- Factors for Consideration of Signal Imaging on Voltage Planes
- Design Discussion: 4 Layer Boards and Signal Imaging
- Design Discussion 2 Layer Circuit Boards – Inductance; Loop Area; and Architectural Topology
- Signal Impedance Matching
- Series and Parallel Signal Trace Terminations
- Circuit Board Functional (Common-mode and EMC Architectural) "Partitioning"
- Blind and Buried Via Applications
- Faraday "Fences" Used for Common-mode Partitioning
- "Picket Fences" for Board-Level Isolation Partitions
- 3-Dimensional Partitions
- Via patterns
- Analogue-Digital Partitioning
- Common-mode Inductor Techniques and Valuations
- Susceptibility / Immunity Partitioning in Circuit Boards
- Derivations of Circuit Board Topologies and EMC Architecture from Systems Electrical Architecture

Section D – Conducted Emissions

- Measurement Concepts of Conducted EMI Emission:
  - o References to LISNs;References to common-mode "ground plane"
- Detailed Circuit Descriptions of LISNs
- Differential-mode Propagation
- Examination of Differential-mode Equivalent in EMI Measurement Schematic
- Common-mode Propagation
- Small Devices, Common-mode Returns, and the Dipole Effect
- Common-mode EMI: Expanded Propagation and inter-relationships with Interconnected Devices

MODULE I: Propagation

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MODULE 2: Design

Integration of multi-card products, paralleled-stacked circuit boards, perpendicular circuit boards, interrelationships of back-planes, mid-planes, and card cages. (501 screens)

The Design Module begins with the relationships between "stacked" (co-planer and parallel) circuit boards. In detail, we'll examine the coupling effect on interface connections, the common-mode losses of inter-board connectors, and the slot antenna structures that are created among the boards; learn about the resonance interactions among stacked and interconnected products, move from parallel to perpendicular structures and examine the common-mode effects on EMC in products with motherboards and perpendicular peripheral boards; learn about the interface effects of common-mode loop structures with the chassis, bus-cards, and motherboard and then take a look at larger-scale products; examine the backplane architecture and bus structure of perpendicular cards, learn about the relationships of common-mode currents and fields between: circuit boards; circuit boards and the back-plane; and circuit boards and the backplane as a path in the card cage structure, we'll turn our attention to the affect these common-mode currents have on the EMC performance of interconnections such as data cables and wiring to the power sub-systems. From interconnections, we'll move to common-mode loop structures and study the resonance and field transfers of rack-mounted card cage sub-systems. Finally, we'll describe what happens when mid-plane configurations are used instead of backplanes and learn about the potential EMC advantages of partitioning a system using mid-planes. We'll conclude the Design Module with a brief discussion of the overall system susceptibility (immunity).

Section A - Paralleled EMC Relationships of "Stacked" Circuit Boards

- Common-mode Developments and Coupling with Interconnected Circuit Boards; Common-mode and EMC Issues Using Interconnected Circuit Boards With Interface Cable Configurations; Common-mode Displacements of Paralleled and Interconnected Circuit Boards With Interface Cables
- Electromagnetic Field Transfers and Displacement Interactions Of Paralleled Circuit Boards
- Field Interactions Between Paralleled Boards and Chassis Structures; Ground "Null" Applications to Paralleled Circuit Boards to Develop Signal / Noise Partitions
- Topology and Partitioning of Paralleled Circuit Boards
- Backbone Implementation for Partitioning Between Paralleled Circuit Boards

Section B - Perpendicular Bus-Structure Circuit Boards with Motherboards

- Common-mode and EMC Essentials of Perpendicularly - Connected Circuit Boards; Common-mode Architectural Considerations With Perpendicular Circuit Boards; Common-mode Field Distributed Transfer Interactions
- Field Displacements to Chassis Planes - Structures
- Common-mode Transfers In Architectural Paths to Interface Cables; Field Transfer Interactions to Interface Cables With Multiple Cards; EMC Implications of Ancillary Connections to Perpendicular Circuit Boards
- Ground Null Applications to Motherboards and Perpendicular Interface Circuit Boards
- Topological Layout Implications of Common-mode Fields

Section C - Backplane and Midplane Products Integrated with Card Cages (including Multiple Card Cages and Common-mode Architecture for Intra-System EMC)

- Backplanes Viewed with a Single Interconnected Systems Board
- "Lumped Effects" of Common-mode Considerations
- Card Cage Impositions With Backplanes With Interconnected Systems Board; Field and Current Transfers to Card Cages from Interconnected Systems Boards with (and to) Backplanes
- Backplane Architecture to Systems Boards
- Differential-mode Signal Approach
- Power Distribution and Common-mode Architecture
- Common-mode Architectural and EMC Implications of Interface Connections
- Conceptual Approach of Midplane Integration
- Common-mode Aspect Ratios of System Boards
- Interface Cable Connections to Backplanes and Systems Boards; Interconnections of Multiple Systems Boards
- Approximation of Antenna Structures Referenced to Chassis
- Common-mode References of Backplanes With Systems Boards; Common-mode Current Circulation Closure
- Chassis References for DC Chassis-Isolated Backplanes
- Reference Technique With Chassis Stripes and Via Patterns
- Establishment of Common-mode "Null Zones" in Backplanes
- Null Zones and Regional Partitions; Inter-layer Backplane Referencing Method With Connection Detail; Backplane Layering Construction, Stack-up Considerations
- System Board Topology for Distributed DC Power Subsystems
- Card Guide Connection Null Approach
- Null Partition References of Interconnected Systems Boards
- Derivation of Common-mode EMC Architecture
- Null Partition References - Card Cage and Backplane Integration; Termination of Null Partitions to Backplane
- Mid-Planes - Partition Integration; Mid-Plane Partitions and Stack-up Concepts; Mid-Plane Common-Mode Architectural Derivation

Section D - EMC Implications of Systems Interconnections

- Implications Related to Systems Interconnections
- EMC Issues Affecting Radiated Field Susceptibility and Emissions; Interrelationships of Currents Between Systems Units
- Spatial EMC Excitations Among Systems Unit Members
- Rack-Mount EMC Integration of Multiple Card Cage Products
- Multiple Card Cage Products - Independently and Remotely Mounted; Common-mode EMC Excitations Imposed to Mechanical Mounting Structures
- Field Transfers (Interactions) Between Multiple Card Cage System Products
- EMC Mitigation Methods for Rack Mount Products
- Distributed Common-mode Attenuation Technique Through Interface Cables
- Implications of Primary (Utility) Power Interconnections
- Historical Implications of Facility Common-mode Events
- Voltage and Current Ground Shifts From Facility Power
- Alternate Architectural Systems Structure to Mitigate Facility Common-mode Events
- Essential EMC Characteristics of Telecommunication Physical Transport Layers:
    - Multi-wire Cables; Twin-axial Cables; Tri-axial Cables

Section E - Immunity / Susceptibility Considerations

- Common-mode Entry and Exit Currents (to or from systems-products); Null Redistributions of Common-Mode Exit Currents
- Implications of Redistributions to Shielded Cables
- Common-Mode to Differential-Mode Conversions; Common-Mode Current Circulating in the Shield of the Cable Wire Pairs
- EMC Reference Interactions with Chassis-Case Structures
- Overview of Case-Structure Apertures and Field Redistribution
- Transfer Mechanisms of Susceptibility Response
- Effects of Product Immersion into Radiated Field Excitation
- Common-mode and Differential-mode Approaches
- Concepts of Demodulation and Detection of RF Carrier Processes
- Electrostatic Discharge (ESD) Processes and Impacts
- Fast Transient (EFT) Coupled Impacts
- Radiated Field Influences.

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MODULE 3: Shielding

EMC Shielding Methodologies and Applications (351 screens)

The Shielding Module contains four sections and examines product shielding strategies. We'll learn how shields function with regard to enclosures, localized shields, and cables. In particular, we'll explore the demands placed on shields at increasingly higher frequencies and shorter wavelengths. We'll begin with a look at the broad concepts of how shield structures function in terms of losses (shielding effectiveness). Next, we'll examine the effects of the incident wave impedance on a shield's performance. Then, we'll investigate the effects from gaps, seams, slots, and perforations. We'll learn how to use "waveguide" apertures in a frequency mode below cutoff and study apertures, gaps, and perforations as phased-array structures. Then, we'll learn how to use heat sinks as shield structures (as noted in the Propagation Module). Next, we'll examine circuit partitioning methods using board-mounted shields and, in particular, learn how to use segmented shields to offset the performance required of a perimeter shield. Finally, we'll apply shielding and partition strategies to shields on cables. We'll focus on cable shield characteristics and termination methods as the completion of a perimeter shield structure.

Section A - Product Shielding: Application of Conceptual Theory

- Properties of Electromagnetic Waves
- Concepts of Electromagnetic Wave Impedance Mismatches With Shields
- Transmission Line Analogies of Shielding Processes
- Electromagnetic Wave Impedances:
  - o Near Field;
  - o Transition Region;
  - o Far Field
- Electromagnetic Wave Impingement - Shield Performance Mechanisms
- Reflection Losses From Shield Surfaces
- Initial Reflection Loss Shielding Function of a Boundary
- Skin Effect Boundaries
- Boundary and Inter-boundary Effects:
  - o Thick Shields;
  - o Thin Shields;
  - o Surface Boundary Shields
- Shielding Effectiveness Functions of a Continuous Shield Boundary:
  - o Reflection Losses;
  - o Absorption Losses
- Compilations of Shielding Effectiveness Parameters

Section B - Perimeter Case and Chassis Shielding

(Gaps, Seams, Slots, Perforations and Waveguides Operating Below Cutoff)

- Factors Limiting Shield Performance
- Coincidence of Apertures to Circuits and Circuit Boards
- Applications of Seams and Gaps as Shield Apertures
- Induction Flux Equivalence in Shield Gap Formations
- Aperture-Arrayed Shield Structures - Ventilation (Cooling) Applications
- Waveguides in Cutoff - Individual Apertures
- Waveguides in Cutoff - Aperture Arrays
- Ventilation Path - Plenum Shield Indirect Impingement Concepts
- Cavity Resonance in Enclosure Plenums
- Waveguides in Cutoff - Performance Examples
- Perforated Metals and Screen Shield Performance Examples
- Honeycomb Shield Arrays
- Waveguides Performance in Cutoff:
  - o Rectangular
  - o Circular

Section C - Shielded Modules Carried on Circuit Board Partitions

- Device-level Heat Sinks Utilized as Shields
- Completing Shields of Device-level Heat Sinks
- Regional Shield Partitions with Lumped Coupling Approximations
- Regional Shield Partition - Topology Routing Plans
- V-Plane Partitioning in Regional Boundaries
- Inner-Board Shielding Partitions with "Picket Fence" Via Patterned Arrays
- Partition Integration with "Shields" for Externally-Removable Circuit Modules
- Partitions Developed Within Boundaries of Removable Circuit Modules
- Cavity Resonance Effects and "Q-Factor"

Section D - Cable Shielding Applications

- Purpose of Cable Shielding:
  - o Tri-axial Cable Shields;
  - o Twin-axial Cable Shields;
  - o Twisted Pairs;
  - o Unshielded Twisted Pairs
- Cable Shield Construction Details
  - o Braids
  - o Braids with Metallized Polyester Underlay
  - o Description of Weave "Bands & Strands", and Braid-Weave Angle with Respect to Current Flow
- Cable Shields as Boundary Partitions
- Common-mode Cable "Image Return" Functions of Chassis, Structures, and Earth
- Importance of Connector Characteristics
- Shield Categories of Multi-Conductor Shielded Cables
- Twisted and Twisted-Shielded Pairs Within Multi-Conductor Cables
- Significance of Shield Termination Impedance

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MODULE 4: Troubleshooting

Evaluation Techniques to Diagnose EMC Performance Issues (206 screens)

The Troubleshooting Module is intended to familiarize viewers with the concepts involved in the techniques of discovering and resolving the causes of non-compliance that may be encountered during Electromagnetic Compatibility compliance testing. The Troubleshooting Module contains a total of 3 sections covering an array of EMC troubleshooting techniques. This module starts off with a discussion of some of the common tools used in the EMC troubleshooting process, such as current probes, capacitive voltage probes, magnetic loop antenna and field probes. This is followed by discussion and experiments related to "ambient noise" in the EMC testing environment and further description of EMI spectra as it relates to formal compliance testing vs engineering evaluation testing. The bulk of the module lies in the remaining two sections, which focus in-depth on troubleshooting techniques for EMI conducted emissions and radiated emissions, respectively.

Section A – Overview: Essential Concepts Common to Most EMC Troubleshooting Evaluations

- Introduction to Localized Explorations:
  - Current Probes – Exploratory Measurements on Primary Power Wires
  - Current Probes – Evaluation of Common-mode Currents related to Excessive Radiated EMI Emission
  - Capacitive Voltage Probes
  - Loop Antennas or Magnetic Field Probes
  - Immunity (Susceptibility) Effects
- Discussion and Experiments Related to Ambient EMI Conditions
- Descriptions and Importance of Congruence of EMI Spectra Between Compliance and Exploration Tests:
  - Narrowband Spectra
  - Frequency Modulation Patterns
  - Amplitude Modulation Patterns
  - Wideband Spectra
  - Modulation Time-Domain Displays
- EMI Immunity / Susceptibility R.F. Continuous Wave Influences
  - References to Demodulation and Detection Mechanisms (Linked to the Design Module)

Section B – Conducted EMI Emission

- Review of Conducted EMI Emission (Measurement) Concepts:
  - References to Line Impedance Stabilization (Artificial Mains) Networks
  - References to Test Setup Ground Plane
- Discussion of Current Probe Relevance to Voltages at LISN
- Conducted Ambient EMI Experimental Setup (in non-shielded labs)
- Experimental Procedures to Identify the Modes of Propagation:
  - Differential-mode
  - Common-mode
- Discussion and Experiments Related to Ambient EMI Conditions
- Current Probe Transfer Impedance, Microamperes, and dB References
- Differential-mode Suppression Concepts
- Exploration of the Common-mode Return Path
  - Safety-earth ground wire
  - Interface Cables to Interconnected Devices
  - Distributed Transfer Impedances
  - Imbalances of Return Path in Power Mains
- Discussion and Experiments Related to Ambient EMI Conditions
- Common-mode Suppression Concepts
- Descriptions and Troubleshooting Expanded Common-mode EMI Distribution

Section C – Radiated EMI Emission

- Introduction to Radiated EMI
  - Propagation from Cables
  - Differential-mode to Common-mode Conversion
  - Slotted-line aperture approximations
  - Dipole-like effects – "Hot" Case Symptoms
  - Cable Propagation From Flux-Induction
  - Leakage From Electromagnetic Fields From
    - Inadequate Case Connections;
    - Gaps;
    - Apertures;
    - Aperture Arrays
    - Penetration Through Thin-Film Coating
    - Propagation From Circuit Devices in Unshielded Cases
- Troubleshooting Radiated EMI Susceptibility / Immunity
- Conceptual Approach: "A View of Wavelength"
- Probing at Microwave Frequencies
  - Use of "Feed Horns" as Probes
- Aperture Arrays at Microwave Frequencies
- Evaluations with Current Probes
- Slotted-line and Loop Apertures (In Cable Arrangements)
- Aperture-based Cable Flux Induction
- Aperture Arrays and Cables
- Common-mode Currents and EMI Propagation From Cables
- Current Probes, Transfer Impedance Functions, Microamperes, Compliance and dB Ratios
- Probing Cable Shield Connections
- Probing Individual Wires in an Interface Cable
- Common-mode Suppression with Coils and Ferrite Sleeves
  - Valuation of Coils or Ferrite Sleeve Impedance
  - Relevance to Common-mode Impedance of Cables
  - Application of dB Ratios to Impedance
- Delta-T Evaluations: Common-mode Conversions
- Evaluations With Loop Probes
  - Construction of Loop Probe
- Use of Loop Probes
  - Field Direction & Orientation
  - Relationship of Fields to Flat Plane
  - Exploration of Thin-Film Shields
  - Exploration and Troubleshooting the "Hot Case" Syndrome
  - Troubleshooting Unshielded or Minimally Shielded Products
  - Probing Inside a Product
  - Exploring Modular Shields on Circuit Boards
  - Field Structures of Apertures in Shields
  - Relevance of Field Structure to Compliance Issues
  - Discussion of Gaps and Wavelength Examples
- Troubleshooting Inter-product / System Interactive Dependencies
  - Appearance of "Hot Case" Syndrome
  - Excitations – Stimuli as Common-mode Currents
  - Excitations – Stimuli as Field Transfers
  - Intersystem Spatial Dependencies
    - Cable Positioning Influences
  - Grouped Cables – Phasing Relationships
  - Induced Currents From Apertures
  - Positioning Relationships to Loop Formations and Slotted Line Approximations
  - Alterations of Radiated EMI Spectra

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