Coupling of Electromagnetic Fields to Circuits in a Cavity

D.R. Wilton, D.R. Jackson, C. Lertsirimit

University of Houston

Houston, TX 77204-4005

N.J. Champagne

Lawrence Livermore National Laboratory

Livermore, CA 94550

This research supported by the U.S. Department of Defense under MURI grant F49620-01-1-0436.

Report Documentation Page

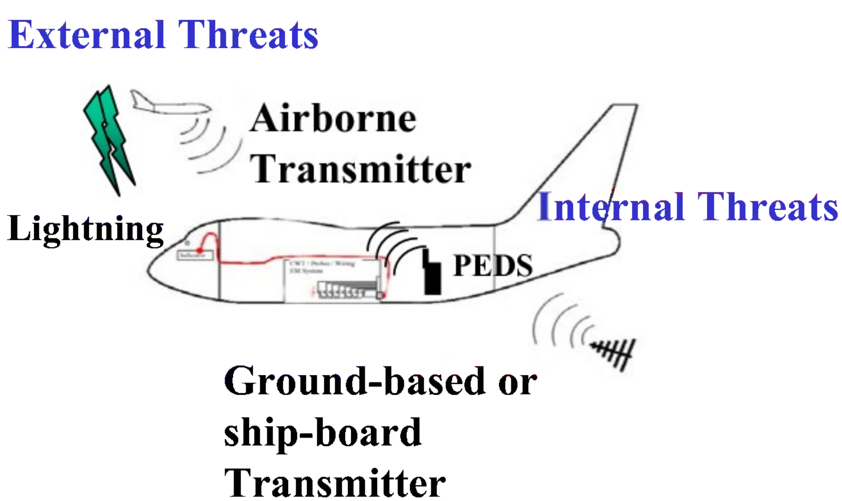
Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2002**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Coupling of Electromagnetic Fields to Circuits in a Cavity**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Houston Houston, TX 77204-4005**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **Presentations given at the First Annual Review Meeting on June 8, 2002 DoD MURI Award F49620-01-1-0436, The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

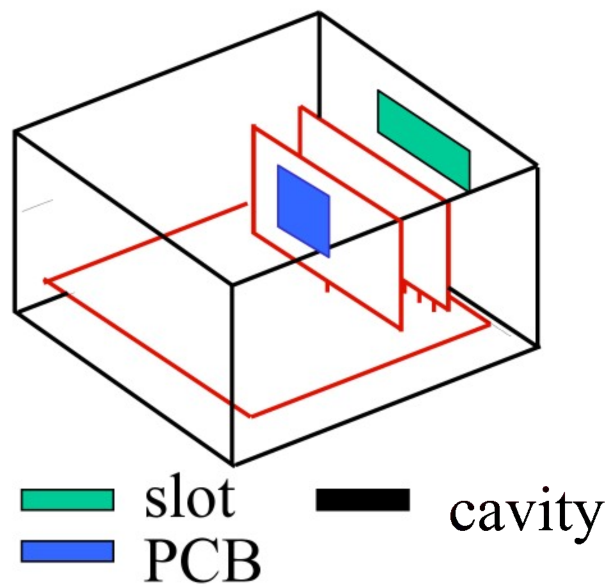
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**39**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

As Part of Our MURI Effort, We Are to Develop Capabilities for Modeling Complex EMC/EMI Problems



(Picture from NASA-Langley)

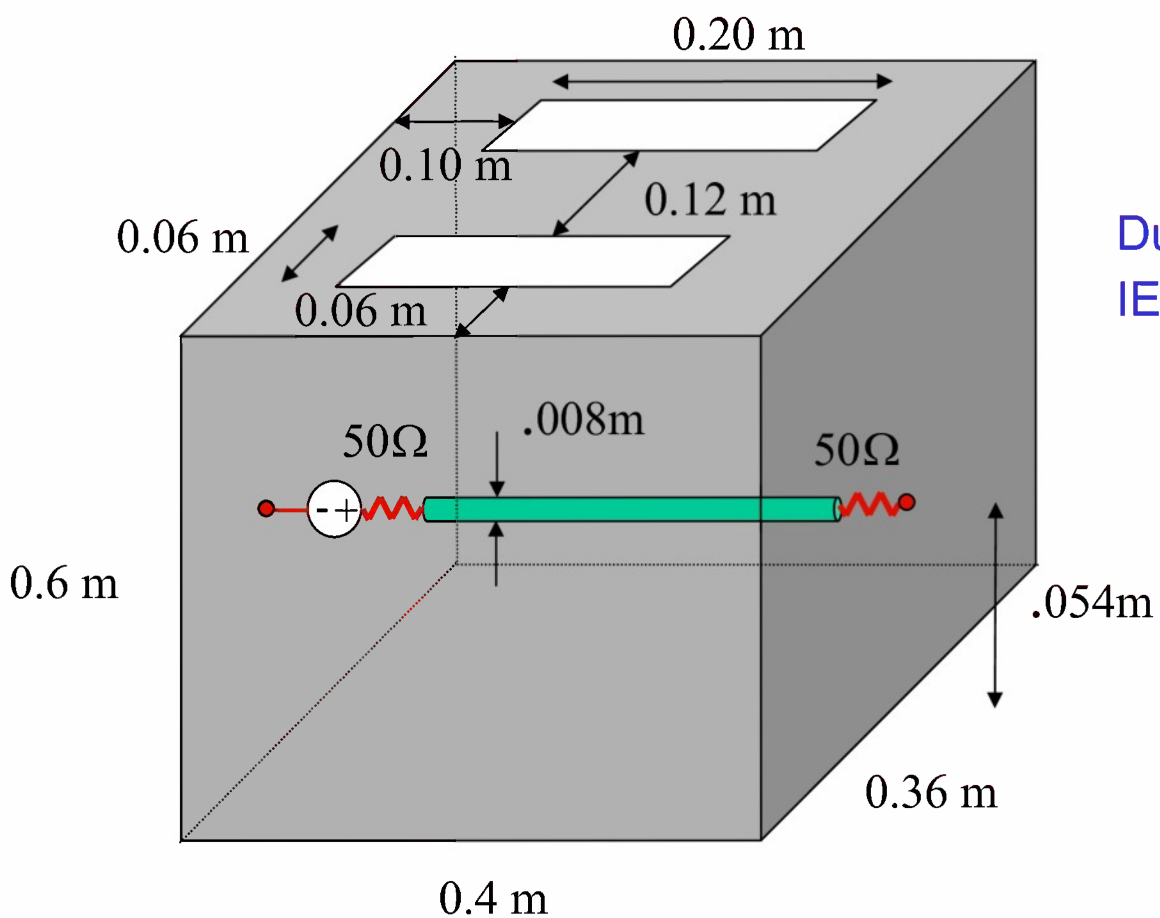


As a First Step, We Want to Determine EIGER's Suitability for Code Validation and for Performing General-Purpose EMC/EMI Calculations

- EIGER is a general-purpose EM frequency domain modeling code being jointly developed by
  - U. Houston/NASA
  - Navy (SPAWAR)
  - Lawrence Livermore National Laboratory
  - Sandia National Laboratories
- Can EIGER be used to obtain quick results and handle difficult-to-formulate EMC/EMI calculations?
- Can EIGER be used to validate new codes, and to efficiently obtain desired model parameters?
- Can it be used as a breadboard for developing more specialized codes?

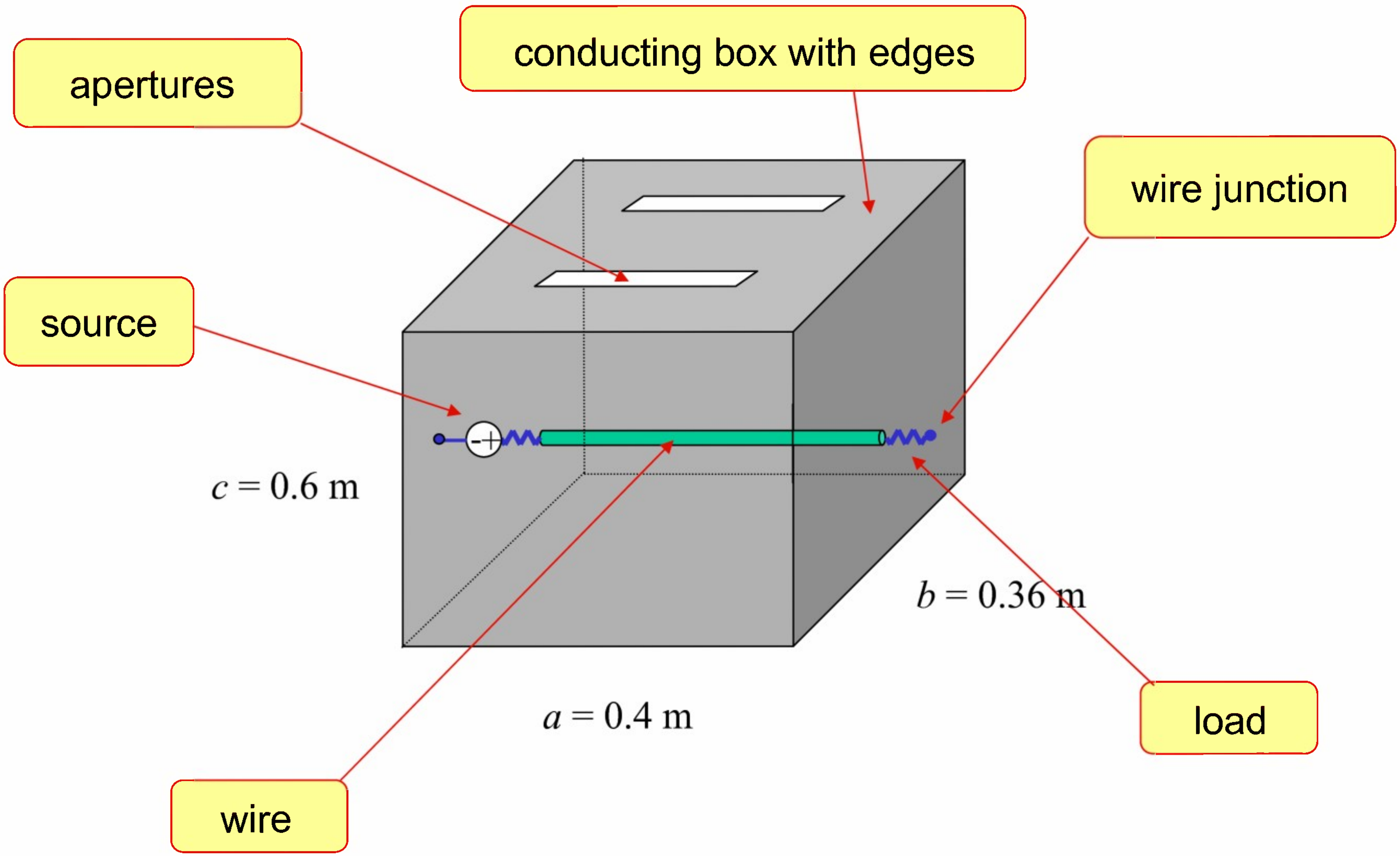
Validation Study

A Conducting Box with Two Apertures, Containing a Conducting Wire with 50 Ω Loads Terminating on Box Walls, Excited by a 1-Volt RF Source



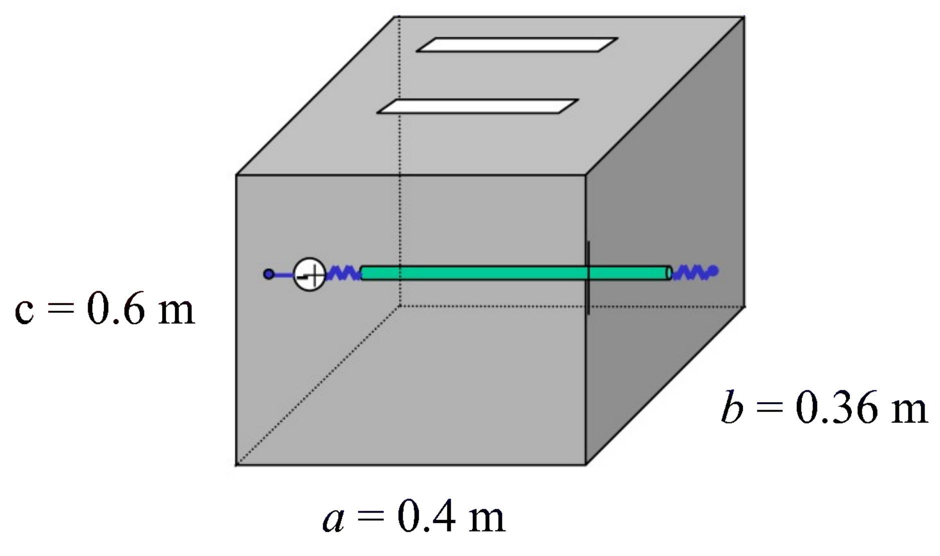
Duffy, Benson, Christopoulos
IEEE EMC, **36** (2), May ‘94

Canonical Problem That Exercises Code Capabilities



Numerical Validation: Three Approaches

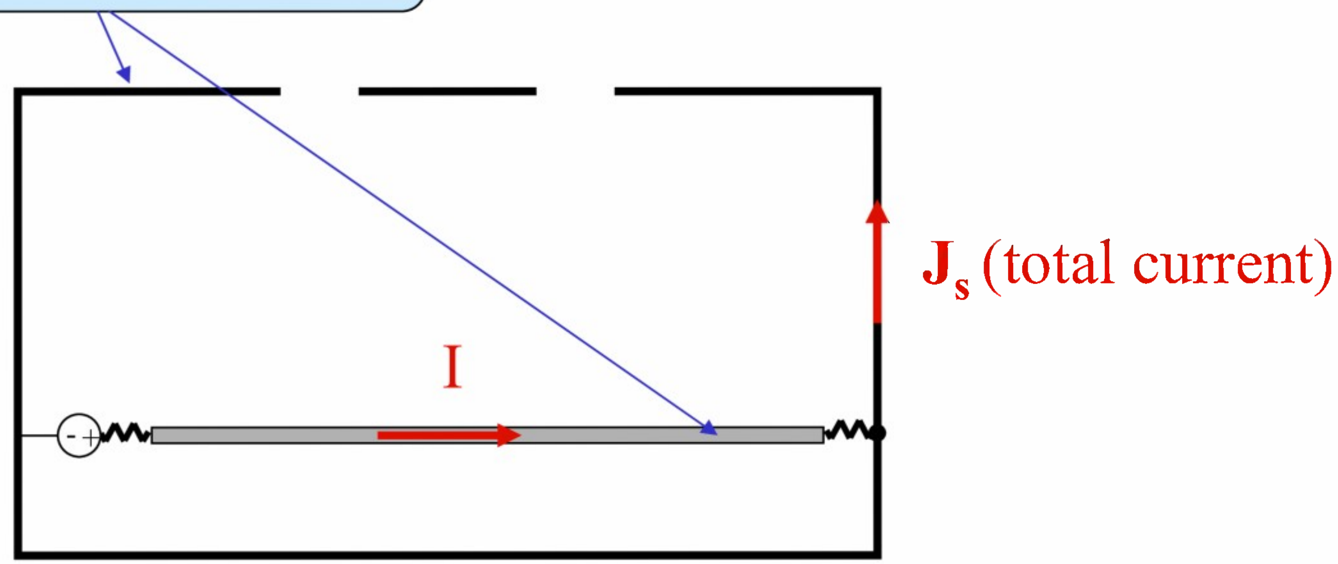
- Direct EFIE approach
- Aperture integral equation with EFIE
- Aperture integral equation with EFIE and cavity Green's function
- These are compared to measurements (EMC paper)



Approach #1: Direct EFIE

The system is treated as one conducting object
(with source, loads, and junctions)

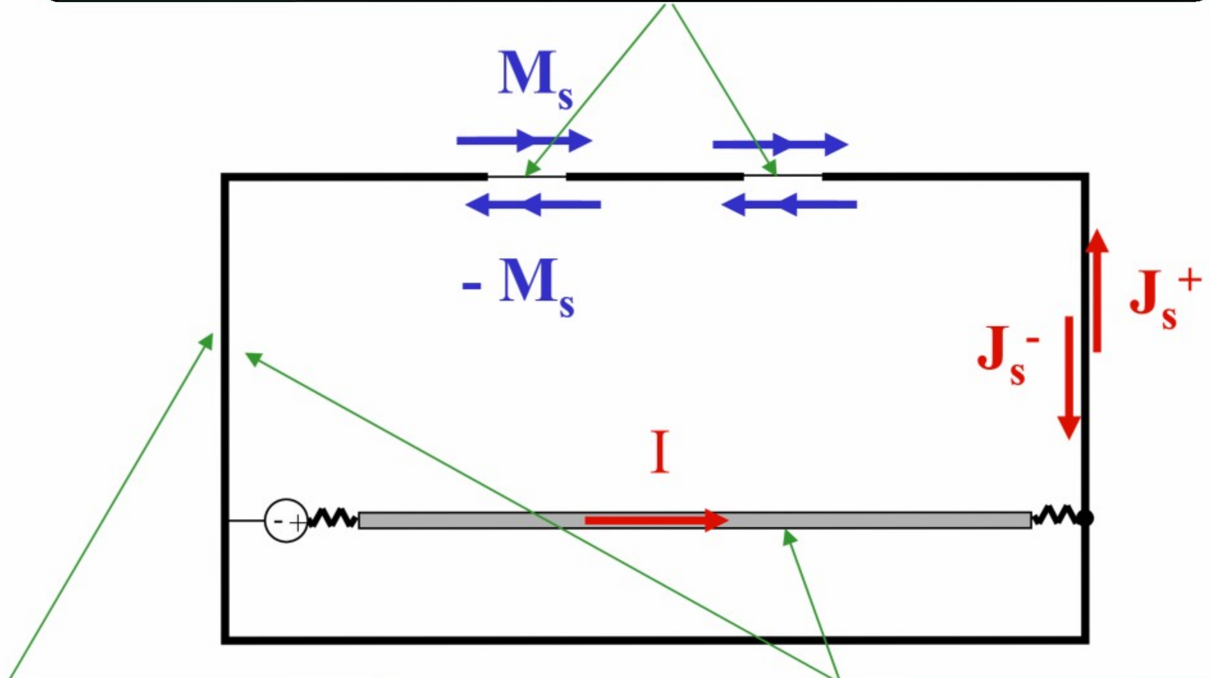
$$\hat{\boldsymbol{n}} \times \boldsymbol{E}\left[\boldsymbol{J}_s, I\right] = \mathbf{0}$$



Approach #2: EFIE with AIE

The system is divided into two regions.
An Aperture Integral Equation (AIE) is enforced.

$$\hat{n} \times H^{+}\left[J_s^{+}, M_s\right] = \hat{n} \times H^{-}\left[J_s^{-}, -M_s, I\right]$$

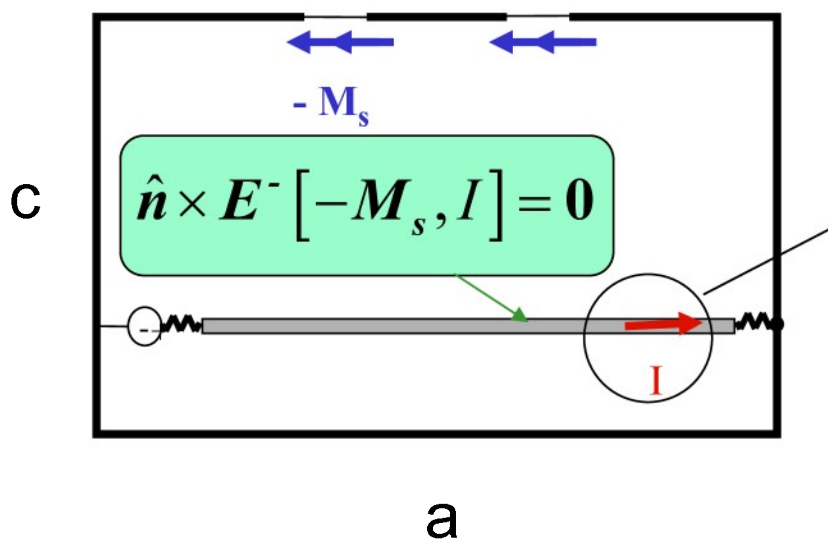


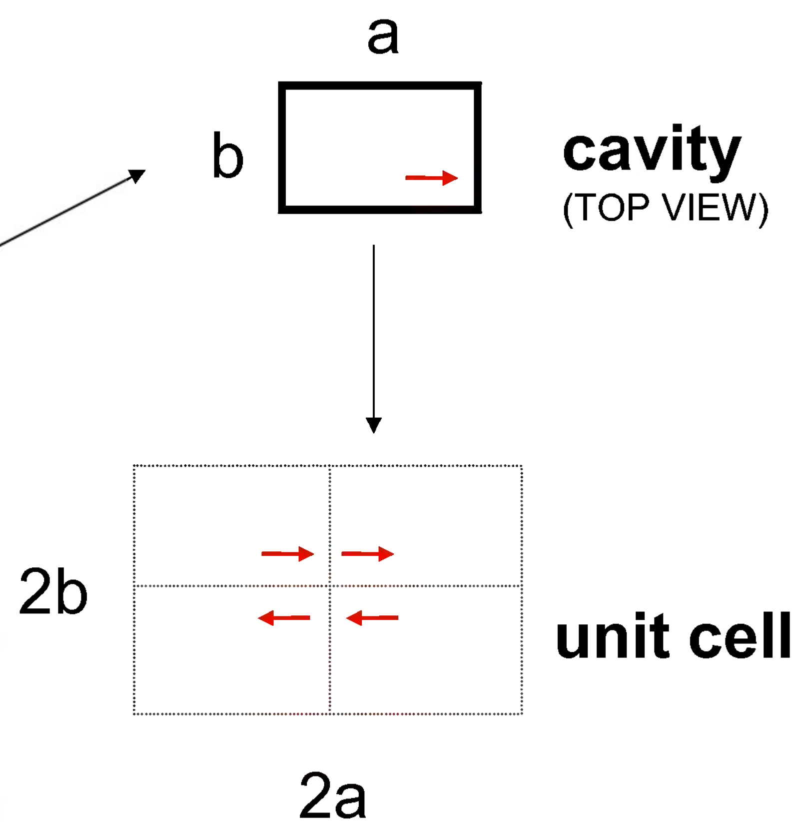
$$\hat{n} \times E^{+}\left[J_s^{+}, M_s\right] = 0$$

$$\hat{n} \times E^{-}\left[J_s^{-}, -M_s, I\right] = 0$$

Approach #3: EFIE with AIE and Cavity Green's Function

An AIE is used as in approach 2. A **cavity Green's function** is used to calculate the interior fields.



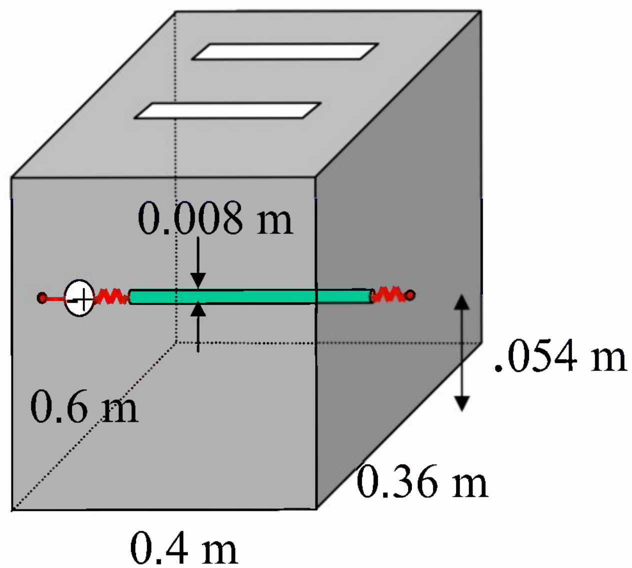


The cavity Green's function is synthesized by using a sum of four periodic layered-media Green's functions. Ewald acceleration is used for each one.

Results

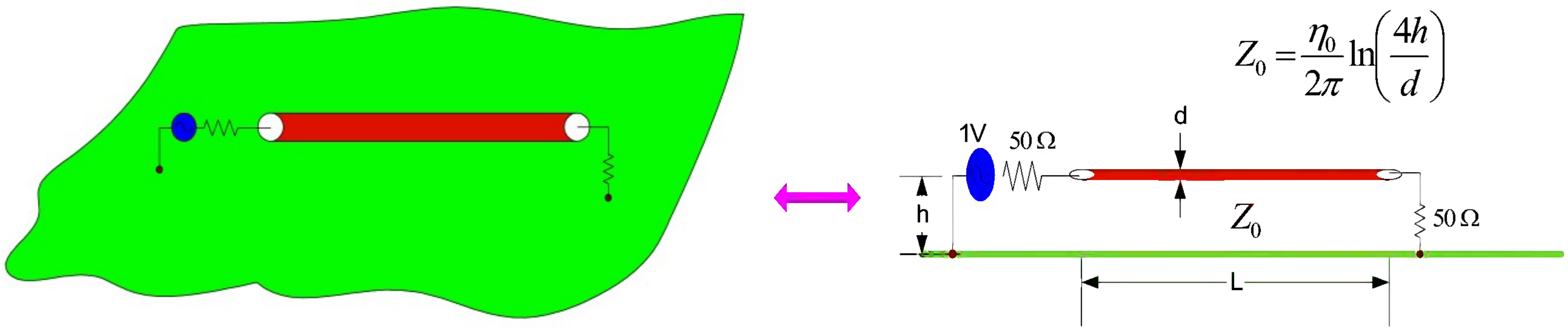
- Determine normalized output current at opposite end of line excited by a 1 V source

- Compare to measurement (Duffy et al., IEEE Trans. EMC, May 1994, pp. 144 -146)



Compare to Transmission Line Approximation...

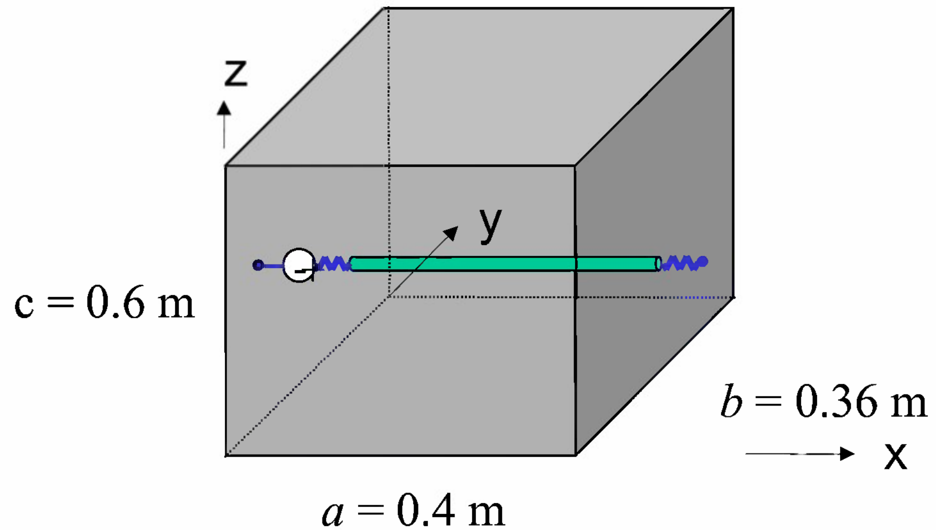
Use transmission line theory to approximate the current at the end load.



$$Z_0 = \frac{\eta_0}{2\pi}\ln\left(\frac{4h}{d}\right)$$

… and Compare Computed vs. Theoretical Cavity Resonances

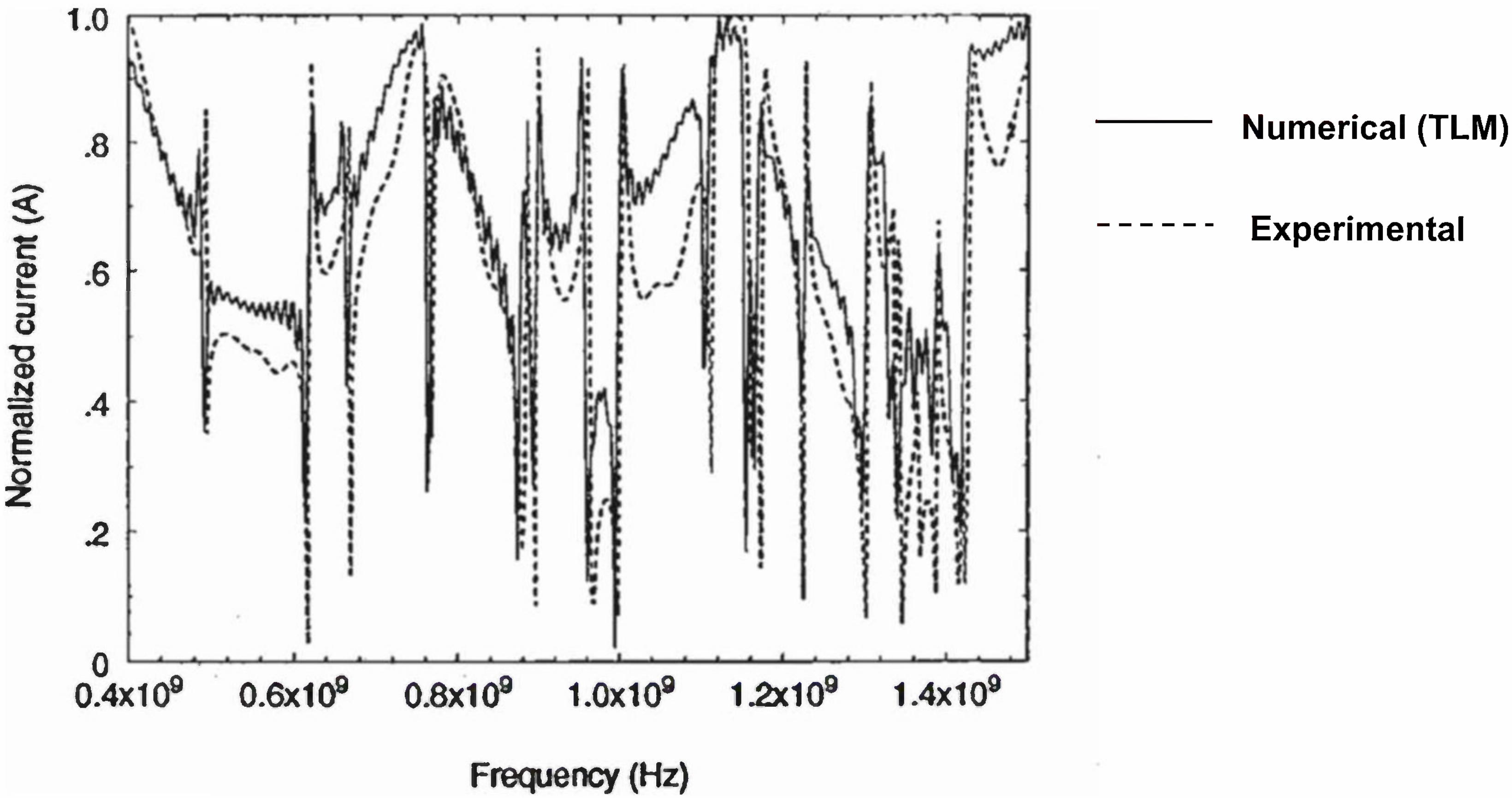
Predict the resonant frequency of the cavity



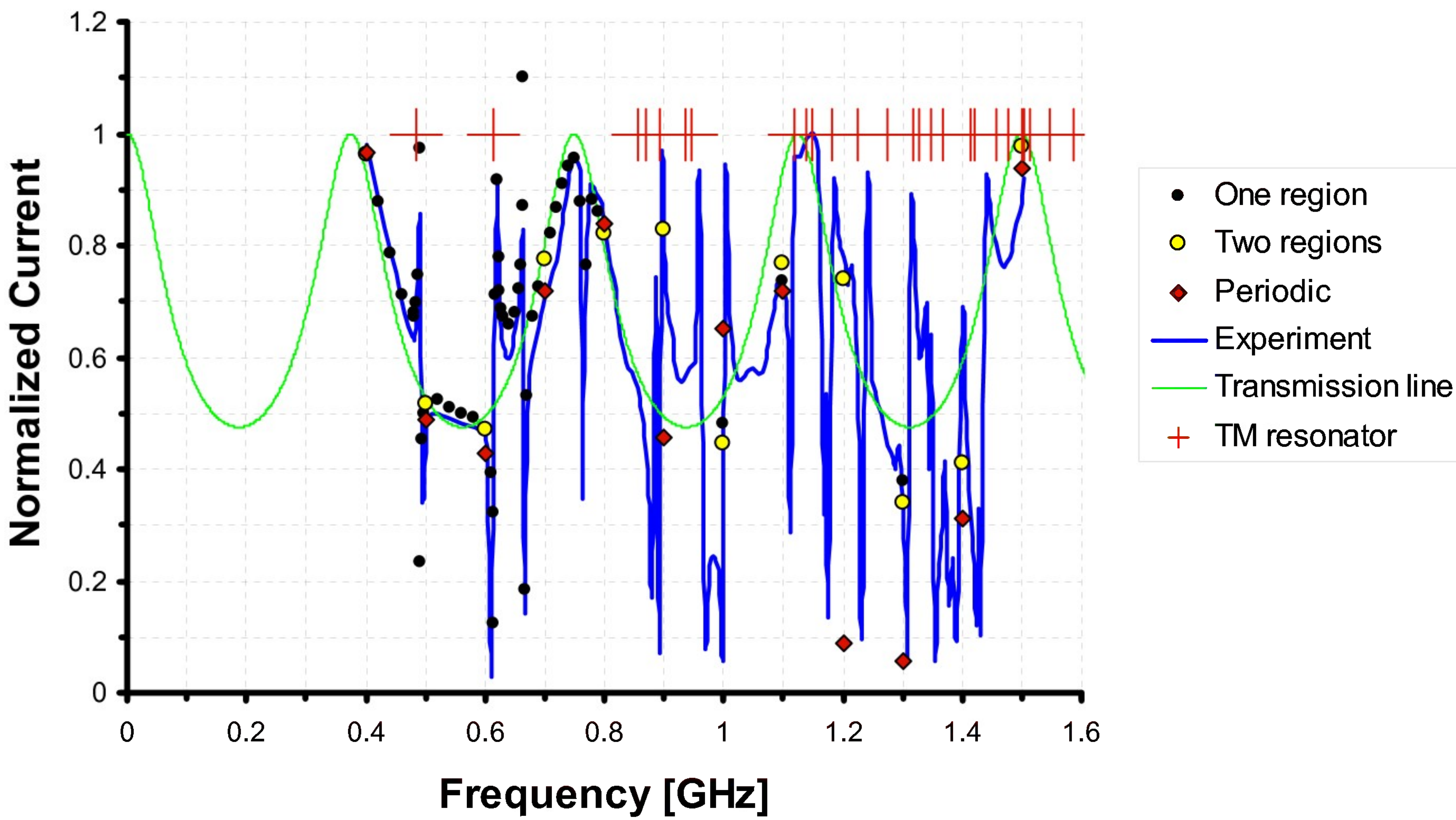
The wire excites TM_{mnp} cavity modes
for m = 0,1,2,… ; n = 1,3,5,…; p = 1,2,3,…

TML and Experimental Results from Duffy et al.

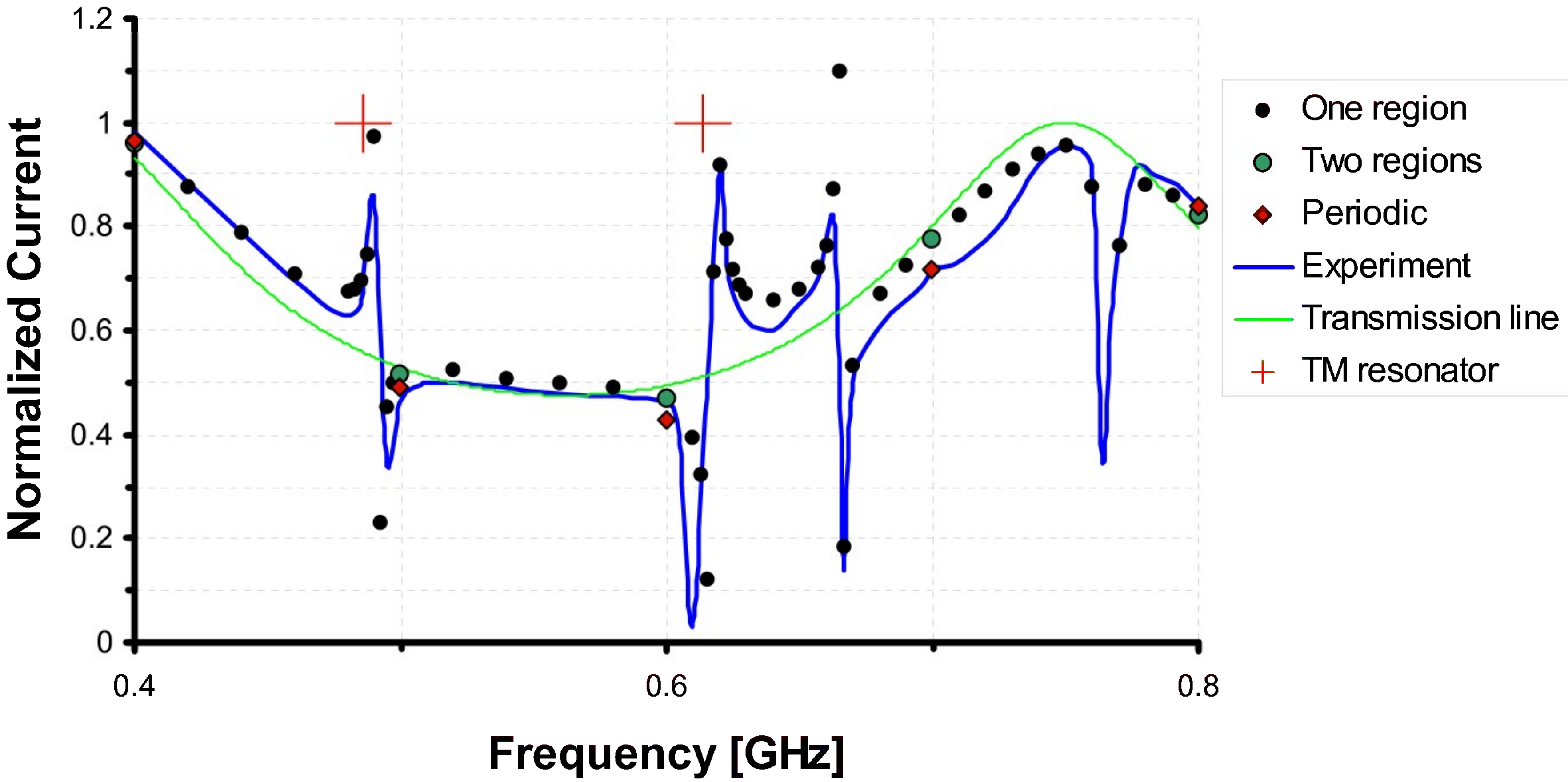
- Fourier transformed TML results
- Both results normalized to peaks



Normalized Current at the Load Opposite the Source



Detail of Current Plot (0.4 to 0.8 GHz)



Summary of EIGER Validation

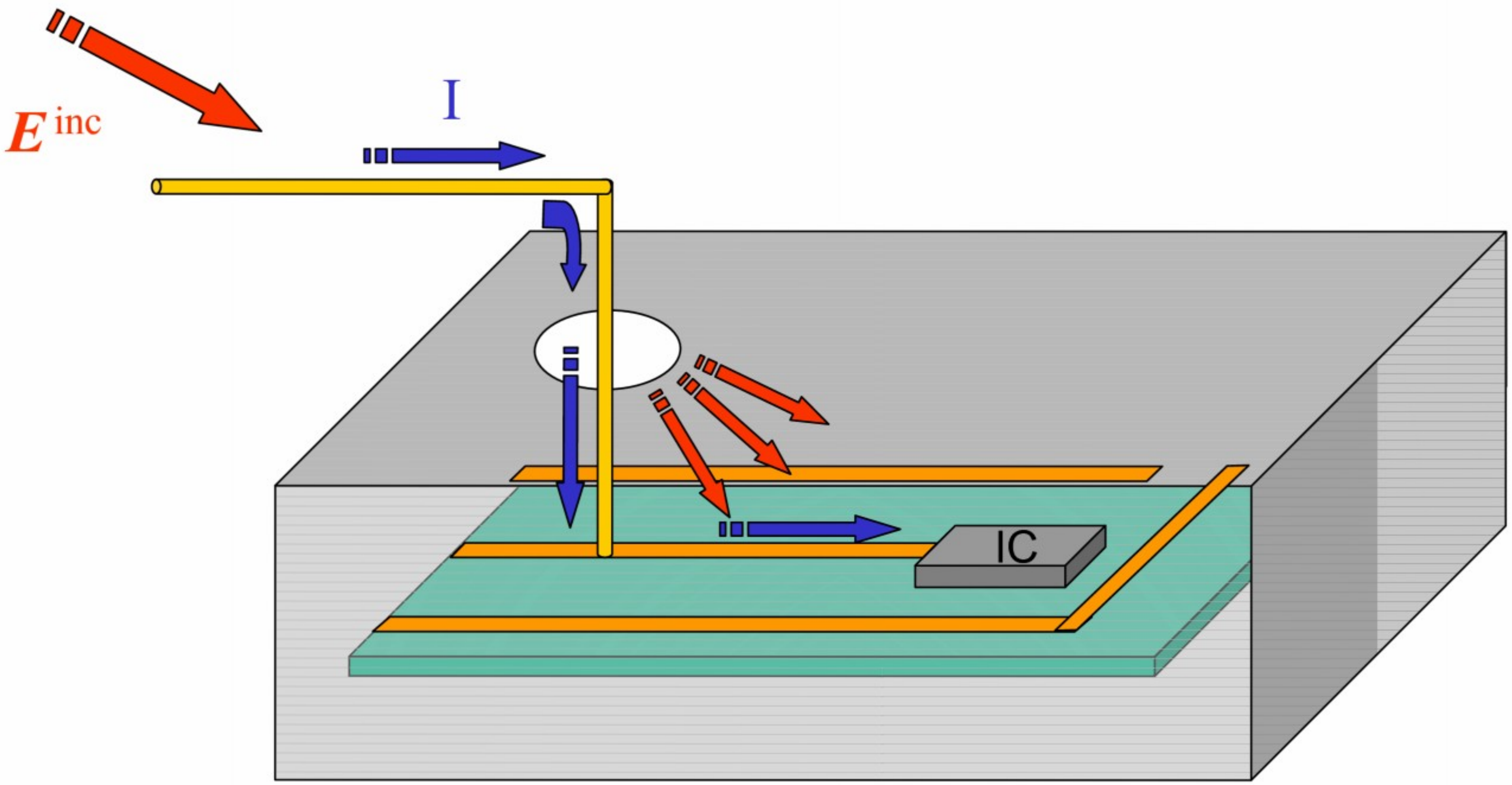
- Consistent results are obtained utilizing three different formulations for a complex cavity/wire/aperture problem

- Results in agreement with independent experiments and calculations

- EIGER can be useful in EMC/EMI applications both as a stand-alone code and as a code validation tool

Canonical Problem
Cable-Through-Aperture Coupling to PCB Traces

This is an important coupling "tube" in the EMC/EMI analysis of digital circuit effects



Canonical Problem
Issues, Goals, and Approaches

Issues:

- The cavity enclosure must be considered for an accurate solution.
- The PCB trace may be very complicated, and on a very different size scale than the cavity.

Goal:

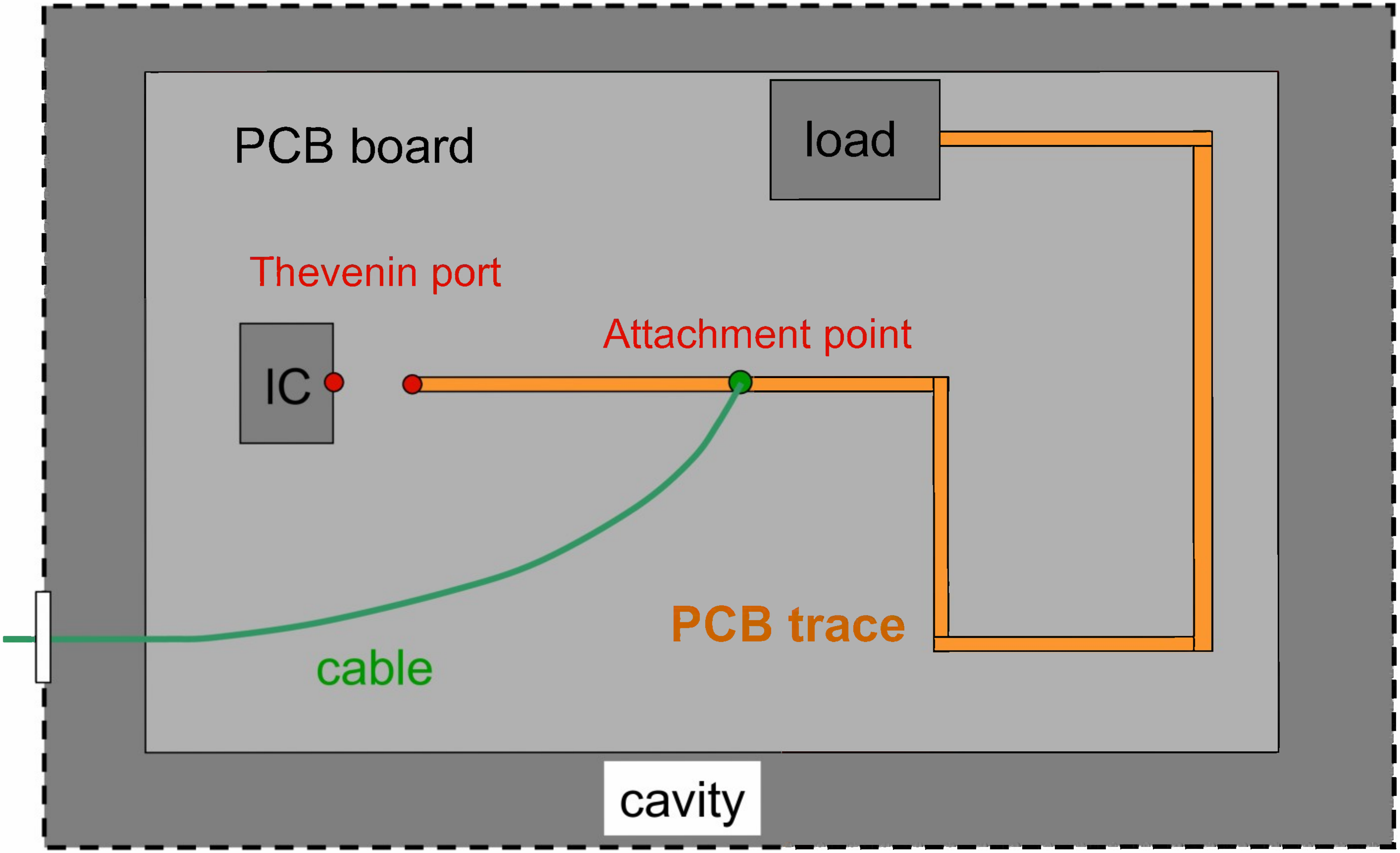
Separate the cavity analysis from the PCB analysis to the maximum extent possible.

Approach

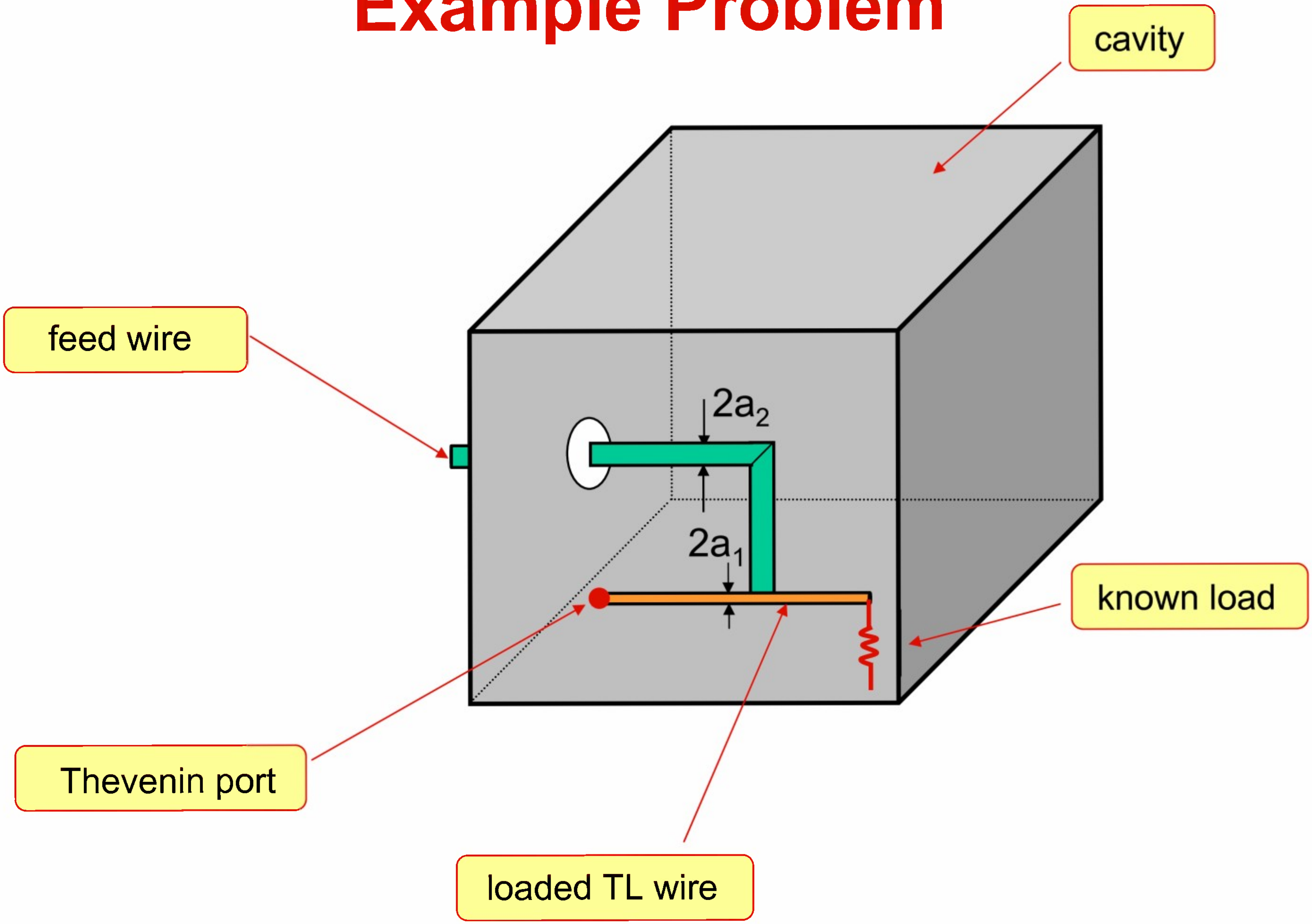
- Calculate a Thévenin equivalent circuit at the input of the digital device (requires V^{oc} and I^{sc}).
- Use transmission line theory (with distributed sources) to model the PCB trace.
- Use EIGER to model the cable inside the cavity and the cavity fields, and combine this with the PCB transmission line modeling.

➡ A hybrid method is developed that combines the rigorous cavity-field calculations of EIGER with transmission line theory.

Top View of Coupling Problem

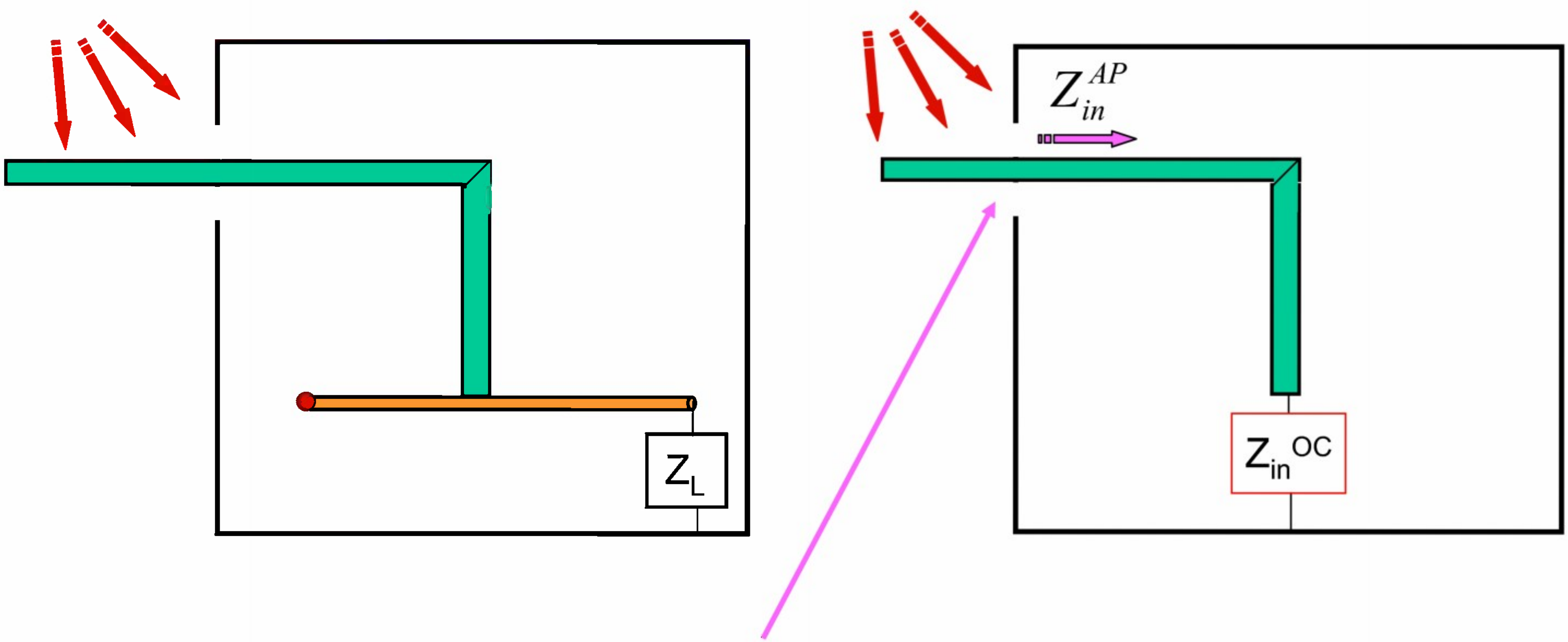


Example Problem



Voltage Source Replaces Gap at the Aperture

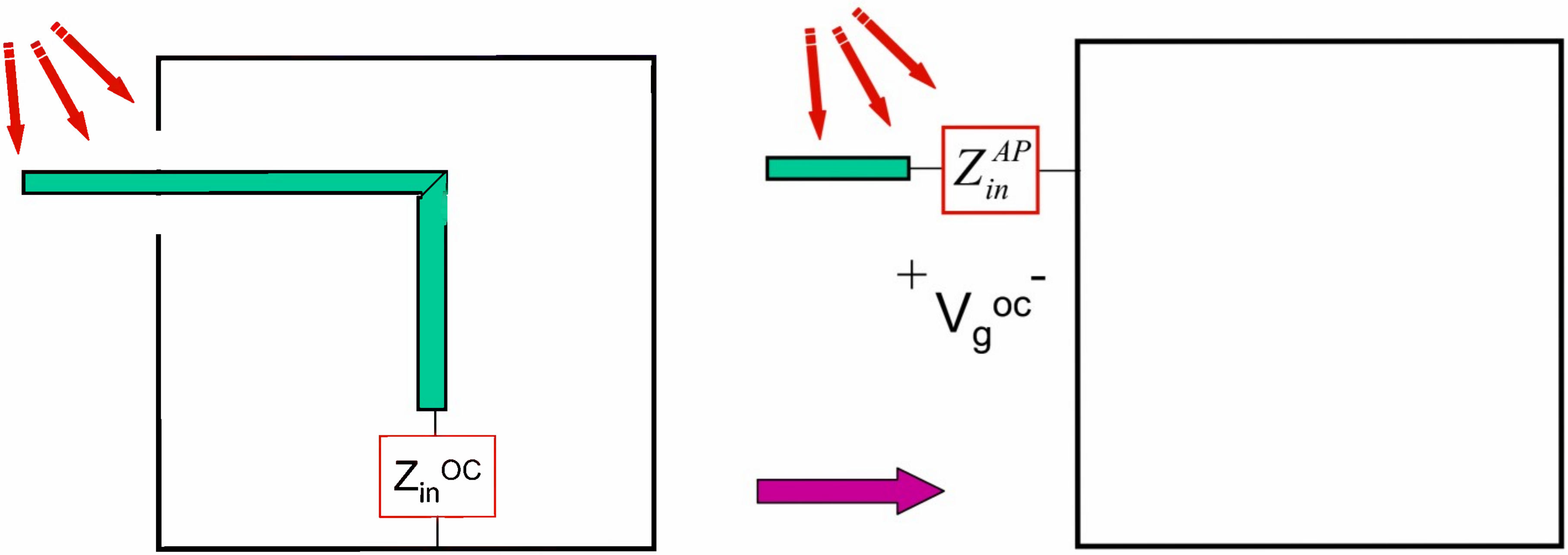
Step 1: PCB trace is replaced by load Zin



Z_{in}^{AP} is the input impedance seen looking into the cavity

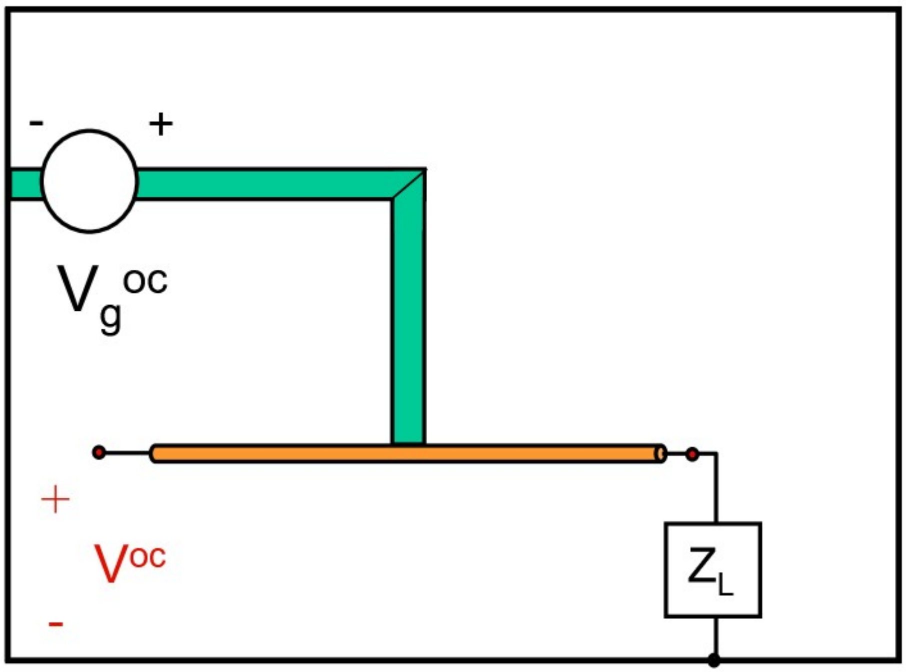
Voltage Source Replaces Gap at the Aperture (cont.)

Step 2: internal wire feed is replaced by load



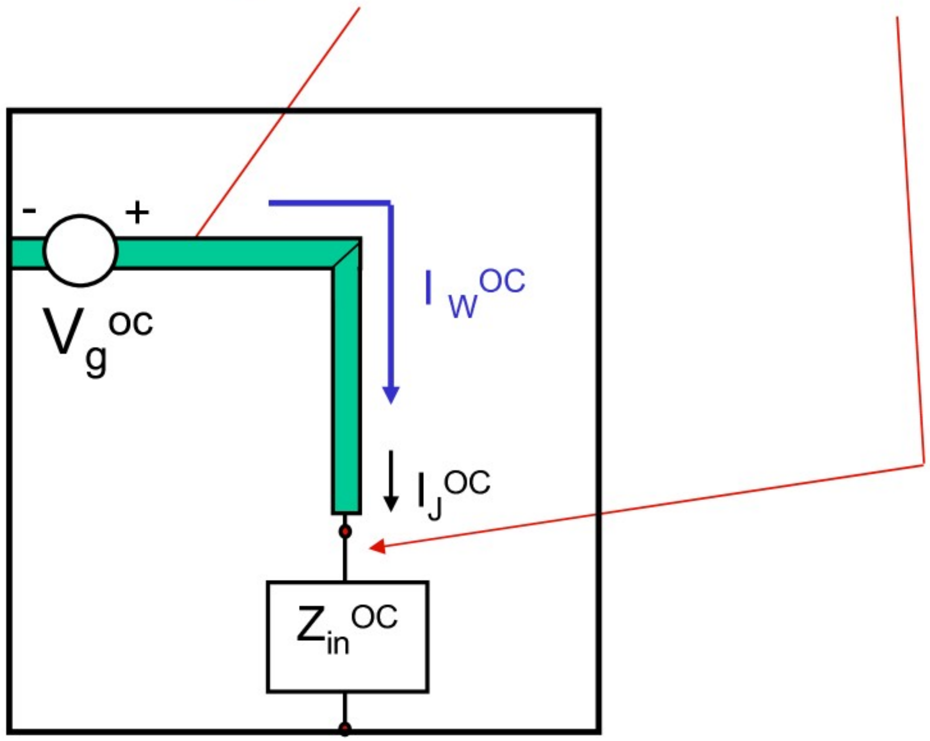
Exterior model for calculation of gap voltage

Voltage Source Replaces Gap at the Aperture (cont.)



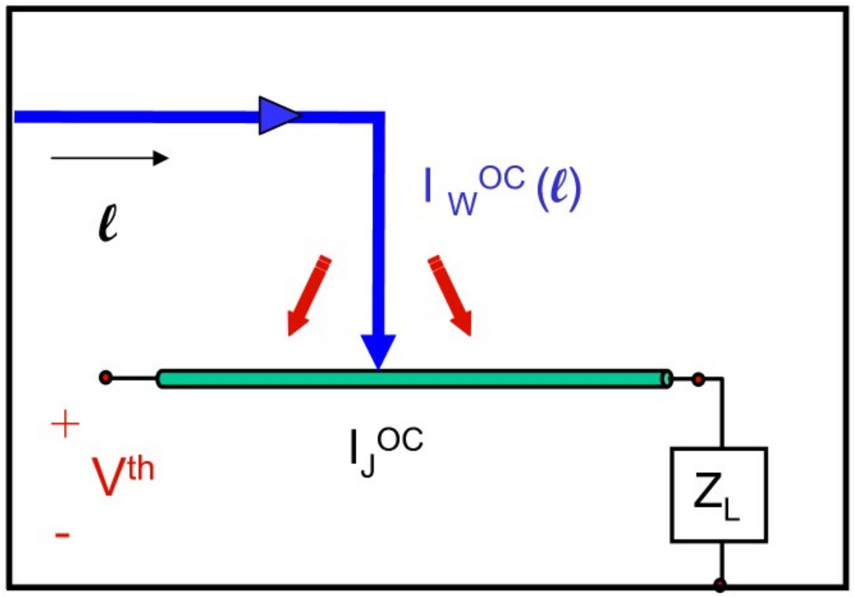
Current on the Wire is Calculated

The current on the feed wire and at the junction can be calculated by using EIGER.



Equivalence Principle Is Applied to the Feed Wire

(metal feed wire is removed)



The feed current produces an output voltage in two ways:

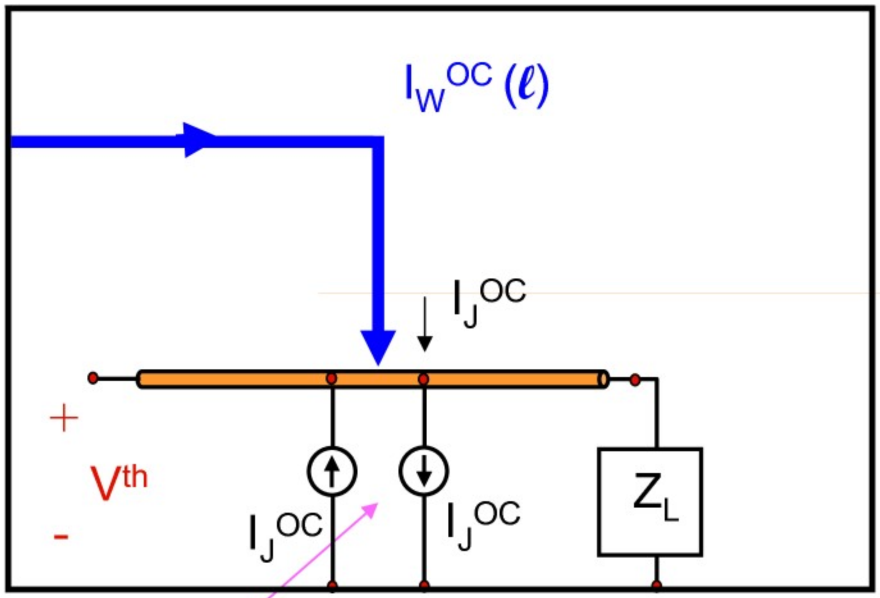
(1) direct current injection

(2) radiation inside cavity

$$V^{th} = V_I^{th} + V_R^{th}$$

Separation of the Two Mechanisms

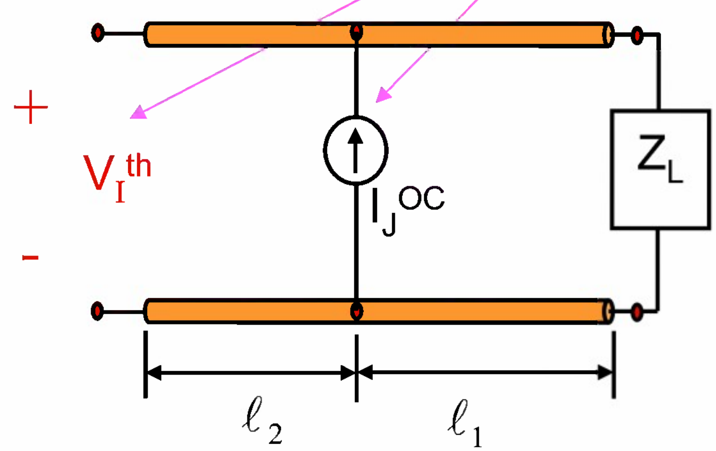
Two ideal current sources are added at the junction



Two ideal current sources

Mechanism 1: Injection Current

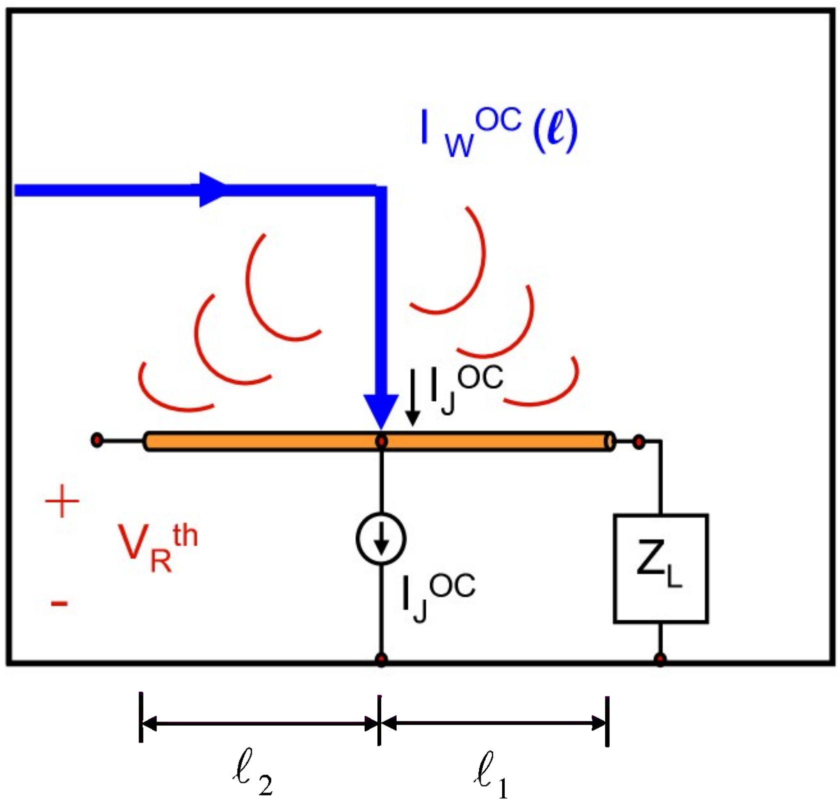
The "injected" Thevenin equivalent voltage comes from the ideal current source I_J^{OC}.



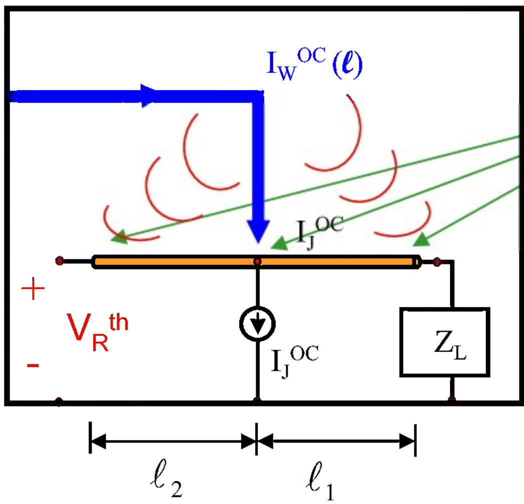
Simple transmission line theory is used to calculate V_I^{th}

Mechanism 2: Radiation From Feed Wire

Radiation from feed wire creates a distributed voltage source along the PCB wire



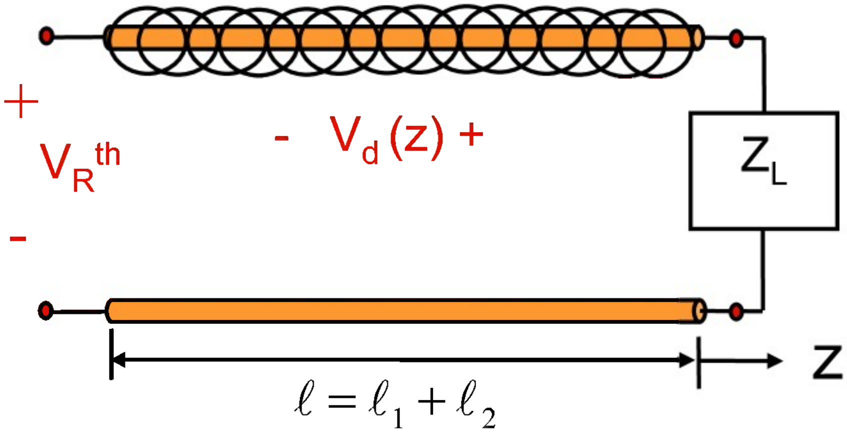
Mechanism 2 (cont.)



Use EIGER to calculate the impressed electric field on the PCB wire (in the presence of the cavity)

$$V_d(z) = E^{imp}(z)$$

$$E^{imp}(z) = -j\omega A - \nabla\Phi$$

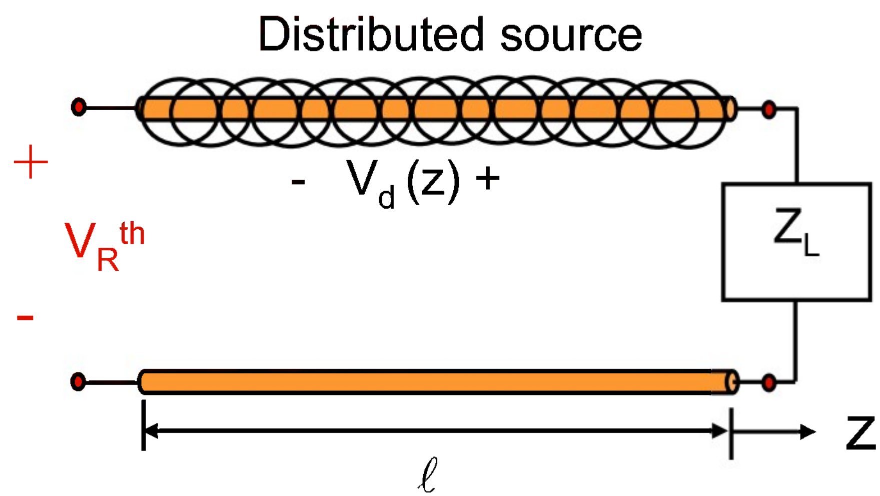


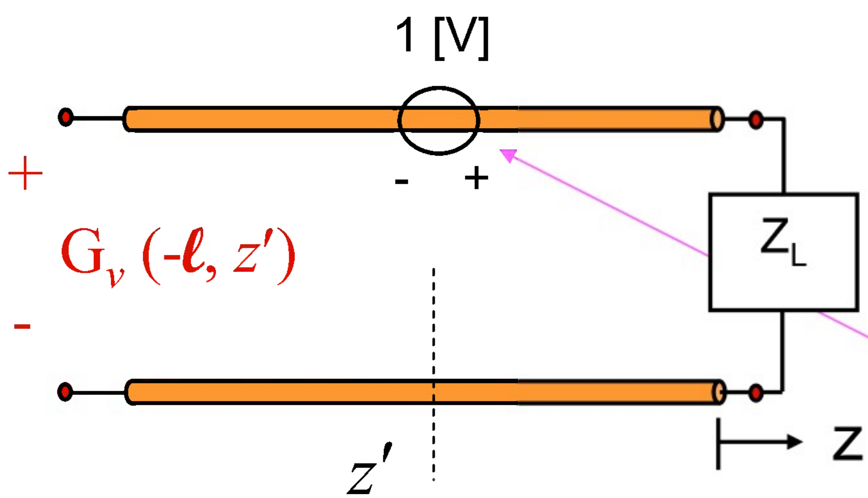
Calculation of potential ignores point charge at the end of the terminated feed current

Mechanism 2 (cont.)

The Thevenin equivalent voltage, V_R^{th}, can be calculated by integrating over the TL Green's function:

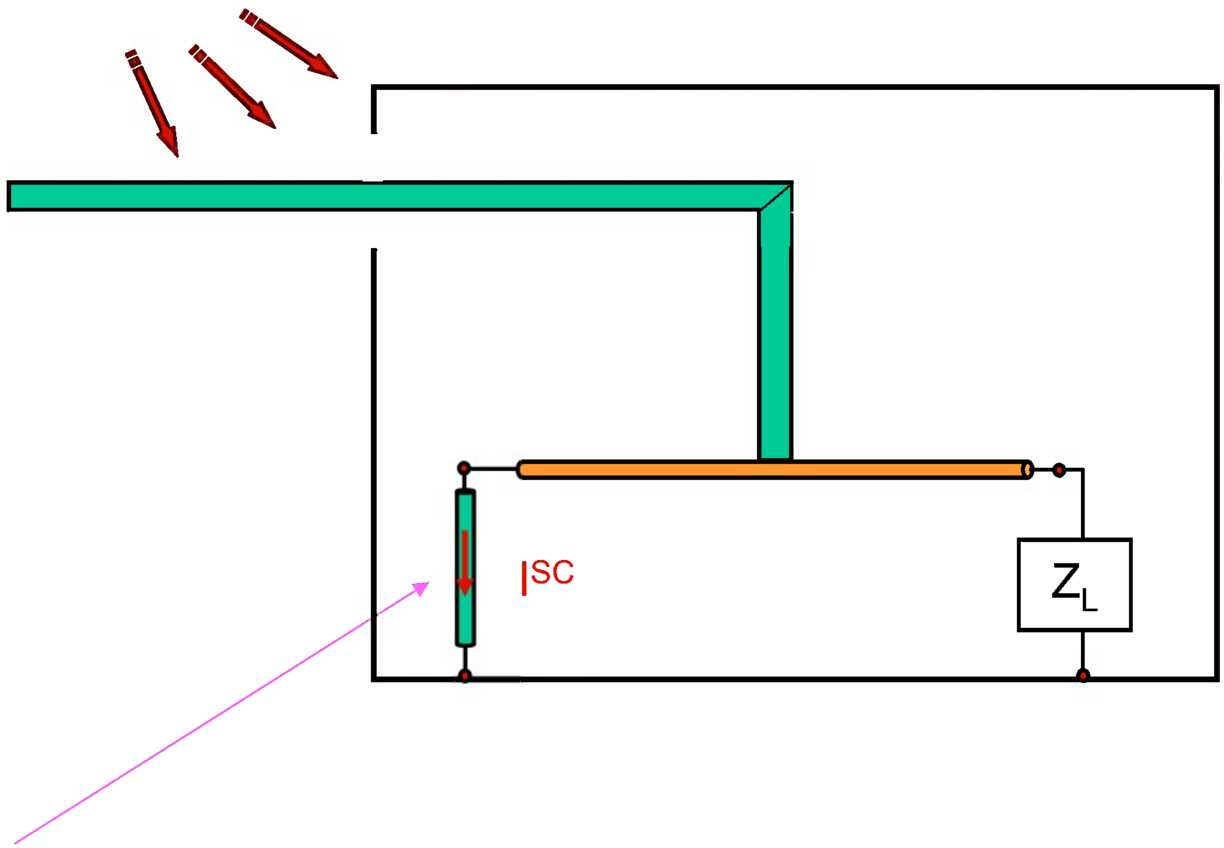
$$V_R^{th} = \int_{-\ell}^{0} V_d(z')\, G_v(-\ell, z')\, dz'$$





A unit voltage source on the transmission line defines the Green's function.

Calculation of Short Circuit Current, I^{SC}

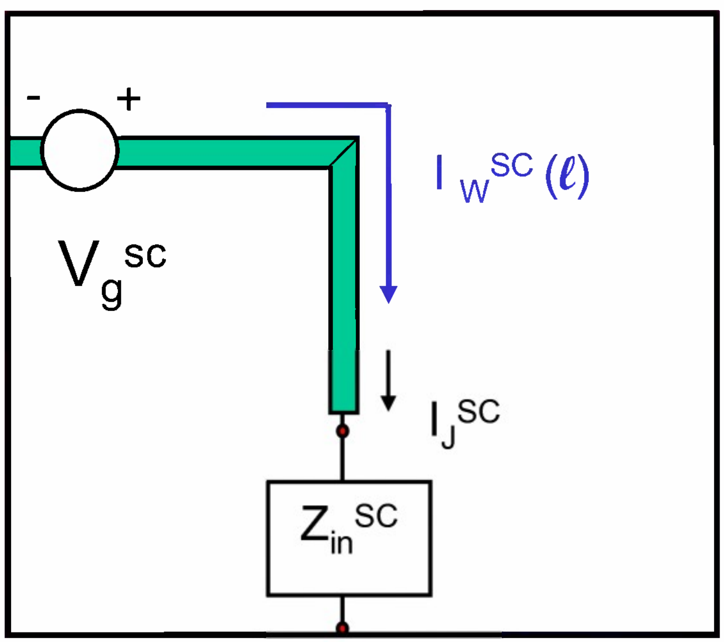


short circuit current at the Thevenin port

Short Circuit Current, I^{SC} (cont.)

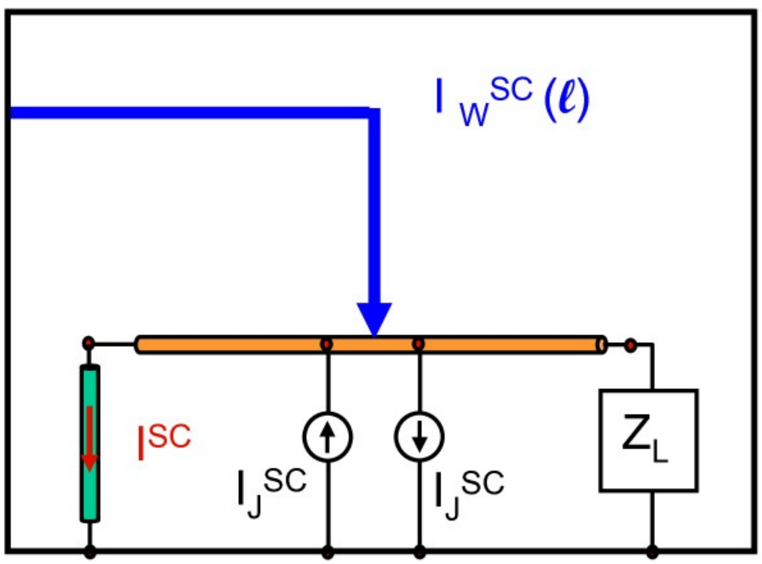
Procedure is similar to that used to obtain Thevenin (open-circuit) voltage:

Different terminating impedance results in a different gap voltage source



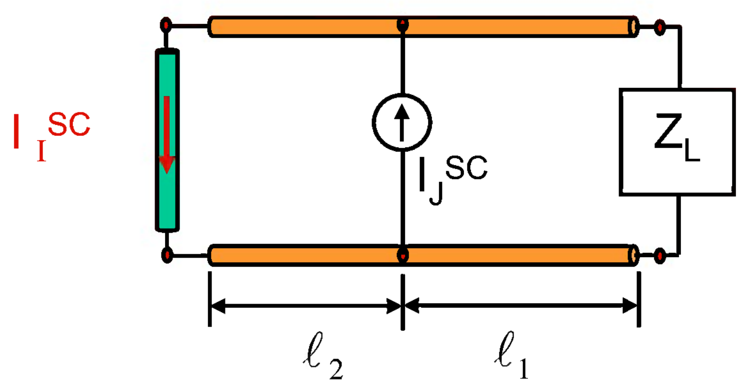
Short Circuit Current, I^{SC} (cont.)

Equivalence principle is used, and two ideal current sources are added, as before.



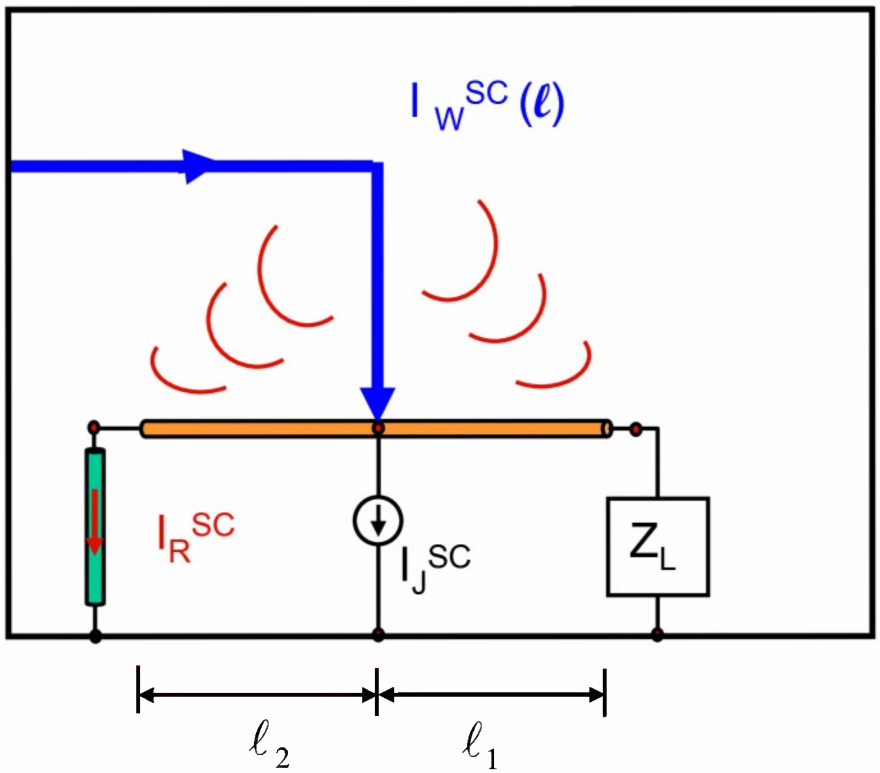
$$I^{sc} = I_I^{sc} + I_R^{sc}$$

Mechanism 1: Injection Current

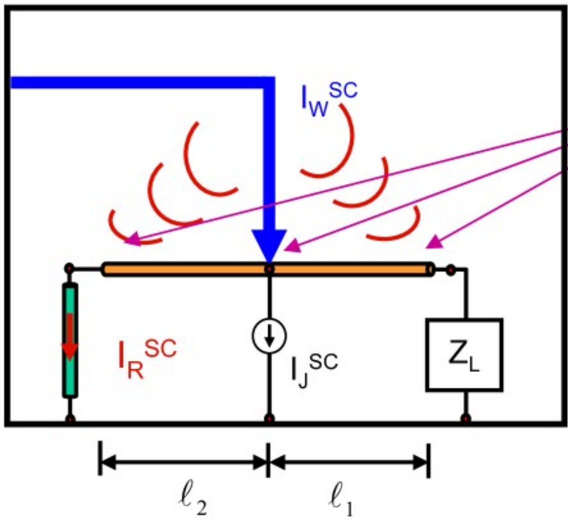


Transmission line theory is used to find the short-circuit current due to the injected source.

Mechanism 2: Radiation From Feed Wire

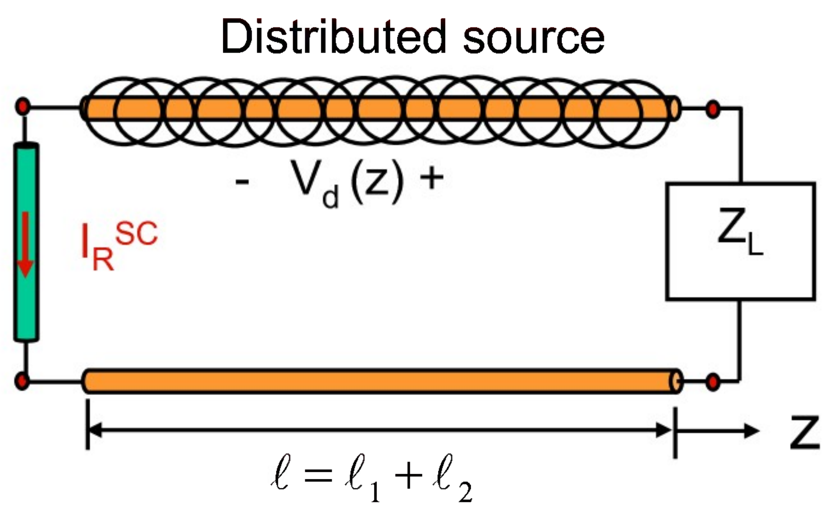


Mechanism 2 (cont.)



Use EIGER to calculate impressed field on the PCB wire.

$$V_d(z) = E^{imp}(z)$$

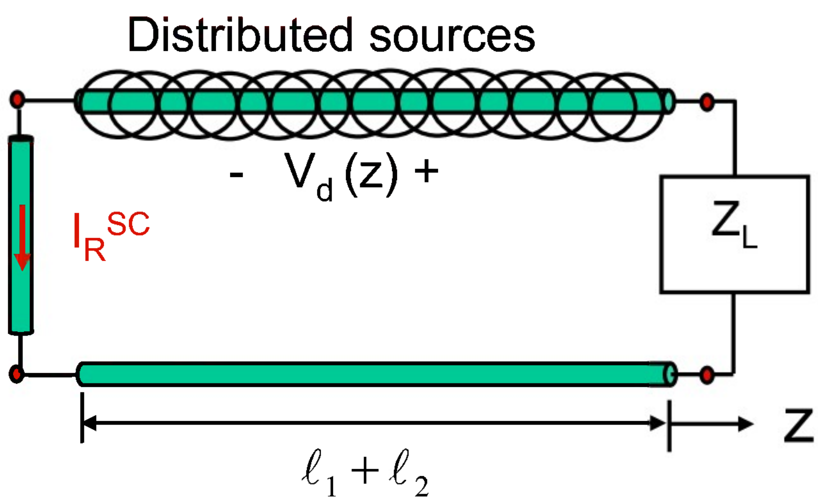


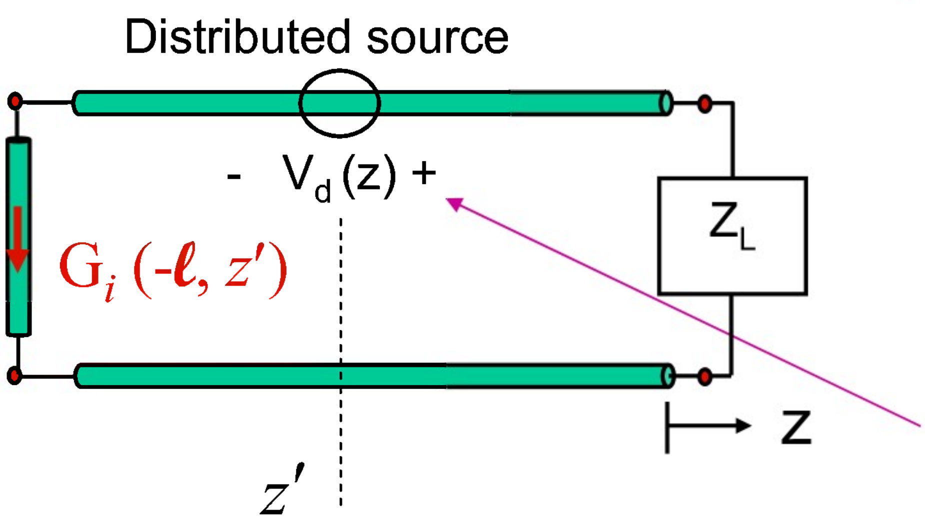
$$\boldsymbol{E}^{imp}(z) = -j\omega\boldsymbol{A} - \nabla\Phi$$

Calculation of potential ignores point charge at the end of the terminated feed current

Mechanism 2 (cont.)

$$I_R^{sc} = \int_{-\ell}^{0} V_d\left(z'\right) G_i\left(-\ell, z'\right) dz'$$





An unit voltage source on the transmission line defines the Green's function.

Future Work

- Obtain numerical results using EIGER for example problem
- Validate approach by “brute force” comparison