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EMPHASIS™/Nevada CABANA User Guide Version 2.1.3

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ABSTRACT

The CABle ANAlysis (CABANA) portion of the EMPHASIS™ suite is designed specifically for the simulation of cable SGEMP. The code can be used to evaluate the response of a specific cable design to threat or to compare and minimize the relative response of difference designs. This document provides user-specific information to facilitate the application of the code to cables of interest.

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1. INTRODUCTION

EMPHASISTM/Nevada CABle ANAlysis (CABANA) [12] solves the electrical portion of a cable system-generated electromagnetic pulse (SGEMP) simulation. It takes specific results from the deterministic radiation-transport code SCEPTR [5] as sources and computes the resulting electrical response to an arbitrary cable load. The cable geometry itself is also arbitrary and is limited only by the patience of the user in meshing and by the available computing resources for the solution. The CABANA simulation involves solution of the quasi-static Maxwell equations using finite-element method (FEM) techniques [12].

The CABANA sources required from SCEPTR are:

- 1) CHARGE_OFF_CONDUCTORS, the net charge knocked off each cable internal conductor (supplied implicitly by SCEPTR),
- 2) CHARGE deposited into each finite element, and
- 3) ENERGY_DEPOSITION at each element node

These data are written to the SCEPTR output in EXODUSII [7] format suitable for reading into CABANA. Since CABANA is written in MKS units, it expects the SCEPTR results in units of Coulomb(C)/m for both CHARGE_OFF_CONDUCTORS and CHARGE. The units of ENERGY_DEPOSITION are expected to be Rads (dielectric).

The sources produced by SCEPTR for CABANA are not time dependent. Instead, they represent the total integrated values over the specified radiation pulse. CABANA applies the time dependence to the simulation by assuring, for example, that the total charge in a given element is applied over the specified pulse shape.

2. CABLE SGEMP SIMULATION PROCESS

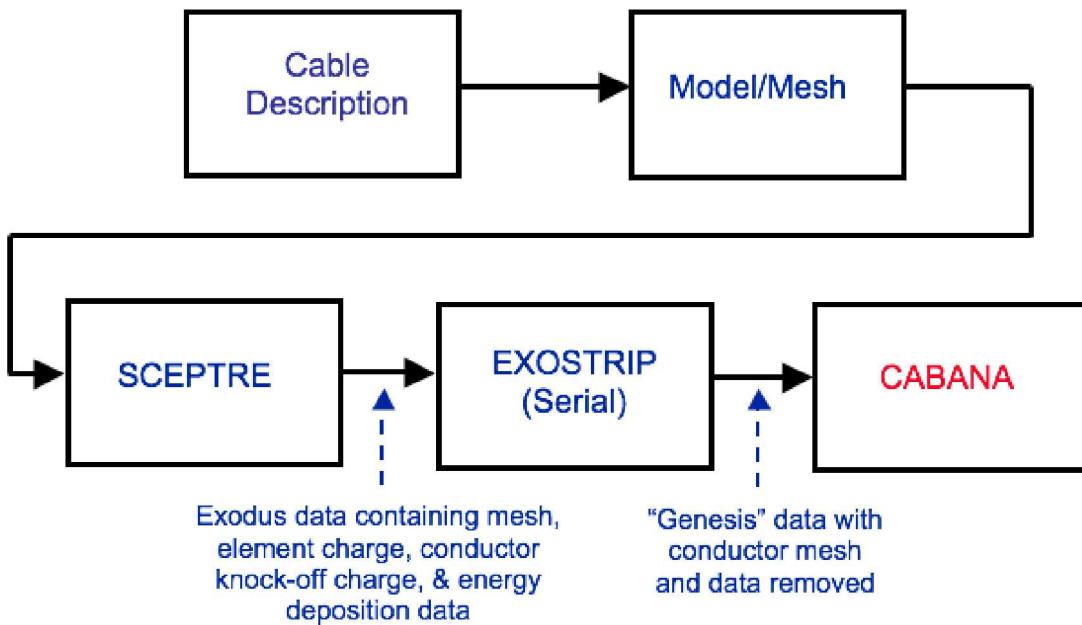


Figure 2-1. The Cable-SGEMP simulation process.

The cable SGEMP simulation process is shown in Fig. 2-1. The cable must first be modeled and meshed with using 2D or 3D-periodic unstructured elements suitable for SCEPTRE and CABANA. This is an involved process and is described in the original CEPTRE user guide [4]. These two types of elements are associated with the two CABANA simulation modes: 2.5D-mode for 2D cable cross section structures and 3D-mode for 3D-periodic cable structures. Examples of 3D-periodic structures are twisted-shielded pair or cables with braided cable shields where the shield breaks can be modeled as approximately periodic.

The critical aspects of the mesh for CABANA are that boundaries are described by EXODUSII sidesets (either single- or double-sided) and that the elements are 2nd order, utilizing quadratic shape functions. This is required to obtain sufficient accuracy in the computation of electric field. The elements can be either 6-node triangles or 8-node quadrilaterals in 2D and 20-node hexahedra in 3D. The elements should also be reasonably well shaped. Quadrilaterals with aspect ratios of up to approximately 80 can

be handled, but expect run times to increase dramatically as the matrix becomes more ill-conditioned requiring significantly more iterations to converge to the required solution tolerance.

After SCEPTRE solves the radiation-transport problem, the data for CABANA are written into an EXODUSII results file. Since SCEPTRE is required to mesh the cable conductors but CABANA has no need for this mesh, it is removed along with the associated data using the SCEPTRE post-processing tools while creating a “Genesis” file for CABANA. “Genesis” normally describes a mesh description file in EXODUSII format containing mesh only, no data, thus the quotation marks. This “Genesis” file, along with a CABANA input file is all that is required for a CABANA simulation. During this process, SCEPTRE post-processing also converts the mesh coordinates from cm to m for CABANA.

3. CABANA RESULTS

The desired result from a CABANA simulation is normally the current delivered to the cable load(s). This is provided in HISPLT format under the name “LOAD-CURRENT” for a cable with a single inner conductor in units of Amps. For a cable with multiple inner conductors, the name is “LOAD-CURRENT-X” where “X” runs from 0 to N-1 where N is the number of inner conductors. The order of these load current results in the HISPLT file is determined by the order that the cable conductors are defined in the input file using the **conductor** keyword described in a later section.

Additionally, a running integral of all load currents is computed and dumped at the end of the simulation as “Conductor # Load Charge= *value*”, where in this case the “Conductor #” is the sideset id identified with the conductor on the **conductor** keyword line for that conductor.

Also monitored is the maximum global electric field magnitude throughout the simulation and is reported at the end of the simulation as “Global Max Magnitude Electric Field = *value*”.

If requested, additional results such as POTENTIAL, ELECTRIC-FIELD, CHARGE-DENSITY, and CONDUCTIVITY are dumped in the EXODUSII results file. A discussion of CABANA output units and their relationship to the SCEPTR simulation is presented in Appendix A.

4. CABANA INPUT FILE AND KEYWORDS

```
cable sgemp
  pulse shape, triangle, risetime 1.e-8, end
  initial time step, 5.e-10, end
  spice model, build
  number sections, 3, end
  section params, sec 1, len .1, exp, no
  section params, sec 2, len .45, exp, yes
  section params, sec 3, len .45, exp, yes
  default section length, .1
  load charge density, no
  load transport charge density, yes
  load dose, yes
  conductor, sideset 1, potential 1., rintp 1.e8, rload 50.
  shield, sideset 21, potential 0.

  block 1
    material 1
  end

  block 2
    material 1
  end

  gradual startup factor 1.0
  maximum time step ratio 1.2
end
```

Figure 4-1. Typical CABANA physics keywords.

CABANA input uses the standard NEVADA input file format, which includes keywords for debugging, physics type, solver control, output control, and more. Details of all of these except for the specific physics can be found in the ALEGRA/NEVADA users guide [6]. A complete input file for one of the CABANA regression problems is given in Appendix B.

The format for specifying cable System Generated ElectroMagnetic Pulse (SGEMP) physics (i.e., CABANA) and associated keywords is shown in Fig. 4-1. The keyword CABLE SGEMP specifies CABANA physics to the code. Most of the remaining keywords are specific to CABANA and are described below.

For verification purposes, another keyword exists for CABANA physics: CABLE SGEMP VERIFICATION, VERIFY *int*. This keyword instantiates a different CABANA object and is NOT used for normal cable simulations. The VERIFY parameter specifies a particular analytic solution to be computed for comparison to the verification simulation.

For a single Poisson solution, the keyword CABANA POISSON instantiates another type of CABANA object for this purpose only. See the **Poisson solution keywords** section.

1. TIME AND TIME HISTORY KEYWORDS

PULSE SHAPE, type, [parameter real], [parameter real], END
 Specifies the time history of the radiation pulse.

Options for type, [parameter real], [parameter real] are:

STEADY_STATE

Unity for all time, useful primarily for verification

TRIANGLE, RISETIME real, FALLTIME real, END

If RISETIME only is given, rises linearly from zero to 1/RISETIME at $t = \text{RISETIME}$, in seconds (s), then falls linearly to zero at time $2 \times \text{RISETIME}$. If RISETIME and FALLTIME are given, rises linearly from zero to $2 / (\text{RISETIME} + \text{FALLTIME})$ at $t = \text{RISETIME}$ (s), then falls linearly to zero at time $\text{RISETIME} + \text{FALLTIME}$. Both have unit integrals.

SQUARE, WIDTH real, END

Amplitude 1/WIDTH at $t = 0$, remains constant until $t = \text{WIDTH}$ (s), jumps back to amplitude zero (integral is unity)

SIN_SQUARED, WIDTH real, END

$$f(x) = \frac{2}{\text{WIDTH}} \sin^2 \left(\frac{\pi t}{\text{WIDTH}} \right), \quad 0 < t < \text{WIDTH}, \text{ zero otherwise (integral is unity)}$$

EXPONENTIAL_PULSE, ALPHA real, END

$$f(x) = \frac{1}{\text{ALPHA}} \exp \left(-\frac{t}{\text{ALPHA}} \right) \text{ (integral is unity)}$$

DOUBLE_EXPONENTIAL_PULSE, ALPHA real, BETA real, END

$$f(x) = \frac{1}{\text{ALPHA-BETA}} \left(\exp \left[-\frac{t}{\text{ALPHA}} \right] - \exp \left[-\frac{t}{\text{BETA}} \right] \right) \text{ (integral is unity)}$$

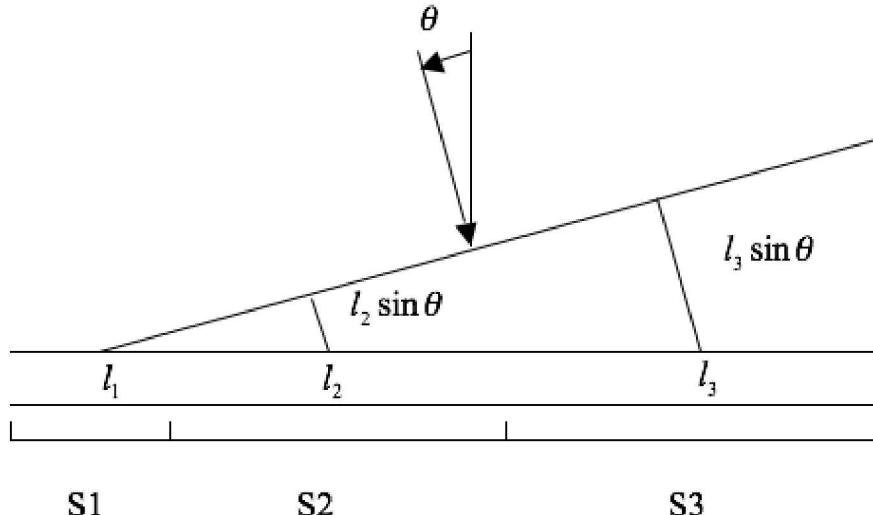
NEVADA, FUNCTION int, END

Use a NEVADA generated function, either built-in or tabulated, with the NEVADA FUNCTION keyword [11].

INITIAL TIME STEP, real, [GAMMA DOT RATIO real], [TIME STEP SCALE real], END
 Specifies the beginning time step (s) for the simulation

GAMMA DOT RATIO and TIME STEP SCALE are optional parameters which, if included, will cause the time step to change to INITIAL TIME STEP * TIME STEP SCALE after the PULSE SHAPE function falls below PULSE_SHAPE_MAX * GAMMA_DOT_RATIO, where PULSE_SHAPE_MAX is computed during the simulation. Typical values for GAMMA DOT RATIO and TIME STEP SCALE are 0.1 and 5.0, respectively. If these optional parameters are not included, the time step will remain constant at INITIAL TIME STEP for the entire simulation.

2. RADIATION-INCIDENCE KEYWORD



$$\text{Section1: } f(t - \frac{(l_1 - l_o) \sin \theta}{c})$$

$$\text{Section2: } f(t - \frac{(l_2 - l_o) \sin \theta}{c})$$

$$\text{Section3: } f(t - \frac{(l_3 - l_o) \sin \theta}{c})$$

Figure 4-2. Non-normal incidence.

By default, CABANA applies the cable excitation as if it were planar, normally incident broadside to the cable sections. In this case, all cable sections are excited simultaneously. The following keyword can be used to change the angle of incidence as shown in Fig. 4-2 for a three-section cable. Here, the cable-section excitations are staggered by the appropriate retarded time based on the timing at the section *centers*. The user should keep in mind also that the “load” end of the cable is the end on the right

in Fig. 4-2. Therefore, if it is desired to have the excitation plane strike the load-end first, the angle should be negative. Also in Fig. 4-2, l_0 is the cable origin, either the left end (for θ positive) or the right end (for θ negative).

NONNORMAL INCIDENCE, ANGLE real

Specifies non-normal planar incidence with angle angle from normal.

The ANGLE is the angle θ in Fig. 4-2, where $-90 < \theta < 90$.

3. SPICE CONTROL KEYWORDS

SPICE MODEL, spice_option

Specifies how SPICE is utilized and the origin of the spice model deck for the simulation.

Options for spice_option are:

NO - SPICE not used in simulation (default and NOT typical)

USE - Lumped-parameter SPICE deck will be read from file

BUILD - Lumped-parameter SPICE deck will be created and written to a file during startup

Generally, the initial simulation for a given cable geometry is accomplished using the BUILD option which writes the SPICE deck to a file (see SPICE FILE keyword below). If custom changes are desired to this SPICE model for subsequent simulations, the file can be edited and the USE option invoked thereafter. See Appendix C. Since the default is NO, either BUILD or USE *must* be specified for cable simulations.

SPICE FILE, "filename"

Specifies the filename from which to read the SPICE model deck if SPICE MODEL, USE is specified or the file to which to write the SPICE deck if SPICE MODEL, BUILD is specified.

"filename" is an ascii string and the quotes are required. If SPICE FILE is not specified, the SPICE deck is either read from or written to the default filename *problem_name.in*. Note that this file, either the default or that specified by SPICE FILE, will be OVERWRITTEN for the next simulation if it is left in place on the file system.

SPICE STEP FRACTION, real

Specifies the fraction of the initial time step (see INITIAL TIME STEP keyword) which SPICE will use as a maximum internal time step.

The default is 0.1. In some cases, it is necessary to increase this value to something like 0.5 to allow SPICE to converge correctly. If such a SPICE error occurs, the error is trapped and the user is notified to modify this value.

SPICE SOLVER, solver_option

Specifies the desired circuit solver. Options are SPICE (default) or XYCE [3]. Either option will provide equivalent results.

4. SECTION KEYWORDS

NUMBER SECTIONS, int, [SEC int, LEN real], [SEC int ,LEN real], [...], END
Specifies the number of sections to divide the cable length into for a 2.5D simulation and
optionally specifies the lengths of each section. However, for a large number of sections, the line
length may exceed the maximum. In this case, use multiple of the below SECTION PARAMS
keywords.

Each [SEC int, LEN real] specifies the section number and length, in meters (m), of one of the
sections. If a section is not specified, its' length is defined by the DEFAULT SECTION LENGTH
keyword below. In addition, it will be exposed to radiation by default (see SECTION PARAMS
below).

SECTION PARAMS, SEC[TION] int, LEN[GTH] real, EXP[OSED], bool [, LOAD real]
Optionally specifies the lengths of each section and whether the section is exposed to radiation.
The length parameter can be specified with the NUMBER SECTIONS keyword above if desired.

Each keyword of this type specifies the section number and length (m) of one section. Options
for EXP are YES (or TRUE) and NO (or FALSE). Note that the comma after EXP must be
present. If a section is not specified, its' length is defined by the DEFAULT SECTION LENGTH
keyword below and EXP is YES.

The optional keyword LOAD specifies a resistive load (ohms) at the *midpoint* of each section.
Loads need not be specified on every section but if one section has a load all will have placeholder
loads inserted into the SPICE deck at the default value of 1.e8, or essentially open. The user may
later modify these loads in the SPICE deck followed by using the SPICE MODEL, USE keyword
to force re-use of the deck.

DEFAULT SECTION LENGTH, real
Specifies the default length (m) of each cable section

MULTISECTION MAP, RADTRANS_FILE "filename", SECTION_INDEX int, [...],END
Optionally specifies the mapping of auxiliary radiation-transport results to cable sections for
multi-section excitation.

Lines of the above form are repeated for each auxiliary SCEPTR simulation results file. Note
that the use of this keyword is OPTIONAL. If no multisection map is specified, the default map
is used: SCEPTR data stored in the simulation Genesis file is applied to ALL SECTIONS in
the cable. The required parameters are:

RADTRANS_FILE: "filename" is an ASCII string for the name of a SCEPTR results (.exo) file

SECTION_INDEX (or shortened to SECTION): an integer value in the range 1 thru NUMBER
SECTIONS specifying each section the specified SCEPTR results will be applied to. Additional
SECTION, int combinations can be added before the END specifying other sections to receive data
from this RADTRANS_FILE.

5. SCEPTRE DATA KEYWORDS

LOAD CHARGE DENSITY, option

Specifies whether the SCEPTRE data for CHARGE density contained in the simulation Genesis file is loaded before the first time cycle

Options are:

NO - CHARGE not loaded up front, typical for actual cable simulation (default)

YES - CHARGE loaded up front, typical for verification simulation

LOAD TRANSPORT CHARGE DENSITY, option

Specifies whether SCEPTRE data for CHARGE density contained in the simulation Genesis file is prepared for loading into the simulation over the radiation pulse defined by PULSE SHAPE.

Options are:

YES - CHARGE prepared for loading, typical for actual cable simulation (default)

NO - CHARGE not prepared for loading, typical for verification simulation

LOAD DOSE, option

Specifies whether SCEPTRE data for ENERGY_DEPOSITION contained in the simulation Genesis file is prepared for loading into the simulation over the radiation pulse defined by PULSE SHAPE

Options are:

YES - ENERGY_DEPOSITION prepared for loading, typical for actual cable simulation (default)

NO - ENERGY_DEPOSITION not prepared for loading, typical for verification simulation or for turning off radiation induced conductivity (RIC)

LOAD CONDUCTOR CURRENT, option

Specifies whether the SCEPTRE data for knock-off charge from each cable CONDUCTOR, contained in the simulation Genesis file, is prepared for loading into the simulation over the radiation pulse defined by PULSE SHAPE

Options are:

YES - CONDUCTOR CHARGE prepared for loading, typical for actual cable simulation (default)

NO - CONDUCTOR CHARGE not prepared for loading, typical for verification simulation

5.1. Conductor knock-off charge keyword

ENFORCE NEGATIVE KNOCK OFF, option

This keyword specifies whether an error is issued and the simulation halted in the case that any conductor has a positive knock-off charge. In the case of a conductor defined by multiple side sets, a positive knock-off charge on any of those side sets will trigger the error. Normally this indicates a poorly resolved SCEPTR E mesh but for high (> 1 MeV) photon energy it may be feasible to get a valid positive knock-off charge. This keyword removes enforcement of this condition and allows the simulation to continue.

Options are:

YES - Fatal error is issued and the simulation halted (default)

NO - Simulation continues with warning

5.2. Cable topology keywords

CONDUCTOR, SIDESET int, [SIDESET int, ...], POTENTIAL real, RINPT real, RLOAD real

Each internal cable conductor is specified with one of these keyword lines.

Required parameters are:

SIDESET: Specifies one (or more) sideset id(s) in the Genesis file defining this conductor

POTENTIAL: Specifies the initial potential, in volts (V), of the conductor (applies only to verification simulations, ignored for actual cable simulations)

Optional parameters are:

RINPT: Specifies the resistance (ohms) to be applied to the “input” (often floating) end of the SPICE model.

RLOAD: Specifies the resistance (ohms) to be applied to the “load” end of the SPICE model. It is through RLOAD that the main CABANA output, LOAD-CURRENT in the HISPLT file, flows.

If the optional cable loads are not specified, the defaults are RINPT=1.e8 ohms and RLOAD=50 ohms. The user should keep in mind that although RINPT can be anything, it is only the current through RLOAD which is monitored and output to the HISPLT file.

INTERFACE, SIDESET int, [SIDESET int, ...], INITIAL CHARGE DENSITY real

Each cable dielectric interface of differing conductivity properties is specified with one of these keyword lines.

Required parameters are:

SIDESET: Specifies one (or more) sideset id(s) in the Genesis file defining this interface

INITIAL CHARGE DENSITY: Specifies the initial charge density (C/m) on the interface before the simulation begins (normally zero for cable simulations)

SHIELD, SIDESET int, [SIDESET int, ...], POTENTIAL real
Specifies the required surrounding cable shield.

Required parameters are:

SIDESET: Specifies one (or more) sideset id(s) in the Genesis file defining the shield

POTENTIAL: Specifies the shield potential (V) for the simulation, normally zero for cable simulations

The user is responsible for properly defining a conductor, interface, or shield with the correct number of sidesets. CABANA has no way of knowing that a portion of the boundary for say, a conductor, has been left out.

CABANA requires these sidesets be single-sided. SCEPTR^E [5] uses either single- or double-sided sidesets. The SCEPTR^E post processor, when it generates stripped CABANA data, will guarantee that the sidesets going into CABANA are single-sided.

SYMMETRY, type

Specifies quarter or half mesh symmetry. A correction is applied to compute the correct response for the full problem.

Options are:

- NONE** No symmetry (default)
- QUARTER** Two symmetry planes
- HALF** One symmetry plane

6. SHOCKLEY METHOD KEYWORD

SHOCKLEY METHOD, option

Specifies the use of the simple Shockley integral method [6]. This method removes the requirement for μm -scale meshing for SCEPTR^E near the interfaces and provides faster convergence as well. However, RIC must be ignored since it cannot be modeled with this formulation. SCEPTR^E must now provide a current density rather than a charge density. This current density is integrated against the computed Green's function solutions using the following:

$$R = - \int_V \bar{E} \bullet \bar{J} dv$$

If this method is specified the other SCEPTR^E data keywords are overridden to NO. Plot data is not available for CHARGE_DENSITY, POTENTIAL, or ELECTRIC_FIELD and should not be specified. Requesting TRANSPORT_CURRENT for plot data will provide the time history and spatial distribution of the source current density.

Options are:

- NO Use standard full-simulation method (default)
- YES Use Shockley method and override everything else

7. CHARGE RELAXATION KEYWORD

ENFORCE RELAXATION LIMIT, option1 [, PRINT WARNING, option2]

If conductivity is present, this keyword specifies whether an error is issued and the simulation halted in the case that an element relaxation time is too short relative to the time step chosen. Here the element relaxation time is defined as *permittivity/conductivity*. Based on convergence verification tests, it has been determined that good results are obtained as long as the element relaxation time is less than twice the time step. In other words, as long as there are at least two time samples per relaxation time.

Options for ENFORCE RELAXATION LIMIT are:

YES - Fatal error is issued and the simulation halted with information about the shortest elemental relaxation time (default)

NO - Simulation continues with or without warning

If ENFORCE RELAXATION LIMIT is YES, PRINT WARNING is irrelevant. Otherwise, the options for PRINT WARNING are:

YES - Simulation continues with warning printed containing the shortest elemental relaxation time

NO - Simulation continues without warning (default)

8. BOX OR CAVITY SGEMP DRIVE INCLUSION KEYWORDS

Current sources can be included in the simulation to accommodate the forward coupling of box and cavity SGEMP drives during the cable simulation for a cable with a single inner conductor. These sources (one for box drive and/or one for cavity drive) are automatically inserted into the SPICE deck across the RINPT end of the conductor, as described by the CONDUCTOR keyword. Typically, the drive is provided through a tabular FUNCTION of samples from a box or cavity SGEMP simulation but it can be provided by one of the functional forms of the FUNCTION keyword as well.

BOX DRIVE, FUNCTION int [,SCALE real SHIFT real]

Specifies that a box-drive current source be created in the SPICE deck and that it be driven with the supplied function.

The tabular function can be scaled or shifted in time as necessary.

CAV DRIVE, FUNCTION int [,SCALE real SHIFT real]

Specifies that a cavity-drive current source be created in the SPICE deck and that it be driven with the supplied function.

The tabular function can be scaled or shifted in time as necessary.

BOX DRIVE is deprecated by the BOX CABLE coupling keyword below.

9. BOX-CABLE SGEMP COUPLING KEYWORD

BOX CABLE

Specifies a full coupled Box-Cable SGEMP simulation.

A detailed use description is found in the UTDEM User Manual [II].

10. POISSON SOLUTION KEYWORDS

POISSON SOLUTION, CHARGE DENSITY real, RESULTS FILE "filename"

Specifies a single Poisson solution and exit

Required parameters are:

CHARGE DENSITY: Specifies a uniform charge density (C/m²) in the elements

RESULTS FILE: ASCII file to which the resulting element electric fields are written

The boundary conditions for the solution are specified using the CONDUCTOR keyword above.

EXPORT RESULTS, GENESIS FILE "filename", SIDESET int

Specifies that the resulting element electric fields are to be exported for a subsequent 3D UTDEM simulation

Required parameters are:

GENESIS FILE: 3D Genesis file for results export

SIDESET: Sideset in Genesis file to store results with

This Genesis file and sideset must be the same used to generate the 2D mesh for the Poisson solution in the first place using the UTDEM SIDESET EXTRACTOR physics option in EMPHASIS™.

The Poisson solution requires the framework keyword TERMINATION CYCLE = 1 to be specified. This ends the simulation after a single solve as desired.

11. SINGLE-CYCLE SOLUTION

If RIC is not important and the time history of the response is not required, it is possible to compute the total charge transferred to the load with a single computation cycle. This is accomplished by setting the following keywords:

SPICE MODEL,	no
NUMBER SECTIONS,	i, end
DEFAULT SECTION LENGTH,	length
LOAD CHARGE DENSITY,	yes
LOAD CONDUCTOR CURRENT,	yes
LOAD TRANSPORT CHARGE DENSITY,	no
LOAD DOSE,	no
TERMINATION CYCLE	i

After a single cycle, the response is computed from the conductor knock-off charge and the rho-induced charge on the conductor as follows:

$$R = q_{ko} - q_i$$

12. FRAMEWORK-RELATED KEYWORDS WITHIN THE PHYSICS BLOCK

These keywords are really framework keywords [6] and must be placed within the physics definition keyword block.

BLOCK int MATERIAL int
Defines a finite-element block.

Relates the mesh block id BLOCK to material definition MATERIAL.

FUNCTION int
Define a user-defined function for use by the box/cavity drive keywords.

FUNCTION int

timeo valueo
timei valuei
time2 value2

. .
. .
. .

END

GRADUAL STARTUP FACTOR **real**

Factor by which the initial time step is multiplied, default is 0.01.

Gradually increases the initial time step. For CABANA, the value is normally set to 1.0.

MAXIMUM TIME STEP RATIO **real**

Maximum ratio by which a time step may grow in a given cycle.

Gradually increases the time step from the old to the new value. This effects CABANA when **TIME STEP SCALE > 1.0** on the **INITIAL TIME STEP** line.

5. FRAMEWORK KEYWORDS

These keywords are framework keywords [6] which are required for a successful CABANA simulation.

1. MATERIAL-RELATED KEYWORDS

MATERIAL int

Define a material model for a material.

MATERIAL int

MODEL int

MODEL int

.

.

END

Relates the material MATERIAL to material model(s). For CABANA only one model applies to each material.

MODEL int string

Define a material model.

MODEL int string

parameter real

parameter real

.

.

END

Relates the material model MODEL to a specific model name defined by the name string.

Options for string and parameter(s) are:

RIC ELECTRICAL

EPS real

MU real

SIGMA0 real

COEFFICIENT real

EXPONENT real

```

END
or
HP GAS ELECTRICAL
EPS           real
MU            real
SIGMA0        real
DENSITY       real
WATER_FRACTION real
END

```

where EPS is the relative permittivity of the medium, MU is the relative permeability of the medium, and SIGMA0 is the initial or dark conductivity (Mho/m) of the material.

The radiation-induced conductivity (RIC) model [2] takes the following form:

$$\sigma = \sigma_0 + \varepsilon K \dot{\gamma}^e$$

where σ is the conductivity in Mho/m, σ_0 is the dark conductivity in Mho/m, ε is the permittivity in Farad(F)/m, K (COEFFICIENT) is in ((Mho/F)/(Rad/s)), $\dot{\gamma}$ is the dose rate in Rad/s, and e is the EXPONENT parameter. Typical values for Kapton are $\varepsilon = 3.5\epsilon_0$, $K = 3.23 \cdot 10^{-6}$, and $e = 0.95$.

The high-pressure (HP) gas model is described in [8][10]. The independent variables in the model are DENSITY (kg/m³) and WATER_FRACTION, nominally 1.23 and 0.02, respectively.

Example input file fragments for these model specifications are shown in Fig. 5-1.

```

Model 1 RIC Electrical
  eps 2.
  mu 1.
  sigma0 1.e-3
  coefficient 3.23e-6
  exponent 0.95
end

Model 2 HP Gas Electrical
  eps 2.
  mu 1.
  sigma0 0.
  density 1.23
  water_fraction 0.02
end

```

Figure 5-1. Typical material model descriptions.

2. SIMULATION TIME AND OUTPUT CONTROL KEYWORDS

Typical simulation time and output control keywords are shown in Fig. 5-2.

```
termination time = 1.e-8

emit screen, cycle interval = 1
emit plot, cycle interval = 10
emit hisplt, cycle interval = 1
plot variable
    potential
    electric_field
    charge_density
    vis_face_charge_density
    econ
    electron_concentration
end
```

Figure 5-2. Typical simulation and output control keywords.

TERMINATION TIME = real

Total time (s) for which to run the simulation

TERMINATION CYCLE = int

Total cycles for which to run the simulation

EMIT SCREEN, CYCLE INTERVAL = int

Print status line to standard out every CYCLE INTERVAL cycles

EMIT PLOT, CYCLE INTERVAL = int

Write PLOT VARIABLES to exodus file every CYCLE INTERVAL cycles

EMIT HISPLOT, CYCLE INTERVAL = int

Write global variables to hisplt file every CYCLE INTERVAL cycles

PLOT VARIABLE

PLOT VARIABLE

registered-variable name

registered-variable name

...

END

Valid plot variables for CABANA are

```

potential
electric_field
charge_density
vis_face_charge_density (interface charge density)
econ (conductivity) (RIC and HP Gas model)
electron_concentration (HP Gas model)
negative_ion_concentration (HP Gas model)
avalanche_rate (HP Gas model)
attachment_rate (HP Gas model)

```

If plot variables are not desired the “emit plot” line can be omitted. If plot variables are desired but not at frequent intervals, the cycle interval should be set to large values to avoid exceedingly large exodus files.

3. LINEAR SOLVER KEYWORDS

Typical linear solver keywords, in this case for AZTEC [9], are shown in Fig. 5-3. In this case, conjugate gradient (cg) is specified with no preconditioning but with symmetric diagonal scaling. No output is requested from AZTEC after each solve to a tolerance level of 1.e-9 with a maximum number of cg iterations set to 1000 (default is 500). The “polynomial order” should always be set to “1” for efficiency.

```

aztec
  solver,      cg
  precond,    none
  scaling,    sym_diag
  output,     none
  tol        = 1.e-9
  polynomial order, 1
  max iterations, 1000
end

```

Figure 5-3. Typical solver control keywords.

4. DEBUG MODE KEYWORD

Specific code debug information at run time can be requested using the following syntax:

DEBUG MODE: debug-opt

Some relevant values for debug-opt are:

CABANA

Produces verbose intermediate Cabana results useful for understanding and following the simulation as it progresses.

LOCATION

Provides a quick way to observe in the standard out stream progress through the code execution, and in particular to see where the most time is being spent.

SIGNALS | FPE

These will catch and report events such as floating-point exceptions.

6. FOLLOW-UP SIMULATIONS WITH STORED CHARGE

It may be desirable to do a series of simulations where the stored charge remaining in the dielectric from previous simulations is used as an initial charge distribution for subsequent simulations. This can be accomplished with CABANA by utilizing the restart capability of the framework. The procedure is as follows:

Add the following restart keywords to the initial input file:

```
RESTART DUMPS, 1
EMIT RESTART, CYCLE INTERVAL = int OR EMIT RESTART, TIME INTERVAL = real
READ RESTART DUMP = -1
```

The first indicates that only one restart dump is saved during the simulation. The second tells the framework to emit a restart dump either every CYCLE INTERVAL cycles or every TIME INTERVAL seconds. The third says that upon restart, the framework should read and load data from the latest restart dump available. In the case of the initial simulation of the series, the user should verify that no restart dumps exist in the directory and the simulation will then start at time=0. as desired. Restart dumps are written to files in the format: *problem_name.dmp.restart_number*.

For subsequent simulations, the user *must* change the TERMINATION TIME to have a later termination time for the next simulation. With this change, the follow-on simulation will begin at the time of the final restart dump from the previous simulation after loading the residual dielectric charge. In addition, the original *problem_name.gen* file can be optionally replaced at this time with a new one having the identical mesh description but containing a different set of radiation-transport results. The user is also free to change other simulation parameters such as pulse shape, time step, etc.

A key assumption in this process is that the SPICE circuit model is completely discharged after each simulation in the series, since no SPICE state is saved. This requires that each simulation be run until such time as this is essentially the case, i.e., all cable reflections have subsided and a reasonably steady-state condition has been reached.

7. CONCLUSION

This document, along with the user guides for a modeling and meshing tool such as CUBIT, the radiation-transport code SCEPTR, and the SCEPTR post-processing tools should allow the user to successfully utilize CABANA to simulate the cable SGEMP response of an arbitrary cable geometry. To gain experience, the CABANA regression suite contains several realistic cable simulations, both 2.5D and 3D. Although these do not have realistic radiation-transport data in their Genesis files, the data does adequately exercise the algorithms in the code and fully demonstrates the cable simulation.

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APPENDICES

A. CABANA OUTPUT UNITS

The units associated with the CABANA output depend on the source normalization applied during the SCEPTR^E simulation. Assume that the source intensity is F cal/cm² with an average spectral energy of E MeV/photon. SCEPTR^E source normalization multiplies the source intensity F by

$$\frac{2.61 \cdot 10^{13}(\text{MeV/cal})}{E(\text{MeV/photon})}$$

yielding the fluence in photon/cm². With this normalization, the load currents from CABANA are in units of Amps (A). Without this normalization, the load currents are in units of A/(photon/cm²). Centimeters appear here because SCEPTR^E is written in CGS units.

The units of other possible CABANA outputs are V for potential, V/m for electric field, C/m³ for charge density, and mho/m for conductivity.

B. COMPLETE CABANA INPUT FILE

```
$-----BEGIN_QA-----  
$ Tags:      cabana physics library  
$ CVS: $Id: coax_quad8.inp,v 1.6 2003/01/22 05:32:12 wjbohn Exp $  
$-----END_QA-----  
  
$debug mode: CABANA  
$debug mode: LOCATION  
  
title  
CABANA: Coax w/coarse quad8 mesh  
  
$$$$$$$$$$$$$$$$$$$$ physics options$$$$$$$$$$$$$$$$  
  
$ The following two lines should be specified instead of CABLE SGEMP  
$ if a verification test is desired rather than a normal simulation  
$CABLE SGEMP VERIFICATION  
$VERIFY, 1  
  
CABLE SGEMP  
pulse shape, triangle, risetime 1.e-9, end  
initial time step, 1.e-10, end  
spice model, build  
number sections, 1, end  
default section length, .1  
load charge density, no  
load transport charge density, yes  
load dose, yes  
conductor, sideset 1, potential 1., rinpt 1.e8, rload 50.  
shield, sideset 21, potential 0.  
  
block 1  
  material 1  
end  
  
block 2  
  material 1  
end  
  
  gradual startup factor 1.0  
  maximum time step ratio 1.2  
  
end
```


C. MODIFYING THE SPICE DECK

As noted in the **SPICE control keywords** section, the SPICE MODEL, BUILD keyword is typically used in an initial simulation to generate the SPICE deck for a cable. For a subsequent simulation, if the user wishes to modify the cable load to something more complicated than the simple resistive load added by the CONDUCTOR keyword then the SPICE deck must be edited manually. For subsequent simulations, the user *must* use the SPICE MODEL, USE keyword to have the code read the modified deck. In addition, if the user desires to change the name of the SPICE deck from the default name of *problem_name.in*, the SPICE FILE, “filename” keyword must be used to specify the new name.

Modifications to the SPICE deck follow standard SPICE conventions. For example, if a complicated load is to be connected to the cable then the load SPICE circuit description can either be inserted directly into the file, using unique node numbers and device names of course, or a SPICE .SUBCKT can be used.

The first step in modifying the file for new load(s) is to determine what nodes the load(s) are connected to. The SPICE deck generation algorithm places resistive loads on each end of each cable conductor. Referring to the CONDUCTOR keyword, the RINPT value is placed on the “input” end of the cable and the RLOAD value is placed on the “output” end. The “output” end is the “LOAD-CURRENT” which is monitored and output by the code in the *problem_name.his* file. The SPICE solver simply returns the node voltage across the output “load”, assumed to be a simple resistor. The return value is then divided by the load resistance to determine the load current.

The algorithm used for numbering the loads is as follows. Assume the cable has N conductors divided into M sections. The “input” load on the first conductor (the first CONDUCTOR keyword line in the *problem_name.inp* file) is R[1]. The “output” load on the first conductor is R[2]. The input load on the second conductor is R[3] and the output load is R[4], etc, down to the final conductor N which has input load R[2N-1] and output load R[2N]. Therefore, for the nth conductor, the input load is R[2n-1] and the output load is R[2n]. Note that the square brackets are used here only for clarity and are not in the actual SPICE deck, *problem_name.in*.

To determine how to modify the return voltages to provide the desired value, the nodes to which the loads connect must be determined. The automated resistive loads always connect between some floating node and ground, which is always node 0. The input load on the first conductor connects to nodes 1 and 0 and the output between nodes M+2 and 0. On the second conductor, the input load is on node (M+2)+1 and the output load node 2(M+2) down to the final conductor N where the input load is on node (N-1)(M+2)+1 and the output load on node N(M+2). Therefore for the nth conductor, the input load connects to node (n-1)(M+2)+1 and the output load to node n(M+2).

To aid in the location of the load nodes, CABANA now places notations into the SPICE deck indicating where the loads are, including section loads if applicable.

At the end of the SPICE deck, there is a series of .PRINT TRAN V(i), V(j), V(k), ... lines. Presently, only the output load voltage, V(n(M+2)) for each conductor n, is monitored by the code. This voltage is divided by the RLOAD value on the appropriate CONDUCTOR keyword line to determine the load current. If this happens to be the desired result across the new load or subcircuit, then nothing need be done in the .PRINT TRAN section. To have the code only report the voltage, then change the RLOAD

value to 1 and remember that the LOAD-CURRENT in the *problem_name.his* file is actually load voltage.

If it is desired to have the voltage between any two nodes instead, then replace each of the $V(n(M+2))$'s, for each conductor n , with something like $V(7,5)$ for example which specifies the voltage between nodes 7 and 5. Again, if the result desired is simply this voltage difference then change the RLOAD value to 1 for that conductor.

A SPICE **.SUBCKT** can be used if the voltage or voltage difference desired is on or between the external nodes of the subcircuit. If results are required from inside the subcircuit, then the circuit must be placed into the SPICE deck inline so that the necessary nodes are global. The desired nodes can then be referred to in the **.PRINT TRAN** line(s).

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